8 Read the passage and answer the questions that follow.

X-Rays

A modern X-ray tube is illustrated in Fig. 8.1. A heated cathode produces electrons, known as cathode ray, and these are accelerated by the potential difference between the cathode and anode. X-ray tubes used by dentists typically use potential differences of 60 kV. As the electrons hit the anode, X-rays are produced. Tungsten metal is an ideal material for the target, or anode, of an X-ray machine. In practice, only about 1 % of the energy of the electron beam produces X-rays. The rest is wasted as heat.

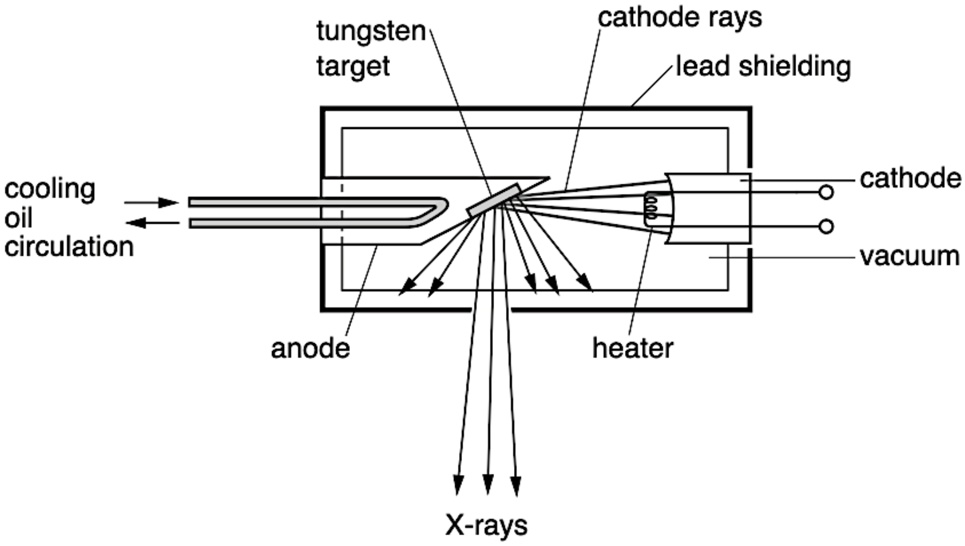

Fig. 8.1

The X-ray spectrum is both a continuous and a superimposed line spectrum, as shown in Fig. 8.2. Fig. 8.2a shows the X-ray spectrum and Fig. 8.2b shows how X-ray intensity varies with the wavelength. The wavelengths of the X-ray spectra are determined by the element from which the target is made.

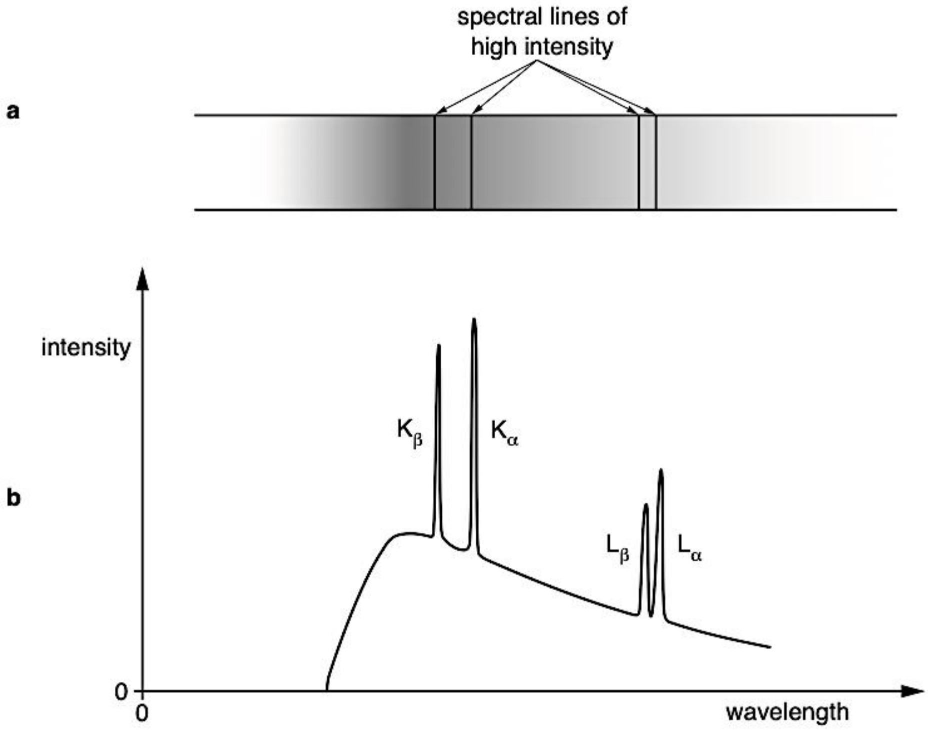

Fig. 8.2

Electrons in the tungsten atom have energy levels in a similar way to the energy levels for a hydrogen atom. Fig. 8.3 shows the logarithm of the energy E of some of the energy levels of electrons in the tungsten atom. E is measured in electron-volts (eV).

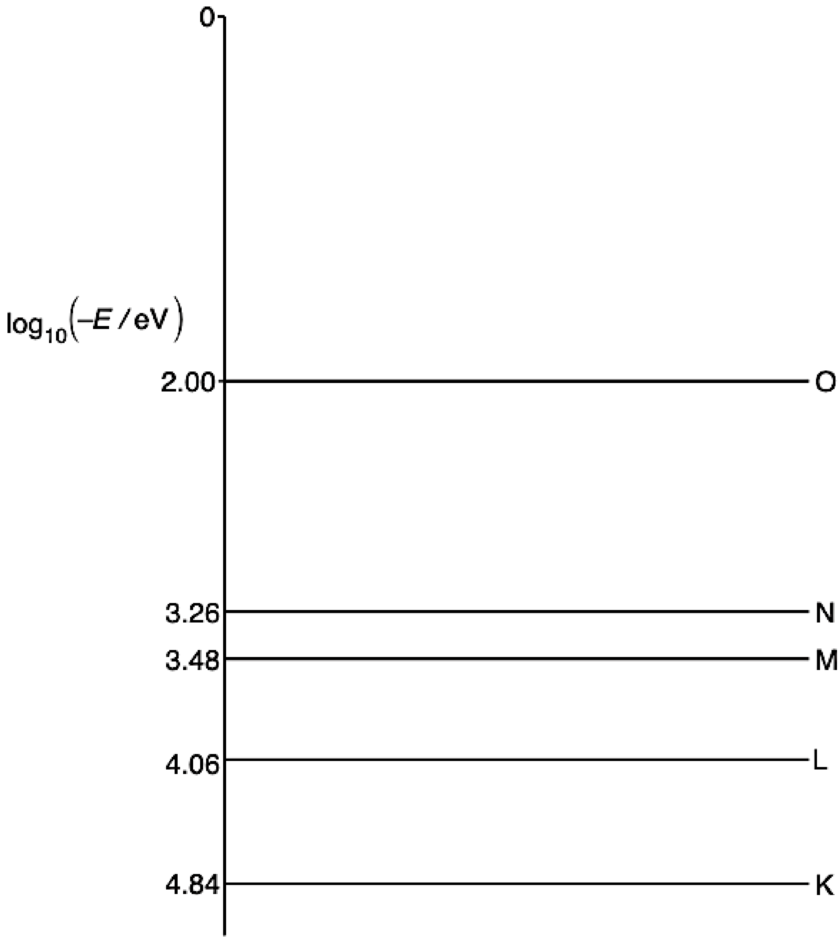

Fig. 8.3

Attenuation of X-ray

When X-ray passes through a medium, it is absorbed by the medium.

The intensity I of a beam of X-ray is related to the distance x it travels through a medium by the relationship:

$$I = I_0 e^{-\mu x}$$

where I_0 is the incident intensity and μ is the **total linear attenuation coefficient**, a constant which depends on the medium and the photon energy of the X-rays.

The decrease variation with distance of the intensity is shown in Fig. 8.4.

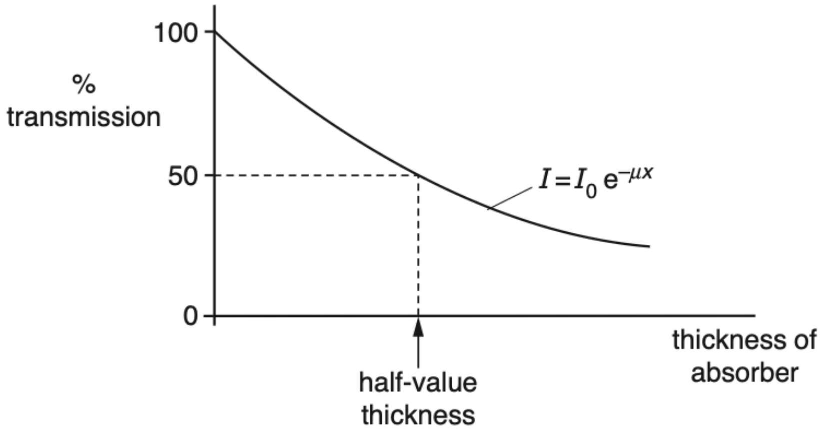

Fig. 8.4

The penetrating power, or quality, of a radiation can conveniently be described in terms of the thickness of material needed to reduce the intensity to half the original value. This is called the **half-value thickness (HVT)**, $x_{\frac{1}{2}}$.

(a) In the production of X-rays, electrons are emitted from the cathode and accelerated in an electric field. The electron energy is often described in terms of electron-volts.

Explain what is meant by the term *electron-volt*.

....

....

.... [2]

(b) **(i)** When an electron strikes the target anode, it can emit energy in creating a single photon.

Determine the minimum wavelength for the X-ray spectrum used by dentist.

minimum wavelength = ... m [3]

(ii) Suggest how the continuous spectrum of X-rays in Fig. 8.2 are produced.

....

....

.... [1]

(c) An electron falling from the L to the K level gives rise to the K_α line. The photon energy of electrons falling from level L to level K depends on the element used for the target. The table in Fig. 8.5 shows the photon energy and the proton number Z for three elements.

element	proton number Z	K_α photon energy / keV
chromium	24	5.40
copper	29	8.03
silver	47	22.10
tungsten	74	

Fig. 8.5

In 1914 Henry G.J. Moseley discovered empirically that the wavelength λ of the K_α line is related to the proton number by the relationship:

$$\sqrt{\frac{1}{\lambda}} \propto Z$$

which is known as the Moseley's law.

(i) Determine the K_α photon energy for the tungsten atom.

energy = ……………………....... keV [2]

(ii) Determine quantitatively, without drawing a graph, whether Moseley's law is valid.

[3]

(iii) Explain why the K_β line has a shorter wavelength than the K_α line.

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

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

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

(d) Suggest and explain one feature of tungsten that makes it an ideal metal for the target of an X-ray machine.

………

………

…… [2]

(e) A beam of X-rays is incident on a hand and the X-ray photograph is taken, as shown in Fig. 8.6.

Fig. 8.6

(i) The beam is attenuated as it passes through the bone. The total linear attenuation coefficient of the bone is 0.528 cm^{-1}.

1. Show that the penetrating power of the X-ray in human bone is 1.31 cm

[1]

2. Calculate the depth of bone required to reduce the intensity of the beam to 40.0% of its initial value.

depth of bone = ……………………......... cm [2]

(ii) An identical beam of X-rays is also attenuated by 40% as it passes through 3.87 cm of human muscle.
Calculate the total linear attenuation coefficient of human muscle.

total linear attenuation coefficient = …………………….…..... cm^{-1} [1]

[Turn over

(iii) Briefly explain how these different values of attenuation coefficient help in the interpretation of X-ray pictures taken of human bodies.

....

....

.... [2]

[Total: 20]