Engineering Physics (B.Tech-1st sem)

Course Code: PHIC 101 **Credits: 4**

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Syllabus

UNIT-I

QUANTUM MECHANICS: Basics of quantum mechanics, De-Broglie's hypothesis, Uncertainty principle, Probability and Wave function, Postulates of quantum mechanics, Time-dependent and Time-independent Schrodinger wave equations, Particle in 1-D potential box, Quantum Tunnelling Phenomenon.

ELECTROMAGNETIC THEORY: Maxwell's equations in vacuum and medium, Electromagnetic Waves, Propagation Energy and Poynting Vector.

UNIT-II

PHYSICS OF SOLIDS: Crystal Structure, Space Lattice, Translation vectors; Crystal Symmetry, Miller indices, Simple and close-packed crystal structures with examples, Free electron theory: Drude's Theory of Conduction; Quantum theory of free electrons, Fermi-Dirac distribution function, Fermi–level and Fermi Energy; Density of States, Classifications of metals-semiconductors-insulators based on resistivity, equilibrium and extrinsic carrier concentration.

UNIT-II

LASER PHYSICS: Basic principle and characteristics of lasers, Einstein's coefficients, Types of the Lasers: He-Ne laser, Semiconductor Laser, Applications of Lasers in research and industry, Safety protocols of lasers.

FUNDAMENTALS OF OPTICAL FIBER: Acceptance angle, Numerical aperture, Classification of optical fibres, Fiber losses, Fiber manufacturing, Applications of optical fibre in industry and cmmunications.

UNIT-IV

SPECIAL THEORY OF RELATIVITY: Frame of references: inertial and non-inertial, , Galilean transformation, The Michelson-Morley experiment, Postulates of Special Theory of Relativity, Lorentz transformations, Length contraction, Time dilation, Velocity addition, Variation of mass with velocity, Mass-energy equivalence.

NUCLEAR TECHNOLOGY: Interaction of radiation with matter, Neutron cross-section, Nuclear Reaction, Moderators, Reactor criticality, Nuclear reactors for power generation, Safety protocols.

Quantum Mechanics-1

From Classical to Quantum-

Limitations/Difficulties of Classical Physics

1. It could not explain the motion of the microscopic bodies like atoms, electrons protons etc. which move with the relativistic speeds.
2. It could not explain stability of atoms. According to classical electromagnetic theory atom must collapse but atom is a stable system.
3. It could not explain line spectra i.e. emission of radiations of some particular wavelengths and not of all wavelengths.
4. It could not explain variation of specific heat of solids with temperature, emission of X-rays etc.

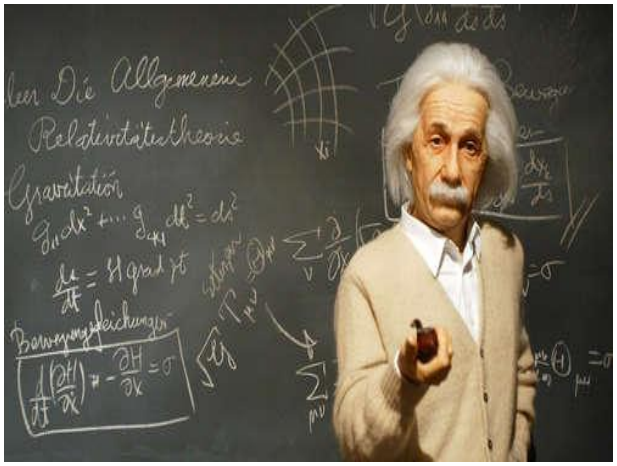
5. It could not explain Photoelectric effect.
6. The classical ideas failed to explain the distribution of energy in black body radiation spectrum.
7. It could not explain the phenomena connected with the spin of particles and Pauli exclusion principle.
8. Compton effect, Raman effect, Radioactivity, scattering phenomenon are not explained by classical theory.

The difficulties faced by classical physics led the scientists to abandon classical ideas and search new ideas.

Quantum Physics came into existence after Plank's hypothesis.

Introduction of Quantum Physics

Max Planck made many contributions to Physics, but his main contribution was as originator of the quantum theory. This theory revolutionized human understanding of atomic and subatomic processes, just as Albert Einstein theory of Relativity revolutionized the understanding of space and time.



Albert Einstein



Max Planck

Quantum physics (1900-1930)

On 14th Dec' 1900 Max Plank stated that Radiations are absorbed and emitted by a matter not in continuous manner but in form of small packet and each packet is called quanta (Photon).

This statement leading to new branch of physics, now called as Quantum mechanics.

Continuing the concept of Planck's and Einstein, Schrodinger and de-Broglie further developed advance concept of quantum mechanics. Schrodinger equation leads to the solutions of problems of quantum mechanics and de-Broglie dual wave nature relates classical and quantum mechanics.





WHAT IS QUANTUM?

In Latin It mans DISCREATE QUANTITY

The quantities can be momentum, energy etc.

Two stages of quantum mechanics:

Max Plank hypothesis (1900): radiations are emitted or absorbed by matter in discrete packets/ quanta.

W. Heisenberg (1925) & E. Schrödinger (1926): The variables like momentum and energy were found to have discrete and discontinuous values.

Planks Quantum hypothesis

The hypothesis that energy is emitted or absorbed in a discrete manner in the form of quanta is called Plank's quantum hypothesis.

a) A body consists of a large number of atomic oscillators vibrating with all possible frequencies.

b) The atoms in a body cannot have any arbitrary amounts of energy.

$$E = n\,hv$$

n = 1,2,3,…..any positive integer, defines as energy state

v= frequency of oscillations

h= Plank's constant (6.63×10^{-34} Joule-sec)

c) The atomic oscillators cannot emit or absorb energy of any arbitrary amount. The energy has discrete units having values hv, $2hv$, $3hv$.

Wave particle duality: De-Broglie waves

The de Broglie equations relate the wavelength λ to the momentum p, and frequency *v* to the kinetic energy E (excluding its rest energy and any potential energy) of a particle:

$$\lambda = h/p$$

where h is Planck's constant. The equation can be equivalently written as

$$p = \hbar k$$

using the definitions

- The reduced Planck's constant (also known as Dirac's constant, pronounced "h-bar"),

$$\hbar = h/2\pi$$

- The angular wavenumber,

$$k = 2\pi/\lambda$$

- The angular frequency

$$w=2\,\pi\,v$$

Matter wave associated with an electron

For an electron moving under a Potential difference of V volts;

$$KE = \frac{p^2}{2m} = eV$$

$$P = \sqrt{2meV}$$

$$\lambda = \frac{h}{\sqrt{2meV}}$$

$$Then \quad \lambda = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2meV}}$$

$$substituting \ for \ h, \ m \ , and \ e \ we \ get$$

$$\lambda = \frac{6.625\times10^{-34}}{\sqrt{2\times9.11\times10^{-31}\times1.602\times10^{-19}\times V}} = \frac{1.226}{\sqrt{V}} \ nm$$

$$thus \quad for \quad V = 100 \ Volts$$

$$\lambda = \frac{1.226}{\sqrt{100}} = 0.1226 \ nm$$

Special relativity

- Using the relativistic momentum formula from special relativity

$$p = \gamma m_0 v$$

- allows the equations to be written as

$$\lambda = \frac{h}{\gamma m_0 v} = \frac{h}{m_0 v}\sqrt{1 - \frac{v^2}{c^2}}$$

$$= \frac{\gamma\, m_0 c^2}{h} = \frac{m_0 c^2}{h\sqrt{1 - \frac{v^2}{c^2}}}$$

where m_0 is the particle's rest mass, v is the particle's velocity, γ is the Lorentz factor, and c is the speed of light in a vacuum.

The Heisenberg Uncertainty Principle

The Heisenberg uncertainty principle states that the uncertainties of an infinitely precise measurement of the particle position x and its momentum p are correlated. If the particle state is such that the first measurement yields a standard deviation of values Δx, then the second measurement will have a distribution of values whose dispersion Δp is at least inversely proportional to Δx. The constant of proportionality is equal to Planck's constant divided by 4π.

$$\Delta x \Delta p \geq \frac{\hbar}{2\pi}$$

$$\Delta x \ \Delta p \approx \hbar$$

Time-EnergyUncertainty

$$\Delta E \ \Delta t \approx \hbar$$

Applications of Uncertainty Principle

Non-existence of the electron inside the nucleus. The radius of the nucleus of an atom is of the order of 10^{-14} m, so if an electron is confined within the nucleus, the uncertainty in its position may not exceed 10^{-14} m.

According to uncertainty principle

$$\Delta x \, \Delta p \approx \hbar$$

or

$$\Delta p \approx \frac{\hbar}{\Delta x} \approx \frac{h}{2\pi \Delta x}$$

$$\approx \frac{6.625\times10^{-34}\ \text{J - sec}}{2\times3.14\times2\times10^{-14}\ \text{m}} \qquad (\because\ \Delta x = 2r = 2\times10^{-14})$$

$$= 5.275\times10^{-21}\ \text{kg ms}^{-1}$$

If this is the order of uncertainty in momentum of the electron then the momentum of the electron, if it exists inside the nucleus, must be at least comparable to this number *i.e.*

$$\Delta p = p \approx 5.275\times10^{-21}\ \text{kg ms}^{-1}$$

The corresponding kinetic energy E of the electron of mass m is given by

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

$$= \frac{(5.275\times10^{-21})^2}{2\times9.1\times10^{-31}}\ \text{J} \qquad (\because\ m = 9.1\times10^{-31}\ \text{kg})$$

$$= \frac{(5.275\times10^{-21})^2}{2\times9.1\times10^{-31}\times1.6\times10^{-19}}\ \text{eV}$$

$$\approx 9.7\times10^{7}\ \text{eV} \approx 97\ \text{MeV}$$

This shows that if the electrons exist inside the nucleus then their K.E. should be of the order of 97 MeV. But the experimental observations show that the energy of the electrons emitted by nuclei is not greater than 4 MeV, which therefore implies that electrons do not exist inside the nucleus.

(*ii*) **Existence of neutrons, protons and α-particles inside the nucleus.** The rest mass of the neutrons and protons is of the order of $m_0 \approx 1.67 \times 10^{-27}$ kg. From the uncertainty principle

$$\Delta p \approx \frac{\hbar}{\Delta x}$$

As the radius of the nucleus of the atom is 10^{-14} m, then

$$\Delta x = 2r = 2 \times 10^{-14}$$

and $$\Delta p = p \approx 5.275 \times 10^{-21} \text{ kg ms}^{-1} \text{ (see previous example)}$$

The corresponding value of the K.E.

$$E = \frac{p^2}{2m_0} = \frac{(5.275 \times 10^{-21})^2}{2 \times 1.67 \times 10^{-27}}$$

$$= 8.4 \times 10^{-15} \text{ J}$$

$$= \frac{8.4 \times 10^{-15}}{1.6 \times 10^{-19}} \text{eV} = \frac{8.4 \times 10^{-15}}{1.6 \times 10^{-19}} \times 10^{-3} \text{ keV} = 52 \text{ keV}$$

The rest mass of α-particle is approximately four times the proton rest mass, thus α-particle should have a minimum kinetic energy of 13 keV. Since the minimum energy carried by protons or neutrons is of the order of 52 keV and that for time and energy of a particle, the product of uncertainties is equal to a number of the order of α-particles is of the order of 13 keV, hence these particles can exist inside the nucleus.

Binding Energy of nucleon in nucleus. If a nucleon is confined with the sphere of radius $r_0 = (= 1.2 \times 10^{-12}$ cm), the momentum must be of the order of $p = \frac{\hbar}{r_0}$. Thus, the K.E. of the nucleon of mass m (proton or neutron) will be of the order

$$T = \frac{p^2}{2m}$$

$$= \frac{1}{2m} \frac{\hbar^2}{r_0^2} \approx 10 \text{ MeV}$$

Now if the nucleon is bound in the nucleus, the binding energy must be more than K.E. and opposite in sign. Thus the nuclear binding energy is of the order of 10 MeV.