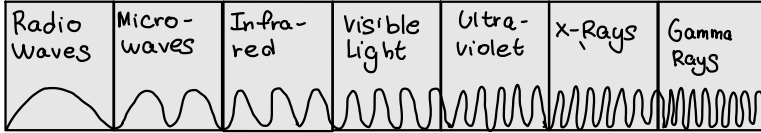


Photons

Electromagnetic radiation

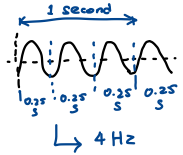
- The **electromagnetic spectrum** is a continuous spectrum of all the possible frequencies of electromagnetic radiation.
- The **frequency** of a wave is the number of complete waves passing a point per second.
- The **wavelength** of a wave is the distance between two adjacent crests of a wave.



How is the wave speed equation derived?

$$\text{frequency (Hz)} = \frac{1}{\text{Period (s)}}$$

Period is time taken for one wave cycle
 → The number of wave cycles per second = $\frac{1}{\text{Time taken for one oscillation}}$



Rearrange →

$$\text{Period (s)} = \frac{1}{\text{Frequency (Hz)}}$$

Substitute Period being time taken

$$\text{speed (ms}^{-1}\text{)} = \frac{\text{Distance (m)}}{\text{Time (s)}}$$

Substitute Wave Distance and Wave Time (Period)

$$\text{Wave Speed} = \frac{\text{Wave Distance / Wavelength } (\lambda)}{\text{Time taken for one wavelength / Period}}$$

Since speed of a wave = c (proven in a vacuum)

Wave Speed Formula →

$$c = f\lambda$$

Rearranged

$$c = \frac{\lambda}{\frac{1}{f}}$$

Photons

When are electromagnetic waves emitted?

- Electromagnetic waves are emitted by a charged particle when it loses energy:
 - ↳ A fast moving electron is stopped / slows down.
 - ↳ An electron in an atom moves to a lower shell / energy level.

What the HECK is a photon?!

← (plural: quanta)

- Photon is the **quantum** (discrete packet) of the electromagnetic radiation and the force carrier for the electromagnetic force.
- To put more simply: photons are **packets of EM waves and energy**. (waves carry energy through vibrations)
- e.g Since visible light belongs to the EM spectrum, photons are the smallest components of light. → A **photon is a quantum** (discrete packet) of **light**.
- Photons are **massless** → they travel at c. (speed of light)

Planck's constant = 6.63×10^{-34} Js

The energy of one photon is:

$$E = hf$$

Energy of a photon (J)

frequency of light (Hz) = colour / wave type

The wave speed equation rearranged:

$$f = \frac{c}{\lambda}$$

Substitute f into $E = hf$

Alternative equation to find energy of one photon:

$$E = hf = \frac{hc}{\lambda}$$

How are quanta (discrete packets) discovered?

- When Max Planck was investigating black body radiation, he suggested that EM waves can only be released in discrete packets, or quanta.
- Einstein went further by suggesting that EM waves and their energy can only exist in discrete packets.
- The photon theory was established by Einstein in 1905, when he used his ideas to explain the **photoelectric effect**. (the emission of electrons from a metal surface when light is directed at the surface)

How is laser power calculated?

works by excitation of electrons in energy levels of atoms

- A laser (Light Amplification by Stimulated Emission of Radiation) beam consists of photons of the same frequency.
- The power of a laser beam is the **energy per second transferred by the photons**, for a beam consisting of photons of frequency f :

From GCSE: power is the amount of energy per second.

$$P = \frac{W}{\Delta t}$$

$$\text{The power of the beam} = nhf$$

number of photons in the beam passing a fixed point each second

energy of each photon

$E = hf$ and lasers

- According to $E = hf$, **violet/purple has a higher frequency than red** and hence carries **more energy**.
↓ hence
- Blue and green lasers are **banned** as they carry **A LOT of energy in terms of photons**.
- Red lasers are hence most widely used and the safest.

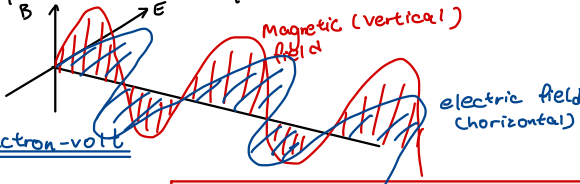
What is a wave really?

- They are a transfer of energy without the transfer of matter.
- Eg. Sound waves transfer energy by vibrations through air.

How are EM waves passed through without vibrations?

• EM radiation is emitted as a burst or "packet" (quantum) of waves with interlocking electric field (E) and magnetic field (B) oscillations at right angles to one another.

- These wave packets are called **photons**.



Joules vs electron-volt

• We calculate the kinetic energy of a charged particle by $E = QV$.

↓ however

• In particle physics the charges of 1 (or small amounts) of electrons/other particles are so small, this will result in extremely small joule values and hence kinetic energy is calculated in **electron-volts**.

$$1 \text{ electron-volt} = 1.6 \times 10^{-19} \text{ Joules}$$

$$E_{\text{Kinetic Energy}} = QV$$

$$E_{\text{Kinetic Energy}} = eV$$

LOTS and LOTS of charge of electrons (in coulombs)

Charge of an electron (number of electrons)

