Dual Nature of Matter and Radiation

1. Introduction: The Conflict of Wave and Particle

By the end of the 19th century, James Clerk Maxwell's equations had established light as an **electromagnetic wave**. However, certain phenomena like the photoelectric effect could not be explained by wave theory, leading to the discovery of the **dual nature** of radiation and matter.

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2. Photoelectric Effect

The phenomenon of emission of electrons from a metal surface when radiation of appropriate frequency falls on it is called the **photoelectric effect**.

- **Hertz's Observations:** In 1887, while investigating electromagnetic waves, Heinrich Hertz observed that high-voltage sparks across a detector loop were enhanced when the emitter plate was illuminated by UV light.
- **Hallwachs and Lenard's Observations:** They observed that when UV radiation fell on a zinc plate connected to an electroscope, the plate became positively charged (if initially neutral) or lost its negative charge, implying the emission of negatively charged particles (electrons).
- **Threshold Frequency (ν_0):** For every metal, there exists a minimum frequency of incident radiation below which no photoelectric emission occurs, regardless of intensity.

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3. Experimental Study of Photoelectric Effect

The experimental setup involves an evacuated glass tube with a photosensitive plate (emitter) and a metal plate (collector).

- **Effect of Intensity:** For a fixed frequency above the threshold, the **photocurrent** is directly proportional to the intensity of incident light.
- **Effect of Potential:**
    - As collector potential increases, current increases up to a maximum called **saturation current**.
    - **Stopping Potential (V_0):** The minimum negative (retarding) potential applied to the collector plate for which the photocurrent becomes zero.
- **Effect of Frequency:** The stopping potential V_0 varies linearly with the frequency of incident radiation. Higher frequency means electrons are emitted with greater maximum kinetic energy (K_{max}): $K_{max} = eV_0$

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4. Einstein's Photoelectric Equation: Particle Nature of Light

In 1905, Albert Einstein explained the effect by proposing that light consists of discrete packets of energy called **quanta** or **photons**.

- **Photon Energy:** Each photon carries energy proportional to its frequency: $E = h\nu$ where h is Planck's constant (6.63×10^{-34} J s).

- **Einstein's Equation:** When a photon strikes an electron, its energy is used in two parts:
  1. To overcome the **work function** (Φ_0) of the metal (minimum energy required to eject an electron).
  2. The remainder is converted into the maximum kinetic energy (K_{max}) of the electron. $h\nu = \Phi_0 + K_{max}$ or $K_{max} = h\nu - h\nu_0$

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5. Characteristics of Photons

- In interactions with matter, radiation behaves as if it is made of particles called photons.

- All photons of light of a particular frequency ν have the same energy ($E = h\nu$) and momentum ($p = h\nu/c$).

- Photons are **electrically neutral**.

- In a photon-particle collision, total energy and total momentum are conserved, but the **number of photons may not be conserved**.

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6. Matter Waves: Wave Nature of Particles

If radiation (a wave) can behave like a particle, then particles of matter (like electrons) should be able to behave like waves. This was proposed by **Louis de-Broglie** in 1924.

- **de-Broglie Relation:** The wavelength (λ) associated with a particle of mass m moving with velocity v is: $\lambda = \frac{h}{p} = \frac{h}{mv}$

- **In terms of Kinetic Energy (K):** Since $p = \sqrt{2mK}$: $\lambda = \frac{h}{\sqrt{2mK}}$

- **For an Electron accelerated through potential V:** $K = eV$ $\lambda = \frac{h}{\sqrt{2meV}}$
  Plugging in constants for an electron: $\lambda = \frac{1.227}{\sqrt{V}}$ nm

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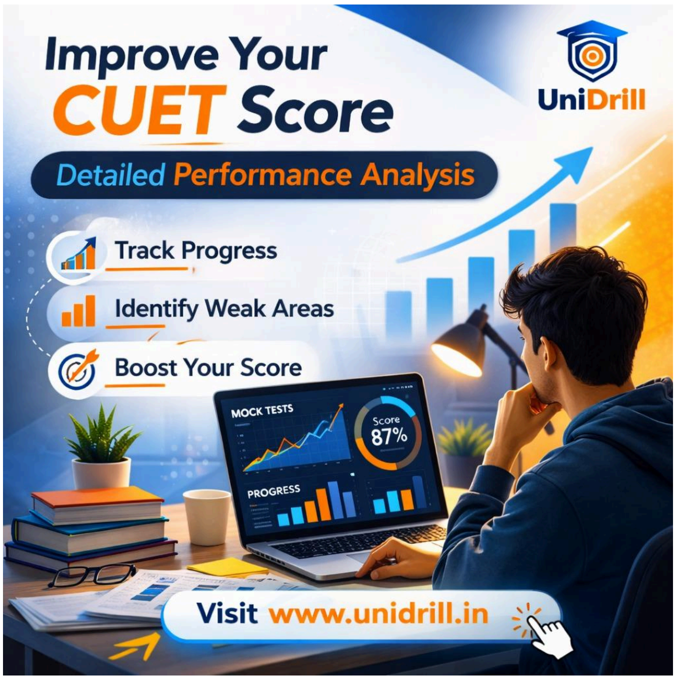

7. Dual Nature of Matter and Radiation: A Summary

- **Radiation:** Exhibits wave properties in phenomena like interference and diffraction (Unit 6), but particle properties in the photoelectric effect and Compton scattering.

- **Matter:** Exhibits particle properties (mass, momentum) in classical mechanics but wave properties (interference, diffraction) at microscopic scales, as demonstrated by the

Davisson-Germer experiment (which confirmed the wave nature of electrons).

Summary of Key Formulas for Unit 7

Concept	Formula
Photon Energy	$E=h\nu=\lambda hc$
Einstein's Equation	$K_{max}=h\nu-\Phi_0$
Stopping Potential	$K_{max}=eV_0$
Work Function	$\Phi_0=h\nu_0$
de-Broglie Wavelength	$\lambda=ph$
Wavelength (Energy)	$\lambda=2mKh$
Electron Wavelength	$\lambda=V1.227$ nm