**Medical Imaging Physics**

**Quiz 1 (x-rays): 29th August 2024; Time: 45 min**

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| Question no. | 1 | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|---|
| Marks allotted | 5 | 8 | 3 | 6 | 3 | 25 |
| Marks obtained | 5 | 7.5 | 3 | 6 | 3 | 24.5 |

1. (a) Why do we use tungsten as anode material? [3]

① Tungsten has high MP (melting point) (around 3300°C) so it will not melt easily due to getting heated up.

② Tungsten has high atomic number (Z), hence its nucleus exerts stronger ~~forces on attraction~~ electrostatic forces on the ~~e~~ tube current e's passing through and hence contribute to higher brehmstralling. Since the rays ~~be~~ will be slowed down more, if Z is high.

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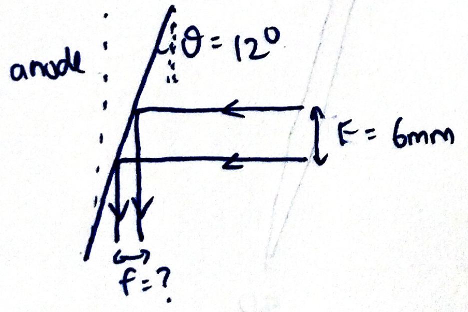
③ Tungsten has lower vapor pressure, so the vaccuum integrity of the tube is maintained (very few or no tungsten atoms will enter the vaccum as gas)

④ Tungsten has good structural integrity.

(b) For an anode bevelled at 12°, what will be the size of the focal spot on patient's side when a filament of 6 mm is used? [2]




$f = F\tan\theta$

$\therefore f = 6\tan(12°) = 1.275\text{ mm}$

Hence focal spot on patient's side will be $\underline{1.275\text{mm}}$

2

2. Sketch all four spectra <u>in the same plot</u> for this question. **Otherwise, you will not get any marks**. Clearly label the plots as (a), (b), (c) and (d).

| Shell | Tungsten (keV) | Molybdenum (keV) |
|---|---|---|
| K | 69.5 | 20 |
| L | 10.2-12.1 | 2.5-2.8 |
| M | 1.9-2.8 | 0.4-0.5 |

(a) Sketch the x-ray spectrum of molybdenum when the x-ray tube is operated at a tube voltage of 15 keV. [2 marks]

(b) On the same plot, now sketch the x-ray spectrum of molybdenum when the x-ray tube is operated at a tube voltage of 40 keV. [2 marks]

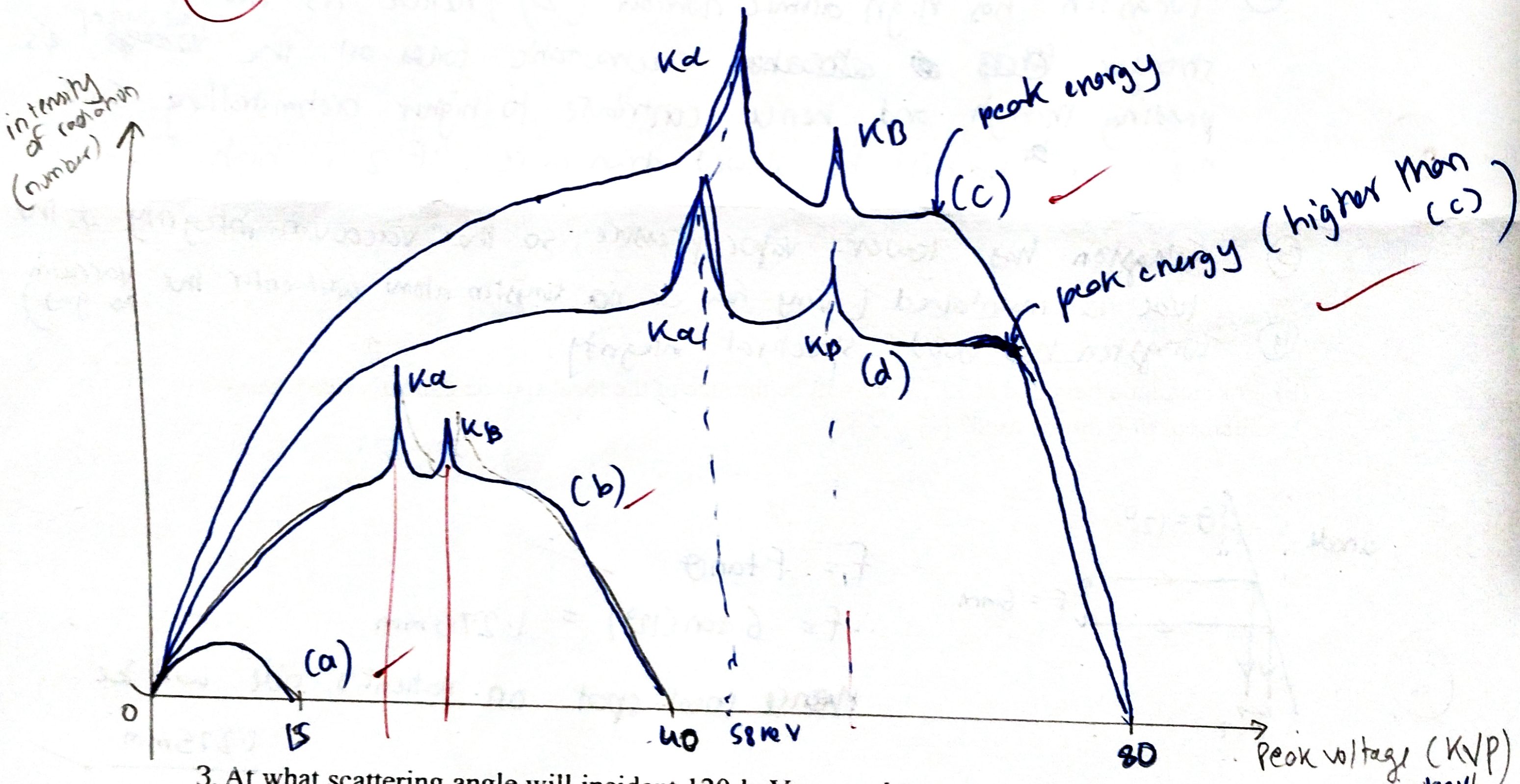
(c) Sketch the x-ray spectrum if the molybdenum target is replaced by a tungsten target operating at 80 keV. [2 marks]

(d) Sketch the qualitative shape of the x-ray spectrum when an external filter of 1 mm thickness is put in the path of the x-ray beam emanating from the tungsten target being operated at 80 keV. [2 marks]

Characteristic rays:

| | Tungsten | Molybdenum |
|---|---|---|
| $K\alpha$ (L→K) | $= 69.5 - \frac{(10.2+12.1)}{2}$ | $20 - \frac{(2.5+2.8)}{2}$ |
| | $= 58.35$ keV | $= 17.35$ keV |
| $K\beta$ (M→K) | $= 69.5 - 2.35$ | $20 - \frac{(0.4+0.5)}{2}$ |
| | $= 67.15$ keV | $= 19.55$ keV |

7.5



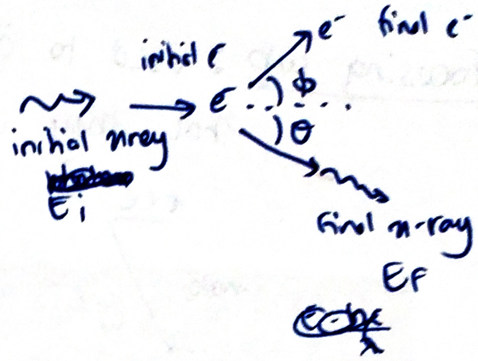

3. At what scattering angle will incident 120-keV x-rays leave a target with an energy of 100 keV? [3]

This phenomenon is compton scattering.

change in wavelength b/w initial & final x-ray

$$\Delta\lambda = \frac{h}{m_0 c}(1-\cos\theta)$$

x-ray scattering angle




$$\frac{hc}{E_f} - \frac{hc}{E_i} = \frac{h}{m_0 c}(1-\cos\theta)$$

$\left(\because \text{ substituting } E = \frac{hc}{\lambda}\right)$

$$\therefore \frac{1}{E_f} = \frac{1}{E_i} + \frac{(1-\cos\theta)}{m_0 c^2}$$

( rest mass for $e^-$ corresponds to 0.5 MeV

$\therefore m_0 c^2 = 0.5\,\text{MeV}$ )

$$\therefore \frac{1}{E_f} = \frac{1}{E_i} + \frac{1-\cos\theta}{0.5\,\text{MeV}}$$

we know $E_f = 100\,\text{keV}$, $E_i = 120\,\text{keV}$

$$\therefore \frac{1}{0.1\,\text{MeV}} = \frac{1}{0.12\,\text{MeV}} + \frac{1-\cos\theta}{0.5\,\text{MeV}}$$

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$$\therefore \frac{1}{0.1} - \frac{1}{0.12} = \frac{1-\cos\theta}{0.5}$$ (all units in MeV)

$$\therefore \frac{0.02}{0.1\times0.12} = \frac{1-\cos\theta}{0.5}$$

$$\therefore 1-\cos\theta = \frac{0.02\times0.5}{0.1\times0.12} = \frac{0.\cancel{01}}{\cancel{0.1}_{10}\times0.12} = \frac{1}{1.2} = 0.833$$

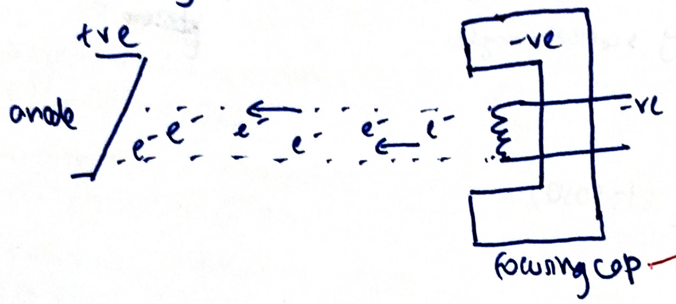
$$\therefore \cos\theta = 1-0.833 = 0.1667$$

$$\therefore \theta = \cos^{-1}(0.16667) = 80.406°$$

$\therefore$ at 80.406° scattering angle, 120keV x-rays leave target with 100keV energy

4. Explain with sketches the different mechanisms that we put in the X-ray tube to ensure a tight focal spot. [6]

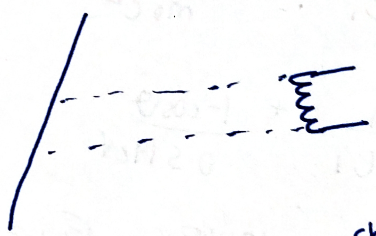
① **Focusing cup**: used to focus beam of $e^-$'s in tube current towards anode so that they don't diverge. This helps keep tight focal point.




The focusing cup is also negatively charged like the cathode filament, to repel electron and prevent their divergence.

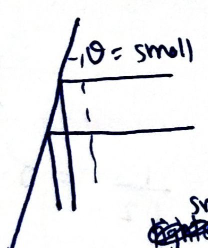
② Short filament helps keep tight focus.

If filament is long, focal spot bigger.

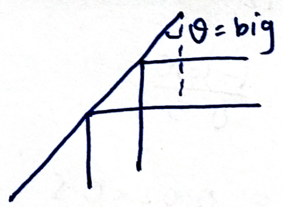


If filament is short, focal spot is smaller, allowing higher resolution.

③ Anode bevel angle is low (around 10°-12°)




If θ (bevel angle) is small, smaller focal spot obtained on patient side




If bevel angle was big, focal spot on patient's side would be bigger.

④ If anode & cathode are closer, $e^-$ will repel each other less and hence wont diverge too much, so focal spot is small.

⑤ If tube current is higher, $e^-$'s will repel each other more and diverge so focal spot is bigger.

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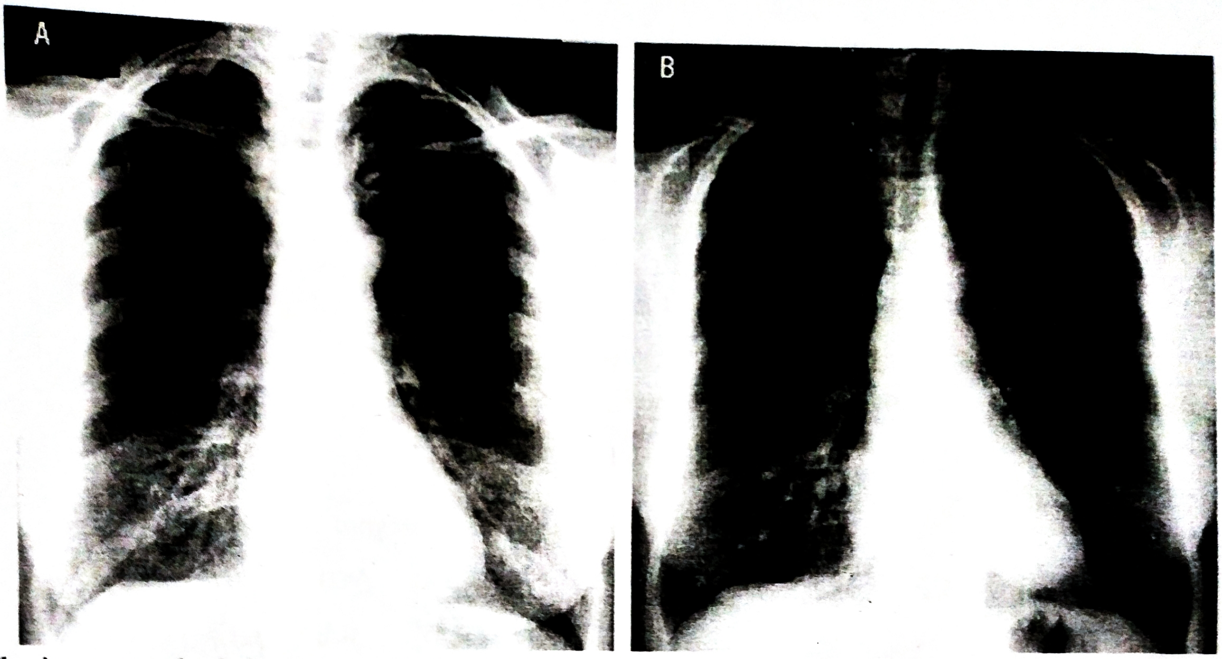
5.




The image on the left was acquired at 50 kVp and the image on the right was acquired with 150 kVp. Which attenuation mechanism is likely to be dominant in each image and how does that specific attenuation mechanism affect image quality? [3]

At 50kVp, attenuation due to photoelectric effect dominates.

In photoelectric effect, the x-rays knock out inner shell e and a transition occurs from outer shell to inner shell to fill in the gap. It results in emission of a characteristic ray which has a few keV energy and is readily absorbed by surrounding tissue. Hence in PE effect, nearly whole energy of affected x-ray is lost. Photo electric effect at lower energy gives good contrast images due to differential attenuation coefficients of bones & surrounding muscle & fat.

($\mu_{bone} > \mu_{muscle}$)

At 150 kVp, attenuation due to Compton scattering is dominant. Here, the scattered x-ray has energy nearly in the same range as incident x-ray. Hence it will again pass through the tissues at a different angle and strike detector at different angles & at different locations. This gives a poor contrast image and the scattered rays also contribute to background noise.

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Hence 50kVp will give us better contrast than 150kVp.