

Planck's Quantum theory and Photoelectric effect

Planck's Quantum theory

(1) **Max Planck** (1900) to explain the phenomena of 'Black body radiation' and 'Photoelectric effect' gave quantum theory. This theory extended by **Einstein** (1905).

(2) If the substance being heated is a black body (which is a perfect absorber and perfect radiator of energy) the radiation emitted is called **black body radiation**.

(3) Main points

(i) The radiant energy which is emitted or absorbed by the black body is not continuous but discontinuous in the form of small discrete packets of energy, each such packet of energy is called a '**quantum**'. In case of light, the quantum of energy is called a '**photon**'.

(ii) The energy of each quantum is directly proportional to the frequency (ν) of the radiation, i.e.

$$E \propto \nu \text{ or } E = h\nu = \frac{hc}{\lambda}$$

where, h = Planck's constant = 6.62×10^{-34} erg. sec. or 6.62×10^{-34} Joules sec.

(iii) The total amount of energy emitted or absorbed by a body will be some whole number quanta. Hence $E = nh\nu$, where n is an integer.

(iv) The greater the frequency (i.e. shorter the wavelength) the greater is the energy of the radiation.

$$\text{thus, } \frac{E_1}{E_2} = \frac{\nu_1}{\nu_2} = \frac{\lambda_2}{\lambda_1}$$

(v) Also $E = E_1 + E_2$, hence, $\frac{hc}{\lambda} = \frac{hc}{\lambda_1} + \frac{hc}{\lambda_2}$ or $\frac{1}{\lambda} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$.

Photoelectric effect

(1) When radiations with certain minimum frequency (ν_0) strike the surface of a metal, the electrons are ejected from the surface of the metal. This phenomenon is called **photoelectric effect** and the electrons emitted are called **photo-electrons**. The current constituted by photoelectrons is known as photoelectric current.

(2) The electrons are ejected only if the radiation striking the surface of the metal has at least a minimum frequency (ν_0) called **Threshold frequency**. The minimum potential at which the plate photoelectric current becomes zero is called **stopping potential**.

(3) The velocity or kinetic energy of the electron ejected depend upon the frequency of the incident radiation and is independent of its intensity.

(7) The de-Broglie equation is applicable to all material objects but it has significance only in case of microscopic particles. Since, we come across macroscopic objects in our everyday life, de-broglie relationship has no significance in everyday life.

Heisenberg's uncertainty principle

(1) One of the important consequences of the dual nature of an electron is the uncertainty principle, developed by **Warner Heisenberg**.

(2) According to uncertainty principle "It is impossible to specify at any given moment both the position and momentum (velocity) of an electron".

Mathematically it is represented as , $\Delta x \cdot \Delta p \geq \frac{h}{4\pi}$

Where Δx = uncertainty in position of the particle, Δp = uncertainty in the momentum of the particle

Now since $\Delta p = m \Delta v$

So equation becomes, $\Delta x \cdot m \Delta v \geq \frac{h}{4\pi}$ or $\Delta x \times \Delta v \geq \frac{h}{4\pi m}$

The sign $\geq$ means that the product of Δx and Δp (or of Δx and Δv) can be greater than, or equal to but never smaller than $\frac{h}{4\pi}$. If Δx is made small, Δp increases and vice versa.

(3) In terms of uncertainty in energy ΔE and uncertainty in time Δt , this principle is written as, $\Delta E \cdot \Delta t \geq \frac{h}{4\pi}$

When Heisenberg's uncertainty principle cannot we apply to a stationary electron because its velocity is 0 and position can be measured accurately.

Schrödinger wave equation

(1) Schrodinger wave equation is given by **Erwin Schrödinger** in 1926 and based on dual nature of electron.

(2) In it electron is described as a three dimensional wave in the electric field of a positively charged nucleus.

(3) The probability of finding an electron at any point around the nucleus can be determined by the help of Schrodinger wave equation which is,

$$\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + \frac{\partial^2 \Psi}{\partial z^2} + \frac{8\pi^2 m}{h^2} (E - V) \Psi = 0$$

Where x, y and z are the 3 space co-ordinates, m = mass of electron, h = Planck's constant,

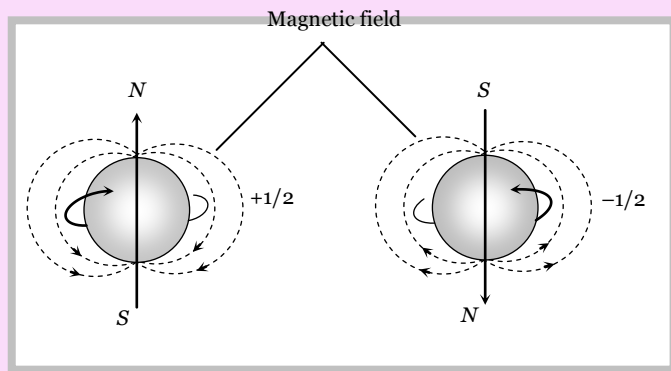
E = Total energy, V = potential energy of electron, Ψ = amplitude of wave also called as wave function.

∂ = stands for an infinitesimal change.

(iii) The spin may be clockwise or anticlockwise.

(iv) It represents the value of spin angular momentum is equal to $\frac{h}{2\pi} \sqrt{s(s+1)}$.

(v) Maximum spin of an atom = $1/2 \times \text{number of unpaired electron}$.



(vi) This quantum number is not the result of solution of schrodinger equation as solved for H-atom.

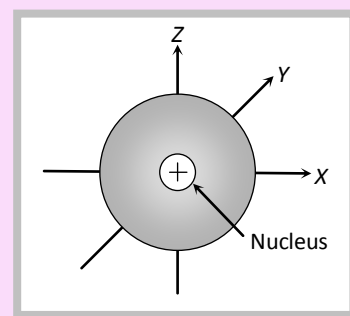
Shape of orbitals

(1) Shape of 's' orbital

(i) For 's' orbital $l=0$ & $m=0$ so 's' orbital have only one unidirectional orientation i.e. the probability of finding the electron is same in all directions.

(ii) The size and energy of s orbital with increasing 'n' will be $1s < 2s < 3s < 4s$.

(iii) It does not possess any directional property. s orbital has spherical shape.

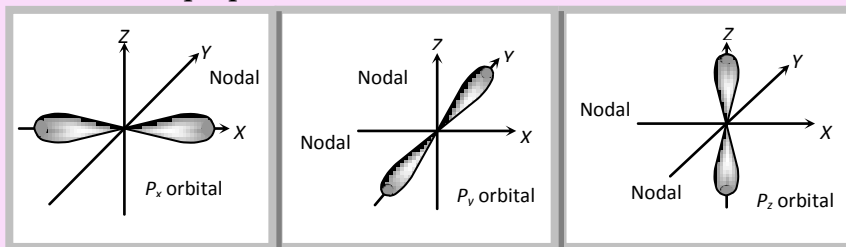


(2) Shape of 'p' orbitals

(i) For 'p' orbital $l=1$, & $m=+1, 0, -1$ means there are three 'p' orbitals, which is symbolised as p_x, p_y, p_z .

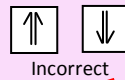
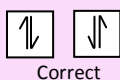
(ii) Shape of 'p' orbital is dumb bell in which the two lobes on opposite side separated by the nodal plane.

(iii) p-orbital has directional properties.



(3) Shape of 'd' orbital

- (ii) In an atom any two electrons may have three quantum numbers identical but fourth quantum number must be different.
- (iii) Since this principle excludes certain possible combinations of quantum numbers for any two electrons in an atom, it was given the name exclusion principle. Its results are as follows :
- (a) The maximum capacity of a main energy shell is equal to $2n^2$ electron.
 - (b) The maximum capacity of a subshell is equal to $2(2l+1)$ electron.
 - (c) Number of sub-shells in a main energy shell is equal to the value of n .
 - (d) Number of orbitals in a main energy shell is equal to n^2 .
 - (e) One orbital cannot have more than two electrons.
- (iv) According to this principle an orbital can accommodate at the most two electrons with spins opposite to each other. It means that an orbital can have 0, 1, or 2 electron.
- (v) If an orbital has two electrons they must be of opposite spin.



(3) Hund's Rule of maximum multiplicity

- (i) This rule provides the basis for filling up of degenerate orbitals of the same sub-shell.
- (ii) According to this rule "Electron filling will not take place in orbitals of same energy until all the available orbitals of a given subshell contain one electron each with parallel spin".
- (iii) This implies that electron pairing begins with fourth, sixth and eighth electron in p , d and f orbitals of the same subshell respectively.
- (iv) The reason behind this rule is related to repulsion between identical charged electron present in the same orbital.
- (v) They can minimise the repulsive force between them serves by occupying different orbitals.
- (vi) Moreover, according to this principle, the electron entering the different orbitals of subshell have parallel spins. This keep them farther apart and lowers the energy through electron exchange or resonance.
- (vii) The term maximum multiplicity means that the total spin of unpaired e^- is maximum in case of correct filling of orbitals as per this rule.

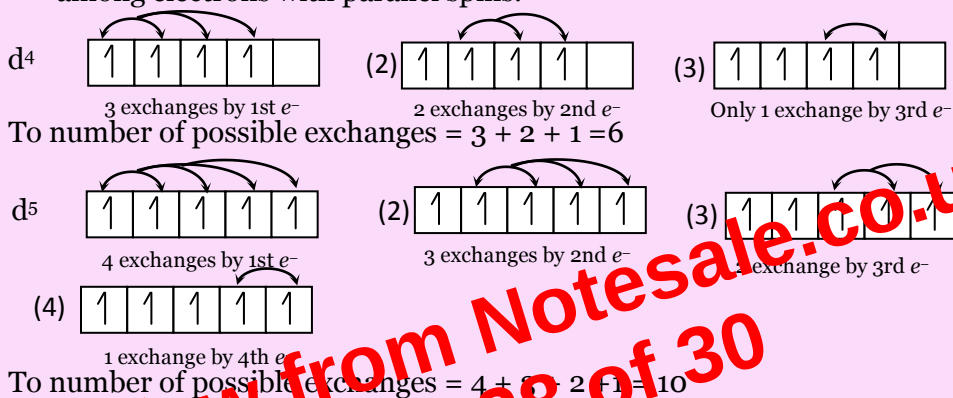
Energy level diagram

The representation of relative energy levels of various atomic orbital is made in the terms of energy level diagrams.

(c) For example p^3, d^5, f^7 configurations are more stable than their near ones.

(ii) *Exchange energy*

- The electron in various subshells can exchange their positions, since electron in the same subshell have equal energies.
- The energy is released during the exchange process within the same subshell.
- In case of half filled and completely filled orbitals, the exchange energy is maximum and is greater than the loss of orbital energy due to the transfer of electron from a higher to a lower sublevel e.g. from 4s to 3d orbitals in case of Cu and Cr.
- The greater the number of possible exchanges between the electrons of parallel spins present in the degenerate orbitals, the higher would be the amount of energy released and more will be the stability.
- Let us count the number of exchange that are possible in d^4 and d^5 configuration among electrons with parallel spins.



Electronic configurations of Elements

(i) On the basis of the electronic configuration principles the electronic configuration of various elements are given in the following table :

Electronic Configuration (E.C.) of Elements Z=1 to 36

Element	Atomic Number	1s	2s	2p	3s	3p	3d	4s	4p	4d	4f
H	1	1									
He	2	2									
Li	3	2	1								
Be	4	2	2								
B	5	2	2	1							
C	6	2	2	2							
N	7	2	2	3							
O	8	2	2	4							
F	9	2	2	5							
Ne	10	2	2	6							
Na	11	2	2	6	1						
Mg	12				2						