Lecture 33

Fri: HW 5pm

Mon: Read 12.2 – 12.3

Electromagnetic waves

The theory of electromagnetism, developed by Maxwell in the 1860s, eventually predicted that, in a vacuum, there can exist waves of electric and magnetic fields. The theory predicted that the speed of these electromagnetic waves is the same as the speed of light. This together with interference phenomena suggested that:

> Light is an electromagnetic wave

DEMO: Show interference patterns with various slits

DEMO: Show Newton's rings.

All electromagnetic waves have the same basic electric and magnetic field nature. There is a wide range of possible frequencies and wavelengths all related by:

$$\text{speed of light} = \text{wavelength} \times \text{frequency}$$

$$3 \times 10^8 \text{ m/s} = \text{wavelength} \times \text{frequency}$$

DEMO: Wikipedia electromagnetic spectrum image.

Quiz 1

Electromagnetic waves of different frequencies are produced and detected in distinctly different physical ways. Thus

* a cellphone antenna does not receive and transmit electromagnetic waves in the visible spectrum
* a human eye does not receive and transmit electromagnetic waves in the microwave spectrum.

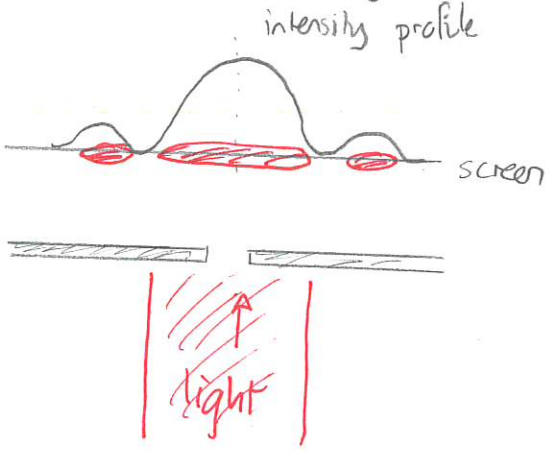
Low intensity light

One of the characteristics of light is its intensity. This describes the rate at which light delivers energy per area. We can consider how light intensity affects interference patterns. We consider light passing through a single slit.

DEMO: Single slit diffraction

Classical electromagnetism and waves predicts a pattern of bright and dark fringes. We can describe this via an intensity profile

* a graph whose height indicates relative intensity at each screen location.



Slide 1

Slide 2

As the intensity is reduced.

1) the basic form/structure of the pattern is unchanged
2) the pattern becomes dimmer.

The same rules apply for any arrangement of slits.

Quiz 2 80%

As we continue to reduce the intensity of the incident light what happens to the pattern? Does it just become dimmer?

DEMO: Am J. Phys Article Aspden AJP 84, 671677 (2016)

Actual experiments reveal:

* the intensity pattern accumulates, one small spot at a time
* the arrival locations of individual spots are random in some way
* eventually the spots build up the pattern observed with more intense light.

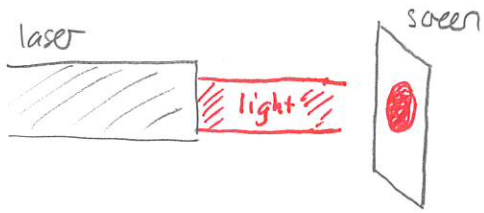
DEMO: PhET Quantum Wave Interference

Tab – High Intensity
→ Double Slit – width 25%
– separation 25%
– vertical position 50%
→ Display – time average intensity
– hits.

Tab – Single particle → fire several photons (auto-repeat)

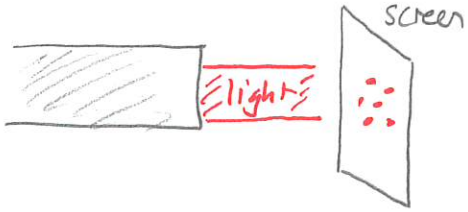
So we have competing models of light

Continuous Waves



* light arrives continuously - smooth pattern
* could be waves

Discrete Entities



* light arrives in discrete entities
* cannot be a continuous wave

Photons

The low-intensity light pattern requires an explanation that does not involve waves. We need

One conceptual model for light →
- Explains arrival of individual entities on screen
- Explains how individual entities eventually form an interference pattern.

The explanation starts by describing any light as consisting of individual particle-like objects called photons:

The following are the crucial properties of photons:

1) a photon is indivisible ⇒ it cannot be split into two or more photons

2) photons do not combine ⇒ two or more photons do not combine into one.

3) when a photon is detected it appears at a single location

4) a photon occupies an extended range in the direction along which it propagates

5) a photon is massless.

Quiz 3 80%-