Electromagnetic Waves

In this lecture

★Introduction
★Photons
★Electromagnetic spectrum
★Wave-particle duality
★Matter & Energy

Waves

Mechanical waves

- Transport energy by mechanical displacement of particles in a medium

Electromagnetic waves

- Transport energy form through empty space
  - How is the energy transferred?

Speed of Electromagnetic Waves

Mechanical Waves

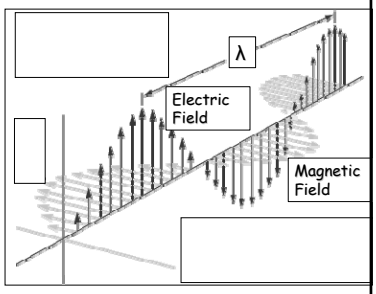
- Transmission via a medium
- Velocity of wave governed by mechanical properties of medium

Electromagnetic Waves

- Requires no medium to transmit
- Velocity is constant

Electromagnetic Waves

- A single-frequency EM wave exhibits a sinusoidal variation of electric and magnetic fields in space
- Magnetic variation is perpendicular to electric field



Electromagnetic Waves

- EM waves transport energy through space
- Energy is stored in the propagating electric and magnetic fields

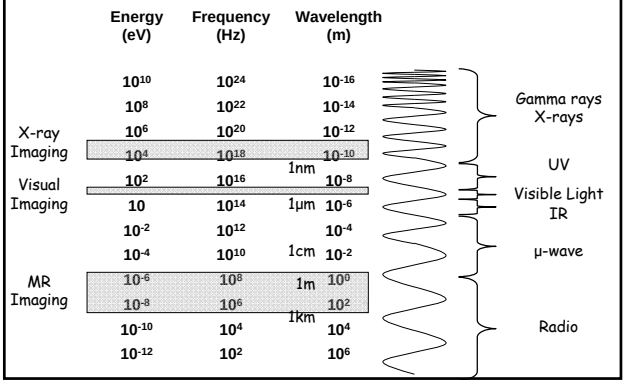
Photons

- A *photon* is the smallest quantity of ANY type of electromagnetic radiation
- Can be pictured as a small bundle of energy travelling through space at the speed of light

Electromagnetic Spectrum

- Frequency Range: $10 - 10^{24}$ Hz
- Wavelength Range: $10^{6} - 10^{-16}$ m
- Three regions relevant to medical imaging
  1. X-radiation
  2. Visible
  3. Radiofrequency

Electromagnetic Spectrum



Measurement of EM Radiation

Frequency, Wavelength & Energy

- Radio: measured via oscillations of electrons in conductors
  - Quoted in Hz
- Visible light: Early experiments describe light as a wave
  - Quoted in meters
- X-rays produced using electric potential
  - Quoted in keV

Wave Particle Duality

- Photons are quanta of radiation, which have energy
  - Particles
- Electromagnetic Radiation is characterised by frequency and wavelength
  - Waves

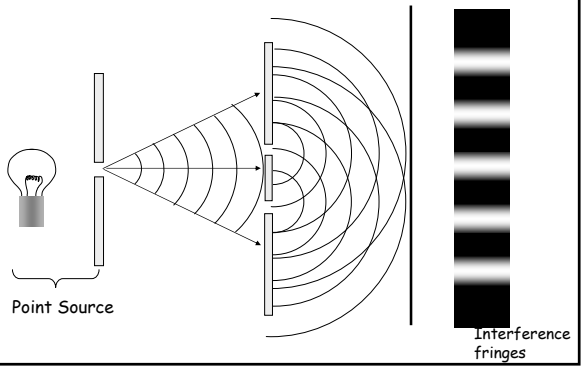
Wave Particle Duality

- Photons interact with matter most easily when the matter is approximately the same size as the photon wavelength
- What is the size of particles in matter?

Wave Particle Duality

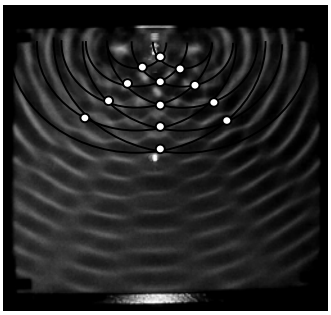
- Photons from different regions of the spectrum are fundamentally the same
- Difference in frequency results differences in the way photons interact with matter
- Visible photons behave more like waves
- X-ray photons act more like particles

Wave Like Behaviour of EM Radiation

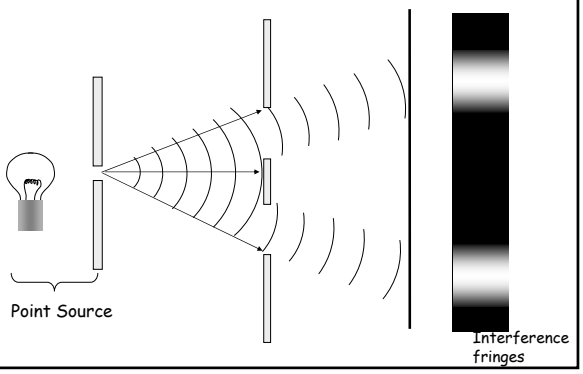


Interference

- This effect can also be observed for mechanical waves



Wave Like Behaviour of EM Radiation



Particle Behaviour or EM Radiation

- X-rays are identified by their energy (1 – 50MeV)
- Wavelength range: 10^{-10} – 10^{-12}m
- Usually smaller than objects!

- Therefore usually behave as particles

Planck's Quantum Theory

- X-ray photons are characterised by energy
- Planck developed relationship between energy and frequency

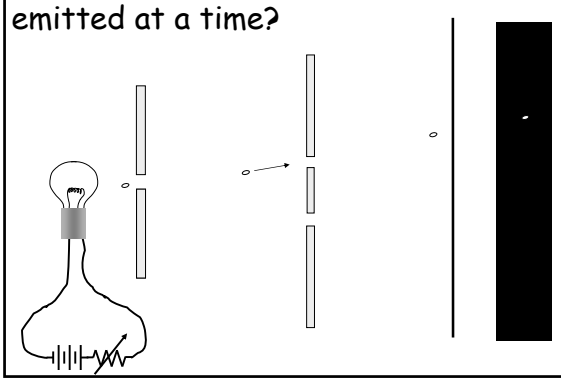
$$E = hf$$

- h is Planck's constant 6.63 X 10^{-34} Js^{-1}

Example:

What is the frequency of a 100keV x-ray photon?

What happens if current through bulb is reduced until only ONE photon is emitted at a time?



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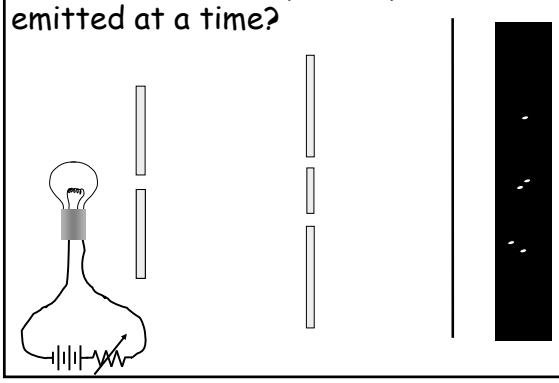

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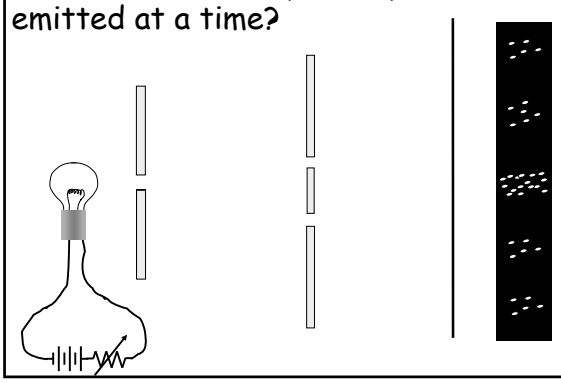

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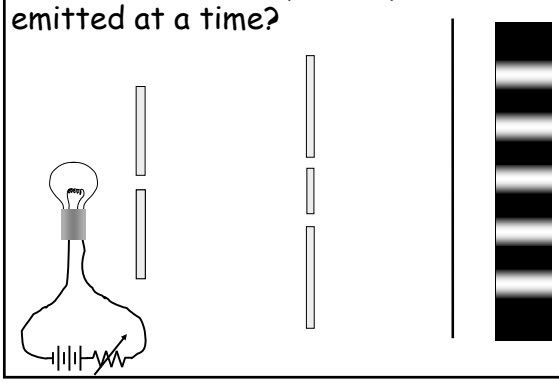

Matter & Energy

Classical Physics

- Matter can neither be created nor destroyed
  - Conservation of matter
- Energy can neither created nor destroyed
  - Conservation of energy

Matter & Energy

- Planck & Einstein extended classical theories
- Matter can be transformed into Energy and vice versa

$$E = mc^2$$

Example

PET scanner

When positron-electron annihilation occurs what are the energies of the two photons produced?

Summary

★What are electromagnetic waves
★Photons
★Electromagnetic spectrum
★Wave-particle duality
★Matter & Energy

Practice Questions

PAM2011: Lecture 11 Problem Sheet

1. What is the energy in Joules of a 50keV x-ray photon?
2. What is the frequency of a 50keV x-ray photon?
3. What is the wavelength of a 50keV x-ray photon?
4. What is the mass equivalence of a 50keV X-ray photon?
5. Calculate the energy of a 400nm photon?