8 X-rays are a form of electromagnetic radiation, just like visible light and ultraviolet light are. Unlike light, however, X-rays have higher energy and can pass through many objects, including the human body.

Most X-ray wavelengths are between 0.01 nm to 10 nm.

Such rays can be produced in an X-ray tube, as shown in Fig. 8.1 below.

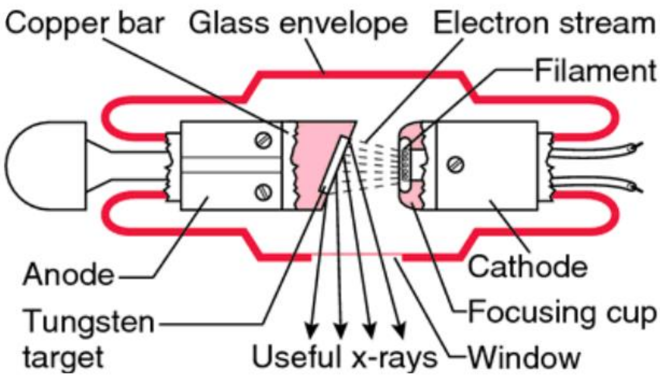

Fig. 8.1

Electrons are emitted at the cathode (C) in a process known as thermionic emission. The electrons then accelerate to the anode (A), thus hitting the target.

Specifications of a particular model of a commercial X-ray tube indicate that it produces a power of 4.0 kW whereas its power supply is 230V, 13A. The range of accelerating voltages is given as 40 – 115 kV.

Similar to other waves, X-rays suffer from attenuation. X-ray attenuation is the reduction in intensity of the X-rays as they are absorbed when travelling through matter. Bones absorb X-rays to a higher extent relative to muscle. That is why bones appear paler on X-ray film.

When X-rays travel through a given material, the intensity of the emergent beam can be calculated using the equation

$$I = I_o e^{-\mu x}$$

where

I_o = the intensity of the incident beam (in W m^{-2})

I = the intensity of the emergent beam (in W m^{-2})

μ = the linear absorption coefficient of a given material (in m^{-1})

x = the distance travelled through the material (in m)

(a) **(i)** Suggest why X-ray production is sometimes known as a reverse photoelectric effect process.

……………………………………………………………………………………………...

……………………………………………………………………………………………...

..……………………………………………………………………………….……… [1]

(ii) Determine the range of C-A currents in the X-ray tube above.

range of current = …………………………….. mA [2]

(iii) Typically, only 1% of the kinetic energy of the electrons is converted to X-rays. Suggest what happens to the rest of the kinetic energy.

……………………………………………………………………………………………...

……………………………………………………………………………………………...

…..……………………………………………………………………………….……… [1]

(b) In the early part of the 20th century, Henry Moseley found that the energy E of the characteristic lines of the X-ray spectrum was related to the atomic number Z of the target material.

Mathematically, Moseley's law is written in the following form:

$$E = aE_1(Z - b)^2$$

where E is in keV and a, E_1 and b are constants.

For K_α lines, a = 0.75 and b = 1, whereas for L_α lines, a = 0.139 and b = 7.4.

Fig. 8.2 below shows the values of E for the L_α lines of different elements.

.

Element	Z	E (in keV)	$(Z - 7.4)^2$
Calcium	20	0.34	159
Manganese	25	0.64	
Zinc	30	1.01	511
Bromine	35	1.48	762
Zirconium	40	2.04	1063
Rhodium	45	2.70	1414

Fig. 8.2

The corresponding graph of E against $(Z - b)^2$ for L_α lines is shown in Fig. 8.3.

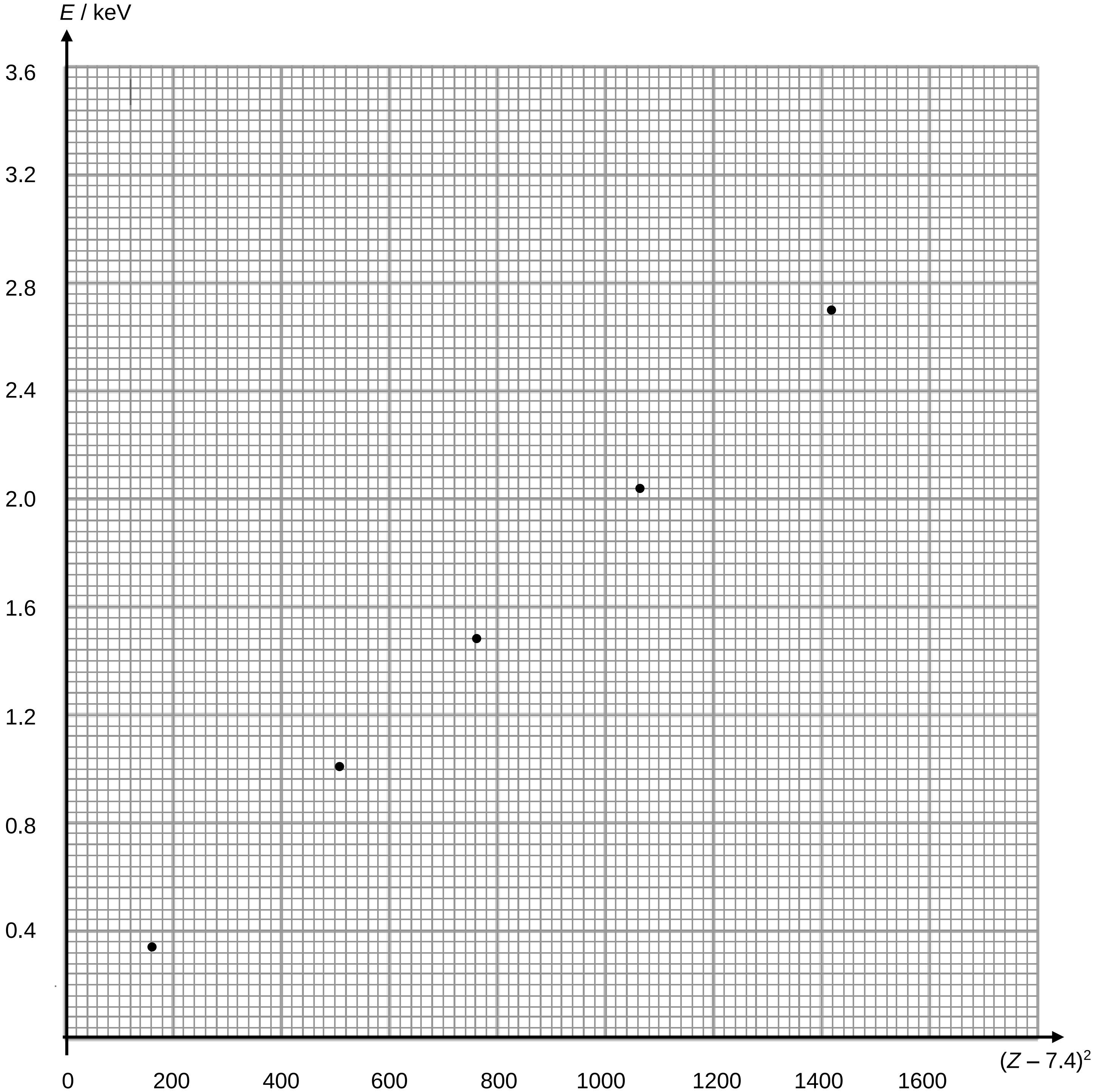
E / keV
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0
200
400
600
800
1000
1200
1400
1600
(Z – 7.4)²

Fig. 8.3

(i) Complete Fig. 8.2 by filling up the missing value for manganese.

[1]

(ii) Plot the corresponding point on Fig. 8.3 and draw the corresponding best-fit line.

[2]

(iii) From the graph, determine the value of E_1.

E_1 = …………………………….. eV [2]

(iv) Based on the graph, suggest if the data is consistent with Moseley's law.

………………………………………………………………………………………...

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………………………………………………………………………………………...

..……………………...………………………………………………………..……… [2]

(v) The notation for the most stable isotope of tungsten is ${}^{184}_{74}W$. Deduce its corresponding value of E for its K_α line.

E = …………………………….. keV [2]

(vi) For rhodium, state and explain the value of the minimum accelerating voltage in the X-ray tube such that the L_α line will show up on its X-ray spectrum.

………………………………………………………………………………………...

………………………………………………………………………………………...

………………………………………………………………………………………...

..……………………………………………………………………………….……... [2]

(c) The diagram of Fig. 8.4 shows the cross-section of a model arm, which is used in the investigation of the absorption of X-ray radiation.

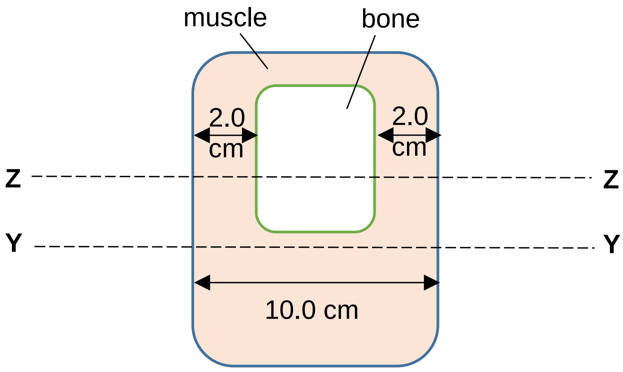

Fig. 8.4

Parallel X-ray beams are directed along the lines YY and ZZ. The linear absorption coefficients of the muscle and the bone are 0.30 cm^{-1} and 10 cm^{-1} respectively.

(i) Calculate the ratio

$$\frac{\text{Intensity of X-ray beam emerging from model}}{\text{Intensity of X-ray beam incident on model}}$$

for a parallel X-ray beam directed along the line

1. YY

ratio = …………………………….. [1]

2. ZZ

ratio = …………………………….. [2]

(ii) Hence, state and explain whether the X-ray images will have good contrast.

…………………………………………………………………………………………………...

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…………………………………………………………………………………………………. [2]

[Total : 20]

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