WL04 LIGHT THEORY, COLOUR & WAVELENGTH

SPH4U

CH 9 (KEY IDEAS)

- analyze and interpret the properties of two-dimensional mechanical waves in a ripple tank and relate them to light
- derive and apply equations involving the speed, wavelength, frequency, and refractive index of waves and apply them to the behaviour light
- analyze two-point-source interference patterns in a ripple tank and in the interference of light (Young's experiment) using diagrams
- derive and apply equations relating the properties of wave interference and wavelength
- outline the historical development of the particle and wave theories of light, including the development of new technologies and discoveries, and summarize the successes and failures of each theory
- apply the wave theory to the property of dispersion and determine the wavelengths of the colours of the visible spectrum

THE NATURE OF LIGHT

- The earliest recorded views on the nature of light were from the Greeks
- Plato thought that light consisted of filaments originating from the eye
- Pythagoreans believed light consisted of a stream of fast-moving particles
- Empedocles taught that light travelled as a wave-like disturbance

THE NATURE OF LIGHT – CONT.

- In the 17th century, there were two main opposing theories
  - Particle theory – supported by Newton and Laplace
  - Wave theory – supported by Huygens and Hooke
- The two chief functions of a scientific model, or theory are
  - to explain the known properties of a phenomenon
  - to predict new behaviour, or new properties, of a phenomenon

NEWTON'S PARTICLE THEORY

- Newton theorized that light particles, which he called "corpuscles", were like bullets shot from a light source

NEWTON'S PARTICLE THEORY
RECTILINEAR PROPAGATION OF LIGHT

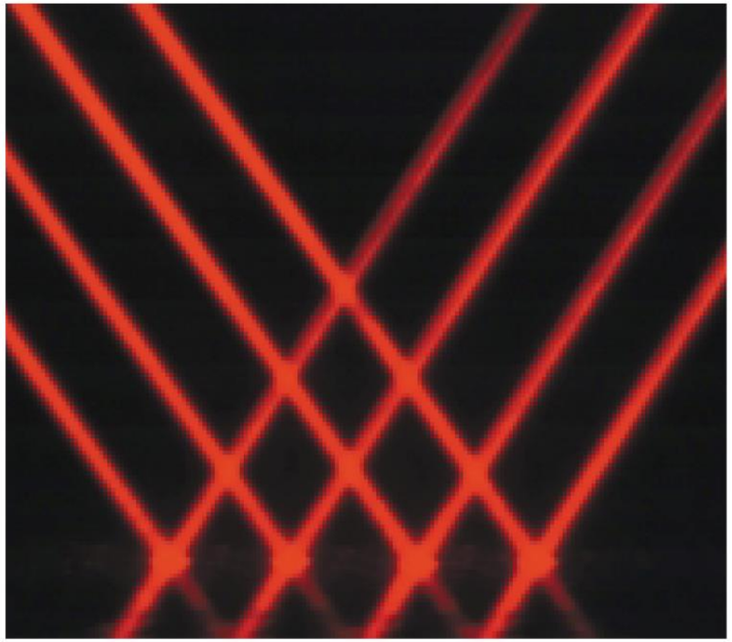
- **Rectilinear Propagation of Light:** the term used to describe light travelling in straight lines
- Faster particles curve less when travelling relative to slower particles
- Light must consist of particles travelling at very high speed
- Also, since there is no noticeable pressure from light, the mass of the particles must be very small

NEWTON'S PARTICLE THEORY DIFFRACTION

- **Diffraction:** the bending of light around an obstacle
- Newton argued that light did not bend, but that collisions between particles at the edge of an obstacle or aperture caused the "spreading" of light

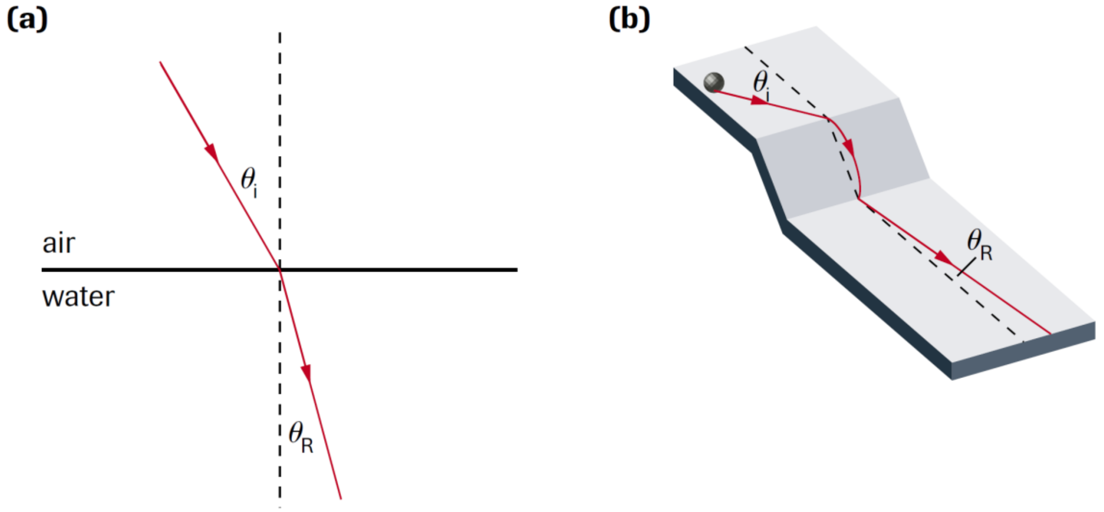
NEWTON'S PARTICLE THEORY REFLECTION

- Newton argued that light particles had perfectly elastic collisions with a surface, similar to a bouncing steel ball



NEWTON'S PARTICLE THEORY REFRACTION

- It was clear that light bent towards the normal when entering water; so do accelerating particles
- Newton theorized that water attracted the particles, accelerating the light through the boundary
- This theory of increasing speed as later disproven, as light travels more slowly in water

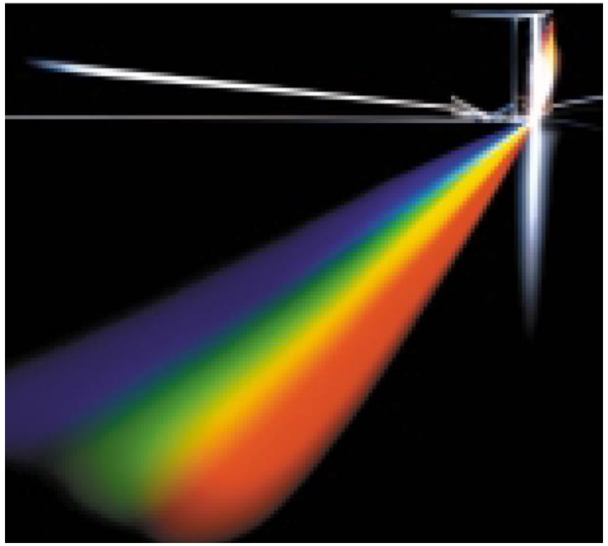


NEWTON'S PARTICLE THEORY
PARTIAL REFLECTION-PARTIAL REFRACTION

- Newton did not have a strong theory for partial reflection-partial refraction
- He stated that particles reached a boundary in a series of "fits"
  - Some "fits" were easier to reflect
  - Other "fits" were easier to refract

NEWTON'S PARTICLE THEORY DISPERSION

- **Dispersion:** white light shone through a prism will have different coloured wavelengths refract at different angles, spreading out the light into spectrum of visible light
- Newton theorized that each colour particle had a different mass, causing it to refract at different angles
  - Violet: least mass, greatest refraction
  - Red: greatest mass, least refraction

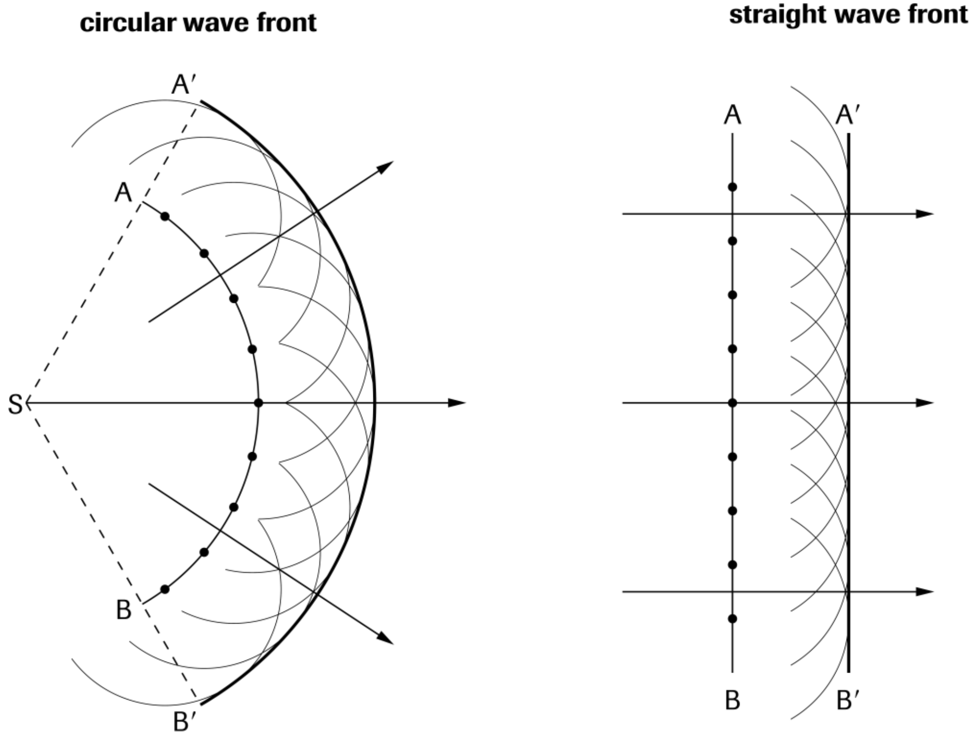


NEWTON'S PARTICLE THEORY

- Newton recognized that both his corpulent (particle) theory and wave theory were possible, but both required further supporting evidence
- Since he preferred the corpulent theory, his successors were even more adamant of its validity
- It took over a century for enough evidence for wave theory to finally convince the scientific community to move away from particle theory due to Newton's influence

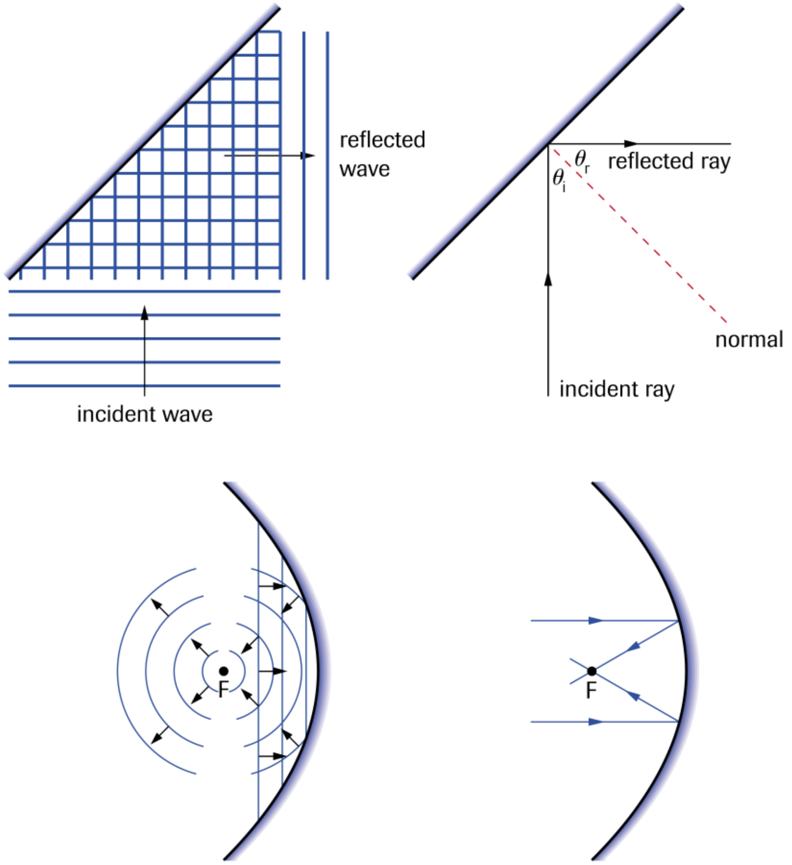
HUYGENS' WAVE MODEL HUYGENS' PRINCIPLE

- **Huygens' Principle:** every point on a wave front can be considered as a point source of tiny secondary wavelets that spread out in front of the wave at the same speed as the wave itself. The surface envelope, tangent to all the wavelets, constitutes the new wave front.



HUYGENS' WAVE MODEL REFLECTION

- Waves, like light, obey the laws of reflection
- The angle of incidence equals the angle of reflection in all cases



HUYGENS' WAVE MODEL REFRACTION

- A wave bends towards the normal when entering a slower medium, similar to light
- Huygens predicted that $v_2 < v_1$, opposite to Newton

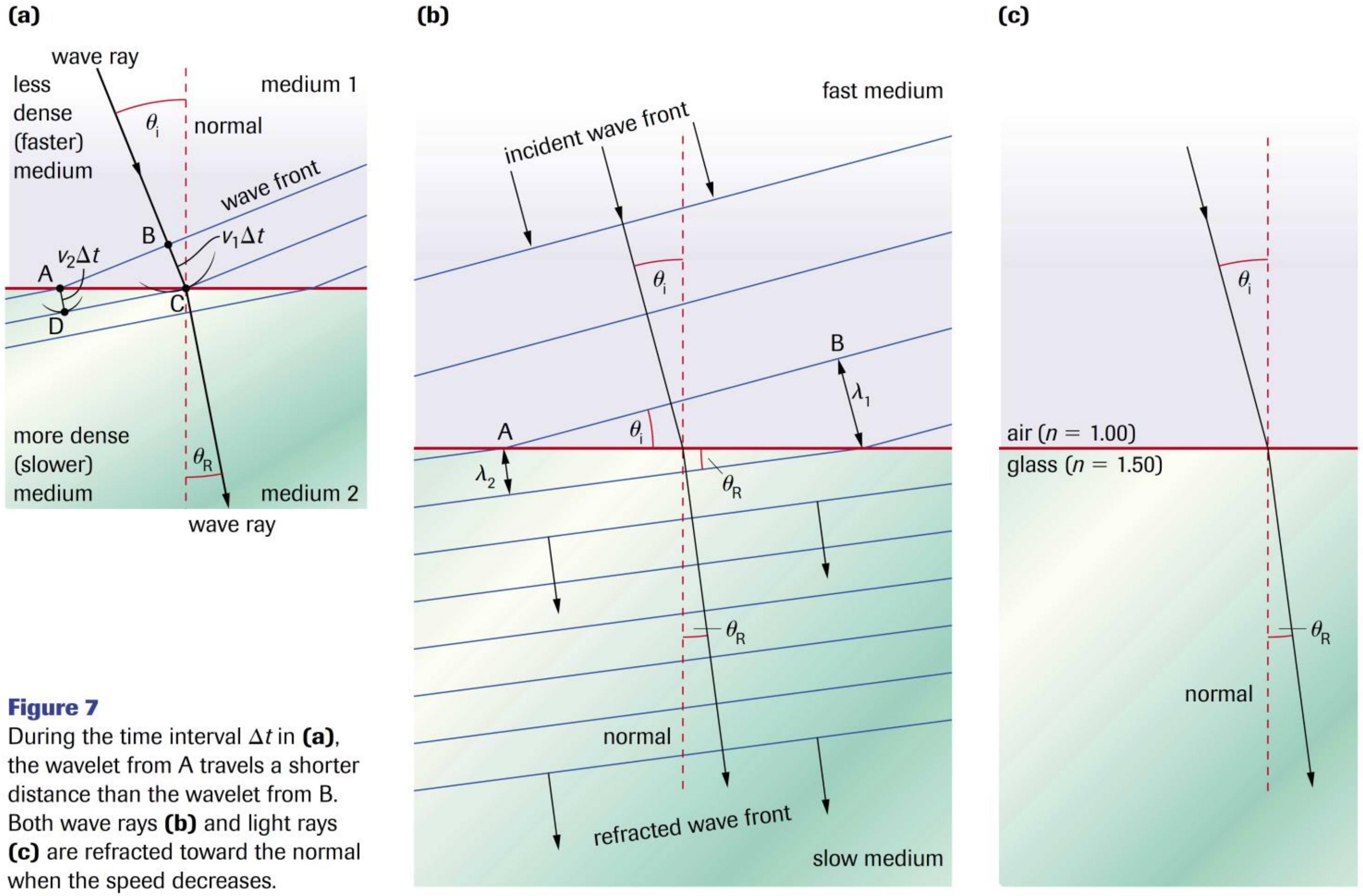
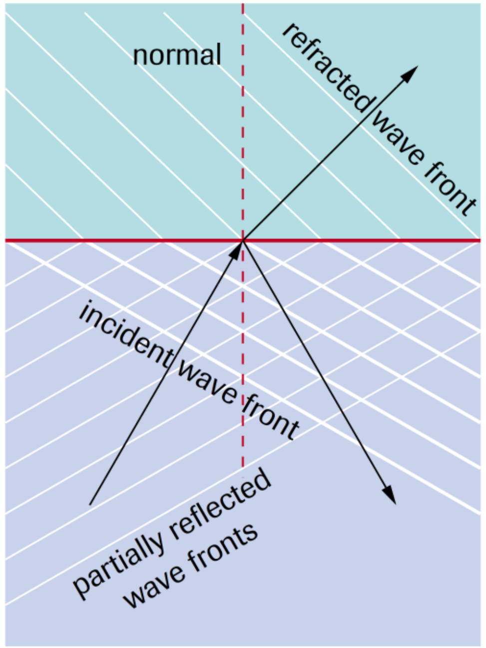
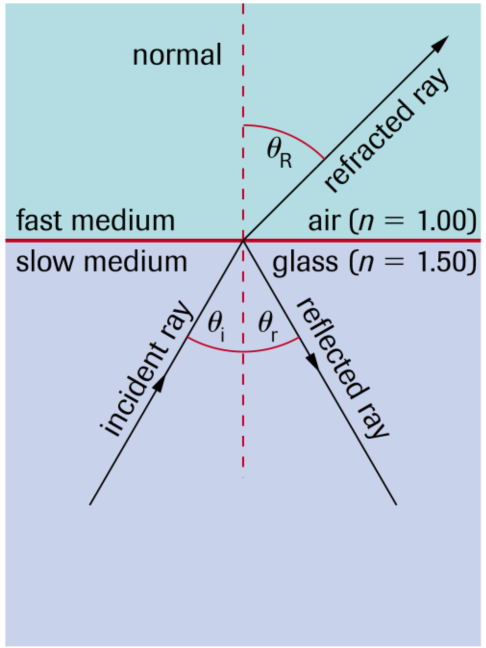


Figure 7
During the time interval Δt in **(a)**, the wavelet from A travels a shorter distance than the wavelet from B. Both wave rays **(b)** and light rays **(c)** are refracted toward the normal when the speed decreases.

HUYGENS' WAVE MODEL
PARTIAL REFLECTION-PARTIAL REFRACTION

- Water waves let us easily see how waves display partial reflection-partial refraction
- This showed very similar behaviour to what is exhibited by light

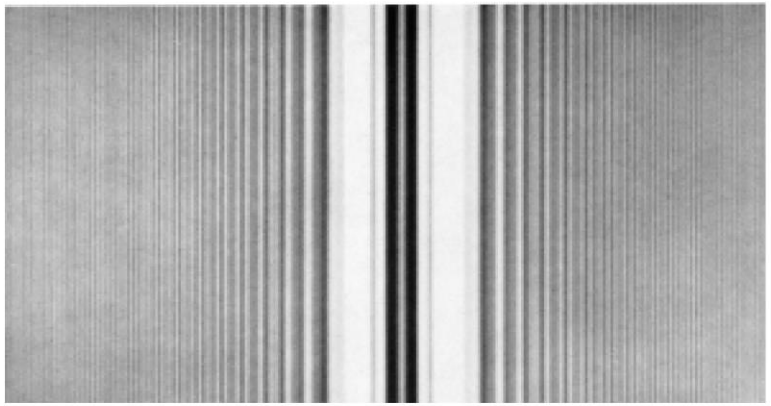




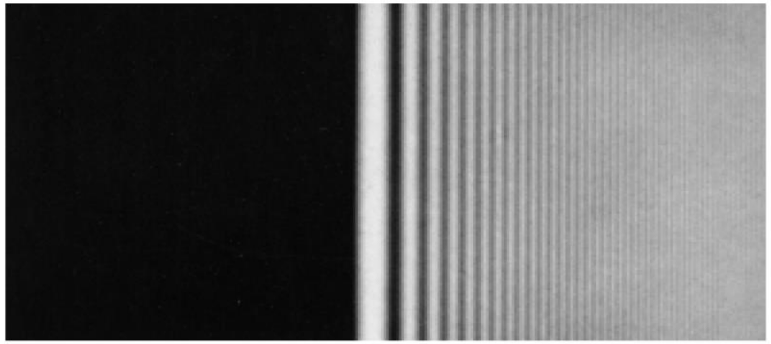
HUYGENS' WAVE MODEL DIFFRACTION

- The minuteness of light was unknown at the time
- Huygens was unable to show the diffraction patterns as his apertures were too large relative to the wavelengths of light
- Later experimentation was able to prove his theories of diffraction true

(a)



(b)



HUYGENS' WAVE MODEL DISPERSION

- Waves of different wavelengths can be observed moving between mediums, with different angles of refraction
- The simplified version of how light waves bend is related to the relative wavelengths of the different colours
  - Violet light bends most with the smaller wavelengths
  - Red light bends least with the largest wavelengths

HUYGENS' WAVE MODEL RECTILINEAR PROPAGATION

- Huygens used the ray to explain the propagation of light waves
- Newton's theory had stronger arguments for rectilinear propagation at the time

COLOUR & WAVELENGTH

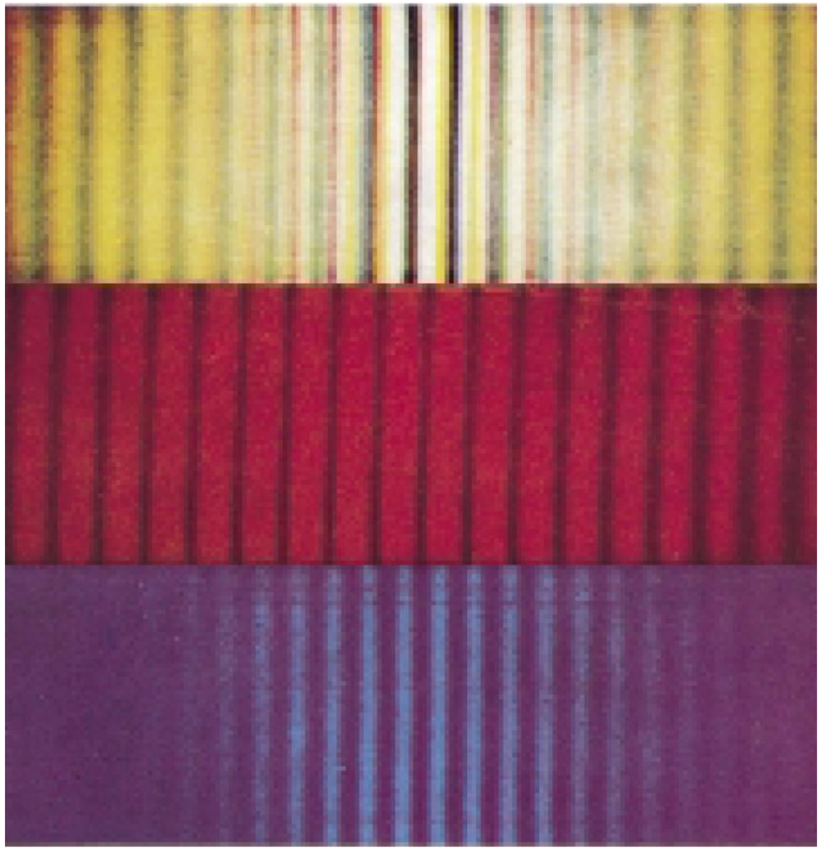
- We recognized that different colours have different wavelengths
- This affects more than just dispersion, influencing interference as well

Table 1 The Visible Spectrum

Colour	Wavelength (nm)
violet	400–450
blue	450–500
green	500–570
yellow	570–590
orange	590–610
red	610–750

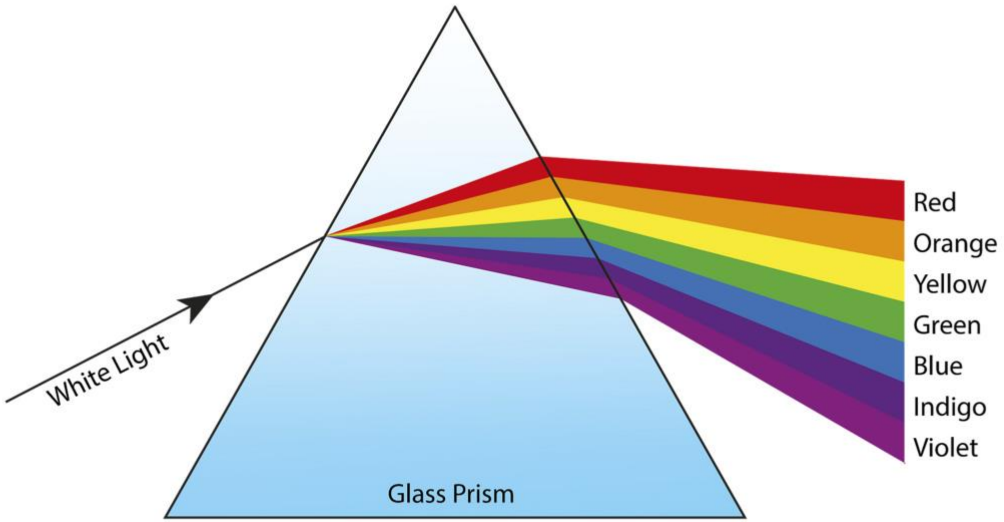
COLOUR & WAVELENGTH INTERFERENCE

- We can see the interference patterns for white, red, and blue light
- Notice the dispersion within the white interference pattern
- Red light has a greater nodal separation due to its longer wavelength
- Blue, by contrast, has a much shorter nodal separation due to its shorter wavelength



COLOUR & WAVELENGTH DISPERSION

- All wavelengths bend a slightly different amount when entering a new medium
- Each wavelength will have a slight different index of refraction
- We use the universal wave equation and Snell's law to solve for the wavelength or freqency



PROBLEM 3

Red light with a wavelength of 6.50×10^2 nm travels from air into crown glass ($n_2 = 1.52$).

(a) What is its speed in the glass?

(b) What is its wavelength in the glass?

PROBLEM 3 – SOLUTIONS

(a) $\lambda = 6.50 \times 10^2$ nm

$n_2 = 1.52$ $\qquad$ $n_1 = 1.00$

$v_2 = ?$ $\qquad$ $v_1 = 3.00 \times 10^8$ m/s

$$\frac{n_2}{n_1} = \frac{v_1}{v_2}$$

$$v_2 = \frac{n_1}{n_2} v_1$$

$$= \frac{1.00}{1.52}(3.00 \times 10^8 \text{ m/s})$$

$$v_2 = 1.97 \times 10^8 \text{ m/s}$$

The velocity of red light in the glass is 1.97×10^8 m/s.

PROBLEM 3 – SOLUTIONS CONT.

(b) $\lambda = ?$

$$\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

$$\lambda_2 = \left(\frac{v_2}{v_1}\right)\lambda_1$$

$$= \left(\frac{1.97 \times 10^8 \text{ m/s}}{3.00 \times 10^8 \text{ m/s}}\right) 6.50 \times 10^2 \text{ nm}$$

$$\lambda_2 = 4.28 \times 10^2 \text{ nm}$$

The wavelength of red light in the crown glass is 4.28×10^2 nm.

YOUNG'S EXPERIMENT TODAY

- In the past, it was impossible to create two light sources emitting the same wavelengths in phase using incandescent bulbs
- Today, we can use lasers (single-wavelength sources of light) that are in phase (or "phase locked") to observe the interference patterns, but there is still some drifting
- To find interference of light, it is still best to use Young's model with a single source sent through multiple slits

SUMMARY:
LIGHT: WAVE OR PARTICLE?

- Newton's particle theory provided a satisfactory explanation for four properties of light: rectilinear propagation, reflection, refraction, and dispersion. The theory was weak in its explanations of diffraction and partial reflection–partial refraction.
- Huygens' wave theory considered every point on a wave front as a point source of tiny secondary wavelets, spreading out in front of the wave at the same speed as the wave itself. The surface envelope, tangent to all the wavelets, constitutes the new wave front.
- Huygens' version of the wave theory explained many of the properties of light, including reflection, refraction, partial reflection–partial refraction, diffraction, and rectilinear propagation.

SUMMARY:
COLOUR AND WAVELENGTH

- White light is made of all of the colours found in the visible spectrum, each with its own range of wavelengths.
- Dispersion occurs because the refractive index of light is slightly dependent on the frequency of the light.

PRACTICE

Readings

- Section 9.4 (pg 461)
- Section 9.6 (pg 476)

Questions

- pg 468 #1-5
- pg 479 #1,3,5,6,7