

Name _____
 PIXE Homework #2 - Physics 100
 Union College Fall 2025

1. Describe the PIXE process using words and/or diagrams. If you use a diagram, please explain what the diagram is about.

PIXE stands for proton induced x-ray emission spectroscopy. This is a technique whereby a high-energy proton interacts with a target nucleus ejecting an electron from an inner atomic orbital of the target atom. An electron from a higher atomic orbital de-excites to the vacancy in the lower atomic orbital with an emission of an x-ray photon. The energy of the photon is characteristic of the atomic nucleus.

2. What are the K_α and K_β transition energies for the following elements: $^{40}_{20}\text{Ca}$, $^{59}_{27}\text{Co}$, and $^{197}_{79}\text{Au}$? (Please use the equations given in the lecture and not the table of x-ray energies to do the calculation.)

The x-ray energies are given by $\Delta E = -Z^2 \frac{me^4}{2(4\pi\epsilon_0)^2 \hbar^2} \left(\frac{1}{n_i^2} - \frac{1}{n_u^2} \right)$, where for the α -transition we have $n_u = 2 \rightarrow n_i = 1$ and for a β -transition $n_u = 3 \rightarrow n_i = 1$. Thus, for a K_α transition (evaluating the constants) we have

$$\Delta E_\alpha = -Z^2 \frac{me^4}{2(4\pi\epsilon_0)^2 \hbar^2} \left(\frac{1}{n_i^2} - \frac{1}{n_u^2} \right) = -Z^2 \left[\frac{9.11 \times 10^{-31} \text{ kg} \times (1.6 \times 10^{-19} \text{ C})^4}{32\pi^2 \left(8.85 \times 10^{-12} \frac{\text{C}^2}{\text{Nm}^2} \right)^2 \left(\frac{6.63 \times 10^{-34} \text{ Js}}{2\pi} \right)^2} \right] \left(\frac{1}{1} - \frac{1}{4} \right)$$

$$\Delta E_\alpha = (1.626 \times 10^{-18} \text{ J}) Z^2 = (10.16) Z^2$$

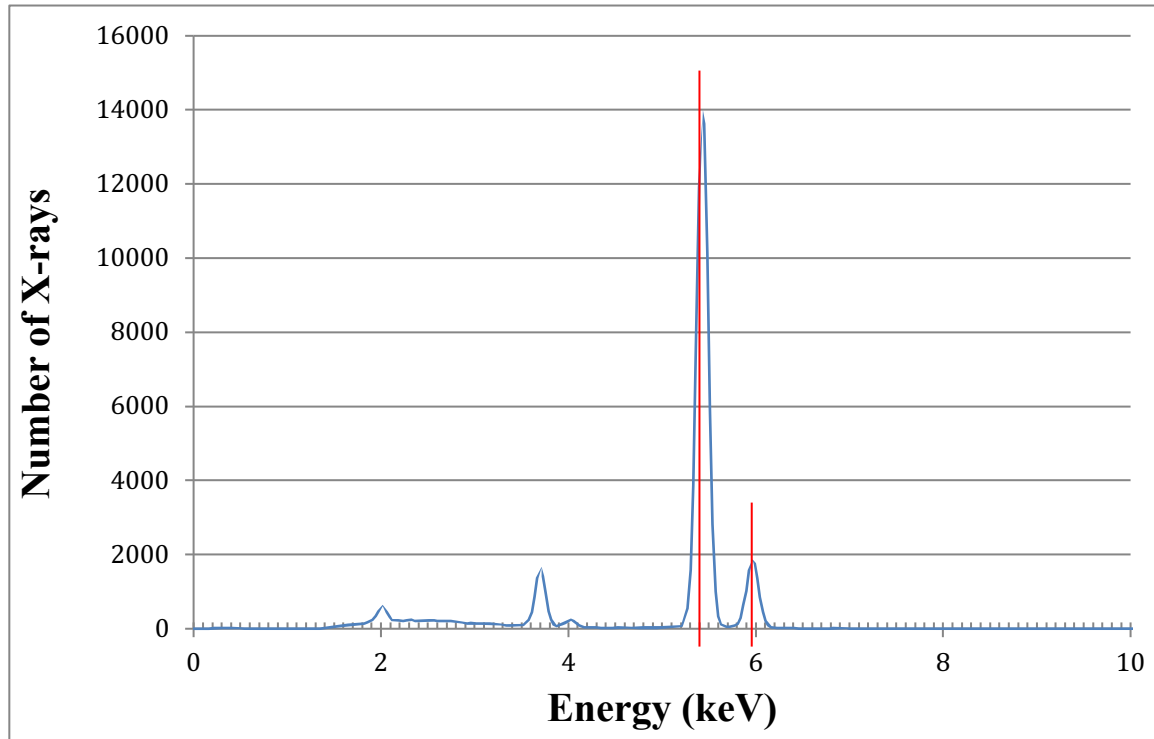
, while for a K_β transition

$$\Delta E_\beta = -Z^2 \frac{me^4}{2(4\pi\epsilon_0)^2 \hbar^2} \left(\frac{1}{n_i^2} - \frac{1}{n_u^2} \right) = -Z^2 \left[\frac{9.11 \times 10^{-31} \text{ kg} \times (1.6 \times 10^{-19} \text{ C})^4}{32\pi^2 \left(8.85 \times 10^{-12} \frac{\text{C}^2}{\text{Nm}^2} \right)^2 \left(\frac{6.63 \times 10^{-34} \text{ Js}}{2\pi} \right)^2} \right] \left(\frac{1}{1} - \frac{1}{9} \right)$$

$$\Delta E_\beta = (1.927 \times 10^{-18} \text{ J}) Z^2 = (12.04 \text{ eV}) Z^2$$

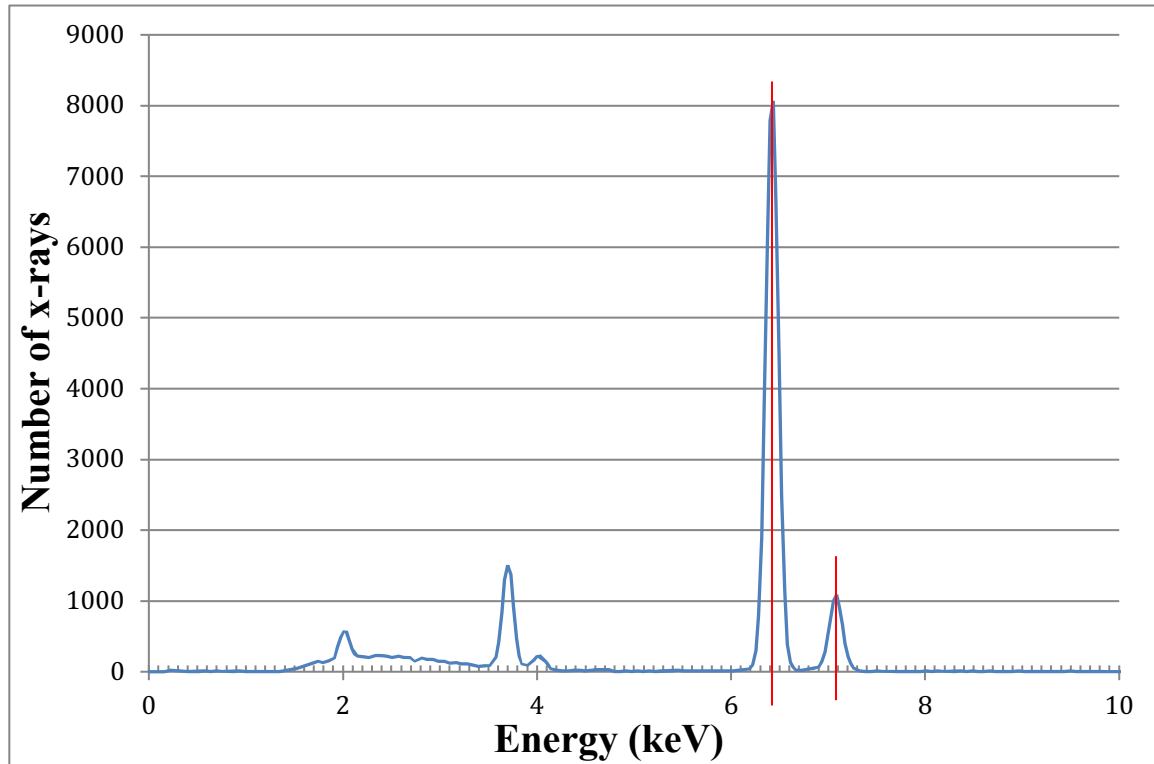
Element	ΔE_α (keV)	ΔE_α (J)	ΔE_β (keV)	ΔE_β (J)
$^{40}_{20}\text{Ca}$	4.064	6.5×10^{-16}	4.816	7.7×10^{-16}
$^{59}_{27}\text{Co}$	7.407	1.19×10^{-15}	8.78	1.4×10^{-15}
$^{197}_{79}\text{Au}$	63.41	1.02×10^{-14}	75.14	1.2×10^{-14}

3. Given the *PIXE* spectrum of a single element standard shown below, what is the element indicated by the red lines? Hint: Approximate the energy of the peaks and use the unmodified energy equations to determine the atomic number of the element. You may need to use a periodic table to identify the element.



The energy of the K_{α} peak is approximately 5.4keV, while the K_{β} peak is 6.0keV. Using the formula from problem #2 we can calculate the atomic number of the unknown element. Using the K_{α} energy, we have $\Delta E_{\alpha} = 5.4\text{keV} = (10.16\text{eV})Z^2 \rightarrow Z = 22.5$ and thus the element could be either Ti ($Z = 22$) or V ($Z = 23$). From the K_{β} energy, we have $\Delta E_{\beta} = 6.0\text{keV} = (12.04\text{eV})Z^2 \rightarrow Z = 22.4$ and thus the element could be either Ti ($Z = 22$) or V ($Z = 23$). Most likely we'd choose titanium.

4. Given the *PIXE* spectrum of a single element standard shown below, what is the element indicated by the red lines? Hint: Approximate the energy of the peaks and use the unmodified energy equations to determine the atomic number of the element. You may need to use a periodic table to identify the element.



The energy of the K_{α} peak is approximately 6.4keV, while the K_{β} peak is 7.1keV. Using the formula from problem #2 we can calculate the atomic number of the unknown element. Using the K_{α} energy, we have $\Delta E_{\alpha} = 6.4\text{keV} = (10.16\text{eV})Z^2 \rightarrow Z = 25$ and thus the element could be Mn ($Z = 25$). From the K_{β} energy, we have $\Delta E_{\beta} = 7.1\text{keV} = (12.04\text{eV})Z^2 \rightarrow Z = 24.3$ and thus the element could be either Cr ($Z = 24$) or Mn ($Z = 25$). We'd most likely choose chromium.