34

X-Rays

BRIEF REVIEW

X-ray was discovered by Roentgen in 1895. It is an *em* radiation whose energy is greater than uv rays and less than γ-rays. The wave length of X-rays is of the order of A° (0.1 A° to 100 A°). The energy range of X-rays is 100 eV to 10^5 eV.

X-rays can be produced in two distinct ways: (a) the electrons are slowed down or stopped by the the target. Their *KE* is directly converted to continous spectrum of photons including X-rays. This process is called **bremsstrahlung** (German for '**braking radiation**'. (b) When a striking electron knocks out an inner electron of the target then the outer electron comes to take its place. The difference in energies of the two is released as X-ray called **characteristic X-ray.** This process is illustrated in Fig. 34.1

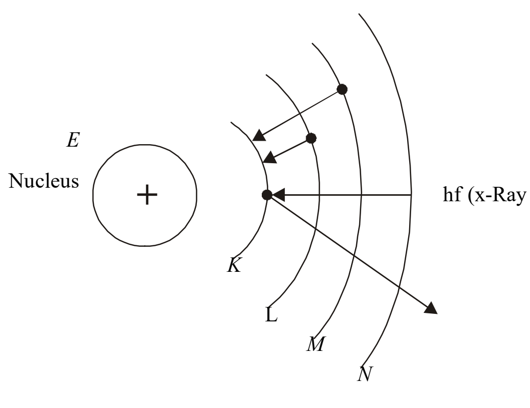

Fig. 34.1 **Emission of characteristic X-ray**

X-ray spectrum is shown in Fig. 34.2 (a). The continuous background represents bremsstrahlung radiations and the peaks represent K_β, K_α, L_β, L_α lines of characteristic X-rays. Fig. 34.2 (b) illustrate the origin of K_β, K_α, L_β, L_α lines. Note that transition from n = 2 to n = 1 gives K_α and transition from n = 3 to n = 1 gives K_β and so on. $\lambda_{\min}$ or threshold wavelength shown in Fig. 34.2 (a) is given by

$$\lambda_{\min} = \frac{1240 \times 10^{-9}}{V} \text{ m}$$

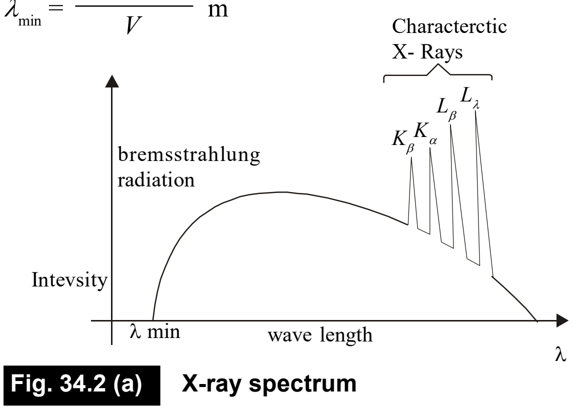

Fig. 34.2 (a) **X-ray spectrum**

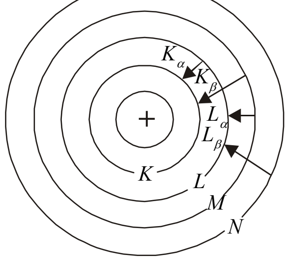

Fig. 34.2 (b) **Illustration of characteristic X-rays.**

where V is potential difference between anode and cathode. λ_{min} may also be called cut off voltage.
Commercially X-rays are produced in a modified coolidge tube as shown in Fig. 34.3. The cathode K is heated by heater H and electrons are emitted by thermionic emission.
$I = Io\ A\ T^2\ e^{-\phi/kT}$

The electrons are accelerated by applying a high voltage (~ 10^4 V) between Anode and Cathode. Cathode K may be made of tungsten and anode A may be made of tungsten or molybdenum. The target shall have high melting point as enormous heat is produced when electrons strike the target. To absorb heat water is circulated. Target is making an angle of 45° so that X-rays move downwards as illustrated in Fig. 34.3. The pressure inside the tube is of the order of $10^{-4} - 10^{-6}$ torr. (1 torr = 1 mm of Hg). The Target is hollow and Wedge shaped. Hardly 1 to 2 % of incident electrons produce X-rays. Hardness of X-ray or penetrating power depends upon the accelerating potential of electrons (V) or the wavelength of X-rays. The penetrating power $\propto \frac{1}{\lambda}$. The intensity of X-rays will depend upon current through X-ray tube or the number of electrons incident per second.

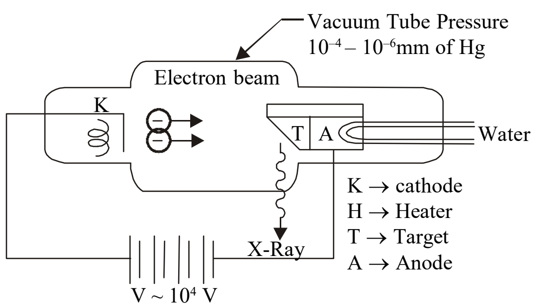

Fig. 34.3 **Modern X-ray tube**

AC can be applied to heater. Since X-rays are *em* radiations, they follow all the properties of *em* radiations. X-rays if incident on animate bodies or WBC (White blood cells), these get destroyed.

Compton Scattering When X-rays strike matter some of the radiation is scattered (analogous to diffusion deflection of visible light from rough surface). Compton found some of the scattered radiation have longer wavelength or small frequency than the incident. The change in wavelength depends upon the angle at which photons are scattered.

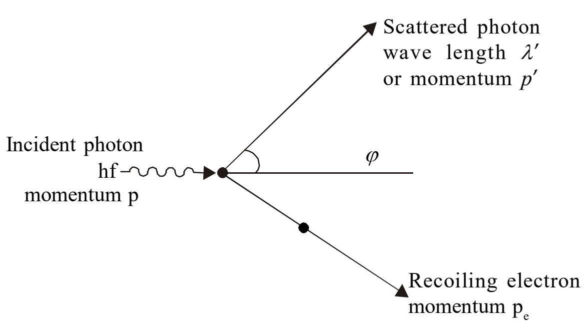

Fig. 34.4 **Compton Scatlering**

$$\Delta\lambda = \frac{h}{mc}(1 - \cos\phi)$$

From Fig. 34.4 $\vec{p} = \vec{p}_e + \vec{p}'$

Absorption of X-rays $I = I_o e^{-\alpha x}$ where α is absorption coefficient.

$\alpha = \frac{0.693}{x_{1/2}}$ Note $\alpha \propto \lambda^3$ and $\alpha \propto Z^4$ where Z is atomic number and λ is wavelength. Lead is the best absorber of X-rays.
X-ray photography is shadow photography.
If potential difference between anode and cathode is increased, frequency of X-rays and intensity of X-rays both increase as shown in Fig. 34.5 (a). However, frequency of characterstic X-rays does not depend upon the applied accelerating potential difference, K_α, K_β, L_α and L_β are most studied characteristic X-rays. The characteristic X-ray energy is given by

$$hf = Rch\ Z^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right].$$

Fig. 34.2 (a) shows the characteristic X-ray superposed on continuous X-ray spectrum.

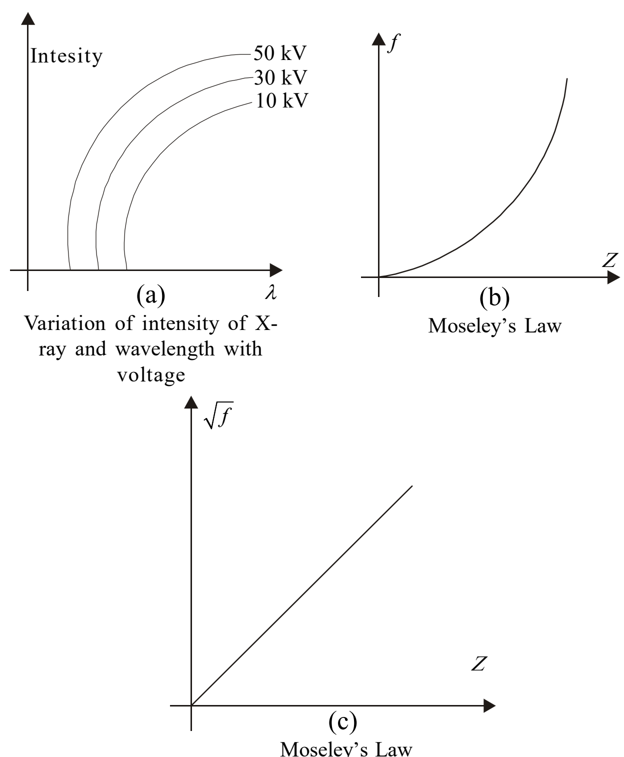

Fig. 34.5

Moseley's Law $\sqrt{f} = a(Z - b)$ where f is frequency and Z is atomic number. a and b are constant Fig. 34.5 (b) and (c) depict variation of characteristic X-ray frequency with atomic number Z. (Moseley's law).
Thus, according to Moseley's law, the basic properties of elements and their place in periodic table depends on their atomic numbers and not on atomic weights.

Lau's spot and Bragg's law confirm X-ray diffraction. Bragg's Law $2d \sin \theta = n \lambda$ is used to study crystallography.
The reverse phenomen of X-ray is photo electric effect.

Applications of X-rays

1. In medical science it is used as a diagnostic tool for fractures or cracks in bones/tooth decay. Ba SO_4 or such dyes are used to study any defect in intenstine, lungs and other organs.

   It can be used as a therapy to treat cancer.
2. It is used in food technology to increase the shelf life of food stuff. Microbes are killed when food is exposed to X-rays.
3. It is used in engineering to check cracks in machined parts particularly in those which are to be sent in space or used in space shuttles.
4. It is used in detectors at airport checkposts.
5. It is used in crystallography to study crystal structures.
6. Non distructive technique of elemental analysis. Every element has different characteristic X-ray and their intensity depends on the concentration of that element present in the salt.
7. In forensic applications, hair of every person has different elements. Even the twins formed from the same egg will have in their hair different % of the elements.
8. It is used in research laboratories.

SHORT CUTS AND POINTS TO NOTE

1. X-rays may be divided into two categories: soft X-ray and hard X-ray. Soft X-rays are mainly used in medical science. (Frequency ~ 10^{16} Hz). Hard X-rays have wave length 0.1 A° to 10 A° and is mainly used in industry. (frequency ~ 10^{18} Hz)
2. Modified coolidge tube is used to produce X-rays. Highly accelerated electrons strike the target at low pressure of the order of 10^{-5} torr.
3. Continuous radiations are called 'Bremsstrahlung radiations' and minimum wavelength is given by

   $\lambda_{\min} = \dfrac{1240 \times 10^{-9}}{V}$, where V is the potential difference applied between anode and cathode.
4. To find crystal structure Bragg's law $2d \sin \theta = n \lambda$ is used. Where d is inter-atomic distance. It is based on diffraction of X-rays from a crystal (as a diffraction grating).
5. Wavelength of characteristic X-ray depends upon atomic number Z. It does not depend upon applied potential. The energy of characteristic X-ray is given by

   $$E = hf = Rhc\, z^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right].$$
6. The characteristic X-rays also follow Moseley's law $\sqrt{f} = a(Z - b)$. The unit of a is $(\text{Hz})^{1/2}$ while b is dimensionless. The values of b are close to 1 for K-X-rays and $b = 7.4$ for L-X-rays.
   $f = 2.48 \times 10^{15} (Z-1)^2$.

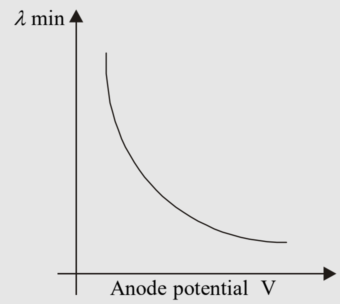

Fig. 34.6

   See variation of $\lambda_{\min}$ with anode potential in Fig. 34.6.
7. Hydrogen atoms cannot give X-rays.
8. X-rays cannot be reflected by ordinary targets. Therefore, these rays can not be used in RADARS.
9. X-ray ionize the gas through which they pass. They affect photographic plate also.
10. X-ray cause photo electric effect and compton scattering. In compton scattering $\Delta\lambda = \dfrac{h}{m_o c}(1 - \cos \phi)$

    $= 0.024 \times 10^{-10} (1 - \cos \phi)$
11. X-rays are absorbed according to the law $I = I_o e^{-\alpha x}$ where α is the coefficient of absorption. $\alpha \propto \lambda^3$ and $\alpha \propto Z^4$. Thus, X-rays can penetrate and pass through low atomic number elements like Al, Wood, Plastics, human flesh etc.
12. Over exposure of X-rays is harmful. It may harm fetus during pregnancy if a pregnant woman is exposed to X-rays.
13. Absorption spectrum of X-ray are not the same as optical spectra. Reverse transition do not occur for $Z \geq 10$. Sudden jumps of absorption are found as shown in Fig. 35.7. If accelerating voltage is gradually increased. For example, in Fig. 34.7 K absorption edge for Mo is shown to occur at 20 keV.

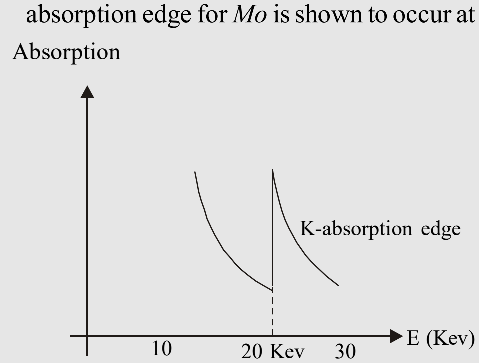

Fig. 34.7

CAUTION

1. Considering X-rays can be reflected from any material surface like light rays.

⇒ X-rays pass through low atomic number metals like Al. This is the reason that X-rays cannot be used in RADAR.

2. Considering like optical spectra absorption spectra of X-ray are reversible.

⇒ With X-ray exposure all reverse transitions are not feasible particularly for $Z \geq 10$.

3. Assuming any X-ray will follow Moseley's law.

⇒ Only characteristic X-rays follows Moseley's law $f = 2.48 \times 10^{15} (Z - 1)^2$ Hz.

4. Assuming $\lambda = \dfrac{hc}{eV} = \dfrac{1240}{V} \times 10^{-9}$ m may be applied to any X-ray.

⇒ It could be applied only to Bremsstrahlung radiation. Characteric X-ray are target specific i.e. they depend upon the atomic number Z of the target used.

5. Considering the efficiency of X-ray production is quite high.

⇒ It is hardly 1%.

6. Confusing about maximum wavelength in Bragg's law

⇒ $2d \sin\theta = n\lambda$ when $n = 1$ $\lambda_{max} = 2d$
For diffraction to occur $\lambda < 2d$.

7. Assuming free electrons are bound in compton scattering.

⇒ The energy of X-rays is several k eV_s and binding energy of electrons is few eV_s. Therefore, free electrons behave like unbounded electrons.

8. Confusing when anode potential is increased intensity of X-rays remain same.

⇒ When anode potential is increased intensity also increases along with frequency i.e., both frequency and intensity increase. Hence, minimum wavelength decreases.

SOLVED PROBLEMS

1. Find the minimum wavelength of X-ray produced if 10 kV potential difference is applied across the anode and cathode of the tube.

(a) 12.4 $A°$ (b) 12.4 nm
(c) 1.24 nm (d) 1.24 $A°$

Solution (d) $\lambda_{min} = \dfrac{1240}{10^4} \times 10^{-9} = .124 \text{ nm} = 1.24\, A°$

2. A photon of frequency f under goes compton scattering from an electron at rest and scatters through an angle θ. The frequency of scattered photon is f' then

(a) $f' > f$ (b) $f' = f$
(c) $f' < f$ (d) none of these

Solution (c) Wavelength of scattered photon increases and hence, frequency decreases.

3. Protons are accelerated from rest by a potential difference 4 kV and strike a metal target. If a proton produces one photon on impact of minimum wavelength λ_1 and similarly an electron accelerated to 4 kV strikes the target and produces a minimum wavelength λ_2 then

(a) $\lambda_1 = \lambda_2$ (b) $\lambda_1 > \lambda_2$
(c) $\lambda_1 < \lambda_2$ (d) no such relation can be established

Solution (a)

4. The minimum wavelength X-ray produced in an X-ray tube operating at 18 kV is compton scattered at 45° (by a target). Find the wavelength of scattered X-ray.

(a) 68.8 pm (b) 68.08 pm
(c) 69.52 pm (d) none of these

Solution (c) $\lambda_{min} = \dfrac{1240 \times 10^{-9}}{18 \times 10^3} = 68.8 \times 10^{-12}$ m

$\Delta\lambda = 2.4 \times 10^{-12} (1 - \cos\phi)$
$= 2.4 \times 10^{-12} (1 - .7)$
$= .72 \times 10^{-12}$ m

$\lambda'\text{min} = (68.8 + .72) \times 10^{-12} \text{ m} = 69.52 \times 10^{-12}$ m

5. K_α wavelength of an unknown element is .0709 nm. Identify the element.

(a) *Co* (b) *Cu*
(c) *Mn* (d) *Mo*
(e) *Sr*

Solution (d) $f = \dfrac{c}{\lambda} = \dfrac{3 \times 10^8}{.0709 \times 10^{-9}} = 4.23 \times 10^{18}$ Hz

From Moseley's law $Z = 1 + \sqrt{\dfrac{f}{2.48 \times 10^5}}$ or

$Z = 1 + \sqrt{\dfrac{4.23 \times 10^{18}}{2.48 \times 10^{15}}} = 42.3$

$Z = 42$ corresponds to *Mo*.

6. The atomic number (Z) of an element whose K_α wavelength is λ is 11. The atomic number whose K_α wavelength is 4λ is equal to

(IIT Screening 2005)

(a) 6 (b) 11

(c) 44 (d) 4

Solution (a) $(Z-1)^2 \lambda = \text{const.}$

$\therefore 10^2 \lambda = (z-1)^2 4\lambda$ or

$z - 1 = 5$ or

$z = 6$

7. Who discovered X-rays?

(a) Roentgen (b) Marie curie

(c) Rutherford (d) all

[BHU 2005]

Solution (a)

8. Consider a photon of continous X-ray coming from a coolidge tube. Its energy comes from

(a) *KE* of the striking electron.

(b) *KE* of free electron of the target.

(c) *KE* of the ions of the target.

(d) an atomic transition in the target.

Solution (a)

9. Fig 34.8 shows intensity wavelength relation of X-rays in two different tubes *A* and *B* operating at V_A and V_B having targets of atomic number Z_A and Z_B then

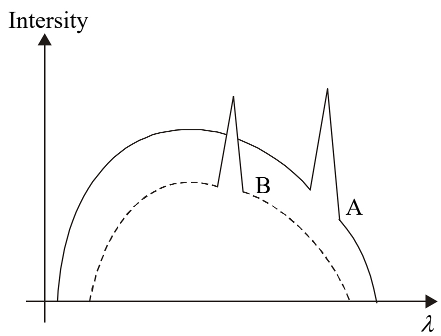

Fig. 34.8

(a) $V_A > V_B, Z_A > Z_b$ (b) $V_A > V_B, Z_A < Z_B$

(c) $V_A > V_B, Z_A > Z_B$ (d) $V_A < V_B, Z_A < Z_B$

Solution (b) $\lambda_{\min}$ of A < $\lambda_{\min}$ of B

$\therefore V_A > V_B$; $\lambda_{K_{\alpha B}} < \lambda_{K_{\alpha A}}$

$\therefore Z_B > Z_A$

10. 40% of the X-rays coming from a Coolidge tube can pass through 0.2 mm thick Al plate. The Anode voltage is increased. Now 40% of the X-rays will pass through Al foil of thickness.

(a) zero (b) < 0.2 mm

(c) = 0.2 mm (d) > 0.2 mm

Solution (d)

11. For harder X-rays

(a) wavelength is higher. (b) intensity is higher.

(c) frequency is higher. (d) all of these.

Solution (c)

12. Consider λ_1 and λ_2 are minimum wavelengths of continous and characteristic X-rays then

(a) $\lambda_1 = \lambda_2$ (b) $\lambda_1 > \lambda_2$

(c) $\lambda_1 < \lambda_2$ (d) none of these

Solution (c)

13. An X-ray tube operating at 20 kV shows a current 1 *mA*. Assuming efficiency 1%. Find the number of X-ray photons emitted per second.

(a) 5.25×10^{13} (b) 6.25×10^{13}

(c) 6.25×10^{15} (d) 5.25×10^{15}

Solution (b) number of electrons/s = $\frac{I}{e}$ and no. of photons/s = $\frac{I}{100e}$

$$= \frac{10^{-3}}{1.6 \times 10^{-19} \times 100}$$

$$= 6.25 \times 10^{13}$$

14. The operating voltage is increased by 2%. By what % cut off wavelength of X-ray decrease in a Coolidge tube

(a) 1 % (b) 1.5 %

(c) 1.8 % (d) 2 %

Solution (d) $\lambda = \frac{1240 \times 10^{-9}}{V}$ or $\frac{d\lambda}{\lambda} = -\frac{dV}{V} = 2\%$

15. The wavelength of K_α and L_α X-rays of a material are 21.3 pm and 141 pm. Find the wavelength of K_β X-ray.

(a) 19 nm (b) 29 nm

(c) 26.1 nm (d) 38 nm

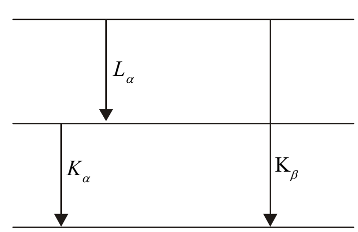

Fig. 34.9

Solution (a) See Fig 34.9 $\frac{hc}{\lambda_{K_\beta}} = \frac{hc}{\lambda_{K_\alpha}} + \frac{hc}{\lambda_{L_\alpha}}$

or $$\frac{1}{\lambda_{K_\beta}} = \frac{1}{\lambda_{K_\alpha}} + \frac{1}{\lambda_{L_\alpha}}$$

$$= \frac{1}{21.3} + \frac{1}{141} = \frac{1}{19}$$

16. A colour TV screen operates at 20 kV. The absorption coeffcient of screen is 0.4 mm^{-1}. Find the mimimum thickness of the screen so that not more than 1% of X-rays come out.

(a) 2.5 mm (b) 5 mm

(c) 9.3 mm (d) 11.6 mm

Solution (d) $I = I_o\, e^{-\alpha x}$

or $$x = \log_e\left(\frac{I_o/I}{\alpha}\right) = 2.303\,\frac{\log 10^2}{.4}$$

$$= 11.6\,\text{mm}$$

17. Solid targets of different elements are bombarded by highly energetic electron beam. The frequency of the characteristic X-rays emitted from different targets varies with atomic number Z as

(a) $f \propto \sqrt{Z}$ (b) $f \propto Z^2$

(c) $f \propto Z$ (d) $f \propto Z^{3/2}$

Solution (b)

TYPICAL PROBLEMS

18. Assume 100 pm X-ray beam is passed through YDSE. Interference pattern is observed on a photographic plate placed 40 cm away from the slits. What should be the separation between the slits so that the separation between two successive maxima is 0.1 mm.

(a) 4 μm (b) 0.4 μm

(c) 4 nm (d) 40 μm

Solution (b) $\beta = \dfrac{\lambda D}{d}$ or $d = \dfrac{\lambda D}{\beta}$

$$= \frac{10^{-10} \times .4}{.1 \times 10^{-3}} = 4 \times 10^{-7}\,\text{m}$$

19. An X-ray tube operates at 40 kV. Suppose the electrons convert 70% its energy into a photon in each collision. Find the lowest 3 wavelength emitted.

Solution $$\lambda_1 = \frac{1240 \times 10^{-9}}{.7(40) \times 10^3} = 44.3\,\text{pm},$$

$$\lambda_2 = \frac{1240 \times 10^{-9}}{0.21(40) \times 10^3} = 148\,\text{pm},$$

$$\lambda_3 = \frac{1240 \times 10^{-9}}{.063 \times 40 \times 10^3} = 493\,\text{pm}.$$

20. Plot the graph between Anode potential and $\dfrac{1}{\lambda_{\min}}$. Also find its slope.

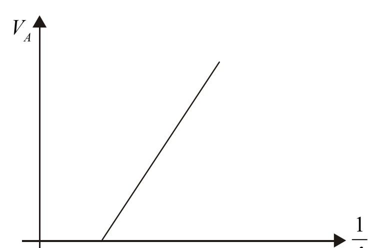

Fig. 34.10

Solution $\dfrac{hc}{\lambda} = e\,V_A$ Slope $= \dfrac{V_A}{1/\lambda} = \dfrac{hc}{e}$

21. The electric current in an X-ray tube operating at 40 kV is 5 mA. If efficiency is 1%. Find

(a) power emitted as X-ray.

(b) power converted to heat.

Solution $P_{\text{X-ray}} = 40 \times 5 \times \dfrac{1}{100} = 2$ W

$$P_{\text{heat}} = 200 - 2 = 198\,\text{W}$$

22. A tissue paper soaked with polluted water showed K_α peaks at 78.9 pm, 146 pm, 158 pm and 198 pm. Find the elements it contained.

Solution $f = \dfrac{c}{\lambda} = 2.48 \times 10^{15}\,(Z-1)^2$

$$Z = 1 + \sqrt{\frac{c}{\lambda \times 2.48 \times 10^{15}}}$$

$$= 1 + \sqrt{\frac{3 \times 10^8}{78.9 \times 10^{-12} \times 2.48 \times 10^{15}}} = 40, \text{ i.e., } Zr$$

$$Z = 1 + \sqrt{\frac{3 \times 10^8}{146 \times 2.48 \times 10^{-3}}} = 30.1, \text{ i.e., } Zn$$

$$Z = 1 + \sqrt{\frac{3 \times 10^8}{158 \times 2.48 \times 10^{-3}}} = 29, \text{ i.e., } Cu$$

$$Z = 1 + \sqrt{\frac{3 \times 10^8}{198 \times 2.48 \times 10^{-3}}} = 26, \text{ i.e., } Fe$$

PASSAGE 1

Read the following passage and answer the questions given at the end.

Electron diffraction can also take place when there is interference between electron waves that scatter from atoms on the surface of a crystal and waves that scatter from atoms in the next plane below the surface, a distance d from the surface. The distance d in a specimen is 0.91 Å. 71 eV electrons are used. see Figure.

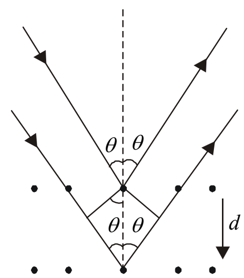

Fig. 34.11

1. Find the equation for θ for which intensity is maximum for electron waves of wavelength λ

(a) $d \sin \theta = n\lambda$. (b) $2d \sin \theta = n\lambda$.

(c) $2d \sin \theta = n\lambda$. (d) $\sin \theta = (2n + 1)\lambda/2$.

2. Find θ for which 71 eV electron shows a maxima.

(a) 53° (b) 37°

(c) 45° (d) 90°

Solution **1.** (b) Path difference $= 2d \sin \theta$. for maxima $2d \sin \theta = n\lambda$

Solution **2.** (a) $2d \sin \theta = n\lambda$

$2(.91) \sin \theta = n\,(1.46)$

or $\sin \theta = \dfrac{1.46}{1.82} = 0.8$

or $\theta = 53^0$

$\lambda = \dfrac{12.27}{\sqrt{V}}$ Å $= \dfrac{12.27}{\sqrt{71}}$

$= 1.46$ Å

PASSAGE 2

Read the following passage and answer the questions given at the end.

A 20 kg satellite circles the earth once every $2h$ in an orbit having a radius of 8060 km. Assume that Bohrs postulates are valid even in the satellite motion as for electrons in Hydrogen atom. Combine Newton's law of gravitation and Bohr's angular momentum to find radius of the orbit as a function of principle Quantum number.

1. Find the radius of first two allowed orbits.

(a) 2.5×10^{-84} m, 10^{-83} m (b) 400 km, 1600 km

(c) 200 m, 800 m (d) 3 km, 12 km

(e) none

2. Do quantized and classical orbits correspond to each other?

(a) yes (b) no

(c) cannot be predicted.

3. Find the value of principal quantum number n corresponding 20 kg satellite.

(a) 1.6×10^{45} (b) 1.6×10^{8}

(c) 7.6×10^{5} (d) 8.3×10^{11}

Solution **1.** (e) $mvR = nh$

$$v_0 = \sqrt{\frac{GM}{R}}$$

$$m\sqrt{\frac{GM}{R}}\,R = nh$$

or $$R = \frac{n^2h^2}{m^2GM}$$

i.e., $R = n^2k$

where $k = \dfrac{h^2}{m^2GM}$

$$= \frac{\left(6.62\times10^{-34}\right)^2}{4\pi^2\times(20)^2\times6.67\times10^{-11}\times6\times10^{24}}$$

$$= \frac{10\times10^{-84}}{16} = 1.6\times10^{-84}$$

$R_1 = 16 \times 10^{-84}$ m

$R_2 = 64 \times 10^{-83}$ m

Solution **2.** (b)

Solution **3.** (a) $n = \dfrac{m}{h}\sqrt{\dfrac{GM}{R}}\,R = \dfrac{20}{6.62\times10^{-34}}$

$\sqrt{6.67\times10^{-11}\times6\times10^{24}\times6400\times10^{3}}$

$8060 \times 10^3 = \dfrac{20\times10^{34}}{6.62} \times 10^9 \times 8 \times \sqrt{40} = 1.6 \times 10^{45}$

QUESTIONS FOR PRACTICE

1. If the potential difference applied to the tube is doubled and the separation between the filament and the target is also doubled the cut off wavelength

(a) will remain uncharged.

(b) will be doubled.

(c) will be halved.

(d) will become four times the original.

2. If the current in the circuit for heating the filament is increased, the cutoff wavelength

(a) will increase. (b) will decrease.

(c) will remain unchanged. (d) will change.

3. For a given material the energy and wavelength of characteratic X-ray satisfy

(a) $E(K_\alpha) > E(K_\beta) > E(K_\gamma)$. (b) $E(M_\alpha) > E(L_\alpha) > E(K_\alpha)$.

(c) $\lambda(K_\alpha) > \lambda(K_\beta) > \lambda(K_\gamma)$. (d) $\lambda(M_\alpha) > \lambda(L_\alpha) > \lambda(K_\alpha)$.

4. Frequencies of K_α X-rays of different materials are measured. Which one of the graphs in figure may represent the relation between the frequency f and the atomic numbe Z.

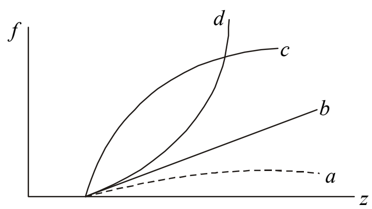

Fig. 34.12

5. The X-ray beam coming from an X-ray tube

(a) is monochromatic.

(b) has all wavelengths smaller than a certain maximum wavelength.

(c) has all wavelengths greater than a certain minimum wavelength.

(d) has all wavelengths lying between a minimum and a maximum wavelength.

6. Choose the correct options.

(a) An atom with a vacancy has smaller energy than a neutral atom.

(b) K X-ray is emitted when a hole makes a jump from the K shell to some other shell.

(c) The wavelength of K X-ray is smaller than the wavelength of L X-ray of the same material

(d) The wavelength of K, X-ray is smaller than the wavelenght of K_v X-ray of the same material.

7. Figure shows the intensity–wavelength relations of X-rays coming from two different Coolidge tubes. The solid curve represents the relation for the tube A in which the potential difference between the target and the filament is V_A and the atomic number of the target material is Z_A. These quantities are V_B and Z_B for the other tube. Then

(a) $V_A > V_B, Z_A > Z_B$ (b) $V_A > V_B, Z_A < Z_B$

(c) $V_A < V_B, Z_A > Z_B$ (d) $V_A < V_B, Z_A < Z_B$

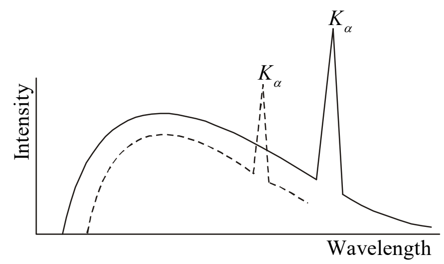

Fig. 34.13

8. 50% of the X-ray coming from a Coolidge tube is able to pass through a 0.1 mm thick aluminium foil. If the potential difference between the target and the filament is increased, the fraction of the X-ray passing through the same foil will be

(a) 0% (b) < 50%

(c) 50% (d) > 50%

9. Cut off wavelength of X-rays coming from a Coolidge tube depends on the

(a) target material. (b) accelerating voltage.

(c) separation between the target and the filament.

(d) temperature of the filament.

10. X-ray from a coolidge tube is incident on a thin aluminium foil. The intensity of the X-ray transmitted by the foil is found to be I_0. The heating current is increased so as to increase the temperature of the filament. The intensity of the X-ray transmitted by the foil will be

(a) zero (b) $< I_0$

(c) I_0 (d) $> I_0$

11. Visible light passing through a circular hole forms a diffraction disc of radius 0.1 mm on a screen. If X-ray is passed through the same set up, the radius of the diffraction disc will be

(a) zero (b) < 0.1 mm

(c) 0.1 mm (d) > 0.1 mm

12. For harder X-rays.

(a) the wavelength is higher.

(b) the intensity is higher.

(c) the frequency is higher.

(d) the photon energy is higher.

13. Moseley's law for characteristic X-ray is $\sqrt{f} = a(Z - b)$. In this,

(a) both a and b are independent of the material.
(b) a is independent but b depends on the material.
(c) b is independent but a depends on the material.
(d) both a and b depend on the material.

14. 50% of the X-ray coming from a Coolidge tube is able to pass through n 0.1 mm thick aluminium foil. The potential difference between the target and the filament is increased. The thickness of aluminium foil, which will allow 50% of the X-ray to pass through will be

(a) zero (b) < 0.1 mm
(c) 0.1 mm (d) > 0.1 mm

15. The potential difference applied to an X-ray tube is increased. As a result, in the emitted radiation

(a) the intensity increases.
(b) the minimum wavelength increases.
(c) the intensity remains unchanged.
(d) the minimum wavelength decreases.

16. When an electron strikes the target in a Coolidge tube, its entire kinetic energy

(a) is converted into a photon.
(b) may be converted in to a photon.
(c) is converted in to heat.
(d) may be converted in to heat.

17. One of the following wavelengths is absent and the rest are present in the X-rays coming from a Coolidge tube. Which one is the absent wavelength?

(a) 25 pm (b) 50 pm
(c) 75 pm (d) 100 pm.

18. The K_α X-ray emission line of tungsten occurs at $\lambda = 0.021$ nm. The energy difference between K and L levels in this atom is about

(a) 0.51 MeV (b) 1.2 MeV
(c) 59 keV (d) 13.6 eV

19. Which of the following pairs constitute very similar radiations?

(a) Hard ultraviolet rays and soft X-rays.
(b) Soft ultraviolet rays and hard X-rays.
(c) Very hard X-rays and low-frequency γ-rays.
(d) Soft X-rays and γ-rays.

20. When a metal of atomic number Z is used as the target in a Coolidge tube, let f be the frequency of the K_α line. Corresponding values of Z and f are known for a number of metals. Which of the following plots will give a straight line?

(a) f against Z (b) $\frac{1}{f}$ against Z
(c) $\sqrt{f}$ against Z (d) f against $\sqrt{Z}$

21. In a Coolidge tube, the potential difference across the tube is 20 kV, and 10 mA current flows through the voltage supply. Only 0.5% of the energy carried by the electrons striking the target is converted into X-rays. The X-ray beam carries a power of

(a) 0.1 W (b) 1 W
(c) 2 W (d) 10 W

22. Let λ_α, λ_β and λ_α' denote the wavelengths of the X-rays of the K_α, K_β and L_α line in the characteristic X-rays for a metal.

(a) $\lambda_\alpha' > \lambda_\alpha > \lambda_\beta$ (b) $\lambda_\alpha' > \lambda_\beta > \lambda_\alpha$
(c) $\frac{1}{\lambda_\beta} = \frac{1}{\lambda_\alpha} + \frac{1}{\lambda_\alpha'}$ (d) $\frac{1}{\lambda_\alpha} + \frac{1}{\lambda_\beta} = \frac{1}{\lambda_\alpha'}$

23. When an electron moving at a high speed strikes a metal surface, which of the following are possible?

(a) The entire energy of the electron may be converted into an X-ray photon.
(b) Any fraction of the energy of the electron may be converted into an X-ray photon.
(c) The entire energy of the electron may get converted to heat.
(d) The electron may undergo elastic collision with the metal surface.

24. X-rays are absorbed maximum by

(a) lead. (b) paper.
(c) copper. (d) steel.

25. X-rays are not used in RADAR, because

(a) X-rays are not reflected by target.
(b) X-rays are completely absorbed by air.
(c) X-rays damage the target.
(d) all of the above.

26. In Coolidge tube, what fraction of incident energy is utilised in producing X-rays ?.

(a) 100% (b) 1%
(c) 50% (d) 25%

27. Water is circulated in Coolidge tube to—

(a) cool the target.
(b) cool the cathode.
(c) cool both cathode and target.
(d) none of these.

28. If the incident electrons in Coolidge tube are accelerated through a potential of V volt, then the maximum frequency of continuous X-rays will be

(a) V (b) hV
(c) $\frac{eV}{h}$ (d) $\frac{h}{eV}$

29. What is the effect of electric and magnetic fields on X-rays?

(a) X-rays are deflected.

(b) X-rays are not deflected.

(c) X-rays are sometimes deflected and sometimes not.

(d) nothing can be said.

30. The wavelength of continuous X-rays is proportional to

(a) intensity of incident electron beam.

(b) temperature of the target.

(c) intensity of X-rays.

(d) inversely to the energy of electrons striking the target.

31. On increasing the applied potential difference in X-ray tube

(a) the intensity of emitted radiation increases.

(b) the minimum wavelength of emitted radiation increases.

(c) the intensity of emitted radiation remains unchanged.

(d) the minimum wavelength of emitted radiation decreases.

32. If anode potential increases then

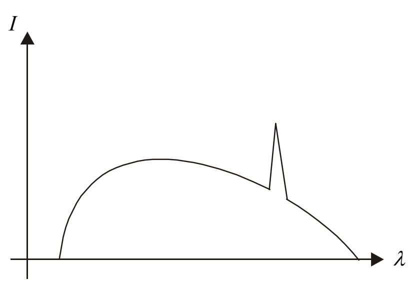

Fig. 34.14

(a) Bremsstrahlung radiation wavelength increases

(b) Bremsstrahlung radiation wavelength decreases

(c) Characteristic wavelength increases

(d) Characteristic wavelength decreases

33. The maximum frequency of X-rays produced by electrons accelerated through V volt is proportial to

(a) V (b) $\frac{1}{V}$

(c) V^2 (d) $\frac{1}{V^2}$

34. Which of the following wavelengths lies in X-ray region?

(a) 10000 Å (b) 1000 Å

(c) 1 Å (d) 10^{-2} Å

35. X-rays and γ-rays both are electromagnetic waves. Which of the following statements is correct?

(a) The wavelength of X-rays is greater than that of γ-rays.

(b) The wavelength of X-rays reduce is less than that of γ-rays.

(c) The frequency of γ-rays is less than that of X-rays.

(d) The frequency and wavelength of X-rays are more than those of γ-rays.

36. Hydrogen atom does not emit X-rays because

(a) its energy levels are very close to each other.

(b) the energy levels are far apart from each other.

(c) its size is very small.

(d) it contains only single electron.

37. Electrons of mass m and charge e are accelerated through a potential difference V and strike the target. The maximum speed of these electrons is

(a) $\frac{eV}{m}$ (b) $\frac{eV^2}{m}$

(c) $\sqrt{\frac{eV}{m}}$ (d) $\sqrt{\frac{2eV}{m}}$

38. In an X-ray tube, when electrons, after being accelerated through V volt, strike the target then the wavelength of emitted X-rays is

(a) not less than $\frac{hc}{eV}$. (b) not greater than $\frac{hc}{eV}$.

(c) $\frac{hc}{eV}$. (d) has all values.

39. Electrons of 10 KeV strike a tungsten target. The radiations emitted by it are

(a) visible light. (b) X-rays.

(c) infrared radiations. (d) radio waves.

40. When a beam of accelerated electrons strikes a target, then continuous spectrum of X-rays is obtained. The wavelength absent from the spectrum of X-rays emitted by an X-ray tube operated at 40 KV will be

(a) 1.5 Å (b) 0.5 Å

(c) 0.25 Å (d) 1.0 Å

41. In an X-ray tube if the electrons are accelerated through 140 KV then anode current obtained is 30 mA. If the whole energy of electrons is converted into heat then the rate of production of heat at anode will be

(a) 968 calorie. (b) 892 calorie.

(c) 1000 calorie. (d) 286 calorie.

42. The wavelength of limiting line of Lyman series is 911A. The atomic number of the element which emits minimum wavelength of 0.7A of X-rays will be

(a) 31 (b) 33

(c) 35 (d) 37

43. When X-rays of wavelength 0.5A pass through 7mm thick aluminum sheet, then their intensity reduces to one fourth. The coefficient of absorption of aluminum for these X-rays will be

(a) $0.198mm^{-1.}$ (b) $0.227mm^{-1.}$

(c) $0.752mm^{-1.}$ (d) $0.539mm^{-1.}$

44. In majority of crystals the value of lattice constant is of the order of 3A. The proper X-rays with which the crystal structure can be studied are

(a) 50 Å to 100 Å. (b) 10 Å to 50 Å.

(c) 5 Å to 10 Å. (d) 0.1 Å to 2.7 Å.

45. The lattice constant of a crystal is 2A. The maximum wavelength of X-rays which can be analysed by this crystal will be

(a) 1A (b) 2A

(c) 3A (d) 4A

46. X-rays cannot produce

(a) compton electron. (b) photoelectron.

(c) electron-positron pair. (d) all of the above.

47. The order of potential difference applied between cathode and anticathode in an X-ray tube will be

(a) 10^3V (b) 10^2V

(c) 10^4V (d) 10^1V

48. Which of the following properties is not exhibited by X-rays?

(a) Interference. (b) Diffraction.

(c) Polarisation.

(d) Deflection by electric field.

49. X-ray region is situated between

(a) visible and short radio wave regions.

(b) ultraviolet and visible regions.

(c) γ-rays and ultraviolet regions.

(d) short and long radio wave regions.

50. The co-efficient of absorption for X-rays is related to the atomic number as

(a) $\mu \propto \frac{1}{Z^4}$ (b) $\mu \propto Z^3$

(c) $\mu \propto \frac{1}{Z^3}$ (d) $\mu \propto Z^4$

PASSAGE 1

Read the following passage and answer the questions given at the end.

X-rays are known to be electromagnetic radiation with wavelength of the order of 1A°. They are produced when accelerated electrons strike target inside an evacuated tube. It is well known that when an electron is accelerated through a potential difference of V it acquires energy eV. If all this energy is used in producing one quantum of *X*-radiation, then $hf = eV$. It is likely that the electron may have lost some of its acquired energy before producing the quantum of radiation. The f gives the maximum possible frequency of *X*-radiation emitted and that corresponds to the short wavelength limit of the emitted spectrum. In general, therefore, *X*-ray spectra consist of a continuous spectrum upon which is superposed a line spectrum that is characteristic of the element used as target. For some time after the discovery of *X*-rays, there was considerable speculation about the nature of *X*-rays. Max Von Laue found, in 1912 that if *X*-rays are passed through a crystal they get diffracted. As Laue paterns are difficult to interpret, Bragg worked out a simple equation that predicts the conditions under which diffracted *X*-rays beams from a crystal are possible. In its simplest form, Bragg's Law is given by $\lambda = 2d \sin\theta$ where d is the perpendicular distance between the planes contining atoms and θ is the glancing angle at which the *X*-rays fall on the crystal. λ is known, the distance may be found from experimental measurements. This is the basis for the field of *X*-ray crystallography in which the structure of crystals is determined by using *X*-rays.

1. The frequency of *X*-rays is of the order of

(a) 3×10^{18} Hz. (b) 3×10^{8} Hz.

(c) 3×10^{10} Hz. (d) 300 Hz.

Solution (a)

2. The photon is the order of energy associated with an x-ray

(a) 100 eV. (b) 10 keV.

(c) 6 MeV. (d) 3 GeV.

Solution (b)

3. The distribution of energy in the continuous *X*-ray spectrum depends on

(a) the nature of the filament of the *X*-ray tube.

(b) the material of target.

(c) the order of vacuum inside the *X*-ray tube.

(d) the potential difference across the tube.

Solution (d)

Answers to Questions for Practice

1.	(c)	**2.**	(c)	**3.**	(b,c)	**4.**	(d)	**5.**	(d)	**6.**	(b,c)	**7.**	(b)
8.	(b)	**9.**	(b)	**10.**	(d)	**11.**	(b)	**12.**	(c,d)	**13.**	(a)	**14.**	(d)
15.	(a,d)	**16.**	(b,d)	**17.**	(a)	**18.**	(c)	**19.**	(a,c)	**20.**	(c)	**21.**	(b)
22.	(a,c)	**23.**	(a,b,c)	**24.**	(a)	**25.**	(a)	**26.**	(b)	**27.**	(a)	**28.**	(c)
29.	(b)	**30.**	(d)	**31.**	(a,d)	**32.**	(b)	**33.**	(a)	**34.**	(c)	**35.**	(a)
36.	(a)	**37.**	(d)	**38.**	(a,c)	**39.**	(b)	**40.**	(c)	**41.**	(c)	**42.**	(d)
43.	(a)	**44.**	(d)	**45.**	(d)	**46.**	(c)	**47.**	(c)	**48.**	(d)	**49.**	(c)
50.	(d)												

EXPLANATION

8. (b) $\because$ absorption coeff $\alpha \propto \lambda^3$

11. (b) $\because$ $r \propto \lambda$

22. (c)

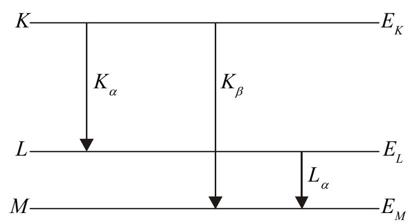

Fig. 34.15

$$E_K - E_L = \frac{hc}{\lambda_a}$$

$$E_K - E_M = \frac{hc}{\lambda_\beta}$$

$$E_L - E_M = \frac{hc}{\lambda_\alpha'} = \frac{hc}{\lambda_\beta} - \frac{hc}{\lambda_\alpha}$$

or $$\frac{1}{\lambda_\beta} = \frac{1}{\lambda_\alpha} + \frac{1}{\lambda_\alpha'}$$

Also, $(E_K - E_M) > (E_K - E_L) > (E_L - E_M)$

or $$\frac{hc}{\lambda_\beta} > \frac{hc}{\lambda_\alpha} > \frac{hc}{\lambda_\alpha'}.$$

21. Power drawn by the coolidge tube = $(20 \times 10^3$ V$)$ $(10 \times 10^{-3}$ A$)$ = 200 W.

Power of X-ray beam = $\frac{0.5}{100} \times 200$ W = 1 W.

20. From Moseley's law; $\sqrt{v} = a(Z - b)$, where a and b are constants.