Chapter 18: The Wave Nature of Light

The Spectrometer

The spectrometer is used to examine spectra and measure the wavelength of light.

Collimator:

• made from 2 tubes

• focal length = distance from slit to lens

• purpose is to make the beam of light parallel.

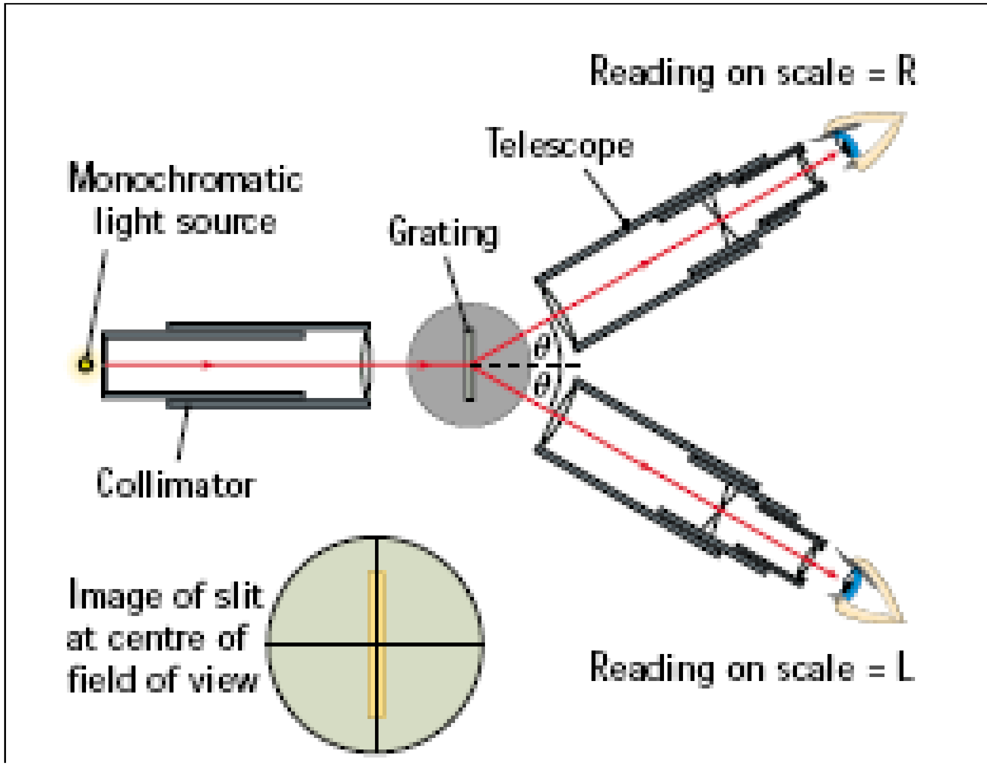
Astronomical Telescope:

• used to view the slit

• free to rotate about the turntable

• contains a vernier scale to measure the angle

• contains 2 convex lens (objective and eyepiece)



The Wave Nature of Light

Light undergoes reflection, refraction, interference and diffraction

Christiaan Huygens proposed light travels as a wave.

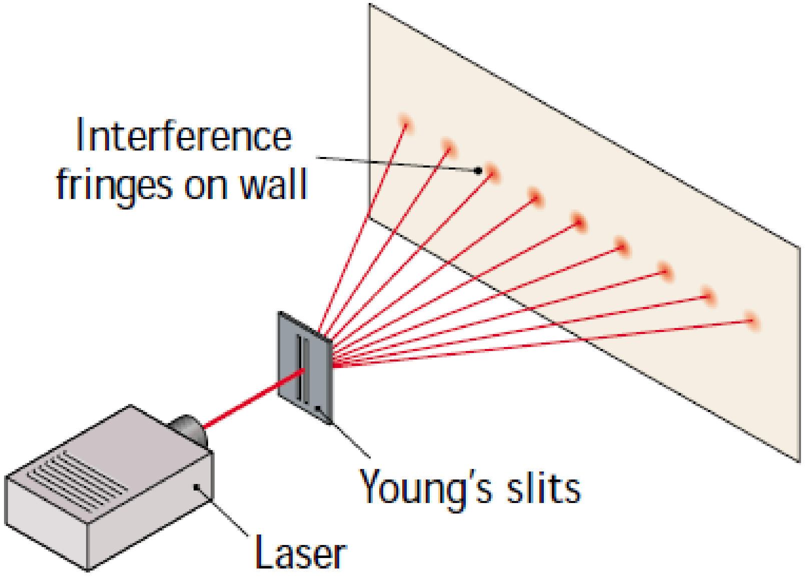
- Could not prove this

Isaac Newton said it was a stream of very fast moving particles.

- obeys reflection and refraction

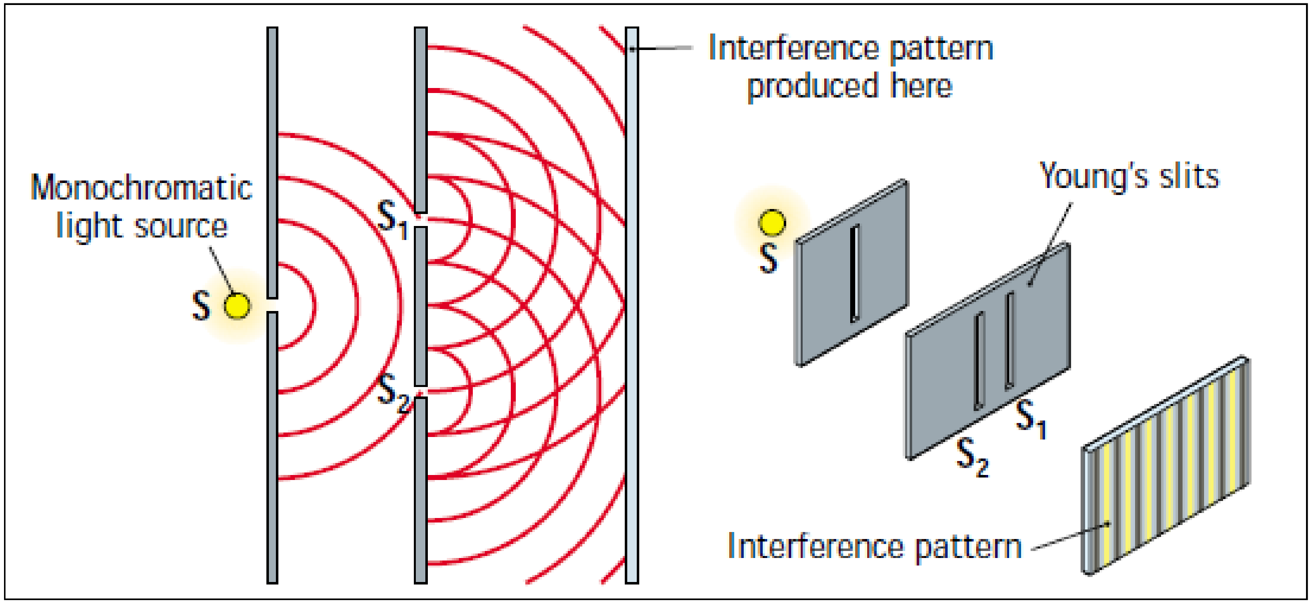
Thomas Young proved it was a wave by showing light undergoes diffraction and interference.

- This can be shown using a laser and a Young's slit.



To Demonstrate the Wave nature of Light (Young's Slits Experiment)

1. The result is that a series of bright lines are seen either on a screen or through a spectrometer.
2. Set up the equipment as shown. S is a **monochromatic light source** (light of one wavelength only).
3. Light from S shines onto the first narrow slit. It undergoes diffraction here and illuminates the slits S_1 and S_2. These two slits are known as Young's Slits.
4. Diffraction occurs at each of these slits; in the region between them (where light from each overlaps) constructive and destructive interference occurs.



Wavelength and Colour

Light is an electromagnetic wave with a wavelength between 4×10^{-7} and 7×10^{-7}

Different colours are seen as different wavelengths strike the eye.

White light is a mixtures of different wavelengths.

Monochromatic light has one wavelength only.

Colour Produced by Interference

When oil/petrol is on water, we see a range of colours.

From the diagram, we can see that light gets reflected both from the petrol and the water. But different wavelengths get reflected at different angles in the petrol. Some of these interfere constructively and we see colours.

This also occurs for soap bubbles.

Diffraction Grating.

Young’s Slits are very unclear and close together so it is difficult to measure the wavelength. But if we increase the number of slits (few hundred per mm), it becomes clearer.

A diffraction grating consists of a transparent medium with parallel lines engraved in it. Light cannot pass through these lines and the spaces behave as slits.

Def: The distance *d* between two adjacent lines on the grating is called the grating constant or slit width.

Question:
A fine diffraction grating has 500 lines per mm ruled on it. Find the grating constant d.

$$d = \frac{1}{500} = 0.002\,mm = 2\ \times 10^{-6}\ m$$

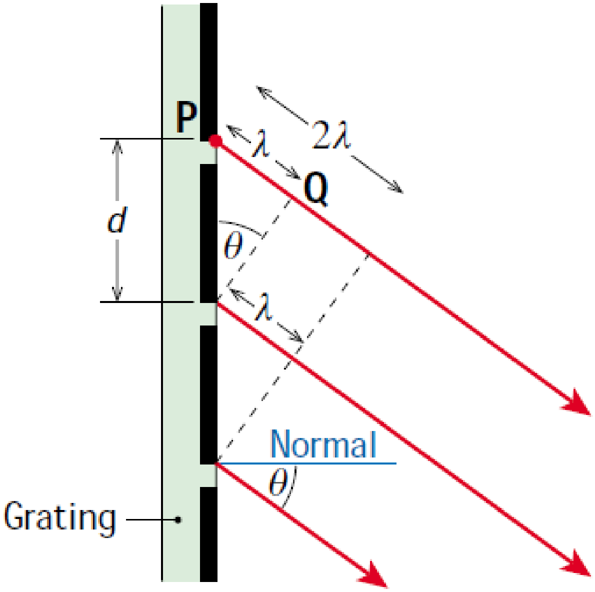
Monochromatic Light (one wavelength) and Diffraction Grating.

Diffraction occurs at each slit. The diffracted waves interfere with each other and form bright images due to constructive interference.

Light passing straight through (n = 0)

When the waves come through the slits, they are parallel and in phase. A convex lens bring the waves to a point and constructive interference takes place, producing a bright line.

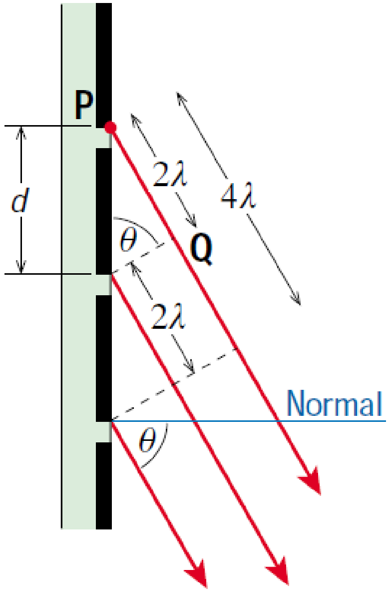
Light making an angle θ (n = 1)



Look at the diagram, the angle θ is chosen so that PQ = λ. The path difference between light from the other slits is also λ. Therefore, light from one slit and it's adjacent slit are out of phase by one λ.

If all the lines are brought together by a convex lens, it will produce a bright line (by constructive interference) called the first order diffracted image or n = 1.

Light making an angle θ (n = 2)



The same thing happens when the angle θ is equal to 2λ. Here the waves can be brought together and form the second order diffracted image.

From this, we can get the formula

For the nth bright line: $n\lambda = d \text{ Sin } \theta$

Most light will form an image at n = 1 and n = 2 (some as far as 3 or 4). For other angles, some light produces constructive interference and other produce destructive interference so no bright line can be seen.

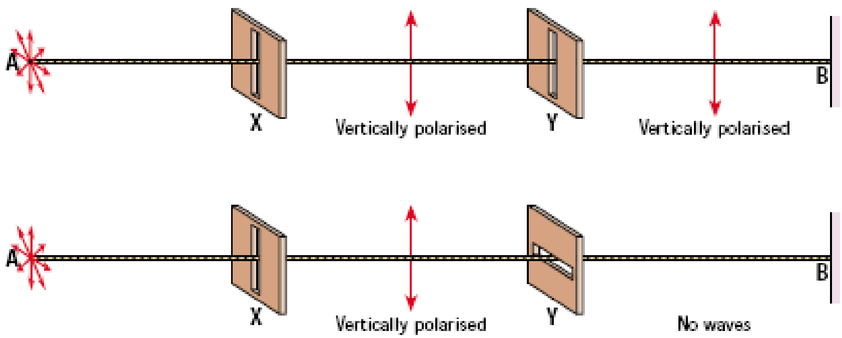
Example

The first order image of monochromatic light source is at an angle 29^{o} to the zero order image. The diffraction grating has 800 lines per millimetre. What is the wavelength of the light? Give your answer in nanometres.

Polarisation

A Polarised wave is a wave which vibrates in one plane only.

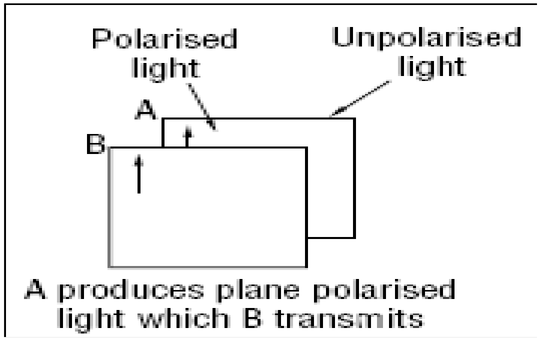
- The diagram shows an unpolarised wave on the left (it vibrates in all directions) and two polarising filters.

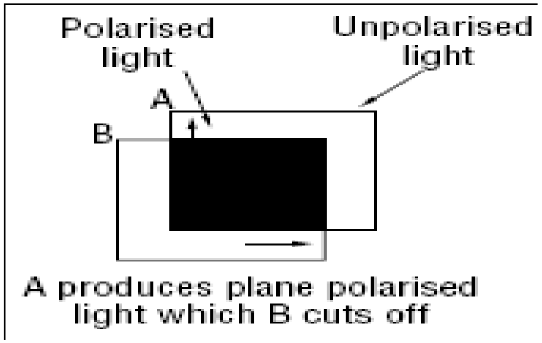


- The first filter will only allow waves which are vertically polarised to pass through it.

- These waves will only pass through a second Polaroid if the second Polaroid is parallel to that of the first

To Demonstration Polarisation using Two Polaroids





- Light from an **incandescent** source (something which emits light when heated) is **unpolarised**, i.e. the electric and magnetic fields are oscillating in many different planes.

- If light from such a source is passed through a substance called a **Polaroid** the emerging rays are now **polarised**, i.e. oscillate in one plane only.

- If this light is then passed through a second Polaroid, it only gets through if the second Polaroid is parallel to that of the first.

- If the second Polaroid is then rotated through 90^0, no light gets through.

Only transverse waves can be polarised so the fact that light can be polarised shows that light is a transverse wave.

Applications: Sunglasses, Stress Polarisation

Stress Polarisation

Engineers use this to test the stress on components.

A piece of Polaroid is placed on either side of the component. Light is passed through one of the Polaroid's and is viewed through the other. If the component is under stress, colours will be seen.

Dispersion

Dispersion is the separating out of the different colours present in white light.

Dispersion can be brought about by either a **prism** or a **diffraction grating**

Dispersion due to a Prism

A Prism causes dispersion because the Refractive Index of the medium is slightly different for different wavelengths, therefore each wavelength gets refracted (bent) by a different amount. In this case Blue gets deviated the most.

Dispersion due to a Diffraction Grating

A Diffraction Grating causes dispersion because from the formula $n\lambda = d \sin \theta$, if λ is different, θ will be different, i.e. different colours are diffracted by different amounts. From this we can see that the colour with the largest wavelength (Red) gets deviated the most.

Dispersion is the principle behind the array of colours seen in rainbows, polished gemstones and on surface of CDs.

Recombination

If a given prism is used to disperse white light, a second identical – inverted - prism can be used to recombine the components back into white light

Primary Colours

The primary colours are three colours such that when combined in equal intensity produce white light. The three primary colours are Red, Green and Blue.

Secondary Colours

When two primary colours are mixed in equal intensity, the colour formed is a secondary colour. Yellow, Cyan and Magenta are the three secondary colours.

Complementary Colours

Complementary colours are pairs of colours consisting of a primary and a secondary colour, such that when combined they give white light.

The Electromagnetic Spectrum

You are expected to know the relative positions of the different radiations in terms of their frequency and wavelength.

Ultraviolet Light

- Has a wavelength between 0.4 µm and 5 nm

- Found beyond violet end of visible light

- UV light is emitted from the Sun (a lamp emits a small amount)

Properties:

- causes some substance to fluoresce (absorbs UV light and re-emits it as visible)
    - Day glow paint and washing powder.

- causes sunburn (but Ozone absorbs majority of UV light)

- does not pass through glass

Think of some lights in a nightclub.

Infra-Red Light

- Has a wavelength of 0.7×10^{-6} m and 1 mm

- Found just below the red end of visible light.

- Emitted from the Sun and ordinary lamps.

- Also emitted from most objects. As their temperature increases, so does their IR radiation. At 500^{o}, objects start to emit red light.

- can be detected using a blackened thermometer bulb

Properties

- When used with a photographic plate, you can take pictures in the dark, fog or mist.
  - Used by the police and military for search and rescue.
  - Hot objects show a white image in these photos.
  - Can be used in medicine to test for abnormalities in the body. (breast cancer)

- Causes substances to heat up.

The Greenhouse Effect

The Earth receives energy from the Sun in the form of radiation, most of which is in the visible wavelength region and which passes through the Earth's atmosphere on the way to the planet's surface. Some of this radiation then gets reflected (re-radiated) off the surface of the Earth as infra-red radiation. Much of this radiation, which would otherwise radiate back out to space, gets absorbed by the atmosphere (by carbon dioxide, water vapour and methane) and as a result the atmosphere heats up.