The Power of Core-level Spectroscopy

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OxfordMaterials

Outline of talk

- Introduction to EELS and XAS
- What you can measure
- What information you can get
- What it is used for

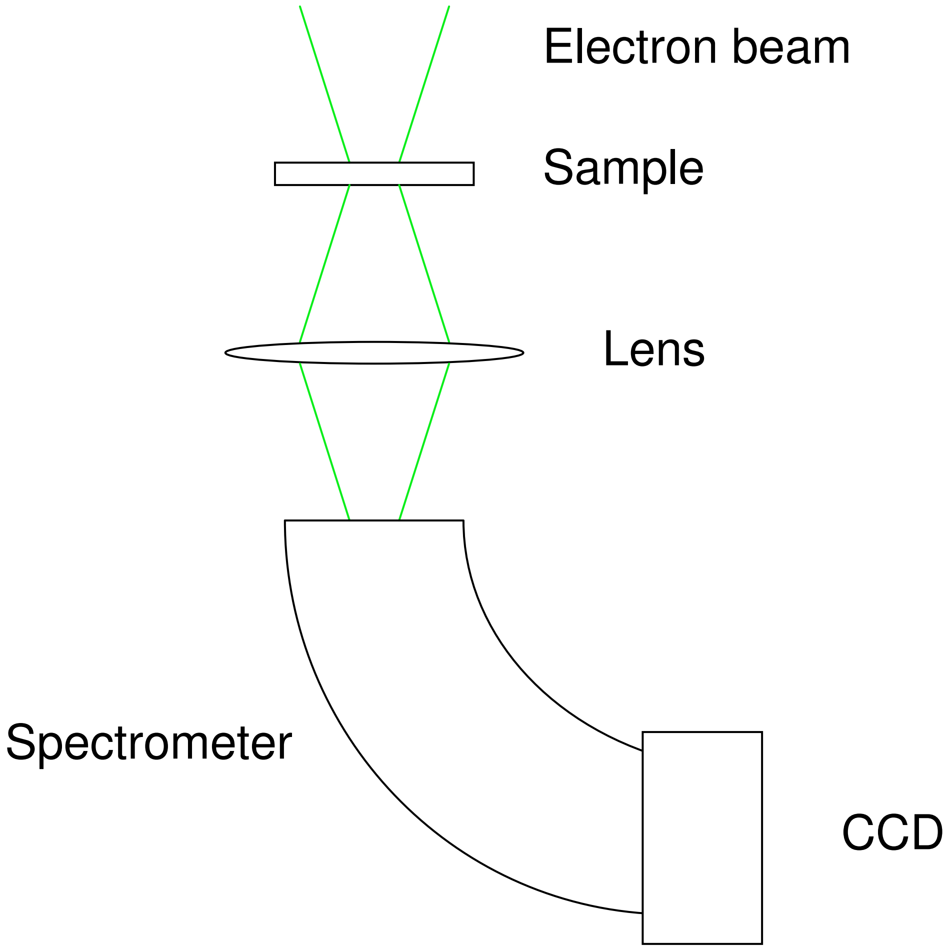
Electron energy loss spectroscopy in a Transmission Electron Microscopy

electron gun

sample
(3mm disc)

spectrometer

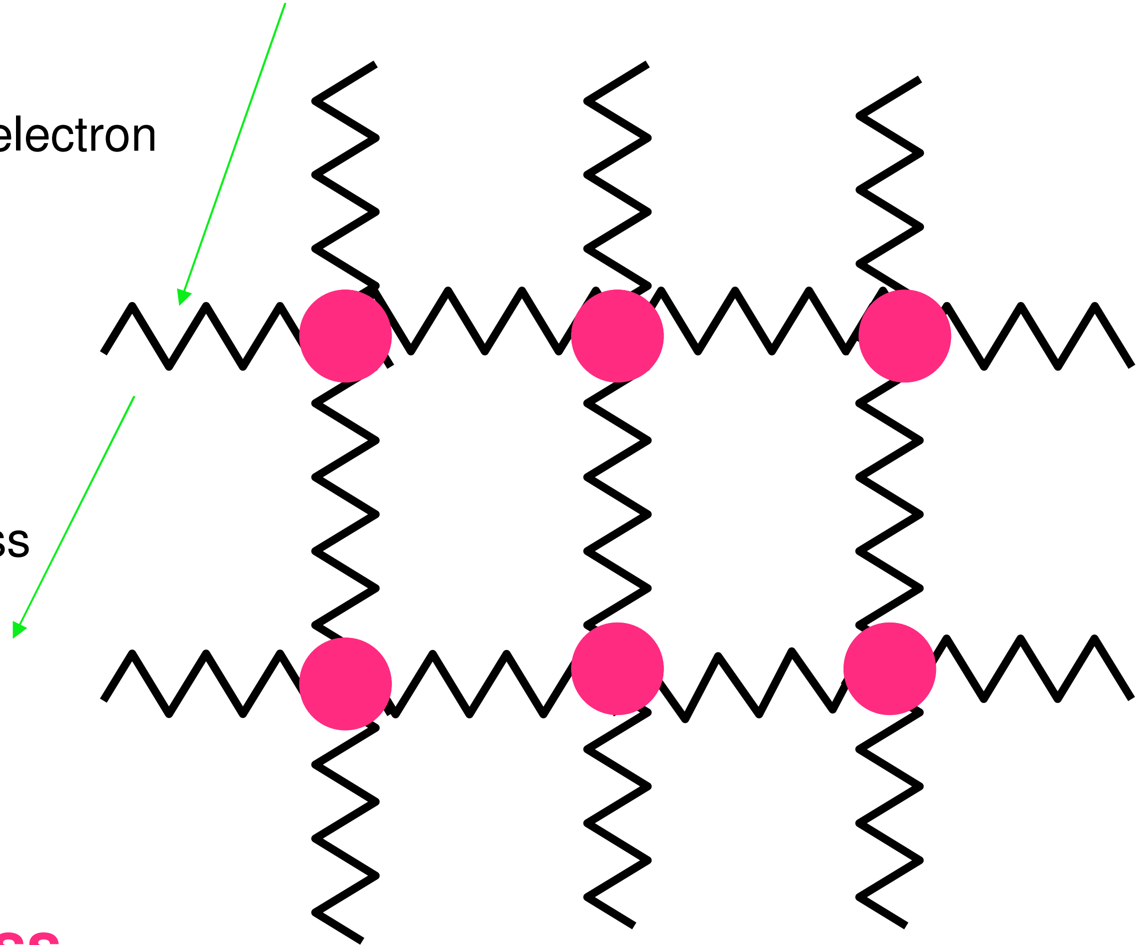
Electron energy loss spectroscopy in a TEM



Inelastic scattering

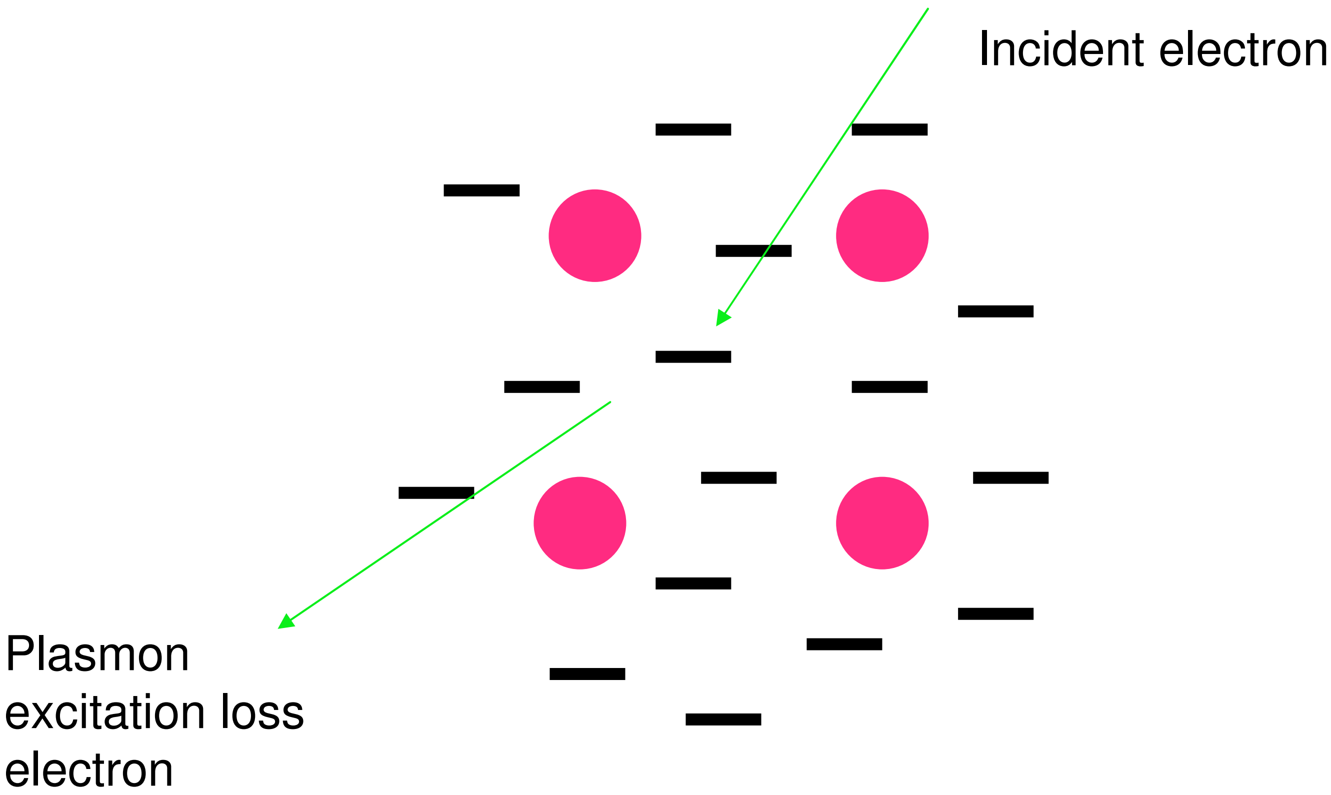
- Phonon excitation
- Plasmon excitation
- Single electron excitation
- Direct radiation losses

Phonon excitations



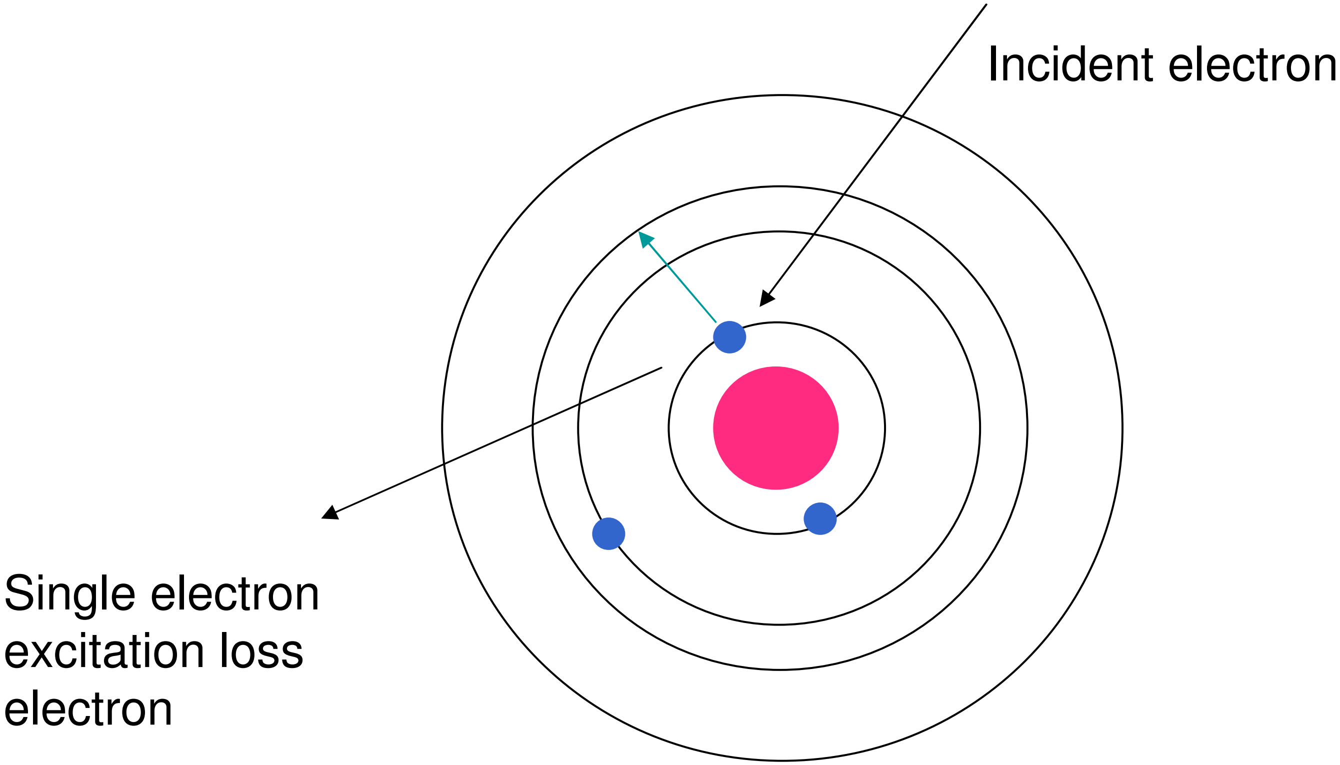
< 1 eV loss

Plasmon excitations



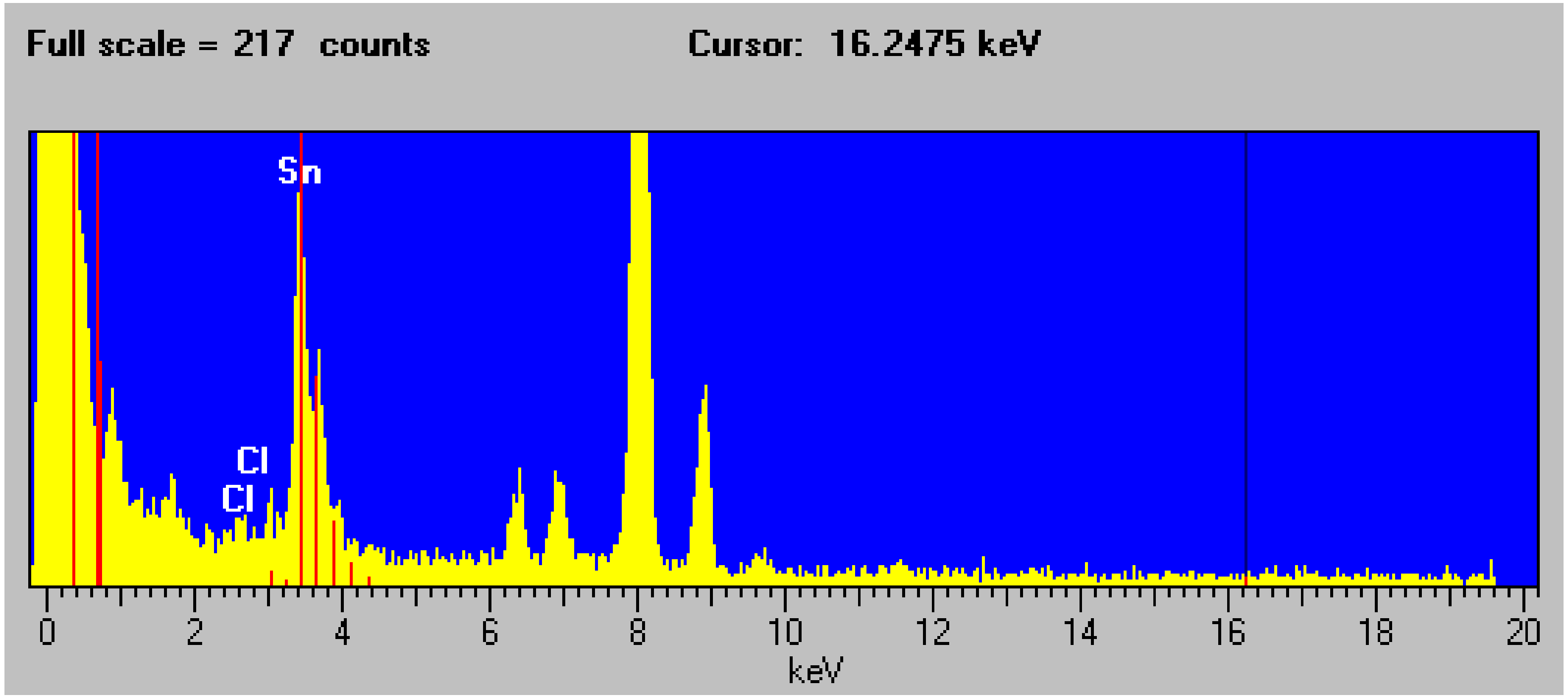
~5-30 eV loss

Single electron excitations



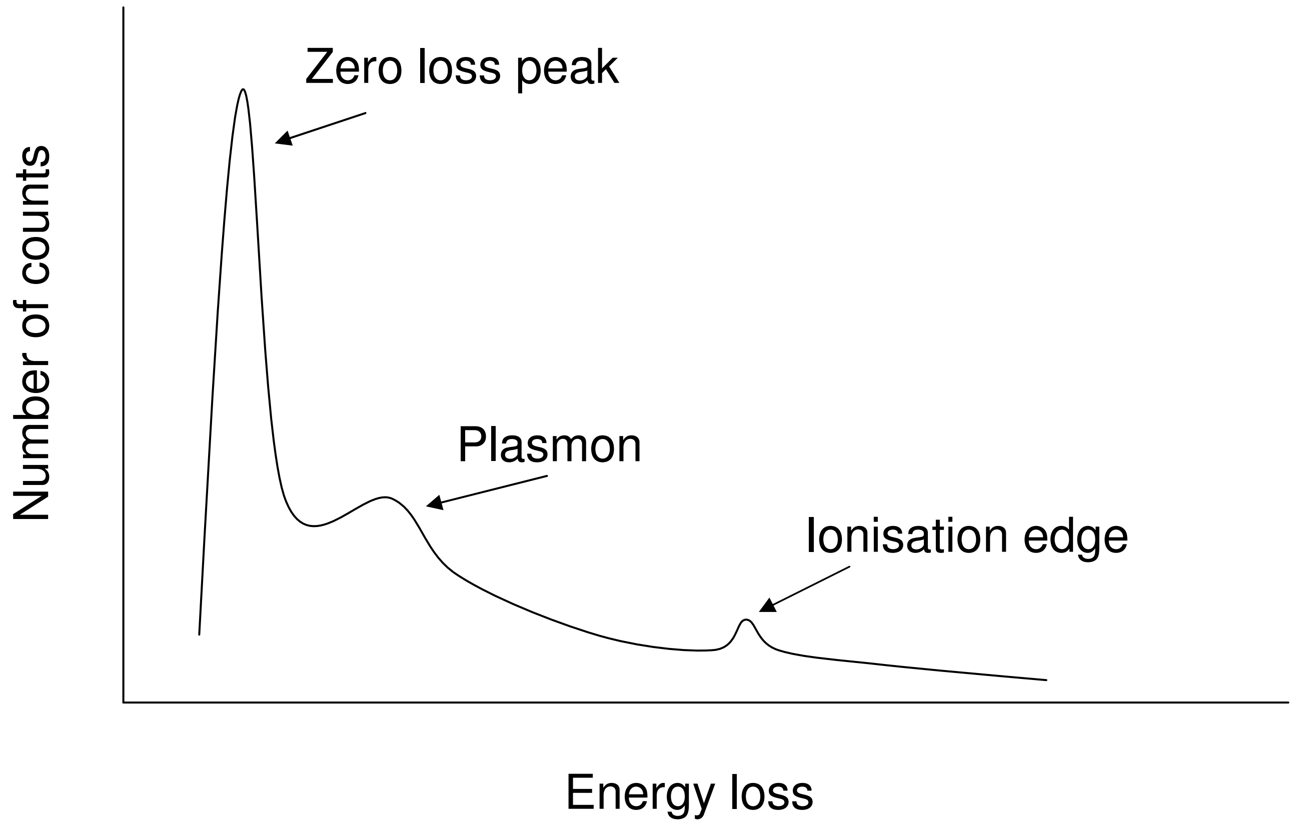
~50 - >2000 eV loss

Direct radiation losses

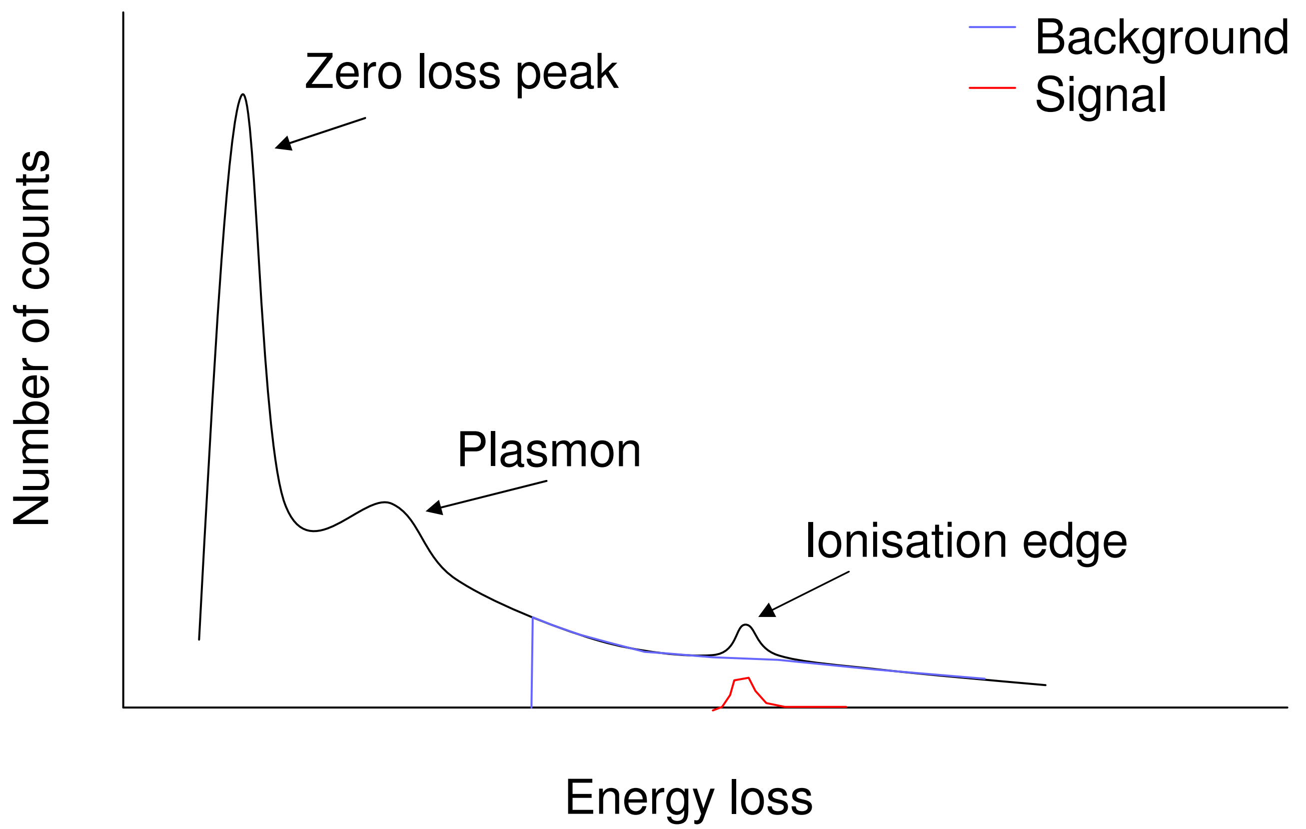


Electron slows down, energy release produces X-rays (Bremsstrahlung)

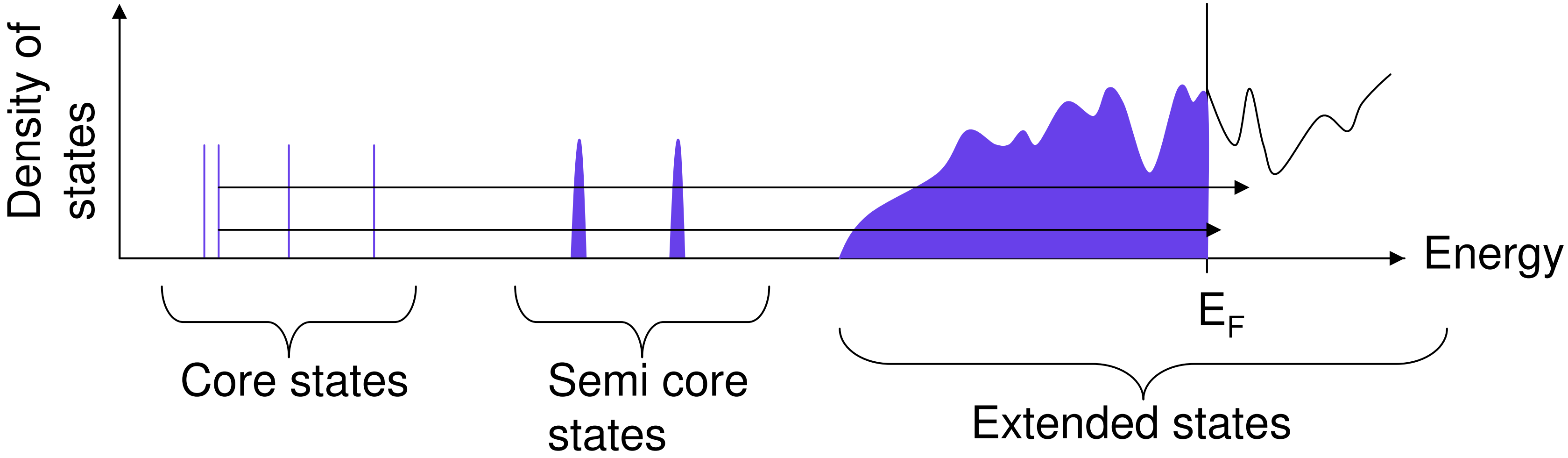
Electron energy loss spectrum



Background removal



Ionization edge



$$I\,(E) \propto N(E)$$

XAS

Diamond light source (http://www.diamond.ac.uk/Home.html)

XANES and ELNES

- XANES

  High energy resolution, ~50nm spatial resolution, need a relatively large amount of sample, collect smaller energy range, less damage

- ELNES

  Good spatial resolution, monochromators give good energy resolution, small amount of sample, collect large energy range

What you can measure

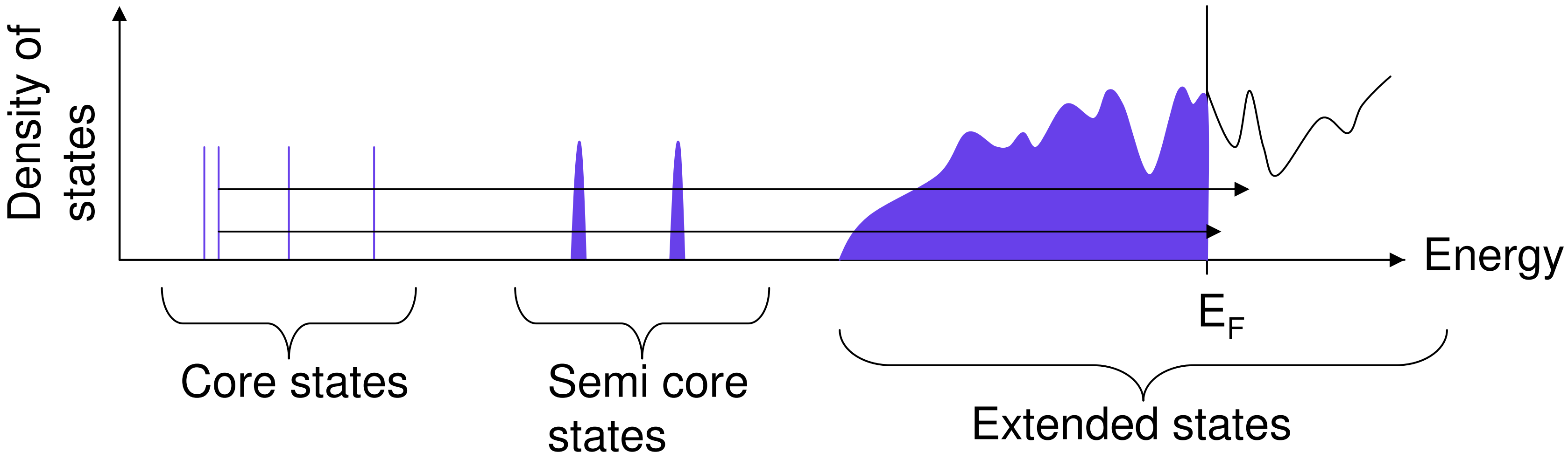
- EELS (TEM)

  Imaging, diffraction, thickness maps, EDX, STEM, EFTEM, in situ experiments, spectrum imaging, energy range 0 – 3000eV

- XAS

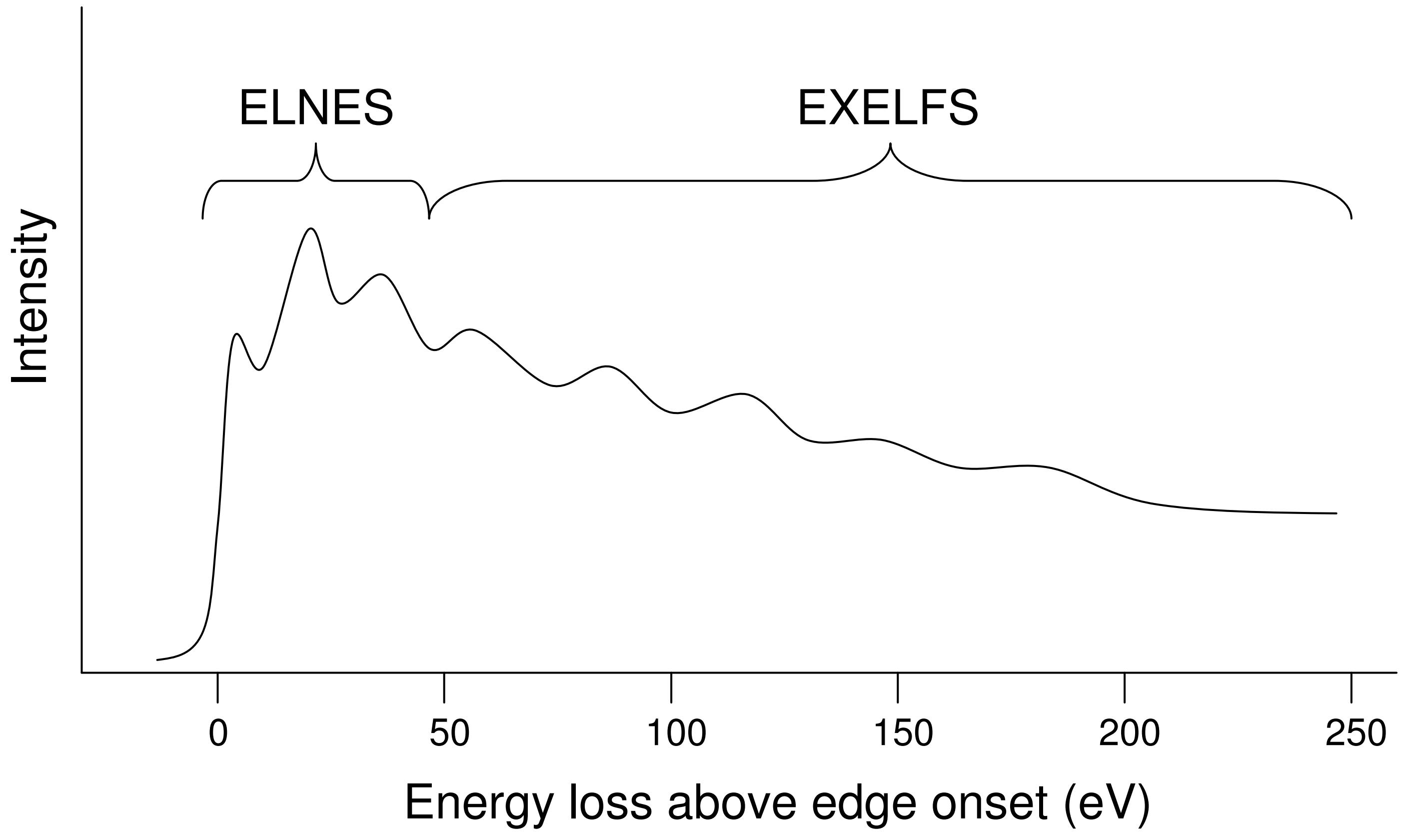
  Diffraction, in situ experiments (temperature and pressure), tuneable energy range

Ionization edge

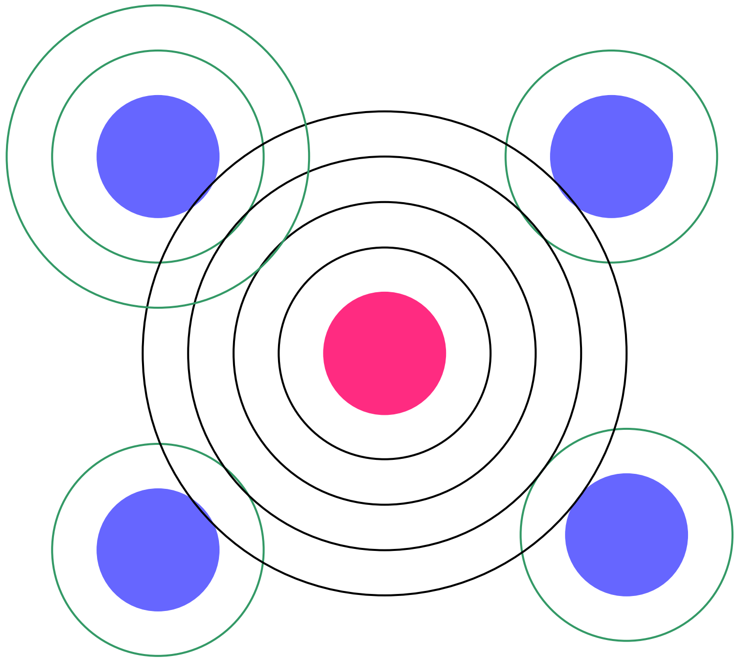


$$I(E) \propto N(E)$$

ELNES and EXELFS



Chemical information from ionization edge



As the energy of the ejected electron increases, it's lifetime decreases

Chemical information from ionization edge

- ELNES – bonding environment
  valence state
- EXELFS – nearest neighbour distances

Edge notation

Core electron	Edge
$1s^{1/2}$	K
$2s^{1/2}$	L_1
$2p^{1/2}$	L_2
$2p^{3/2}$	L_3
$3s^{1/2}$	M_1
$3p^{1/2}$	M_2
$3p^{3/2}$	M_3
$3d^{3/2}$	M_4
$3d^{5/2}$	M_5

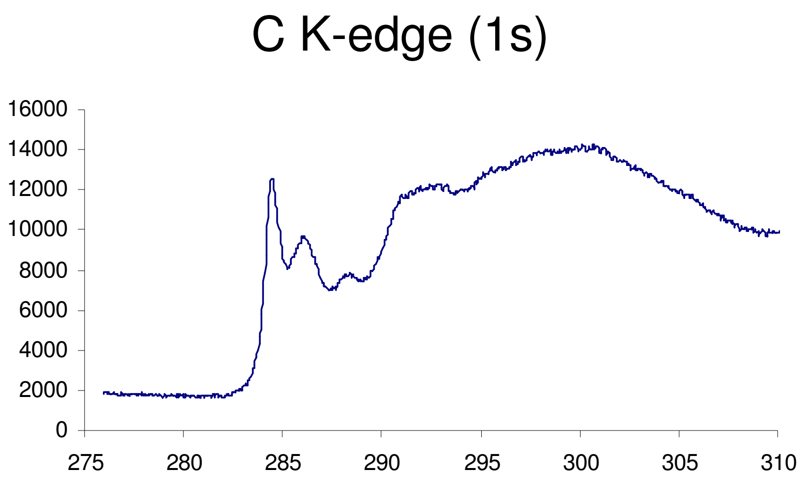
Angular momentum state

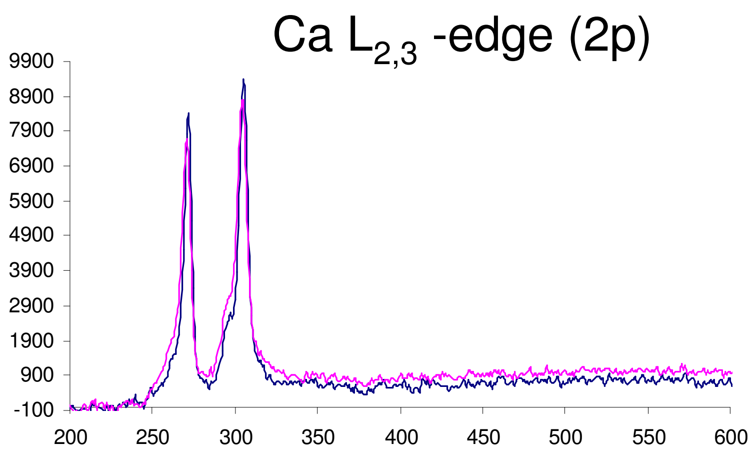
$$2p^{1/2}$$

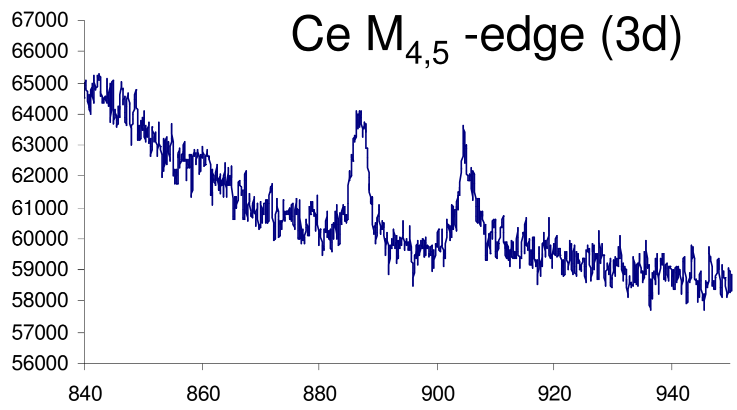
Principle quantum number

j quantum number (combination of spin and angular momentum)

Examples of edge shapes







Periodic table

1 H													2 He
3 Li	4 Be						5 B	6 C	7 N	8 O	9 F		10 Ne
11 Na	12 Mg						13 Al	14 Si	15 P	16 S	17 Cl		18 Ar
19 K	20 Ca	21 Sc	22 Ti	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr		
37 Rb	38 Sr	39 Y	40 Zr	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe		
55 Cs	56 Ba	71 Lu	72 Hf	79 Au	80 Hg	81 Ti	82 Pb	83 Bi	84 Po	85 At	86 Rn		

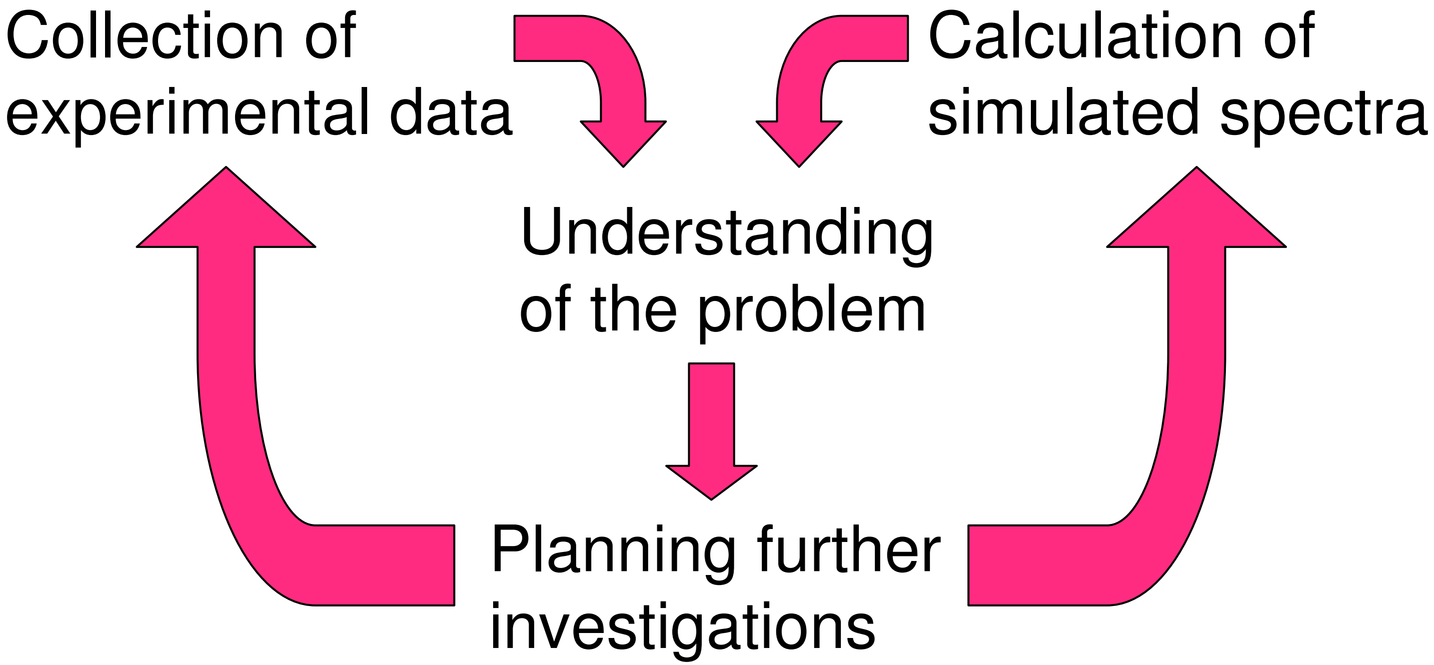
Information you can get

- Bonding environment
- Valence state
- Nearest neighbour distances

- Combine with other techniques / experiments

- Low-loss data

Combining experiment and modelling



Recommended books and useful websites

R Egerton – *Electron Energy Loss in the Electron Microscope* Plenum

R Brydson – *Electron Energy Loss Spectroscopy* RMS Microscopy Handbook

EELS database - http://www.cemes.fr/eelsdb/

Diamond light source - http://www.diamond.ac.uk/Home.html

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