MATE 318

Spring 2025

Homework #6

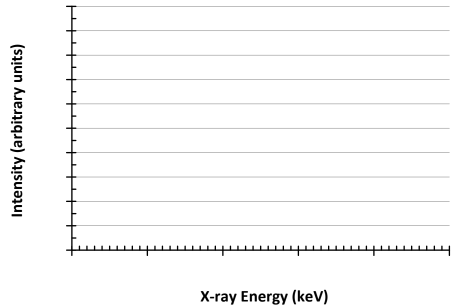
Due: May 30th, 2025

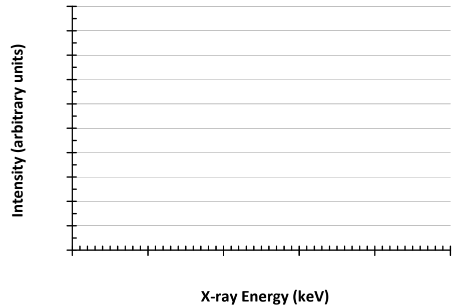
Group submission (up to 3 students per group) is allowed.

Question 1

a) **On the figures below, sketch as accurately as you can the <u>K_α x-ray energy spectrum</u> measured with an EDX detector in an electron microprobe for a sample consisting of a homogeneous solder alloy of composition 37 wt.% Pb and 63 wt.% Sn. Assume an electron beam energy of 90 keV was used. State other assumptions you make (if any).**

b) **How would the spectrum differ if the electron beam energy was 45 keV? Why?**





To make a rough estimate of the EDX x-ray spectrum, we calculate the K_{alpha} x-ray energies for Pb and Sn as 74.04 and 25.12 keV, respectively.

From the appendix we read Pb K_α as 0.1674 Å and Sn K_α as 0.4933Å.

Energy of an x-ray = hc/λ

For Pb = $([6.61\times10^{-34} * 3\times10^{8}]/0.1674\times10^{-10})$= 1.185×10^{-14} J

$1.185\times10^{-14} / 1.6\times10^{-19}$ = **74037 eV = 74.04 keV**

For Sn = $([6.61\times10^{-34} * 3\times10^{8}]/0.4933\times10^{-10})$= 4.019×10^{-14} J

$4.019\times10^{-14} / 1.6\times10^{-19}$ = **25124 eV = 25.12 keV**

We have to convert weight percentages into atomic percentages:

Atomic weight of Pb = 207.2 g/mole, Atomic weight of Sn = 118.71 g/mole,

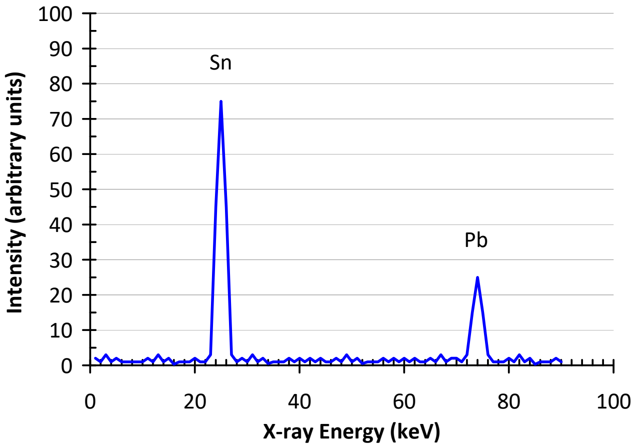
For Pb: 100*(37/207.2) / [(37/207.2) + (63/118.71)] = **25.2 at.% Pb**

For Sn: 100*(63/118.71) / [(37/207.2) + (63/118.71)] = **74.8 at.% Sn**

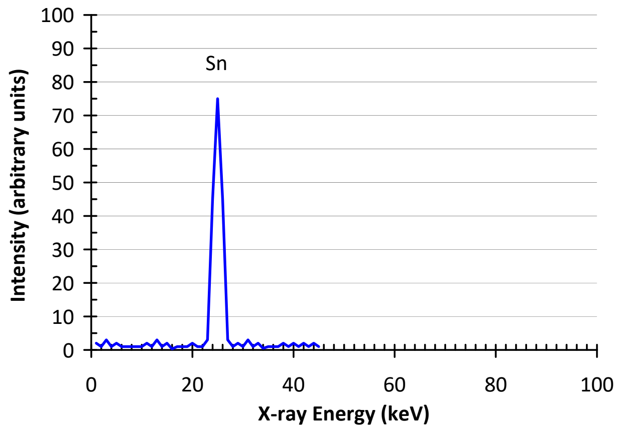
The peaks should appear such that the area under the peaks has the ratio of Sn/Pb = 74.8/25.2 ≅ 3.

If the peaks have the same width, then the area is directly proportional to the height of the peak.

a) for an electron beam energy of 90 keV:



b) The incident electron beam energy (45 keV) is not large enough to excite the K_{alpha} Pb x-ray, and so Pb peak does not appear.



Question 2

EDS counts of two Ti-Al-Nb ternary alloy samples one with a composition of 45 at.% Al and 4 at.%Nb, and the other with unknown composition are given in the table below. Determine the composition of the unknown alloy.

		Ti Kα	Al Kα	Nb Kα
Reference Sample	Comp. (at.%)	51	45	4
	EDS Count	15228	6335	918
Unknown Sample	Comp. (at.%)	?	?	?
	EDS Count	14391	5132	831

Question 2

The EDS counts of a Ti - 45 at.% Al – 4 at.%Nb alloy and a Ti-Al-Nb alloy of unknown composition are given in the table below. Determine the composition of the unknown alloy.

		Ti Kα	Al Kα	Nb Kα
Reference Sample	Comp. (at.%)	51	45	4
	EDS Count	15228	6335	918
Unknown Sample	Comp. (at.%)	100 -(x+y)	x	y
	EDS Count	14391	5132	831

Nb to Al ratio

4/45 ↔ 918/6335

y/x ↔ 831/5132

y/x = 0.0993 **y = 0.0993x**

Al to Ti ratio

45/51 ↔ **5132/14391**

x /(100-(x+y)) ↔ **6335/15228**

(45/51)*(5132/14391) = [x /(100-(x+y))]*(6335/15228)

(45/51)*(5132/14391) = [x /(100-(x+0.0993x))]*(6335/15228)

0.75637 = x /(100-(1.0993x)

75.637 -0.8315x = x

75.637 = 1.8315x

x = 41.3 at.% Al
y = 0.0993*41.3 = 4.1 at.% Nb
100 - (41.3 + 4.1) = 54.6 at.% Ti

Al to Ti ratio

(45/51)*(5132/14391) = [x /(100-(x+y))]*(6335/15228)

Nb to Ti ratio

(4/51)*(831/14391) = [y /(100-(x+y))]*(918/15228)

Solving these two equations with two unknowns would give the same results.

Question 3

A WDS spectrometer which uses (200) planes of LiF as the analyzing crystal detects x-ray peaks from a sample at 24.31° and 43.02° in θ. Assuming that the detected peaks are Kα peaks, determine which elements are present in this sample.

d(200) of LiF = 0.2015 nm **$\lambda = 2d\sin\theta$**

$\lambda 1 = 2d\sin\theta_1$

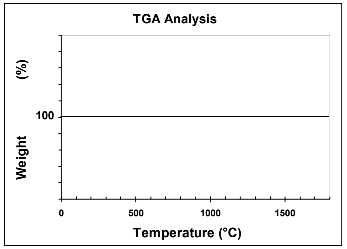
$\lambda 1$ = 2*0.2015nm*sin(24.31°) = 0.16590 nm
Closest match is Ni Kα (weighted ave: 0.165919nm)

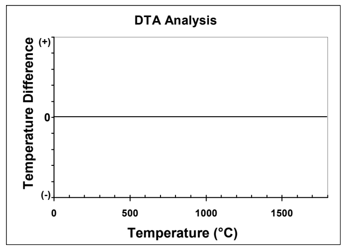
$\lambda_2 = 2d\sin\theta_2$

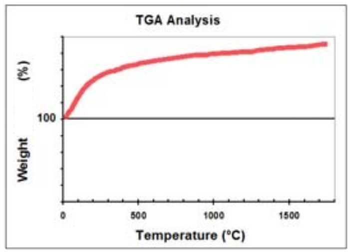
λ_2 = 2*0.2015nm*sin(43.02°) = 0.27495 nm
Closest match is Ti Kα (weighted ave: 0.274973nm)

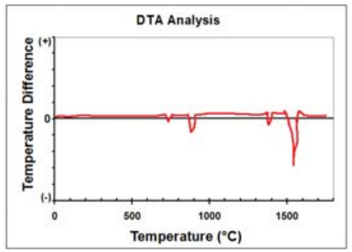
Question 4

A sample of pure iron has been analyzed in ambient air using a combined TGA-DTA instrument with a heating rate of 1°C/min. Schematically draw the TGA and DTA curves you would expect for the temperature range of 0°C-1600°C.





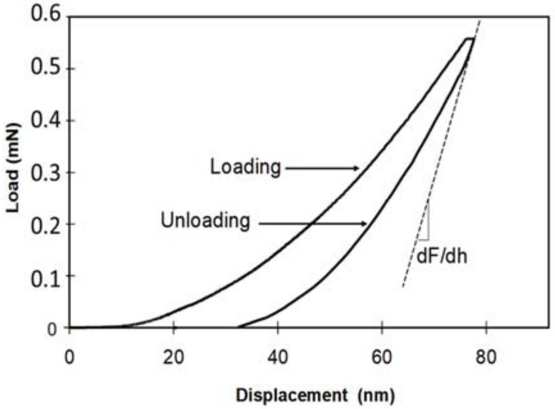


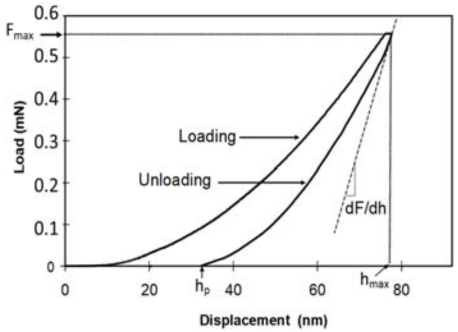


Question 5:

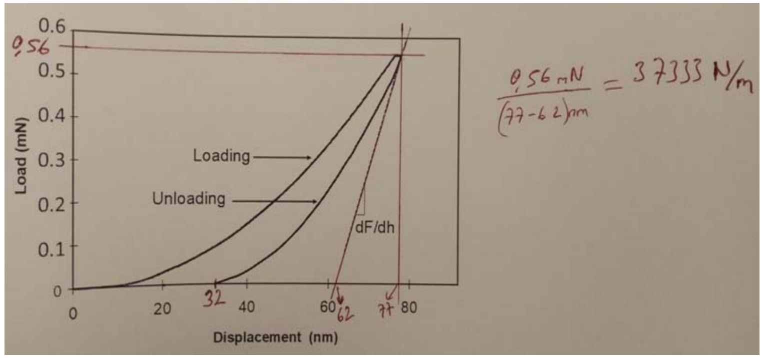
The load vs. displacement curve given below belongs to a nanoindentation test performed on a hard coating using a diamond tip with perfect Berkovich geometry. Find the hardness (H) and elastic modulus (E) values of this coating in GPa.

For diamond take E as 1000 GPa and the Poisson's ratio as 0.06. Take the Poisson's ratio of the coating as 0.21. Take β as 0.75.





From the graph, we measure h_{max} as 77 nm, h_p as 32 nm, and F_{max} as 0.56 mN



$A = 24.5h^2$

$A_{max} = 24.5 \times (77\text{nm})^2 = 1.45 \times 10^{-13}\ \text{m}^2$

$A_p = 24.5 \times (32\text{nm})^2 = 2.51 \times 10^{-14}\ \text{m}^2$

$\mathbf{H = F_{max} / A_p} = 0.56 \times 10^{-3}\ \text{N} / 2.51 \times 10^{-14}\ \text{m}^2$

$= 2.23 \times 10^{10}\ \text{N/m}^2 = 2.23 \times 10^{10}\ \text{Pa} =$ **22.3 GPa**

$$\frac{dF}{dh} = \beta \left(\frac{2}{\sqrt{\pi}} \right) E^* \sqrt{A_{max}}$$

dF/dh = **37333 N/m** = $0.75(2/\sqrt{\pi}) \times \mathbf{E^*} \times \text{sqrt}(1.45 \times 10^{-13}\ \text{m}^2)$

$E^* = 1.16 \times 10^{11}$ Pa

$$\frac{1}{E^*} = \frac{(1 - v_i^2)}{E_i} + \frac{(1 - v_s^2)}{E_s}$$

$1 / (1.16 \times 10^{11}) = (1 - 0.06^2) / (1000 \times 10^9) + (1 - 0.21^2) / E_s$

$\mathbf{E_s} = 1.25 \times 10^{11}$ Pa = **125 GPa**