

Chapter 12

Dual Nature of Radiation

- Introduction to dual nature of light and theories
 - Nature of light
 - Newton's Corpuscular theory
 - Huygens theory
 - Maxwell's electromagnetic wave theory
 - Max Planck's quantum theory of light
 - De Broglie Hypothesis
- Radiation Pressure
 - Radiation Pressure: - Complete absorption, Complete reflection, Partial reflection
 - Radiation Pressure: - Oblique Incidence
 - Radiation Pressure: - on Sphere
- Particle vs Wave Nature and photon
 - Particle vs Wave Nature
 - Properties of Photon
- Photoelectric Effect and Einstein Relation
 - Photoelectric effect
 - Threshold Wavelength/Frequency
 - Work function
 - Photons and Einstein Relation
 - Failure of Wave Theory
- Stopping Potential and saturation current in Photoelectric effect
 - Photoelectric effect - Effect of potential applied
 - Saturation current
 - Stopping Potential
- Matter waves and it's properties
 - Matter waves
 - De-Broglie Wavelength

INTRODUCTION TO DUAL NATURE OF LIGHT AND THEORIES

Nature of light:

Several theories have been proposed to explain the dual nature of light and reconcile its wave-like and particle-like behavior. One of the earliest theories, proposed by Albert Einstein in 1905, introduced the concept of quanta of light, or photons, to explain the photoelectric effect, where light shining on a metal surface ejects electrons. Einstein's theory suggested that light is composed of discrete packets of energy, each behaving like a particle.

Another significant theory, developed by Louis de Broglie in the 1920s, proposed that particles, including photons, exhibit wave-like properties. This theory, known as wave-particle duality, introduced the idea of matter waves, suggesting that particles such as electrons and photons have associated wavefunctions that determine their behavior.

The wave-particle duality of light has profound implications for our understanding of the universe, influencing fields ranging from quantum mechanics to cosmology. It challenges our classical intuition about the nature of reality and underscores the need for a more nuanced understanding of the fundamental building blocks of the universe.

Newton's Corpuscular theory:

Sir Isaac Newton introduced the Corpuscular Theory of Light, also referred to as the emission theory, during the 17th century. Newton proposed that light consists of minuscule, distinct particles known as "corpuscles" or "particles," which are emitted by luminous entities. According to Newton's postulation, these corpuscles travel in straight paths and at exceedingly high velocities through a medium termed the "luminiferous ether," which permeates the space between objects. Upon encountering an object, these corpuscles undergo absorption, reflection, or refraction, contingent upon the characteristics of the object.

Huygens theory:

According to Huygens' theory, light is considered to be a wave phenomenon rather than consisting of particles.

- Properties of matter waves
- Experimental Verification of Dual Nature of Matter
- Bohr's Model
- Davisson and Germer Experiment, Microscope and Dalton Atomic theory
 - Davisson and Germer Experiment
 - Bragg's Law for waves
 - Optical Microscope
 - Electron Microscope
 - Dalton Atomic Theory
 - J.J. Thomson's Atomic Model

Huygens postulated that every point on a wavefront acts as a source of secondary spherical waves, and the wavefront at any subsequent moment can be determined by constructing the envelope of all these secondary wavelets. This principle is known as the Huygens-Fresnel principle.

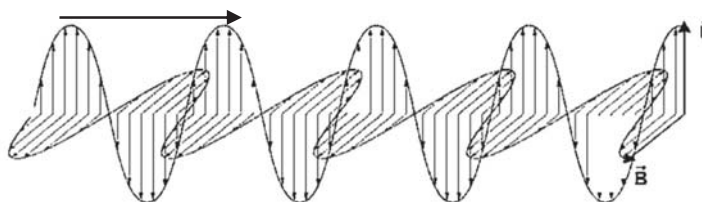
One of the significant contributions of Huygens' theory was its ability to explain phenomena such as diffraction and interference, which were challenging to explain using Newton's corpuscular theory. Diffraction refers to the bending of light around obstacles or through apertures, while interference occurs when waves overlap, leading to the reinforcement or cancellation of amplitudes.

Huygens' theory laid the foundation for the wave theory of light, which later became the dominant explanation for various optical phenomena. It provided a more comprehensive framework for understanding the behavior of light and played a crucial role in the development of modern physics.

Maxwell's electromagnetic wave theory:

Maxwell's theory amalgamated electricity and magnetism into a unified framework, illustrating their interconnectedness and their capacity to propagate as waves through space. As delineated by Maxwell's equations, alterations in electric fields induce corresponding changes in magnetic fields, and conversely, leading to the transmission of electromagnetic waves.

The pioneering work of Maxwell anticipated the existence of electromagnetic waves traveling at the velocity of light, indicating that light itself is an electromagnetic phenomenon. This assertion was subsequently validated through experimental verification, furnishing compelling evidence in favor of the wave nature of light.



A noteworthy aspect of Maxwell's theory was its recognition that light represents merely one manifestation of electromagnetic radiation, spanning a diverse spectrum of wavelengths extending beyond the visible range. This electromagnetic spectrum encompasses a plethora of phenomena, including radio waves, microwaves, infrared radiation, ultraviolet radiation, X-rays, and gamma rays, each possessing distinctive characteristics and applications.

Maxwell's Electromagnetic Wave Theory laid the groundwork for modern physics and technology, enriching our comprehension of electromagnetism, light, and the cosmos on a grand scale. Its profound impact reverberates across diverse fields, from telecommunications and electronics to astronomy and particle physics, perpetually fostering new breakthroughs and advancements.

Max Planck's quantum theory of light:

Max Planck's Quantum Theory of Light, formulated by the German physicist Max Planck in the early 20th century, represents a pivotal advancement in our understanding of the nature of light and energy. Planck's theory fundamentally challenged classical physics by proposing that electromagnetic radiation, including light, is quantized, meaning it exists in discrete packets of energy known as "quanta" or "photons."

According to Planck's hypothesis, the energy of these quanta is directly proportional to the frequency of the radiation, as expressed by the equation $E = hf$, where E is the energy of a quantum, h is Planck's constant, and f is the frequency of the radiation.

This groundbreaking concept addressed the long-standing problem known as the "ultraviolet catastrophe," which arose from classical theories of blackbody radiation.

Classical physics predicted that the intensity of radiation emitted by a blackbody should increase indefinitely with increasing frequency, leading to infinite energy. However, Planck's quantum theory successfully explained the observed spectrum of blackbody radiation by attributing it to the discrete energy levels of photons.

Planck's Quantum Theory of Light laid the foundation for the development of quantum mechanics, a revolutionary branch of physics that describes the behavior of matter and energy at the smallest scales. It provided a theoretical framework for understanding various phenomena, including the photoelectric effect, where the emission of electrons from a material is triggered by the absorption of photons. Furthermore, Planck's theory profoundly influenced subsequent developments in physics, leading to the realization that matter and energy are inherently interconnected at the quantum level. It played a crucial role in shaping our modern understanding of the fundamental principles governing the universe and continues to be a cornerstone of quantum physics.

De Broglie Hypothesis:

De Broglie proposed that similar to light, which can behave as both waves and particles, matter particles like electrons also exhibit wave-like characteristics. In his hypothesis, he suggested that every particle with momentum possesses an associated wavelength, described by the equation

$$\lambda = h/p,$$

where λ represents the wavelength, h is Planck's constant, and p denotes the momentum of the particle.

This groundbreaking concept introduced a fresh perspective on the nature of matter, implying that particles can manifest interference and diffraction patterns akin to those observed in wave phenomena like light. De Broglie's hypothesis played a crucial role in reconciling the apparently contradictory behaviors of particles observed in experiments, such as the double-slit experiment, where electrons exhibit interference patterns upon passing through narrow slits.

Subsequently, De Broglie's hypothesis was empirically validated through the observation of electron diffraction patterns, offering compelling evidence for the wave-like behavior of matter. This confirmation laid the groundwork for the advancement of wave mechanics and quantum mechanics, significantly reshaping our comprehension of the microscopic realm.