Wave Motion and Electromagnetic Radiation

Introduction
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Introduction

- This class is about the physics of LIGHT.

Content

• What is light?  (Ch2)

• Part 1: Geometric Optics (not covered)

• Part 2: Vibration and Waves
  – Simple Harmonic Motion, Forced Vibration (Ch7)
  – Fourier Series (Ch8)
  – The Dirac Delta Function and Fourier Transform (CH9)
  – Group Velocity and Pulse Dispersion (Ch10)
  – Wave Propagation and Wave Equation (Ch11)
  – Huygen’s Principle and Its Applications (Ch12)

• Part 3: Interference
  – Superposition of Waves (Ch13)
  – Two-Bean Interference by Division of Wave Front (Ch14)
  – Interference by Division of Amplitude (Ch15)
  – Multipe-Beam Interferometry (Ch16)
  – Coherence    (Ch17)
Content (cont.)

• Part 4: Diffraction
  – Fraunhofer Diffraction I (Ch18)
  – Fraunhofer Diffraction II and Fourier Optics (Ch19)
  – Fresnel Diffraction (Ch20)
  – Holography (Ch21)

• Part 5: Electromagnetic Character of Light
  – Polarization and Double Refraction (Ch22)
  – Electromagnetic Waves (Ch23)
  – Reflection and Refraction of Electromagnetic Waves (Ch24)

• Part 6: Photons (Ch25)

• Part 7: Lasers and Fiber Optics (Ch26 – 29)

• Part 8: Special Theory of Relativity (Ch30-31)
About me: Space Weather

It starts from an eruption from the Sun.
Space Weather: the Systems

SUN:
- convection zone
- radiative zone
- core
- surface
- atmosphere
- sunspot
- plage
- coronal mass ejection

EARTH:
- particles and magnetic fields
- photons
- bow shock
- heliosphere
- plasmasphere
- magnetosphere

Other terms:
- surface atmosphere
- solar wind
Space Weather: the Effects

On Communication and Navigation

- Micrometeorites
- Solar radiation: X-Rays, UV, Energetic Particles
- Galactic Cosmic Rays
- Charging
- IC Upsets and Failures
- Solar Cell Damage
- Signal Scintillation
- Crewed Spacelift
- Radio Wave Disturbance
- Navigation Error
- Disturbed Reception
- Electricity Grid Disruption
- Pipeline Corrosion
- Aurora
- Ionosphere Currents
- IC Upsets and Failures

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Space Weather: the Driver

Coronal mass ejections
What is Light? (Ch2)

- Rays from eyes (Greeks, ~ 400 BC)
- Rays of Particles (1672, Newton)
- Light is wave (1678, Huygens)
- Light is wave (1801, Young)
- Light is electromagnetic wave (1865, Maxwell)
- Light is energy quanta, or photon (1905, Einstein)
- Light is particle (1922, Compton)
- Light is a wave-particle duality (1927, Heisenberg)
Corpuscular Model

- Light is a stream or ray of particles
- Easy to understand the shadow
- The reflection law: incidence angle = reflection angle
- The refraction law – Snell’s law

\[ P : \text{the momentum}; \ v : \text{the velocity} \]
\[ n : \text{the refraction index} \]

It is conserved along the tangential direction of the surface

\[ p_1 \sin \theta_1 = p_2 \sin \theta_2 \]
\[ \frac{\sin \theta_1}{\sin \theta_2} = \frac{p_2}{p_1} = \frac{v_2}{v_1} = \frac{n_2}{n_1} \]

- Domain of Geometric optics, e.g., glasses, telescopes
Wave Model

• However, the corpuscular model can not explain
  • Diffraction
  • Interference
  • Polarization
• Huygen’s wave model (1978) can explain all these phenomena including refraction
• However, no one believed in Huygen’s wave theory until 1801 Yong’s double-slit experiment
  • People around Newton had more faith in his corpuscular theory than Newton himself
Wave Model

Thomas Young’s sketch of his double-slit experiment of diffraction of light (1801)
Electromagnetic Wave

- James Maxwell generalized Ampere’s law and summed all the laws of electricity and magnetism in the form of a set of four differential equations (1865).
- He derived a wave equation and predicted the existence of electromagnetic wave.
- He calculated the electromagnetic wave speed about $3.1 \times 10^8 \text{ m s}^{-1}$.
- He suggested “Light waves are electromagnetic Waves”.
- Heinrich Hertz experimented with an electric spark gap, and produced and detected electromagnetic wave in 1888.
Particle Nature of Radiation

• In 1897, J.J. Thomson discovered electrons
• In 1899, He showed the electrons are emitted when light falls on a metal surface
• In 1902, Philip Lenard observed
  1. the kinetic energy of the emitted electrons was independent of intensity of incident light
  2. the energy of the emitted electrons increased when the frequency of the incident light was increased
• In 1905, Einstein proposed the photon theory
  \[ E = h \nu \]
  “monocromatic radiation behaves as if it consists of mutually independent energy quanta of magnitude \( h \nu \)”
• In 1926, Gilber Lewis coined the word “photon”
Particle Nature of Radiation

- In 1923, Compton experimented the interaction between X-ray photon and electrons, and verified that photon has the momentum as expected.
- Max Planck’s blackbody radiation obtained from experiment (1900) can be explained by the photon theory.
Wave Nature of Matter

- In 1925, Louis De Broglie proposed the wave nature of electrons
- In 1927, Davisson & Germer experimented with the diffraction of electrons and found the diffraction pattern.
- In 1928, G.P. Thompson carried out electron diffraction experiment and deduced the wavelength of the electron beam

Max Jammer wrote:” Thomson, the father, was awarded the Nobel Prize for having shown that the electron is a particle, and Thompson, the son, for having shown that electron is a wave”
The Uncertainty Principle

- The reconciliation of the corpuscular nature with the wave character of light is made through modern quantum theory.
- Light has a property of wave-particle duality.
- Uncertainty principle of Heisenberg

If the x coordinate of the position of a particle is known to an accuracy $\Delta x$, then the x component of the momentum cannot be determined to an accuracy better than $\Delta p_x = h / \Delta x$, where $h$ is Planck’s constant.

$$\Delta x \Delta p_x \geq h$$

$h = 6.6 \times 10^{-34}$ J S

- The diffraction pattern can be explained by the corpuscular theory, when the uncertainty theory is taken into account.
The End