

1. Describe the PIXE process.

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: ${}^{19}_9F$, ${}^{59}_{27}Co$, and ${}^{197}_{79}Au$? (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 $n_u = 2 \rightarrow n_l = 1$ and for a β -transition $n_u = 3 \rightarrow n_l = 1$. Thus for a K_α transition (evaluating the constants) we have

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

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

, while for a K_β transition

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

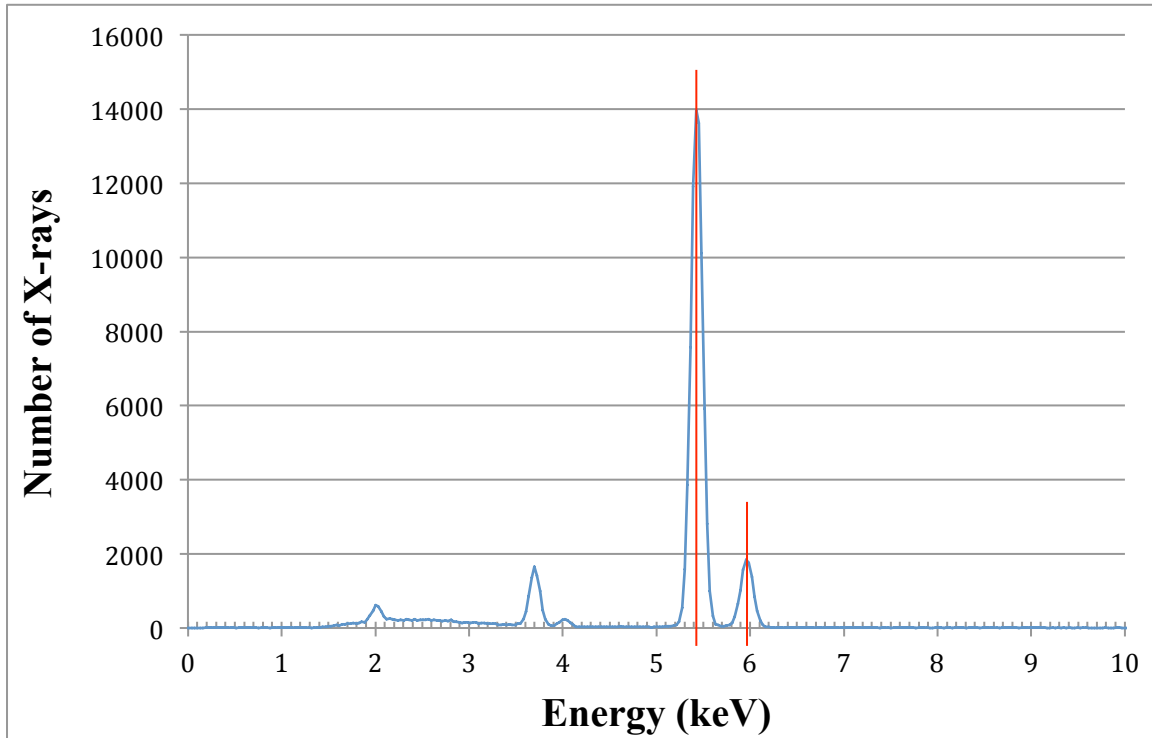
$$\Delta E_\beta = (1.927 \times 10^{-18} \text{ J}) Z^2 = (12.04 \text{ eV}) Z^2$$

Element	ΔE_α (keV)	ΔE_α (J)	ΔE_β (keV)	ΔE_β (J)
${}^{19}_9F$	0.822	1.31×10^{-16}	0	0
${}^{59}_{27}Co$	7.407	1.19×10^{-15}	8.78	1.40×10^{-15}
${}^{197}_{79}Au$	63.41	1.02×10^{-14}	75.14	1.20×10^{-14}

3. What is the ratio of the K_α energies of $^{238}_{92}\text{U}$ to $^{12}_6\text{C}$?

Using the formula above: $\frac{U_{K_\alpha}}{C_{K_\alpha}} = \frac{(92)^2}{(6)^2} = 235$ where all of the constants cancel by taking the ratio.

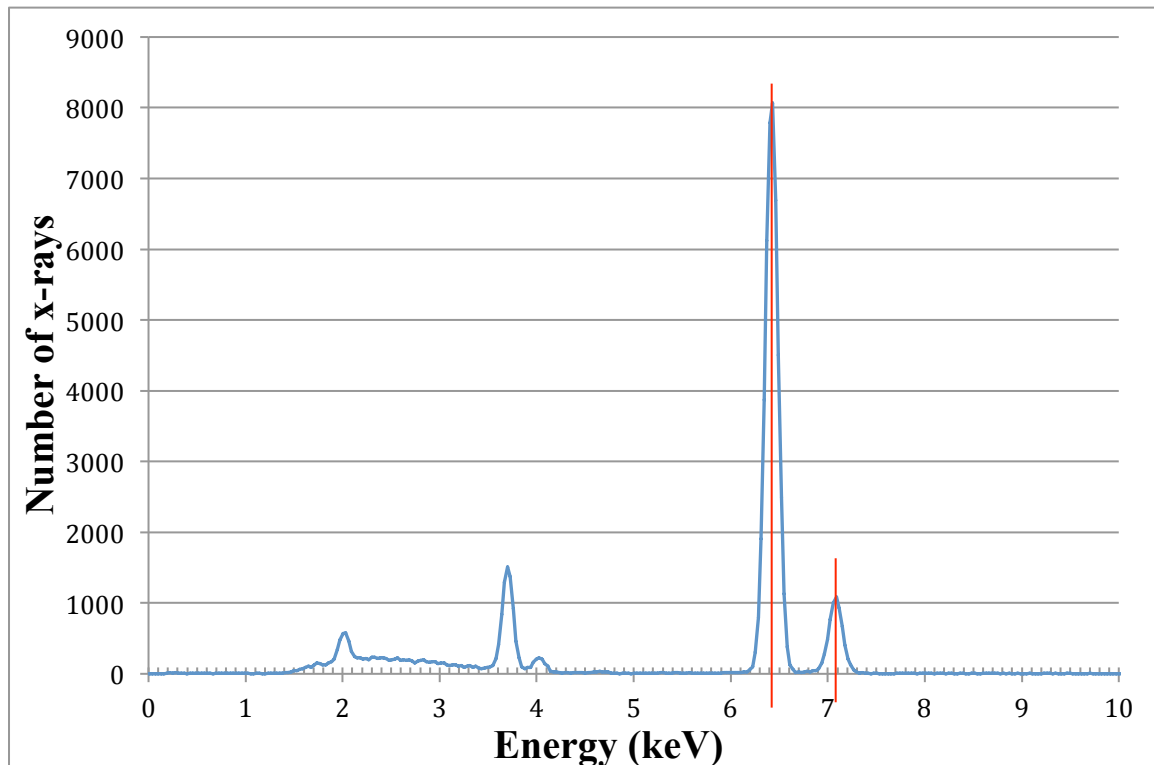
4. Given the PIXE spectrum of a single element standard shown below, what are the elements?



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 ($Z = 23$).

5. Given the *PIXE* spectrum of a single element standard shown below, what are the elements?



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 ($Z = 25$).