Modern Physics

Rutherford Seattening :

Rutherford seattering experiments helped in understanding structure of atom. Rutherford bombarded a narrow beam of $\alpha-$particles on a gold foil and observed visible light scintillations on a zinc surplide screen. Rutherford observed that :

(1) Most of the $\alpha-$particles were either undeflected or deflected through small angles of the order of $1°$.

(2) A few $\alpha-$particles were deflected through angles as large as $90°$ or more.

Bohr Model of Hyrogen atom

Bohr proposed his theory of structure of atom on the basis of following assumptions :

(1) Electrons move in circular orbits about proton under the influence of coulomb force of attraction. These orbits are stationary states in which electrons do not continuously radiate electromagnetic energy.

(2) The emission or absorption of electron takes place only when there is a transition of electrons between two stationary states.

(3) The angular momentum of this system in a stationary state is an integral multiple of $\frac{h}{2\pi}(=\hbar)$.

On the basis of these assumptions :

(a) Radius of nth Bohr's orbit

$$r_n = \frac{4\pi \in n^2\hbar^2}{me^2} = n^2 a_0$$

(b) Velocity of electron

$$V_n = \frac{1}{n}\frac{e^2}{4\pi \in_0 \hbar} = \frac{V_0}{n} = \frac{1}{n}\frac{\hbar}{ma_0}$$

(c) Energy of electron in nth orbit,

$$E = -\frac{e^2}{8\pi \in_0 r_n} = -\frac{e^2}{8\pi \in_0 a_0 n^2} = -\frac{E_0}{n^2} = \frac{13.6\,eV}{n^2}$$

A quanta of light is emitted when an atom in excited state decays to a lower energy state.

$$h\upsilon = E_f - E_i$$

(d) Frequency, wavelength, wave number of transitions

$$\frac{1}{\lambda} = \frac{\nu}{c} = \frac{E_f - E_i}{hc}$$

$$= -\frac{E_0}{hc}\left[\frac{1}{n_i^2} - \frac{1}{n_i^2}\right] \quad = R\left[\frac{1}{n_i^2} - \frac{1}{n_f^2}\right]$$

Where $R = \frac{E_0}{hc}$ = Rydberg constant = $1.097373 \times 10^7\ m^{-1}$

X-RAYS

These are electromagnetic wave whose wavelengths typically range from 0.01 to 1 nm.

When an electron strikes a metallic target, before stopping it makes several collisions with atoms. Electrons may interact with the atom in either of the two ways :

(i) Due to strong nuclear electric field, electron is decelerated. In the process it radiates electromagnetic energy. Electron emits a series of photons with varying energy. These photons are x-rays. The x-rays produced in this process are called continuous x-rays.

(ii) When the high energy electron collides with one of the lower shell K electrons in a target atom, if enough energy can be transfered to this electron, the atom may be ionised. An electron from one of the higher shells will change its state and fill the inner shell vacancy at lower energy emitting radiation. The emitted radiation in heavy atoms is x-ray. Photons emitted in this way is called characteristic x-ray.

De Broglie or Matter Waves :

De Broglie proposed that material particles also have both wave and particle properties.

The wavelength to be associated with a particle is given by Planck's constant divided by the particle's momentum.

$$\lambda = \frac{h}{p}$$

This relation for photons was extended to all particles by De Broglie. Waves associated with particles are called matter waves, and the wavelength is called the de Broglie wavelength of a particle.

- The DeBroglie wavelength of the electron is large enough to be observed. Because of their small mass, electrons can have a small momentum and in turn a large wavelength.
- If m is the mass and v the velocity of the material particle, then

$$p = mv$$

$$\lambda = \frac{h}{mv}$$

- If E is the kinetic energy of the material particle, then

$$E = \frac{1}{2}mv^2 = \frac{p^2}{2m}$$

$$p = \sqrt{2mE}$$

Therefore, the de Broglie wavelength is given by $\lambda = \frac{h}{\sqrt{2mE}}$

- For electrons ($m_e = 9.1 \times 10^{-31}$ kg)

$$\lambda = \frac{h}{\sqrt{2mqV}} = \frac{6.62\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.6\times10^{-19}V}}\,m = \frac{12.27}{\sqrt{V}}\,\text{Å}$$

Bohr's Quantisation Condition :

The angular momentum of the electron in this orbit is L = rp. Using the above relation,

$$L = rp = \frac{nh}{2\pi} = n\hbar \quad \text{which is Bohr's quantisation condition.}$$

Atomic Nucleus

Nuclear size is of the order of femtometre (1 fm = 10^{-15} m).

The radius of a nucleus is given by $R = R_0 A^{1/3}$

The value of R_0 is, $R_0 \approx 1.2\times10^{-15}$ m ≈ 1.2 fm

Radioactivity

1. Radioactive decay is a statistical process; we cannot precisely predict the timing of a particular radioactivity of a particular nucleus. The nucleus can disintegrate immediately or it may take infinite time. We can predict the probability of the number of nuclei disintegrating at an instant.
2. Radioactivity is independent of all the external conditions. We caannot induce radioactivity by applying strong electrical field, magnetic field, high temperature, high pressure, etc.
3. The energy liberated during radioactive decay comes from within individual nuclei.
4. When a nucleus undergoes alpha or beta decay, its atomic number changes and it transforms into a new element. Thus elements can be transformed from one to another.
5. The rate, at which a particular decay process occurs in a radioactive sample, is proportional to the number of radioactive nuclei present (i.e., those nuclei that have not decayed). If N is the number of radioactive nuclei present at some instant, the rate of change of N is,

$$\frac{dN}{dt} = -\lambda N$$

where λ is called decay constant. The minus sign indicates that $\frac{dN}{dt}$ is negative.

$$N = N_0 e^{-\lambda t}$$

where the constant N_0 represents the number of nuclei or radioactive nuclei at $t = 0$.

- Half life of a radioactive substance is the time it takes half of a given number of radioactive nuclei to decay. Setting $N = N_0/2$ and $t = T_{1/2}$ we get

$$\frac{N_0}{2} = N_0 e^{-\lambda T_{1/2}}$$

Writing the above equation in the form $e^{\lambda T_{1/2}} = 2$ and taking natural logarithm of both sides, we get

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$$

- Mean life (average life) τ is defined as the average time the nucleus survives before it decays.

$$\tau = \frac{1}{\lambda} = \frac{T_{1/2}}{0.693}$$

PHOTOELECTRIC EFFECT

The phenomenon of emission of electrons from a metallic surface by the use of light (or radiant energy) of certain minimum frequency (or maximum wavelength) is called photoelectric effect.

The incident photon interacts with a single electron and loses its energy in two parts.

(a) Firstly, in getting the electron released from the bondage of the nucleus.

(b) Secondaly, to importing kinetic energy to emitted electron.

Accordingly, if hv is the energy of incident photon, then

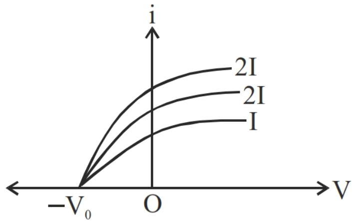
$$h\nu = \phi_0 + E_{max}$$

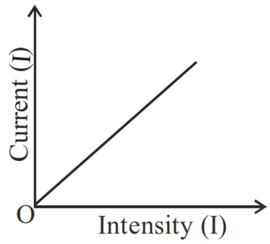
$$h\nu = h\nu_0 + K_{max.} = h\nu = e\nu_0$$

This is Einstein's photoelectric equation, where ϕ_0 is work function and $E_{max} = \frac{1}{2}mv_{max}^2 = eV_s$ is the maximum kinetic energy of photo-electrons emitted. v_0 is the reverse potential differenic required to stop the electron from ejecting, called stopping potential.

Effect of Intensity

For a given frequency, if intensity of incident light is increased, the photoelectric current increases but the stopping potential remains the same. In photoelectric effect current (i) is directly proportional to intensity(I) of incident light.

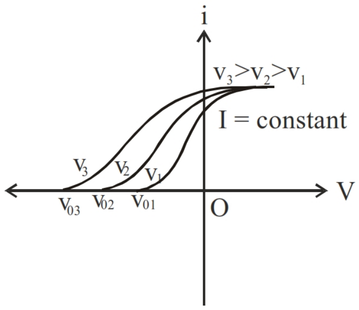




The intensity of incident light affects the photoelectric current but leaves the maximum kinetic energy of photoelectrons unchanged.

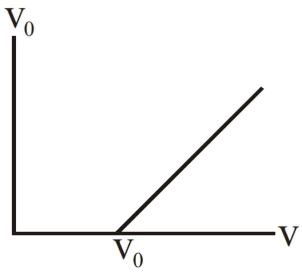
Effect of Frequency

When the intensity of incident light is kept fixed and frequency is increased, the photoelectric current remains the same but the stopping potential increases. If the frequency is decreased, the stopping potential decreases and at a particular frequency of incident light, the stopping potential becomes zero. This value of frequency of incident light for which the stopping potential is zero is called threshold frequency v_0, No photoelectric emission takes place below this frequency. Thus the increase of frequency increases maximum kinetic energyof photoelectrons but leaves the photoelectric current unchanged.



Effect of Photo-Metal

- When frequency and intensity of incident light are kept fixed and photo-metal is changed, we observe that stopping potential (V_0) versus frequency (ν) graphs are similar, cutting, frequency axis at different points. This shows that threshold frequency are different for different metals, the slope $\left(\frac{v_0}{v}\right)$ for all the metal is same and hence a universal constant.



Effect of Time

There is no time lag between incidence of light and the emission of photo-electrons.