ATOMIC PHYSICS

3.X- RAYS

POINTS TO REMEMBER

1. X-rays:

a. These are discovered by Roentzen
b. These are short wavelength electromagnetic waves which are produced when a metal anode is bombarded by high energetic electrons.
c. The wavelength of X-rays ranges from 0.1Å - 100Å
d. Hard X rays are produced at high voltage and low pressure.These are high energetic and have more penetrating power.
e. Soft X-rays are produced at low voltage and high pressure.These are low energetic and have less penetrating power.
f. The intensity of X-rays depends on the no of electrons striking the target i.e., filament current.
g. The quality of penetration depends on the potential difference between the electrodes.

2. X – ray spectra:

a) Continuous X-ray spectrum:

i) It is formed due to scattering of high speed electrons that strike the target. When high energy electrons move close to the nucleus of target atom then these get decelerated and X-rays of continuous frequency are emitted

ii) **Duane and Haunt's rule:** Continuous x-ray spectrum suddenly ends at a certain minimum wavelength called limiting wavelength, which decreases with increase of applied voltage $\lambda_{\min} = \frac{hc}{e\nu} = \frac{12400}{V} \overset{0}{A}$

3.. Characteristic X-rays spectrum :

a)When electron with high energy penetrate atoms, they strike the electrons of inner shells and knock out them from the atoms, then deficiency of electron is created in the inner shell. Electron from higher shell jumps into this shell to fulfill this deficiency. In this process photons with energies equal to difference of energies of initial and final shells are emitted. These are characteristic X-rays.

For K-series, $\frac{1}{\lambda} = R(Z-1)^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$

4. Moseley's law

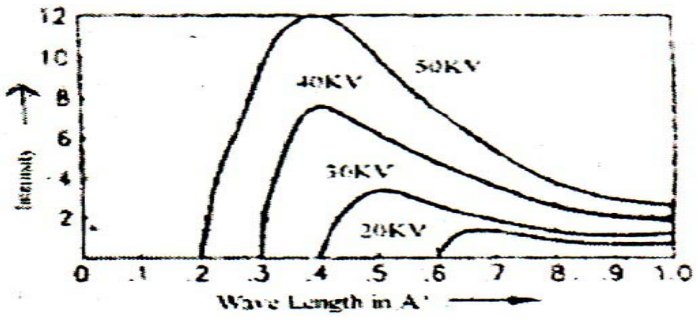
a. The frequency of a spectral line in the characteristic X-ray spectrum is directly proportional to the square of the atomic number (Z) of the element concerned. $\sqrt{\nu} = a(z-b)$, where a, b are constants.
b. Here b is called screening constant. For K- series b = 1 and for - series b = 7.4.
c. Moseley's law helped in the rearrangement of elements according to their atomic numbers and perfecting periodic table by determining atomic number of rare earth elements.

LONG ANSWER QUESTIONS

1. Explain continuous and characteristic X-ray spectra. Discuss their origin.

A: X-ray spectra of an element consist of two parts. They are:

1) Continuous spectrum and 2) Characteristic line spectrum



Continuous X-rays spectrum

2) Continuous spectrum :- It is formed due to scattering of high speed electrons that strike

the target. When high energy electrons move close to the nucleus of target atom, then these

get decelerated and X-rays of continuous frequency are emitted. The electron rarely loses whole of its energy in a single collision. Generally it undergoes a sequence of collisions with atoms of the target before coming to rest, thus emitting photons of smaller energies or longer wavelength.

Duane and Haunt's rule: Continuous x-ray spectrum suddenly ends at a certain minimum

wavelength called limiting wavelength , which decreases with increase of applied voltage .

When the electron loses the whole of its energy in a single collision with the target atom, then X-ray photon of maximum energy is emitted.

$$h\nu_{max} = eV \quad \Rightarrow \quad \lambda_{min} = \frac{hc}{e\nu} = \frac{12400}{V}\,\overset{0}{A} \;\Rightarrow\; \lambda_{max}\ \alpha\ \frac{1}{V}$$

Greater the applied voltage, smaller will be the value of λ_{min} .

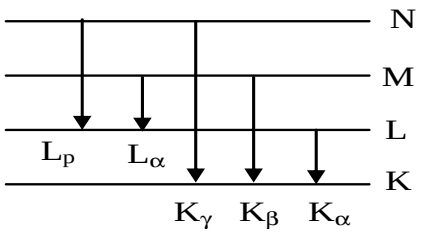
These X –ray wavelengths do not depend on the atomic number of target element.

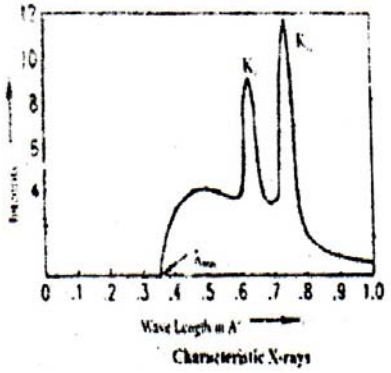
i) The intensity increases rapidly on the lower wavelength side and falls slowly on the higher wavelength side.
ii) When the target potential is increased, the wavelength corresponding to peak of curve decreases.
iii) When the potential applied to the target is increased, the intensity corresponding to every wavelength increases.
iv) As the PD across the tube increases, the wavelength corresponding to the maximum intensity decreases.

2. Characteristic X-rays spectrum :

a)When electron with high energy penetrate atoms, they strike the electrons of inner shells and knock out them from the atoms, then deficiency of electron is created in the inner shell. Electron from higher shell jumps into this shell to fulfill this deficiency. In this process photons with energies equal to difference of energies of initial and final shells are emitted. These are characteristic X-rays. This is the characteristic nature of the target material and it is independent of the potential difference across the tube. The

frequencies of the characteristic X-rays do not depend on the applied potential difference. Thus a line spectrum in which series of various frequencies or wavelength are obtained.





When electron makes transitions from L, M, N…… shells to K shell, and then K-series of X-rays is emitted. When electron makes transitions from M, N … shells to L shell, L series is emitted. The first lines of the series are called K_α, L_α, M_α...Similarly the second liens are called K_β, L_β, M_β.....Wavelength of K-series are generally less than 1 A° and those of L-series are about 10 times longer. The frequencies of these spectral lines will be 1000 times higher to the frequency of visible light.

For K-series, $\frac{1}{\lambda} = R(Z-1)^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$

The wavelength of K_α is greater than that of K_β line. This spectrum is also called line spectrum and it is due to high energetic electrons. Characteristic X-ray spectrum is useful in identifying the elements from which they originate.

Short Answer Questions

1. What is Moseley's law? Discus briefly its importance.(March2010,March2009)

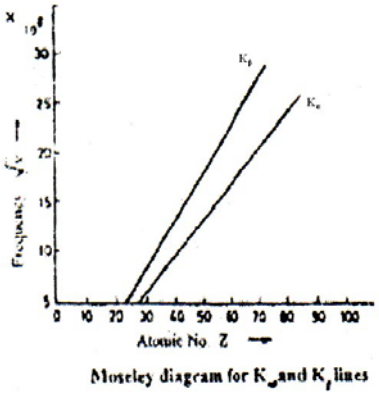
A: **Moseley's Law:** The frequency of a particular spectral line (υ) in X-ray characteristic spectrum is proportional to square of atomic number

$\upsilon \alpha z^2$ or $\sqrt{\upsilon} \alpha Z$

$\sqrt{\upsilon} = a(z-b)$ where a and b are constants. b is called screening constant

b = 1 for K series and b = 7.4 for L series

This is known as Moseley's law.



Moseley diagram for K_α and K_β lines

Importance:

1. Moseley's Law helped to arrange the elements in periodic table according to atomic number only. This helped to decide the position of elements like Argon, Potassium, Cobalt, Nickel, etc.

2. Moseley's Law helped to discover the elements like Masurium (43) and Illinium (61) etc.

2. Describe the origin of X-rays spectra.

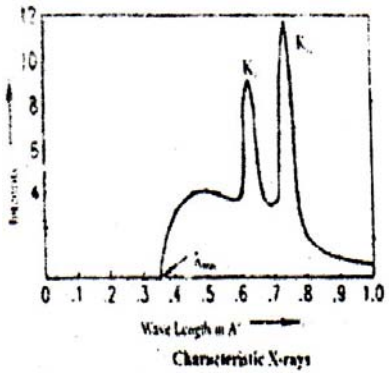
A: There are two types of x-ray spectra: 1) Continuous spectrum, 2) Characteristic spectrum

Continuous spectrum: It is formed due to scattering of high speed electrons that strike the target. When high energy electrons move close to the nucleus of target atom, then these get decelerated and X-rays of continuous frequency are emitted. The electron rarely loses whole of its energy in a single collision. Generally it undergoes a sequence of collisions with atoms of the target before coming to rest, thus emitting photons of smaller energies or longer wavelength. Continuous x-ray spectrum suddenly ends at a certain minimum wavelength called limiting wavelength , which decreases with increase of applied voltage . When the electron loses the whole of its energy in a single collision with the target atom, then X-ray photon of maximum energy is emitted.

Characteristic spectrum : The fast moving electron from cathode knock out most orbitary electrons of the target material. This gap in the orbit is filled by the higher orbit electrons, resulting in the emission of energy in the form of X-ray photons. Since the energy of these x-rays depends on the energy gap of orbits of target material, this spectrum depends on the nature of target material. Thus the spectrum is called characteristic spectrum.

$$E_{k\alpha} < K_{k\beta} < K_{k\gamma} \Rightarrow \lambda_{k\alpha} > \lambda_{k\beta} > \lambda_{k\gamma}$$

K-series X-ray photons result from the de-excitation of electrons from higher energy of k-shell.



VERY SHORT ANSWER QUESTIONS

1. State Moseley's law? What is its importance?(June2010)

A: Moseley's Law : The square root of frequency of a characteristic x-ray spectra line is directly proportional to the atomic number of the element emitting it.

$\sqrt{v}\,\alpha\, Z$ or $\sqrt{v}\,a\,(Z-b)$ Where 'a' and 'b' are constants.

Importance: 1.Moseley's law confirmed that the determining factor for the arrangement of elements in the periodic table is atomic number but not the atomic weight.

2.It led to the discovery of new elements like masurium (Z = 43), Illinium (Z = 61) and Hafnium (Z = 72).

3. It also helped in determining the atomic numbers of rare earth elements.

SOLVED PROBLEMS

1. Calculate the voltage to be applied to an X-ray tube to produce X-rays of wavelength of $1\overset{0}{A}$ ($h = 6.62\times10^{-34}\ Js$ and $c = 3\times10^{8}\ ms^{-1}$)

Sol: $\lambda = 1\overset{0}{A} = 1\times10^{-10}\ m,\ h = 6.62\times10^{-34}\ Js$ and $c = 3\times10^{8}\ ms^{-1}$.

$$E = h\nu = \frac{hc}{\lambda} \Rightarrow E = \frac{6.62\times10^{-34}\times3\times10^{8}}{1\times10^{-10}} = 19.8\times10^{-16}\ J$$

$$V = \frac{19.8\times10^{-16}}{1.6\times10^{-19}} = 12.38\times10^{3}\ V$$

2. An X-ray tube produces a continuous spectrum of radiation with its short wavelength end at $0.40\overset{0}{A}$. **Find (i) maximum energy of the photon of the emitted radiation (ii) Find also the accelerating voltage required for electron to produce this radiation**

($c = 3\times10^{8}\ ms^{-1}, h = 6.63\times10^{-34}\ Js$)

Sol: $\lambda = 0.40\,\overset{0}{A} = 0.4\times10^{-10}\,m$, $c = 3\times10^{8}\,ms^{-1}$, $h = 6.63\times10^{-34}\,Js$.

i) $h\nu_{max} = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{0.4\times10^{-10}} = 4.9725\times10^{-15}\,J$.

ii) $V = \frac{h\nu_{max}}{e} = \frac{4.9725\times10^{-15}}{1.6\times10^{-19}} = 31.08\,kV$.

3. Calculate the maximum frequency of X-rays produced in an X-ray tube at an operating voltage of 25kV. ($c = 3\times10^{8}\,ms^{-1}$, $h = 6.63\times10^{-34}\,Js$)

Sol: V = 25kV = 25000V, $\lambda = 0.40\,\overset{0}{A} = 0.4\times10^{-10}\,m$, $\nu_{max} = ?$

But $h\nu_{max} = eV$

$\therefore \nu_{max} = \frac{eV}{h} = \frac{6.63\times10^{-19}\times25000}{6.63\times10^{-34}} = \frac{40}{6.63}\times10^{18} = 6.08\times10^{18}\,Hz$.

UNSOLVED PROBLEMS

1. An X-Ray tube produces a continuous spectrum of radiation with its shortest wavelength of $45\times10^{-2}\,A^{0}$ **. What is the maximum energy of a photon in the radiation?**

Sol: $\lambda_c = 45\times10^{-2}\,A^{0} = 45\times10^{-12}\,m$

E = $\frac{hc}{\lambda} = \frac{6.6256\times10^{-34}\times3\times10^{8}}{45\times10^{-12}} = 2.77\times10^{4}\,eV$.

ASSESS YOURSELF

14. The wavelength X-ray radiation is $0.1A^{0}$. What will be its momentum?

A. 6.63×10^{-23} Kg-m/s

15. Can a hydrogen atom emit characteristic X-ray?

A. No, because the energy levels are very close.

16. Characteristic x-ray may be used to identify the element from which they are emitted. Can continuous X-rays be used for this purpose?

A No.

17. Can X-rays produce photoelectric effect from Zinc?

A. Yes.

18. By increasing operating voltage can we get hard X-rays?

A. Yes, because this increase the energy of the cathode rays.