X-Ray Fluorescence

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January 21, 2011

Abstract

X-ray fluorescence is explored in this lab using a germanium X-ray detector, several radioactive sources and five unknown samples. The sources emit gamma rays which excite the electrons in the sample to a higher orbital level. Upon returning to a lower orbital level the electron emits a photon with a certain energy specific to the element. The detector can measure this energy and after a calibration process the element can be identified. This process was used to identify samples 1, 2, 3, 4 and 5 as tungsten (1), plantium and frankium (2), an alloy of gold, silver and copper (3), einsteinium (4) and a mixture of plutonium and cinnamon (5).

1 Theory

X-ray fluorescence is the process of the emission of characteristic X-rays from a sample which has been irradiated by a radioactive source. This process can be used to identify an unknown material as each element has it's own characteristic rays of certain known energies.

A source emitting X-rays of sufficient energy is used to excite the orbital electrons in the given sample to a higher state. The electrons can absorb

certain values of energy raising them to a higher orbital and after a short period drop down to a lower energy state and emit a photon, this is referred to as fluorescence. Due to the quantized nature of the electron orbitals the emitted X-rays will also be quantized and have known values which are specific to each element, and will have the energy of the potential difference of the orbital drop.

The change in electron orbital energy releases a photon which can be between several different orbital level pairs. The photon emitted in the drop in energy from the second lowest shell (the L shell) to the lowest energy shell (the K shell) is the K_α X-ray. Similarly the electron dropping from the M shell to the K shell emits the K_β ray, as seen in Figure 1

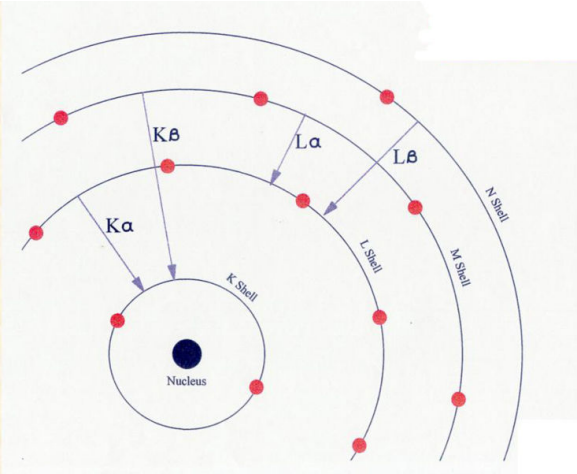

Figure 1: Diagram of electron transitions and their labels in a calcium atom [2]

Atoms can also de-excite by the 'Auger Effect' whereby the excess energy of an inner excited electron passes the energy to an outer electron and this

outer electron is expelled from the atom. [2]

By referring to a table of X-ray emissions for each element one can identify a given sample by analyzing the energy of the released X-rays. For this an X-ray detector must be used as well as an exciting source. In this experiment a germanium X-ray detector was used.

To reduce thermal noise on the detector due to the small band gap of germanium, the structure is cooled to about $-200°C$ using liquid nitrogen. This reduces thermal generation of charge carriers and thus the measured leakage current to a level deemed acceptable. [1]

2 Apparatus / Experimental Procedure

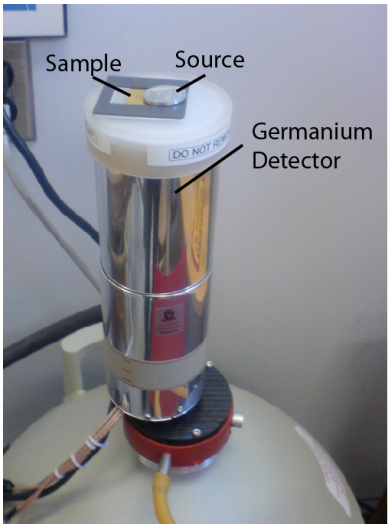

Figure 2: Setup of the germanium X-ray detector with a source and sample

- Radioactive sources Am^{241} and Co^{57}
- Canberra Germanium X-ray detector
- Unknown Samples 1, 2, 3, 4, 5
- Ortec 117B pre-amplifier
- Ortec 450 amplifier
- Aptec Multi-Channel Analyzer (MCA - 4096 channels) with spectral analysis software

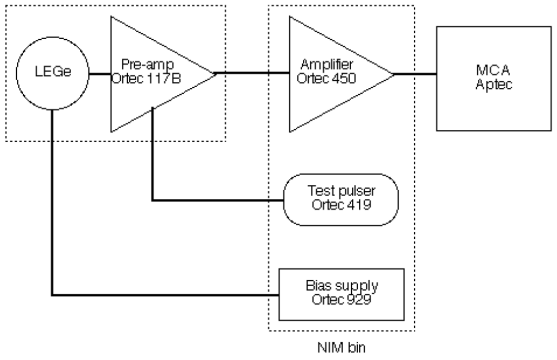

Figure 3: Setup of the germanium X-ray detector with amplifiers, hardware and the MCA

3 Experimental Results

3.1 Calibration

The first and main calibration curve can be seen in Figure 4 and was obtained using the calibration spectrum Figure 5 and the known peak energies in Table 1. The main peaks of Am^{241} as well as the two K_α peaks of gold, other peaks

caused by the excitation of neptunium (the element to which americium decays) were not used in the calibration. The second calibration data and curve used for sample 3 can be seen in Appendix A.

Peak Energy (keV)	Peak Label	Channel Number	FWHM
11.887	Am^{241}	557.39	14.41
13.9	Am^{241}	652.61	17.65
17.8	Am^{241}	828.95	17.54
20.8	Am^{241}	969.21	18.49

Table 1: Calibration source X-ray energies and measured channel number

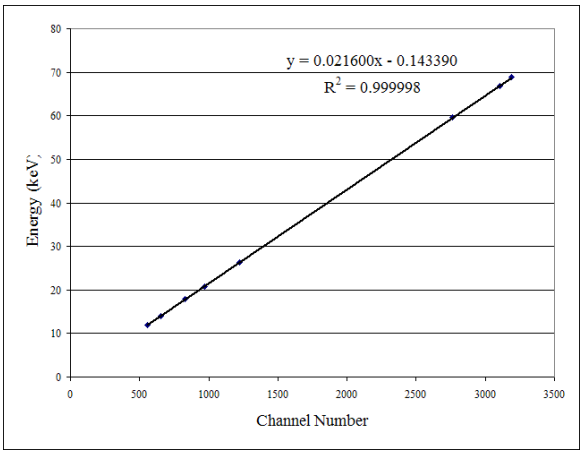

Figure 4: Calibration curve used to convert channel number to X-ray energy

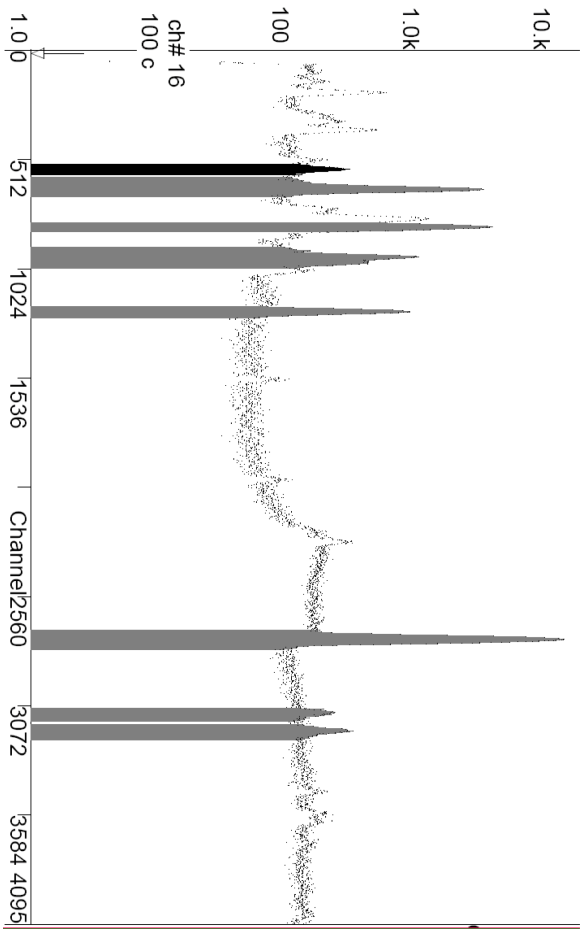

Figure 5: Spectrum of Am^{241} and Gold used for the calibration of channel number to X-ray energy

References

[1] Canberra Industries Inc., "Germanium Detectors," (80D Research Parkway, Meriden, CT 06450 U.S.A.)

[2] "X-Ray Fluorescence," *http://en.wikipedia.org/wiki/X-ray_fluorescence*, Accessed on March 27^th 2007.

[3] "Thorium," *http://en.wikipedia.org/wiki/Thorium*, Accessed on March 27^{th} 2007.

[4] "Tungsten," *http://en.wikipedia.org/wiki/Tungsten*, Accessed on March 27^{th} 2007.

A Source Data

Source	Line Energy keV	Sigma	Relative Intensity (%)
Co^{57}	14.36	0.05	11
	121.97	0.05	100
	136.3	0.04	13

Table 2: Source energy lines, relative intensity, sigma of the peaks and half lives