Verifying Moseley's law with energy-dispersive x-ray spectroscopy or x-ray fluorescence

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Moseley's Law

Moseley's law relates the atomic number (Z), to the characteristic x-ray energy of the specimen. X-ray analysis of high Z elements, typically metals, is easily accomplished using EDS in an SEM or using an XRF analyzer. Moseley's law is given by the equation

$$E = h\nu = B(Z-\sigma)^2$$

where B is on the order of the Rydberg energy and σ is the screening parameter. To plot the energy versus the atomic number and to determine the values of B and σ experimentally, the data is linearized and plotted using the equation,

$$\sqrt{E} = \sqrt{B}(Z-\sigma)$$

Energy Dispersive X-Ray Fluorescence

Hitachi SU1510 scanning electron microscope

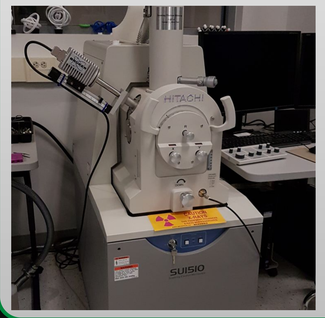
Scanning electron microscopy is a form of electron microscopy in which a beam of electrons is scanned across a sample to image a surface at much higher resolution than optical microscopy. When the beam interacts with the sample, energy is emitted in various forms, including electrons which distinguish not only topography but also composition of the sample.

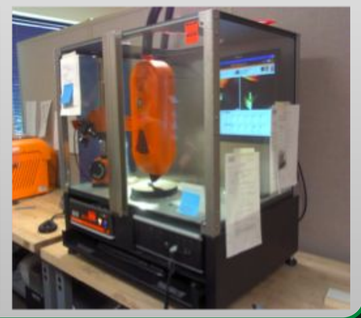
Bruker Quantax EDS solid state detector

The electron beam interacts with the sample, bumping an electron in the sample out of it's orbit. An electron in another shell drops into the vacancy and releases an x-ray that is characteristic of the specimen.

HD prime XRF

X-ray fluorescence (XRF) is a powerful quantitative and qualitative analytical tool for elemental analysis of materials.

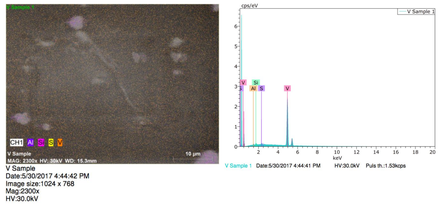




Data Options

1. Select energies from the instrument summary output.

SEM-EDS HD Prime XRF

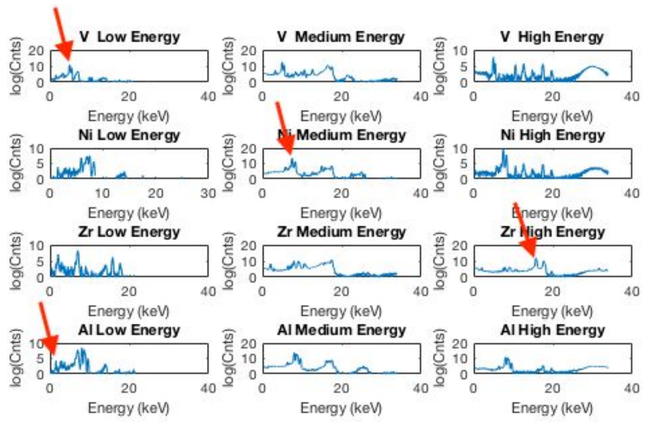


2. csv output

Analysis

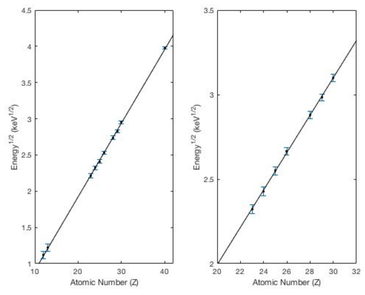
XRF data:

Students create plots for low, medium, and high energies from XRF csv files. Energy peaks are identified from the graphs or using code.



Moseley plots for SEM-EDS: from the SEM-EDS data is plotted to linearize the data, add error bars, and find the line of best fit.

Elements	Z	$K\alpha$ Energy (keV)	$K\beta$ Energy
Mg	12	1.25	–
Al	13	81.5	–
V	23	4.9	5.4
Cr	24	5.4	5.9
Mn	25	5.8	6.5
Fe	26	6.4	7.1
Ni	28	7.5	8.3
Cu	29	8	8.9
Zn	30	8.7	9.6
Zr	40	15.8	–



Uncertainty

Uncertainty calculations for the error bars for the plot and for the slope and y-intercept for the line of best fit.

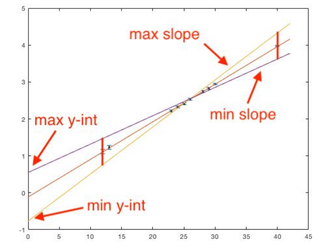
$$\sqrt{E} = \sqrt{B}(Z-\sigma) \qquad m = \sqrt{B}$$

$$dE = 133eV \qquad B = m^2$$

$$Q = x^n \qquad dB = 2\frac{dm}{m}B$$

$$\frac{dQ}{Q} = n\frac{dx}{x} \qquad \sigma = \frac{b}{m}$$

$$d(\sqrt{E}) = \frac{1}{2}\frac{dE}{\sqrt{E}} \qquad d\sigma = \sqrt{(db)^2 + (dm)^2}$$



Specimen	Z	$K\alpha$	$K\beta$
		$\sqrt{dE}(\sqrt{eV})$	
Mg	12	55.9	–
Al	13	51.0	–
V	23	28.2	26.9
Cr	24	26.9	25.7
Mn	25	26.0	24.5
Fe	26	24.7	23.5
Ni	28	22.8	21.7
Cu	29	22.1	21.0
Zn	30	21.2	20.2
Zr	40	15.7	–

Coefficients of line of best fit:

$$B_{K\alpha} = 10.4 \pm 0.01eV, \quad \sigma_{K\alpha} = 1.1 \pm 0.7$$

$$B_{K\beta} = 12.2 \pm 0.02eV, \quad \sigma_{K\beta} = 2.0 \pm 0.4$$

Versatility

The experiment may be used as:

- a TBL activity,
- a short or longer lab, and
- an independent research project.

Analysis can be performed in:

- Excel, Matlab, Excel

Sources

C. W. S. Conover and J. Dudek, An undergraduate experiment on x-ray spectra and Moseley's law using a scanning electron microscope, Am. J. Phys. 64, 335 (1996).

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