Verification and Application of Moseley's Law through X-Ray Spectroscopy

Background

X-ray spectroscopy is a process by which a beam of x-rays is fired at a sample of material. This causes the sample to fluoresce in the x-ray range with a spectrum unique to each element. Spectral lines are labelled using K, L, etc. for the final electron level, and α, β, etc. to describe size of the jump between levels.

These spectral lines are predicted using Moseley's law, which gives a linear relationship between the square root of the frequency of emitted x-rays and the atomic number of the sample:

$$\nu = a(Z-b)^2$$

where $a \equiv \left(\frac{1}{n_f} - \frac{1}{n_i}\right) * cR_\infty$ and b is found experimentally.

In x-ray spectroscopy, one must also account for Bremsstrahlung (braking radiation), a phenomenon whereby incoming x-rays collide with atomic nuclei. This creates a continuous spectrum of lower energies.

Experimental Setup

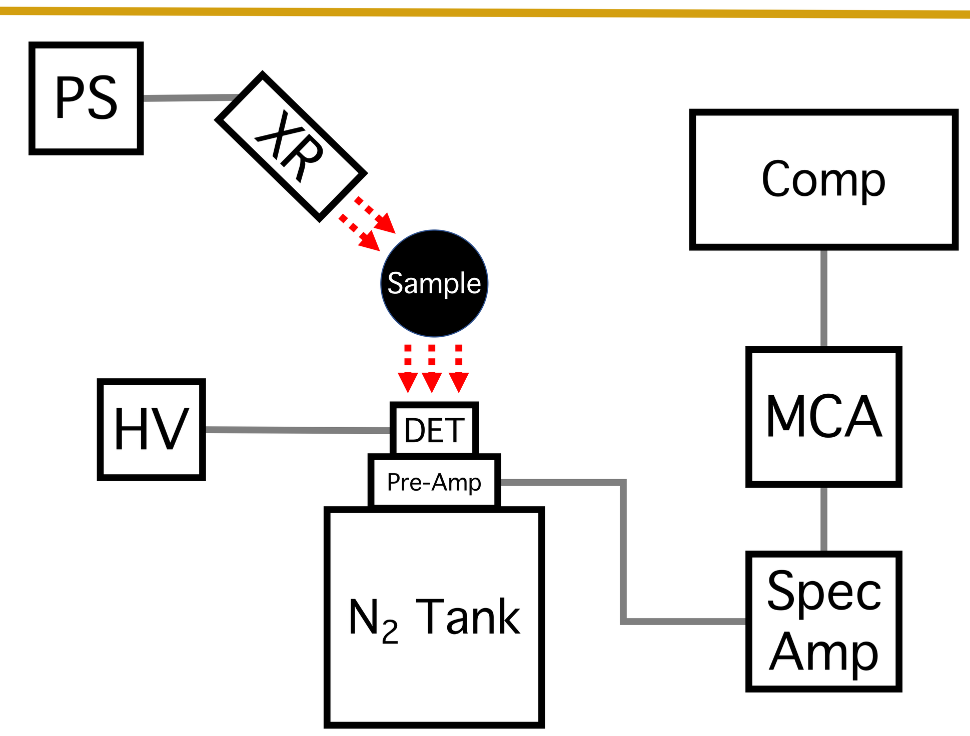

Fig. 1: Block diagram of experimental setup

Samples were placed under an X-ray tube (XR) with its own power supply (PS). Fluoresced photons travelled into a nitrogen-cooled SiLi detector (DET), powered by a high-voltage supply (HV). A pre-amplifier, spectroscopy amplifier, and multichannel analyzer cleaned up the raw signal and converted it into a readable format to be read by the computer. This setup is pictured in Fig. 1.

Spectroscopic Results

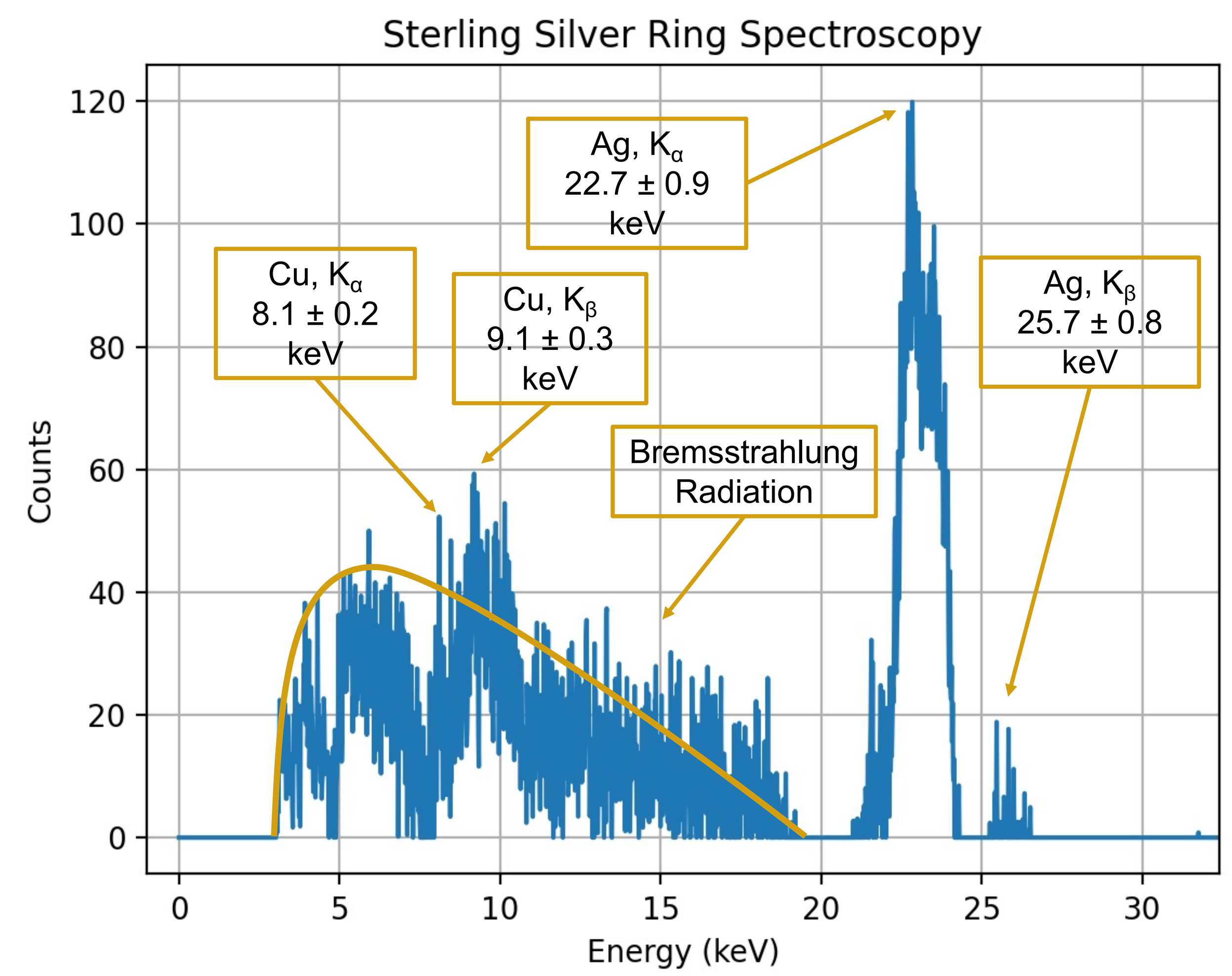

Fig. 2: Annotated spectroscopy results for a sterling silver ring. Background noise has been accounted for.

First, a series of samples of known composition were analyzed. Most samples had very clear K_α and K_β peaks due to the energy range of our detector.

The energies for each peak were determined manually, with the error range being given as the width of the peak. Fig 2. shows an annotated example.

To account for background noise, one run was performed without a sample in place, with the results being subtracted from the spectroscopy data.

Channels were scaled to energy by calibrating with radioactive materials of known energy output.

Table 1: Experimental results for Moseley's law. Included square roots to match with linear plot. *Note that there is no well-established theoretical value for b with K_β.

Line	Cnst.	Theoretical*	Experimental	Offset*
K_α	$\sqrt{a}$	4.97×10^7	$(5.09 \pm 0.05)\times10^7$	±3σ
K_α	b	~1.00	1.26 ± 0.34	±σ
K_β	$\sqrt{a}$	5.41×10^7	$(5.47 \pm 0.09)\times10^7$	±σ
K_β	b		1.87 ± 0.55	

Verifying Moseley's Law

The experimentally determined energy for each K_α and K_β spectral line was converted to the frequency using the following:

$$\nu = E/h$$

where h is Plank's constant. These results were plotted and fit using linear regression. These plots are shown in Fig. 3 and Fig. 4.

The calculated results for a and b from Eq. 1 are given in Table 1, and were determined based on the parameters of the fit lines.

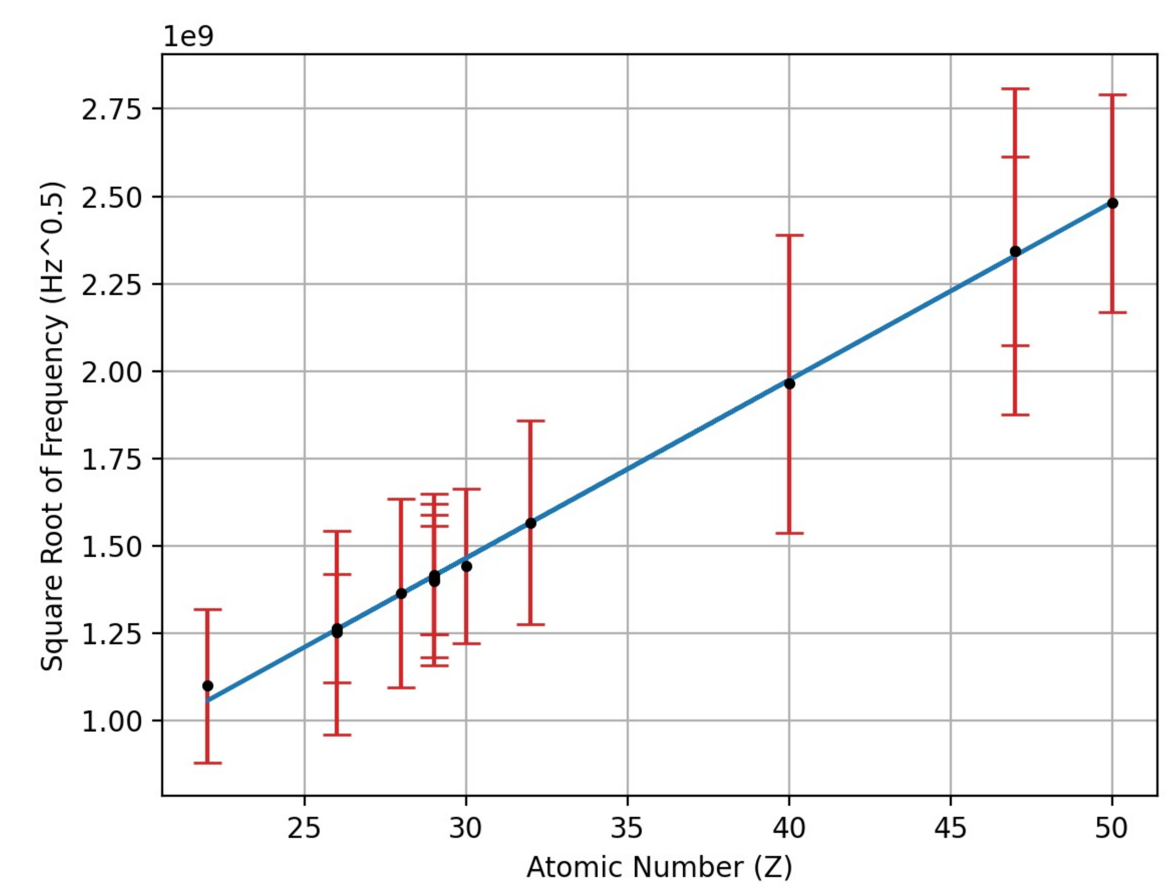

Fig. 3: Overall K_α results, plotted as atomic number vs. square root of frequency.

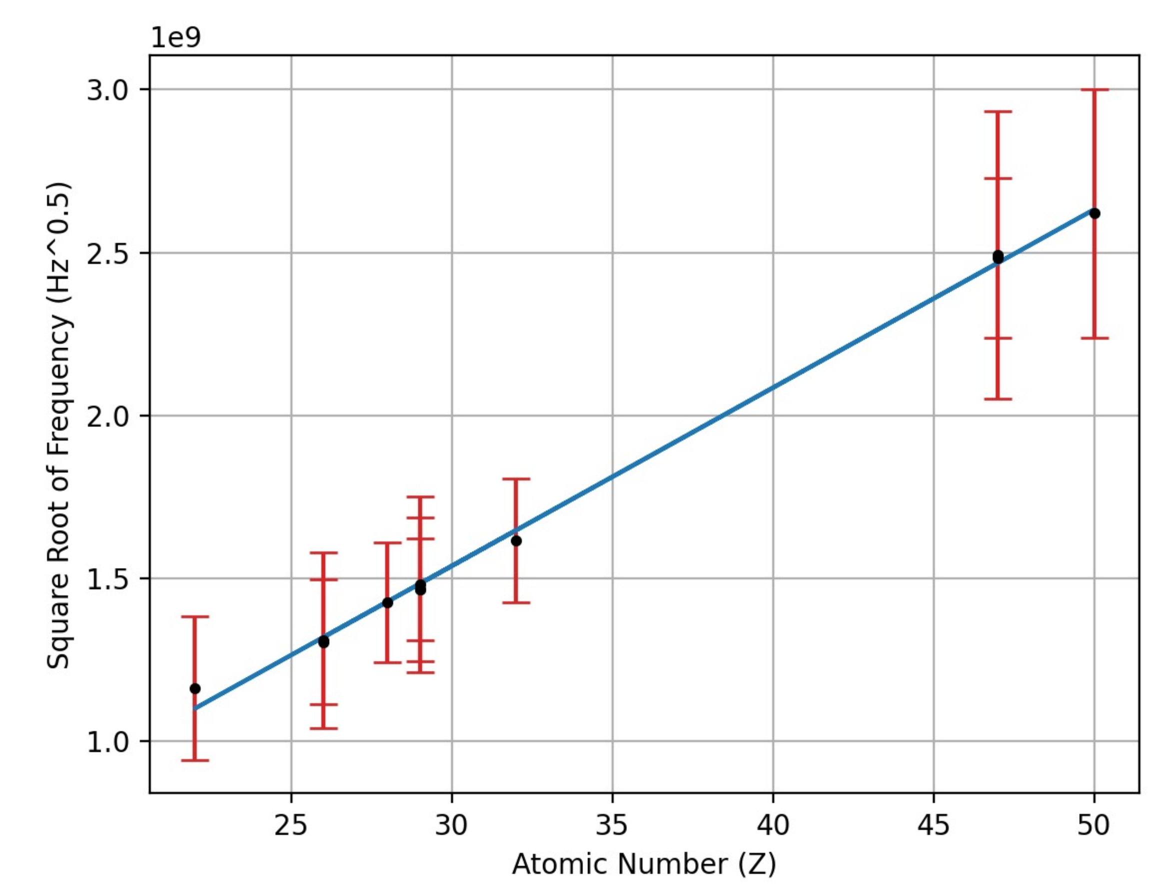

Fig. 4: Overall K_β results, plotted as atomic number vs. square root of frequency

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Unknown Samples

Several unknown samples were analyzed using our experimental results for Eq. 1. By plugging in the peak energies, we can determine the elemental composition. Fig. 5 shows an example of this.

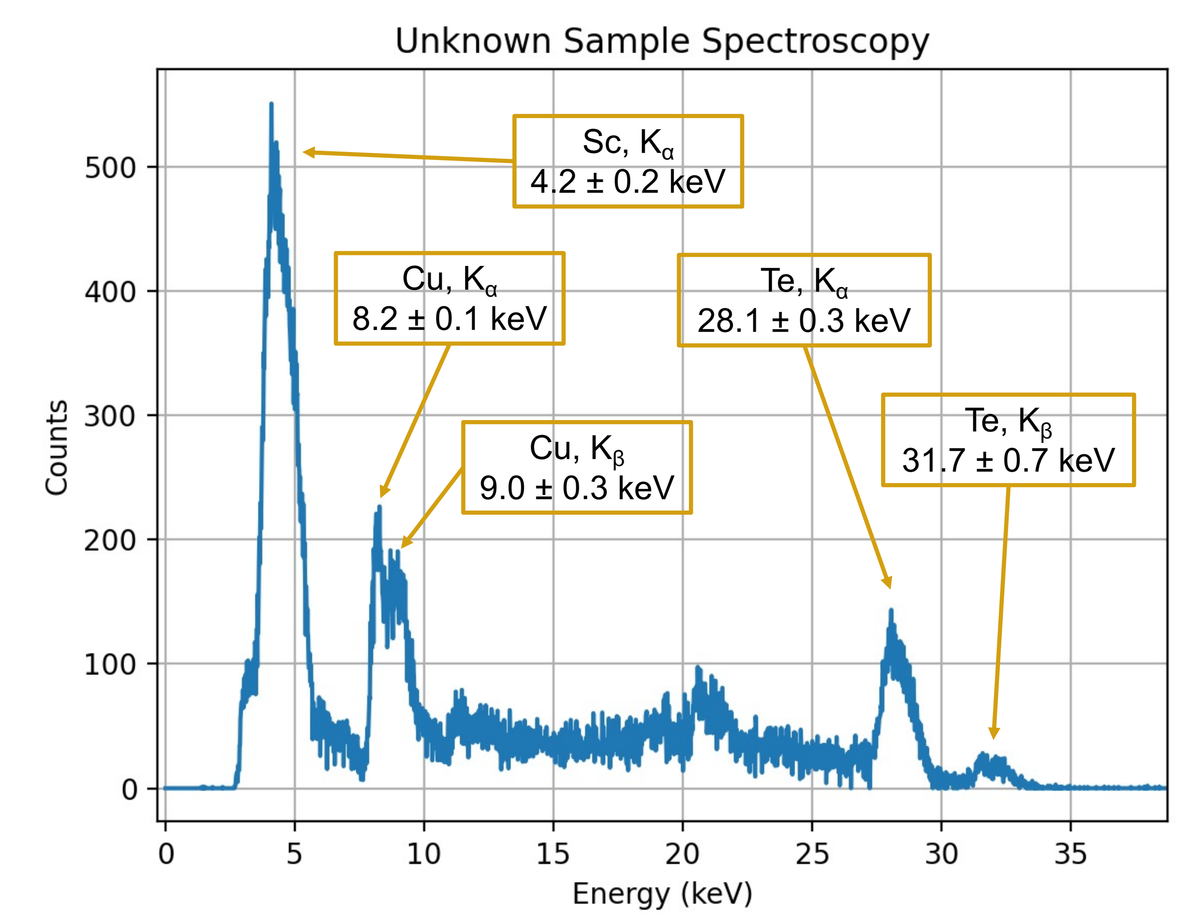

Fig. 5: Annotated spectroscopy results for an unknown sample. Background noise has been accounted for.

Discussion

The results here were well in line with the predictions of Moseley's law. While the peaks did seem to come in at energies above the literature value (either due to imprecise calibration or through calibration drift), by recalculating the constants in Moseley's law it was possible to account for this, thus reliably predicting the composition of unknown samples.