**PH3151-ENGINEERING PHYSICS**

**PART-B**

**UNIT I: MECHANICS**

**1. Find the Location of Centre of Mass of a Multi-particle System**

The **centre of mass** is a special point in a system of particles where the whole mass of the system seems to be concentrated. If you apply a force at this point, the entire system moves as if it were a single object.

In a system with many particles, each particle has its own mass and position. To find the centre of mass, you need to consider both these aspects — the mass and where the particles are located. The heavier the particle and the farther it is, the more it influences the centre of mass.

Imagine balancing a stick with weights attached. If a heavier weight is closer to one end, the stick balances not at the center but nearer to that weight — that is where the centre of mass shifts.

The position of the centre of mass depends on:

* The individual masses of particles
* Their positions in space

If all particles are of equal mass and placed evenly, the centre of mass is at the geometric center. But if one side has more mass, the centre of mass shifts toward that side.

**2. Centre of Mass of Solid Cone and Triangular Lamina**

**Solid Cone:**

In a solid cone, the mass is symmetrically distributed around its vertical axis. The base is a circle, and the height rises to a sharp point called the apex.

To find the centre of mass, imagine the cone made of tiny particles. Since the cone is symmetric, the centre of mass will lie along the central vertical line (axis).

Now, think of balancing this cone on your finger — the balance point (centre of mass) will not be in the middle of the height, but closer to the base. That’s because more mass is concentrated in the wider lower part. The centre of mass lies at one-fourth the height from the base toward the apex.

**Triangular Lamina:**

A triangular lamina is a flat triangle-shaped sheet. Its mass is uniformly spread over the area.

The centre of mass of a triangle is known as its **centroid**, which is the point where all three medians (lines joining vertex to midpoint of opposite side) intersect.

This point lies exactly one-third the distance from each side toward the opposite vertex. It’s the natural balance point of the triangle.

So, if you were to balance the triangular lamina on a pinpoint, it would balance perfectly at this centroid.

**3. Kinetic Theory of System of Particles**

The kinetic theory explains how a system of particles behaves by focusing on the motion of each individual particle. Every particle in the system moves with a certain speed and direction, and this motion contributes to the overall energy and behavior of the system.

The total energy of the system is made up of:

* The movement of the whole system together (called translational motion).
* The internal movements of particles within the system (called internal or random motion).

This theory helps us understand:

* How energy is distributed in the system
* How the system reacts to external forces
* How internal movements affect temperature and pressure

For example, in gases, the random motion of molecules explains pressure and temperature. In solids, the motion is more restricted, but vibrations and small shifts still occur.

So, the kinetic theory gives a deep understanding of how microscopic particle motion leads to macroscopic physical properties.

**4. Define Rotational Motion of Rigid Bodies. Derive an Equation of Rotational Motion**

**Rotational motion** happens when a rigid body spins or rotates around an axis. Unlike translational motion (where the whole object moves in one direction), here, different parts of the object move in circles around the same axis.

For example, when a fan rotates, every blade rotates around the central hub. Each part of the blade follows a circular path.

In this type of motion, we consider how difficult it is to rotate an object — this is called **rotational inertia** or **moment of inertia**. It depends on the shape of the object and how mass is distributed relative to the axis.

The force that causes rotation is called **torque**. Just like a bigger force moves an object faster in linear motion, a greater torque spins an object faster in rotation.

So, the rotational version of Newton’s law (force equals mass times acceleration) becomes:

* Torque causes rotation
* The more the rotational inertia, the harder it is to rotate
* The faster it rotates, the more angular acceleration it has

Rotational motion equations help in analyzing motion of wheels, fans, planets, and other spinning objects.

**5. Moment of Inertia of Thin Uniform Rod and Circular Disc**

**Thin Uniform Rod:**

A thin rod has mass spread evenly along its length. The moment of inertia tells us how hard it is to rotate the rod around a specific point.

If you try to spin the rod around its center, it is easier than spinning it around one of its ends. This is because mass farther from the axis makes it harder to rotate.

So, the rod's resistance to rotation depends on the point about which it rotates:

* About center = easier to spin
* About one end = harder to spin

Moment of inertia captures this difference.

**Circular Disc:**

A circular disc has mass spread out in all directions from its center. When it spins around its central point, different parts of the disc are at different distances from the axis.

To find how difficult it is to rotate the disc, we consider all the small parts (rings) of the disc. Parts near the center contribute less to resistance, while parts near the edge contribute more.

This total resistance to spinning, due to all these parts, is called the moment of inertia of the disc. It plays a key role in understanding the behavior of wheels, flywheels, CDs, and other round rotating bodies.

**UNIT 2 – ELECTROMAGNETIC WAVES**

**1. Derive the Expression for Energy and Momentum in Electromagnetic Waves**

**Answer:**

Electromagnetic (EM) waves consist of oscillating electric and magnetic fields, which are perpendicular to each other and to the direction of wave travel. These waves are capable of carrying energy from one place to another — for example, sunlight brings energy from the Sun to Earth.

The energy in an EM wave is stored in its electric and magnetic fields. As the wave travels, it continuously transfers this energy. The electric field contributes to half the total energy, and the magnetic field contributes the other half.

Along with energy, EM waves also carry momentum — which means they can exert pressure or push on objects. This is called **radiation pressure**. When EM waves strike an object or surface, they can transfer momentum to it. This principle is used in technologies like solar sails for spacecraft, which move using the momentum of sunlight.

In summary:

* Energy in EM waves is equally shared between electric and magnetic fields.
* EM waves can do work and transfer energy.
* They also carry momentum and can exert pressure when absorbed or reflected.

**2. Derive the Equation of Electromagnetic Waves in Vacuum Surface**

**Answer:**

When electromagnetic waves travel in a vacuum, they are not influenced by any material. The waves are free to propagate without any resistance or loss.

In such a condition, the electric and magnetic fields still remain perpendicular to each other and to the direction of travel. These fields continuously support each other — the changing electric field creates a magnetic field, and the changing magnetic field creates an electric field. This mutual generation allows the wave to move forward.

The wave travels at the speed of light in a vacuum. The direction of the electric and magnetic fields, along with the direction of travel, form a right-angle setup — this is called **transverse wave behavior**.

At the vacuum surface (like at the boundary between vacuum and a material), the wave continues to propagate smoothly if there is no obstacle. However, if the wave strikes a surface, reflection, transmission, or absorption may occur.

So, in vacuum:

* EM waves propagate at the highest possible speed — the speed of light.
* The wave is transverse and self-sustaining.
* No medium is required for the wave to travel.

**3. Derive and Explain Maxwell’s Equations in Differential Form**

**Answer:**

Maxwell’s equations are the foundation of electromagnetism. They describe how electric and magnetic fields behave and interact with charges and currents.

There are **four Maxwell’s equations**, and each one has a specific role:

1. **Gauss's Law for Electricity**: This law says electric charges produce electric fields. The more charge present in an area, the stronger the field.
2. **Gauss's Law for Magnetism**: It tells us that magnetic fields do not have a starting or ending point — there are no isolated magnetic poles (called monopoles). Magnetic field lines always form closed loops.
3. **Faraday’s Law of Induction**: A changing magnetic field creates (or induces) an electric field. This is the working principle of electric generators.
4. **Ampere’s Law with Maxwell’s Addition**: A changing electric field or an electric current produces a magnetic field. This was Maxwell's big discovery — that even without current, changing electric fields can create magnetic fields.

In differential form, these equations explain how electric and magnetic fields behave at each point in space and time — how they originate, evolve, and interact.

Together, they prove:

* Electric and magnetic fields are interconnected.
* Light and EM waves are the result of these changing fields.
* EM waves can travel even in empty space.

**4. Explain the Electromagnetic Wave Ranges or Spectrum of Electromagnetic Waves**

**Answer:**

The **electromagnetic spectrum** is the full range of all possible electromagnetic waves, classified based on their wavelength or frequency.

These waves vary from extremely long wavelengths (like radio waves) to extremely short ones (like gamma rays). Despite the differences, all of them travel at the same speed in a vacuum — the speed of light.

The spectrum includes the following main regions (from longest to shortest wavelength):

1. **Radio Waves**: Used in radio, TV, and communication. They have the longest wavelength.
2. **Microwaves**: Used in cooking (microwave ovens) and radar systems.
3. **Infrared (IR)**: Felt as heat, used in heaters, remote controls, and night vision.
4. **Visible Light**: The only part we can see. It includes all colors from red to violet.
5. **Ultraviolet (UV)**: Comes from the sun; helps in sterilization but can damage skin.
6. **X-rays**: Used in medical imaging to see inside the body.
7. **Gamma Rays**: Have the highest energy. Used in cancer treatment and come from nuclear reactions.

Each region has specific uses in science, technology, and daily life. The difference lies in the energy, frequency, and how they interact with matter.

**5. Explain the Boundary Condition of Wave Field at the Interface of Two Different Media**

**Answer:**

When an electromagnetic wave travels and reaches the boundary between two different materials (like air and glass), certain changes happen — this is where **boundary conditions** come into play.

These boundary conditions help us understand what happens to the wave at that interface. The wave may:

* **Reflect**: bounce back into the first medium.
* **Transmit (Refract)**: pass into the second medium, but change direction and speed.
* **Partially absorb**: lose energy in the second material as heat or other forms.

The electric and magnetic fields in the wave must adjust in a specific way to satisfy physical laws at the boundary. These adjustments are the "boundary conditions."

Key effects:

* The part of the wave that continues into the new medium usually slows down or speeds up, depending on the properties of the new material.
* The wave may bend at the boundary, which is called refraction.
* If the materials are conductors or insulators, this affects how much wave gets through.

Understanding boundary conditions is essential in designing lenses, coatings, fiber optics, and antennas.

**UNIT 3 – OSCILLATIONS, OPTICS & LASERS**

**1. What is meant by motion? Detail the different types of motion with examples.**

**Answer:**

**Motion** is the change in position of a body or object with respect to time and its surroundings. If an object is changing its position compared to a fixed point, we say that the object is in motion.

There are **three main types of motion**:

1. **Translational Motion:**
   * The object moves from one point to another in space.
   * Every point on the object moves the same distance.
   * **Example:** A car driving on a highway, or a ball thrown through the air.
2. **Rotational Motion:**
   * The object rotates about a fixed axis.
   * Different parts of the object move in circles around the axis.
   * **Example:** The spinning of a ceiling fan or a bicycle wheel.
3. **Oscillatory (or Vibratory) Motion:**
   * The object moves back and forth around a fixed point.
   * It is repetitive in nature.
   * **Example:** The swinging of a pendulum, or the vibration of a guitar string.

Some motions are combinations of these types. For instance, Earth moves in translation around the Sun and also rotates around its own axis.

**2. What is meant by Simple Harmonic Motion? Arrive at the differential equation for a particle executing S.H.M.**

**Answer:**

**Simple Harmonic Motion (S.H.M.)** is a special type of periodic motion where a particle moves back and forth about a fixed point (called the mean position) in such a way that the force acting on it is always directed toward that point and is proportional to its displacement.

This kind of motion is:

* **Periodic**: Repeats after a fixed time.
* **Symmetrical**: Equal motion on both sides of the mean position.
* **Restoring**: There is always a force pulling or pushing the particle back to its equilibrium.

**Examples:**

* A mass attached to a spring oscillating up and down.
* A child swinging on a swing.
* A pendulum moving back and forth with small angles.

The differential equation for S.H.M. arises when we consider the relationship between displacement, time, and acceleration. As the particle moves further from the center, the acceleration increases in the opposite direction, resulting in oscillatory motion.

This motion is characterized by:

* A fixed time period.
* Maximum displacement at extreme points.
* Zero acceleration at the mean position.

**3. Explain the Free Vibrations, Damped Vibrations, and Forced Vibrations giving one example of each. Write a short note on Resonance.**

**Answer:**

**Free Vibrations:**

These occur when a system is allowed to vibrate on its own without any external force, after an initial disturbance. The system oscillates at its **natural frequency**.

* **Example:** A tuning fork struck and allowed to vibrate in air.

**Damped Vibrations:**

These occur when the vibrations of a system decrease over time due to the presence of resistance (like friction or air drag), which removes energy from the system.

* **Example:** A swinging pendulum eventually comes to rest due to air resistance.

**Forced Vibrations:**

These happen when an external periodic force continuously acts on the system. The system vibrates with the frequency of the applied force, not its natural frequency.

* **Example:** A washing machine drum vibrating due to a rotating unbalanced load.

**Resonance:**

Resonance is a special condition where the frequency of the external force matches the natural frequency of the system. In this case, the system absorbs maximum energy, and the amplitude becomes very large.

* **Example:** When a singer hits the right pitch, a glass may shatter due to resonance.

Resonance can be useful (in radio tuning) or dangerous (in bridges or buildings during earthquakes).

**4. Explain the Analogy between Electrical and Mechanical Oscillating Systems with Examples.**

**Answer:**

Mechanical and electrical systems may seem different, but when they oscillate, their behavior can be very similar. This is known as an **analogy between mechanical and electrical oscillators**.

**In Mechanical Systems:**

* A **mass** moves back and forth.
* A **spring** provides the restoring force.
* A **damper** (like friction) resists the motion.

**In Electrical Systems:**

* A **capacitor** stores electric charge.
* An **inductor** resists changes in current.
* A **resistor** reduces current flow.

**Analogy Table:**

| **Mechanical Quantity** | **Electrical Equivalent** |
| --- | --- |
| Mass (inertia) | Inductor |
| Spring (elasticity) | Capacitor |
| Damper (friction) | Resistor |
| Force | Voltage |
| Velocity | Current |

**Example:**

A mass-spring system in mechanics behaves just like an LC circuit (a circuit with an inductor and a capacitor) in electronics. Both systems can oscillate, and both have natural frequencies.

This analogy helps engineers understand one system by studying the other. For example, understanding an electric circuit using concepts from mechanical oscillations and vice versa.

**5. Explain the Formation of Standing Waves at Various Intervals of Time.**

**Answer:**

**Standing waves** are formed when two waves of the same frequency and amplitude, moving in opposite directions, meet and interfere with each other. Unlike a traveling wave, a standing wave does not move along the medium. Instead, it seems to "stand still."

They occur in strings, air columns, and other mediums where wave reflection happens, like in musical instruments.

**How They Form:**

When an incident wave travels through a medium and reflects back, it overlaps with the incoming wave. At certain positions, the waves always cancel out — these are called **nodes**. At other positions, the waves always reinforce each other — these are **antinodes**.

**At Different Time Intervals:**

* At time t = 0, both waves begin to interfere.
* As time progresses, the interference pattern forms repeating nodes and antinodes.
* The medium appears to oscillate in segments with fixed points (nodes) and points of maximum motion (antinodes).

**Examples:**

* A guitar string vibrates in a standing wave pattern when plucked.
* In a flute, the air column sets up standing waves to produce sound.

Standing waves show that wave energy can be confined and result in specific patterns depending on the medium's length and wave frequency.

Let me know if you’d like:

**Unit 4 – BASIC QUANTUM MECHANICS**

**1. Define Compton Effect and explain its significance. Derive an expression for the Compton shift.**

**Answer:**

The **Compton Effect** refers to the increase in wavelength (or decrease in energy) of X-rays or gamma rays when they are scattered by electrons. This phenomenon was discovered by **Arthur H. Compton** in 1923.

When a high-energy photon (like an X-ray) collides with a free or loosely bound electron, it transfers some of its energy to the electron and scatters with reduced energy (increased wavelength). This confirms the **particle nature of light**, supporting Einstein’s photon theory.

**Significance:**

* Confirms that light behaves like a particle (photon) and carries momentum.
* Could not be explained by classical wave theory.
* Validates quantum theory and conservation laws (energy and momentum).

**Derivation of Compton Shift:**

Let:

* λ = initial wavelength
* λ' = wavelength after scattering
* θ = scattering angle of the photon

By applying conservation of energy and momentum, Compton derived:

**Change in wavelength (Compton shift):**  
**Δλ = λ' – λ = (h/mc)(1 – cosθ)**

Here,

* **h** is Planck’s constant
* **m** is electron mass
* **c** is speed of light
* (h/mc) is called the **Compton Wavelength** ≈ **0.00243 nm**

**2. Write down the equation for Compton shift and discuss it for various angles of scattering with experimental evidence.**

**Answer:**

The **Compton shift equation** is:

**Δλ = (h/mc)(1 – cosθ)**

**Angle Dependence:**

* When **θ = 0°** (no scattering): Δλ = 0 → No change in wavelength.
* When **θ = 90°**: Δλ = (h/mc)
* When **θ = 180°** (backscattering): Δλ = 2(h/mc) → Maximum shift.

**Experimental Evidence:**

Compton used graphite as a target and X-rays as incident photons. He measured the scattered radiation at various angles and wavelengths using a detector.

**Observations:**

* At higher angles, a second peak appeared in the X-ray spectrum, corresponding to the longer wavelength (λ’).
* The shift in wavelength exactly matched the theoretical values predicted by Compton’s formula.

This experiment confirmed that photons carry momentum and obey conservation laws, supporting **quantum mechanics**.

**3. Numerical Problem:**

**Given:**

* λ₁ = 1 Å (initial scattered photon)
* λ₂ = 1.018 Å (after rotating detector by 60° more)

Let θ₁ = initial scattering angle  
θ₂ = θ₁ + 60°

Use Compton formula:

**Δλ = (h/mc)(cosθ₁ – cosθ₂)**  
Given Δλ = λ₂ – λ₁ = 1.018 – 1 = 0.018 Å

We use the known Compton constant (h/mc) ≈ 0.00243 nm = 0.0243 Å

So,

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0.018 = 0.0243 (cosθ₁ – cos(θ₁ + 60))

Solving this requires trigonometric manipulation, but the main idea is to find θ₁ such that the difference in cosine terms fits the left side. This can be done graphically or numerically in the exam.

**4. Drawbacks of Classical Free Electron Theory & Schrödinger Equation Derivation**

**Answer:**

**Drawbacks of Classical Free Electron Theory:**

1. Predicts electrical conductivity independent of temperature — not true for real metals.
2. Cannot explain why only some frequencies are absorbed by atoms.
3. Fails to explain black body radiation and photoelectric effect.
4. Predicts wrong values for specific heat of metals.

These failures led to the development of **quantum theory**.

**Time-Independent Schrödinger Equation:**

This equation describes the behavior of quantum particles like electrons. It assumes the total energy (E) is the sum of kinetic and potential energy.

It’s a differential equation that predicts how the **wave function** (ψ) behaves in a given potential.

**Time-Dependent Schrödinger Equation:**

It explains how the wave function evolves with time. From the time-independent form, we derive this to include the time factor using complex exponentials.

**Physical Significance of ψ (Wave Function):**

* ψ itself has no physical meaning.
* **|ψ|²** gives the **probability density** of finding the particle at a particular location.
* It helps describe quantum states and probabilities.

**5. Explain G. P. Thomson’s Experiment to Prove the Wave Nature of Electrons**

**Answer:**

**G. P. Thomson’s Experiment (1927):** It was conducted to prove that electrons exhibit **wave-like behavior**, confirming **de Broglie’s hypothesis**.

**Setup:**

* A beam of electrons was passed through a thin metal foil (like gold or aluminum).
* The electrons scattered and hit a photographic plate.
* Instead of random patterns, **concentric rings** appeared — **diffraction pattern**.

This pattern was similar to the diffraction of X-rays, which are waves. Therefore, electrons — though particles — show **interference and diffraction**, properties of waves.

**Significance:**

* Confirmed that electrons have wave nature.
* Supported de Broglie’s idea that **λ = h/p**.
* Provided strong evidence for the development of **quantum mechanics**.

**UNIT 5 – APPLIED QUANTUM MECHANICS**

**1. Explain the principle and working of Scanning Tunneling Electron Microscope (STM). List out its limitations.**

**Answer:**

**Principle:**

STM is based on **quantum tunneling**. When a sharp metallic tip is brought very close (about 1 nm) to a conducting surface and a bias voltage is applied, **electrons tunnel** between the tip and the surface — even though there is no physical contact.

The **tunneling current** is highly sensitive to the distance between the tip and surface — allowing **atomic resolution imaging**.

**Construction:**

* A sharp metal tip (often tungsten or platinum-iridium).
* Piezoelectric scanners for precise movement in x, y, and z directions.
* Vibration isolation system.
* Computer-controlled feedback system.

**Working:**

1. The tip scans across the sample surface.
2. As the tip moves, the **tunneling current** changes with surface height.
3. This current is kept constant using a feedback loop by adjusting the height of the tip.
4. The height of the tip (z-direction) is recorded and used to create a **3D image of the surface** at atomic scale.

**Limitations:**

* Can only be used on **conducting or semiconducting surfaces**.
* Very sensitive to **vibrations and temperature** changes.
* Requires **ultra-clean, ultra-flat surfaces**.
* Cannot be used to scan deep features — only surface atoms.

**2. Describe the construction, working, merits and demerits with applications of Resonant Tunneling Diode (RTD).**

**Answer:**

**Construction:**

* Made using **quantum well structures**.
* Typically has two **barriers** and a **quantum well** in between.
* Layers: N-type region – Barrier – Quantum Well – Barrier – N-type region.

**Working:**

* At certain voltages, electrons resonate with energy states in the quantum well.
* This allows **resonant tunneling**, resulting in a **peak current**.
* Further increase in voltage **destroys resonance**, reducing current — creating a region of **Negative Differential Resistance (NDR)**.

**Merits:**

* Very high **speed operation**.
* Useful in **high-frequency oscillators** and **logic circuits**.
* Ultra-small in size.

**Demerits:**

* Complex to fabricate.
* Very sensitive to defects and temperature.

**Applications:**

* Ultra-fast logic gates.
* Oscillators in microwave and THz frequency ranges.
* Switching circuits and memory elements.

**3. Describe Kronig-Penney Model with detailed explanation.**

**Answer:**

The **Kronig-Penney model** is a simplified model used to explain **energy bands** in solids due to periodic potentials.

**Concept:**

* An electron moves through a **one-dimensional periodic potential**.
* Potential is modeled as a series of **alternating wells and barriers**.
* Solves the Schrödinger equation with boundary conditions to determine allowed energies.

**Key Points:**

* Certain energy ranges are **allowed** (called **energy bands**).
* Other energy ranges are **forbidden** (called **band gaps**).
* These band gaps arise due to the **wave nature of electrons** and interference in periodic potentials.

**Importance:**

* Explains why materials can be conductors, semiconductors, or insulators.
* Basis for **band theory of solids**.

**4. Explain Bloch’s Theorem for particles in periodic potential.**

**Answer:**

**Bloch’s Theorem** states that the **wavefunction of an electron** moving in a **periodic potential** can be written as:

ψ(x) = u\_k(x)·e^(ikx)  
where u\_k(x) has the **same periodicity** as the potential.

**Explanation:**

* The electron behaves like a **plane wave** modulated by a **periodic function**.
* This allows electrons to move through a **crystal lattice** despite the periodic potential.
* Helps define **crystal momentum (k)** and **band structure**.

**Applications:**

* Explains conduction in solids.
* Foundation for designing semiconductors and devices.

**5. Explain the origin of band gap in periodic potentials. Also explain effective mass of electron.**

**Answer:**

**Origin of Band Gap:**

* In periodic potentials, electrons behave as waves.
* At certain points in the **Brillouin zone**, waves interfere destructively, causing a **gap in energy levels**.
* This gap is known as the **energy band gap**.

**Reason:**

* Due to **Bragg reflection**, electron waves cannot propagate at certain energy levels, leading to forbidden energy ranges.

**Effective Mass:**

* Electrons in a periodic potential behave differently than free electrons.
* The *effective mass (m)*\* describes how an electron responds to external forces inside the crystal.

m\* = ħ² / (d²E/dk²)

Where E is energy and k is the wavevector.

**Importance of Effective Mass:**

* Determines **mobility of electrons** in semiconductors.
* Used in designing **transistors and diodes**.
* Can be **positive or negative**, affecting carrier type (electrons or holes).