Wallace Hall Academy
Physics Department

Advanced Higher Physics

Waves

Problems

Data

Common Physical Quantities

QUANTITY	SYMBOL	VALUE
Gravitational acceleration	g	9.8 m s^{-2}
Radius of Earth	R_E	6.4×10^6 m
Mass of Earth	M_E	6.0×10^{24} kg
Mass of Moon	M_M	7.3×10^{22} kg
Mean radius of Moon orbit		3.84×10^8 m
Universal constant of gravitation	G	$6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$
Speed of light in vacuum	c	$3.0 \times 10^8 \text{ m s}^{-1}$
Speed of sound in air	v	$3.4 \times 10^2 \text{ m s}^{-1}$
Mass of electron	m_e	9.11×10^{-31} kg
Charge on electron	e	-1.60×10^{-19} C
Mass of neutron	m_n	1.675×10^{-27} kg
Mass of proton	m_p	1.673×10^{-27} kg
Planck's constant	h	6.63×10^{-34} J s
Permittivity of free space	ε_0	$8.85 \times 10^{-12} \text{ F m}^{-1}$
Permeability of free space	μ_0	$4\pi \times 10^{-7} \text{ H m}^{-1}$

Astronomical Data

Planet or satellite	Mass/ kg	Density/ kg m^{-3}	Radius/ m	Grav. accel./ m s^{-2}	Escape velocity/ m s^{-1}	Mean dist from Sun/ m	Mean dist from Earth/ m
Sun	1.99×10^{30}	1.41×10^3	7.0×10^8	274	6.2×10^5	--	1.5×10^{11}
Earth	6.0×10^{24}	5.5×10^3	6.4×10^6	9.8	11.3×10^3	1.5×10^{11}	--
Moon	7.3×10^{22}	3.3×10^3	1.7×10^6	1.6	2.4×10^3	--	3.84×10^8
Mars	6.4×10^{23}	3.9×10^3	3.4×10^6	3.7	5.0×10^3	2.3×10^{11}	--
Venus	4.9×10^{24}	5.3×10^3	6.05×10^6	8.9	10.4×10^3	1.1×10^{11}	--

Tutorial 1.0

Simple Harmonic Motion

1. (a) On object undergoes simple harmonic motion. State the condition which must apply to the unbalanced force acting on the object.
   (b) Give three examples of simple harmonic motion (SHM).

2. (a) State the equation which defines SHM.
   (b) (i) Show by differentiation that *each* of the following is a solution of the equation for SHM: $y = a\cos\omega t$ and $y = a\sin\omega t$.
   (ii) State the condition under which the equation for SHM is given by *each* of the following: $y = a\cos\omega t$ and $y = a\sin\omega t$
   (c) Derive the equation for the velocity $v = \pm\sqrt{a^2 - y^2}$ using:
   (i) $y = a\cos\omega t$
   (ii) $y = a\sin\omega t$.

3. An object moves with SHM with a frequency of 5 Hz and an amplitude of 40 mm.
   (a) Find the acceleration at the centre and extremities of the motion.
   (b) Determine the velocity at the centre and extremities of the motion.
   (c) Calculate the acceleration and velocity at a point midway between the centre and extremity of the motion.

4. A horizontal platform oscillates vertically with SHM with a slowly increasing amplitude. The period of the oscillations is 0.10 s.
   What is the maximum amplitude which will allow a mass resting on the platform to remain in contact with the platform?

5. (a) Derive expressions for the kinetic energy and potential energy of a particle executing SHM.
   (b) An object of mass 0.20 kg oscillates with SHM with an amplitude of 100 mm. The frequency of the oscillations is 0.50 Hz.
   (i) Calculate the maximum value of the kinetic energy of the object. State where this occurs.
   (ii) State the minimum value of the kinetic energy. State where this occurs.
   (iii) Find the maximum value of the potential energy of the object. State where this occurs.
   (iv) Calculate the potential energy and the kinetic energy at a point mid way between the centre and extremity of the motion.
   (v) What can you state about the value of the sum of the potential energy and the kinetic energy at any point?

6. The displacement, y, in mm of a particle is given by $y = 0.44\sin 28t$.
   (a) Find the amplitude of the motion.
   (b) Find the frequency of the motion.
   (c) Find the period of the motion.
   (d) Find the time taken for the particle to move a distance of 0.20 mm from the equilibrium position.

7. (a) What effect does damping have on an oscillatory system?
   (b) Briefly explain the terms critical damping and overdamping.
   (c) Give two examples where damping is useful.

Tutorial 1.1

Simple Harmonic Motion

1 The displacement, in cm, of a particle is given by the equation: $y = 4 \cos 4\pi t$.
- (a) State the amplitude of the motion.
- (b) Calculate the frequency, and hence the period, of the oscillation.
- (c) Calculate the location of the particle, in relation to its rest position, when;
  - (i) $t = 0$
  - (ii) $t = 1.5$ s.

2 A body, which is moving with SHM, has an amplitude of 0.05 m and a frequency of 40 Hz.
- (a) Find the period of the motion.
- (b) State an appropriate equation describing the motion.
- (c) (i) Calculate the acceleration at the mid-point of the motion **and** at the position of maximum amplitude.
  - (ii) Calculate the maximum speed of the body and state at which point in the motion this speed occurs.

3 An object of mass 0.50 kg moves with SHM. The amplitude and period of the motion are 0.12 m and 1.5 s respectively. Assume that the motion starts with a = + 0.12 m.

From this information, calculate:
- (a) the position of the object when $t = 0.40$ s
- (b) the force (magnitude and direction) acting on this object when $t = 0.40$ s
- (c) the minimum time needed for the object to travel from its starting point to a point where the displacement is - 0.06 m.

4 A prong of a tuning fork, which can be assumed to be moving with simple harmonic motion, has the following equation governing its motion:

$$y = 2.0 \sin (3.22 \times 10^3 t)$$ where y is in mm.

- (a) Find the maximum amplitude and the frequency of the tuning fork's motion.
- (b) Calculate the maximum acceleration of the prong on the tuning fork.
- (c) On graph paper, draw the variation of displacement against time for the first two cycles of the motion. Assume that the motion starts from the equilibrium position.
- (d) As the sound of a tuning fork dies away, the frequency of the note produced does not change.
  What conclusion can we draw about the period of this, and indeed any object, moving with SHM?

5 A sheet of metal is clamped in the horizontal plane and made to vibrate with SHM in the vertical plane with a frequency of 40 Hz.

When some sand grains are sprinkled on to the plate, it is noted that the sand grains can lose contact with the sheet of metal. This occurs when the acceleration of the SHM is ≥ 10 m s^{-2}. Calculate the maximum amplitude of the motion for which the sand will always be in contact with the metal sheet.

6 A vertical spring stretches 0.10 m when 1.2 kg mass is allowed to hang from the end of the spring.

(a) Calculate the spring constant, k, given by these figures.

(b) The mass is now pulled down a distance of 0.08 m below the equilibrium position and released from rest.

(i) State the amplitude of the motion.

(ii) Calculate the period **and** the frequency of the motion.

(iii) Find the maximum speed of the mass **and** the total energy of the oscillating system.

7 A block of mass 5.0 kg is suspended from a spring which has a force constant of 450 N m^{-1}.

A dart which has a mass of 0.060 kg is fired into the block from below with a speed of 120 m s^{-1}, along the vertical axis of the spring. The dart embeds in the block.

(a) Find the amplitude of the resulting simple harmonic motion of the spring/block system.

(b) What percentage of the original kinetic energy of the dart appears as energy in the oscillating system?

8. Explain what is meant by the terms 'damping' and 'critical damping' when applied to oscillating systems.

Tutorial 2.0

Waves

1. (a) State the relationship between the intensity and the amplitude of a wave.
   (b) The amplitude of a wave increases ninefold.
   What is the change in the intensity?

2. 'All waveforms can be described by the superposition of sine or cosine waves'.
   Explain what is meant by this statement using either a square wave or a sawtooth wave as an example.

3. (a) The relationship $y = a \sin 2\pi(ft - x/\lambda)$ represents a travelling wave.
   State clearly the meaning of each symbol in this equation.
   (b) A travelling wave is represented by the relationship $y = 0.60 \sin\pi(150t - 0.40x)$ where standard SI units are used throughout.
      (i) What is the amplitude of the wave?
      (ii) Determine the frequency of the wave.
      (iii) State the period of the wave.
      (iv) Calculate the wavelength of the wave.
      (v) What is the wave speed?

4. Two waves are represented by the relationships:
   $y1 = 4.0 \sin 2\pi(8t - 5x)$ and $y2 = 4.0 \sin\pi(16t - 21x)$ respectively.

   (a) Which of the following quantities are the same for the two waves:
   amplitude, frequency, wavelength, period.
   (b) Are the two waves in phase? You must justify your answer.

5. (a) Explain what is meant by a 'stationary wave'.
   (b) Define the terms 'nodes' and 'antinodes'.

Tutorial 2.1

Waves

1 A travelling wave is represented by the equation $y = 3 \sin 2\pi(10t - 0.2x)$ where y is in cm. Calculate, for this wave:

(a) the amplitude;
(b) the frequency;
(c) the wavelength;
(d) the speed.

2 Write the equation for a plane sinusoidal wave travelling in the + x direction which has the following characteristics:
amplitude = 0.30 m, wavelength = 0.50 m and frequency = 20 Hz.

3 A travelling wave is represented by the following equation:

$$y_1 = 0.20 \sin (220\pi t - 30\pi x) \qquad \text{(i)}$$

where y_1 and x are measured in m from the origin.
Write the equation for the displacement, y_2, of a wave travelling in the opposite direction which has twice the frequency and double the amplitude of the wave represented by equation (i) above.

4 The equation of a transverse wave on a stretched string is represented by:

$$y = 0.04 \sin[2\pi(\frac{t}{0.04} - \frac{x}{2.0})]$$ where y and x in metres and t in seconds.

(a) What is the amplitude of the wave?
(b) Calculate the wavelength of the wave.
(c) What is the frequency of the wave?
(d) Describe the movement of any particle of the string over one complete period, T, of the wave.

5 The equation of a transverse wave travelling in a rope is given by:

$$y = 0.01 \sin \pi (2.0\,t - 0.01\,x)$$ where y and x in metres and t in seconds.

(a) Calculate the velocity of the wave in the x-direction.
(b) Find the maximum **transverse** speed of a particle in the rope.

6 The following equation represents a wave travelling in the positive x-direction

$$y = a \sin 2\pi (ft - \frac{x}{\lambda})$$

Using the relationships $f = 1/T$, $v = f\lambda$, and $k = 2\pi/\lambda$, show that the following are also possible equations for this wave.

(a) $y = a \sin 2\pi(\frac{t}{T} - \frac{x}{\lambda})$ (b) $y = a \sin (\omega t - kx)$

(c) $y = a \sin 2\pi f (t - \frac{x}{v})$ (d) $y = a \sin \frac{2\pi}{\lambda} (vt - x)$

7 A wave of frequency 500 Hz has a velocity of 350 m s^{-1}.

(a) How far apart are two points which are 60° i.e. $\frac{\pi}{3}$ out of phase?
(b) What is the phase difference between two displacements at the same point, at a time separation of 0.001 s?

8 A progressive wave and a stationary wave each have the same frequency of 250 Hz and the same velocity of 30 m s^{-1}.

(a) Calculate the phase difference between two vibrating points on the progressive wave which are 10 cm apart.

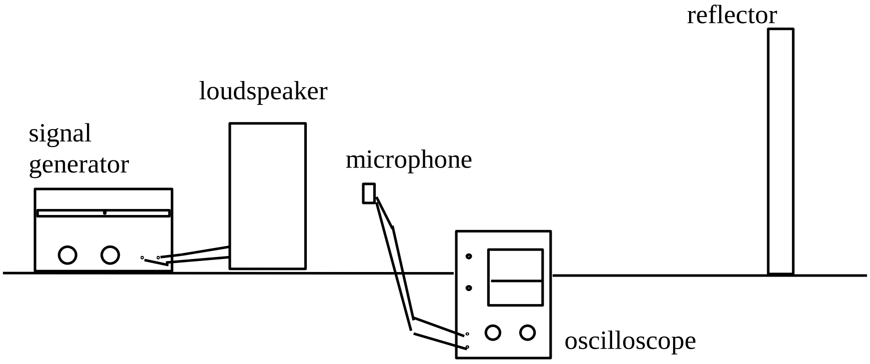
(b) State the equation for the travelling wave if its amplitude is 0.03 m.

(c) Calculate the distance between the nodes of the stationary wave.

9 (a) Explain what is meant by a 'travelling wave' and a 'stationary wave'. State clearly the differences between the two.

(b) Describe a method involving the formation of standing waves which you could use to measure the wavelength of microwaves. In your answer you should include:
- a sketch of any apparatus you would use;
- details of measurements taken;
- details of how you would arrive at a final answer.

10 (a) The sketch below shows an experimental arrangement to measure the wavelength of sound waves coming from a loudspeaker.



The oscilloscope trace shows the level of sound picked up by the microphone which is moved between the loudspeaker and the reflector.
In one particular trial it was noted that the microphone travelled a distance of 0.24 m between adjacent maxima. The signal generator was set at
700 Hz.
Calculate:
(i) the wavelength and
(ii) the velocity of the sound wave emitted from the loudspeaker.

(b) Another loudspeaker is connected in parallel with the first and the two sound waves allowed to overlap. The two speakers are facing in the same direction and the reflector is removed.

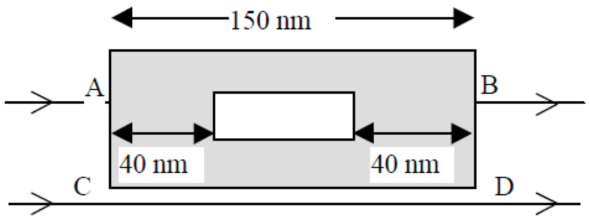
Describe and explain what a listener would hear as he walks across in front of the two speakers.

Tutorial 3.0

Interference – division of amplitude

1. (a) State the condition for two light beams to be coherent.
   (b) Explain why two light beams, of the same frequency, but from different sources are unlikely to be coherent.
   (c) Can two loudspeakers connected to the same signal generator emit coherent beams of sound waves? Explain your answer.

2. (a) Define the term optical path difference.
   (b) State the relationship between the optical path difference and phase difference.
   (c) A hollow air filled perspex microfibre is shown below. Light of wavelength 700 nm passes through and around the microfibre.



   (i) Determine the optical path length between AB.
   (ii) A ray of light follows the path AB above. Another ray follows the path CD, just outside the block.
   What is the phase difference between the two rays?

3. (a) Light in air is reflected from a glass surface. What is the change in phase of the light waves?
   (b) What change in phase occurs when light in glass is reflected at a glass/water boundary back into the glass.

4. A thin parallel sided film is used to produce interference fringes.
   (a) Using the thin film as an example, explain the term 'interference produced by division of amplitude'. Include a sketch of the path of the light rays through the film
   (b) (i) State the condition for a minimum to be produced in the fringes formed by reflection from the film of monochromatic light of wavelength λ.
   (ii) What is the effect on the fringe pattern when the thickness of the film increases?

5. (a) Derive the expression for the distance between the fringes which are formed by reflection of light from a thin wedge.
   (b) Two glass slides are 100 mm long. A wedge is formed with the slides by placing the slides in contact at one end. The other ends of the slide are separated by a piece of paper 30 μm thick. Interference fringes are observed using light of wavelength 650 nm. Calculate the separation of the fringes.
   (c) When looking at a slightly different part of the fringe pattern the fringes are observed to be slightly closer together. What does this imply about the paper.
   You must justify your answer.

6. (a) Derive the expression $d = \lambda/4n$ for the thickness of a non-reflecting coating.
   (b) What thickness of coating is required to give non-reflection in green light of wavelength 540 nm for a lens of refractive index 1.53.
   (c) Explain why some lenses with a non-reflective coating appear coloured.

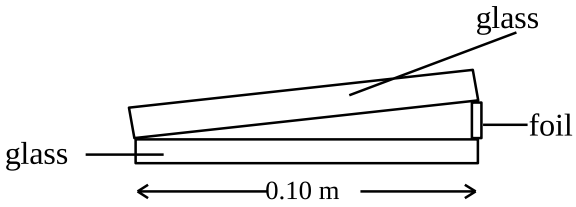
Tutorial 3.1

Interference – division of amplitude

1 To observe interference effects with light waves the sources must be coherent.
(a) Explain carefully what is meant by coherent waves.
(b) Explain why the conditions for coherence are usually more difficult to satisfy for light than for sound or microwaves.

2 (a) Explain what is meant by division of amplitude.
(b) Explain why an extended source can be used in experiments which involve division of amplitude.

3 An air wedge 0.10 m long is formed by two glass plates in contact at one end and separated by a thin piece of foil at the other end as shown below.



Interference fringes are observed in reflected light of wavelength 6.9×10^{-7} m. The average fringe separation is 1.2×10^{-3} m.
(a) Explain how the fringes are formed.
(b) Calculate the thickness of the foil.
(c) The foil is now heated and its thickness increases by 10%.
Calculate the new separation of the fringes.

4 (a) Derive the expression for the thickness of a non-reflecting coating on a lens. Your answer should be in terms of the incident wavelength and the refractive index of the coating.
(b) Calculate the thickness of the coating required to produce destructive interference at a wavelength of 4.80×10^{-7} m, given that the refractive index of the coating is 1.25.

5 A lens is coated with a thin transparent film to reduce reflection of red light of wavelength 6.7×10^{-7} m. The film has a refractive index of 1.30.
Calculate the required thickness of the film.

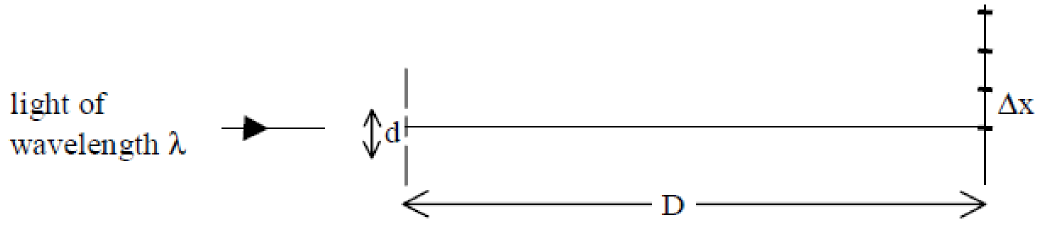
6 A soap film of refractive index 1.3 is illuminated by light of wavelength 6.2×10^{-7} m. The light is incident normally on the soap film.
Calculate the minimum thickness of soap film which gives no reflection.

Tutorial 4.0

Interference – division of wavefront

1. (a) An interference pattern is obtained by division of wavefront. What is meant by 'division of wavefront'.
   (b) Why must the source be a point source to produce interference by division of wavefront?
   (c) Explain why an extended source can be used to produce an interference pattern by division of amplitude.

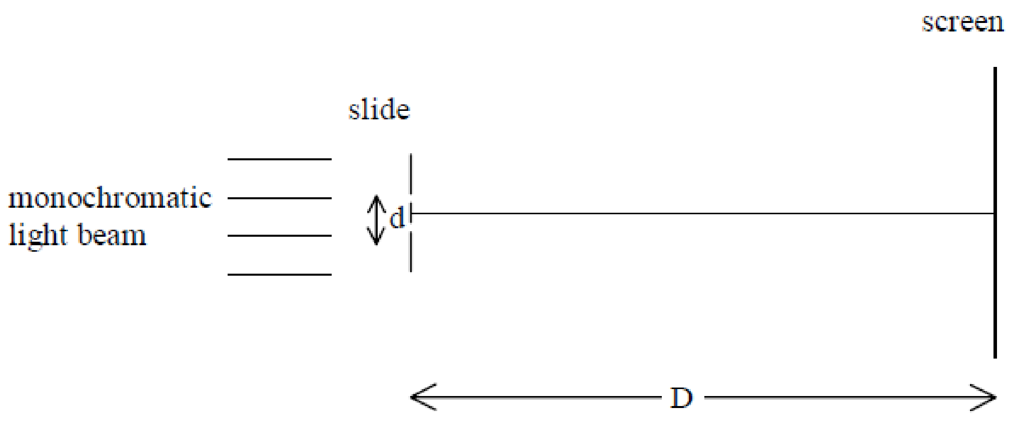
2. The diagram below shows the set up for a Young's double slit experiment.



   (a) Derive the expression $\Delta x = \dfrac{\lambda D}{d}$ for the fringe spacing.
   (b) State any assumptions made in the above derivation.

3. Two parallel slits have a separation of (0.24 ± 0.01) mm. When illuminated by light an interference pattern is observed on a screen placed (3.8 ± 0.1) m from the double slits. The fringe separation is observed to be (9.5 ± 0.1) mm.
   (a) Calculate the wavelength of the light used.
   (b) Determine the uncertainty in this wavelength.

4. Two slits, of separation d, are made on a slide. The slide is illuminated by monochromatic light as shown below.



   Fringes are observed on the screen.

   (a) The fringe spacing is observed to be too small to make accurate measurements.
   State one way of increasing the fringe spacing using this apparatus.
   (b) The light beam is replaced by one of light of a higher wavelength.
   What effect will this have on the fringe spacing?
   (c) The slide is removed and replaced with another slide. The second slide has two slits with a smaller separation, d.
   What effect does this have on the fringe pattern?
   (d) What can be used to measure the slit separation?
   (e) Describe how the fringe separation could be measured.

Tutorial 4.1

Interference – division of wavefront

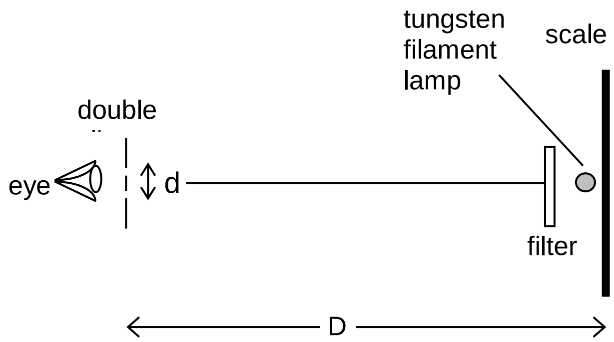
1 There are two methods of producing interference with light, namely;
division of amplitude and division of wavefront.
Give an example of each of the above and explain, with the aid of diagrams, the difference between the two methods.

2 White light illuminates two narrow closely spaced slits. An interference pattern is seen on a distant screen.
(a) Explain how the interference pattern occurs.
(b) The white fringes have coloured edges. Explain how this occurs.

3 A laser beam is directed towards a double slit and an interference pattern is produced on a screen which is 0.92 m from the double slit. The separation of the double slit is 2.0×10^{-4} m. The wavelength of the light used is 695 nm.
(a) Calculate the separation of the bright fringes on the screen.
(b) The double slit is now replaced with a different double slit of separation 1.0×10^{-4} m. State and explain what effect this change will have on the interference pattern.

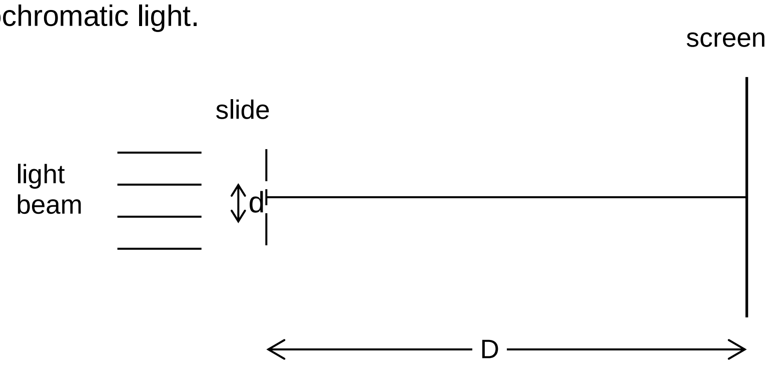
4 Two parallel slits have a separation of 5.0×10^{-4} m. When illuminated by light of unknown wavelength an interference pattern is observed on a screen placed 7.2 m from the double slit. The separation of the bright fringes on the screen is 8 mm.
Calculate the wavelength of the light used.

5 A pupil holds a double slit in front of his eye and looks at a tungsten lamp with a scale immediately behind it.



(a) A red filter is placed in front of the lamp. Describe what he sees and explain in terms of waves how this arises.
(b) The red filter is then replaced by a blue one. Explain any difference in fringe separation with blue and with red.
(c) Explain why the fringes have coloured edges when no filter is used.
(d) With the red filter in place, the student estimates the apparent separation of the bright fringes to be 5.0 mm when the distance D is 2.0 m. The slit separation is 0.25 mm. Calculate the wavelength of the light passing through the filter from these measurements.

6 In a Young's slit experiment designed to demonstrate the interference of light, two parallel slits scratched on a blackened microscope slide are illuminated by an intense beam of monochromatic light.



Bright fringes with an average separation Δx are observed on a distant screen.

(a) State the effect of

(i) bringing the screen closer to the slits

(ii) reducing the separation of the slits.

(b) Explain the effect on the Young's interference pattern of

(i) covering one of the slits

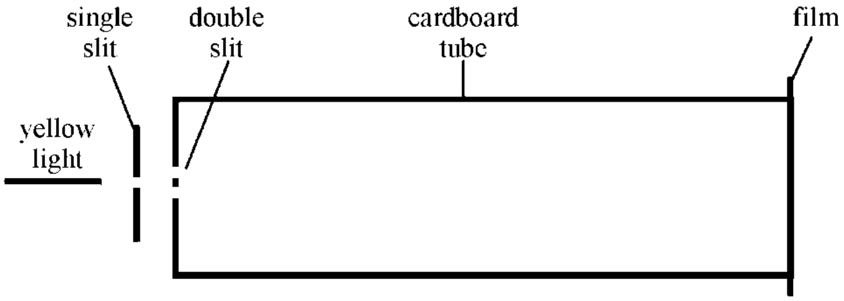
(ii) using light of a longer wavelength

(iii) using white light.

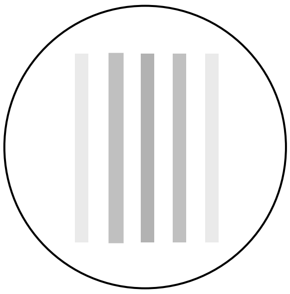
(c) Two parallel slits 0.5 mm apart are found to produce fringes with an average separation of 10 mm on a screen placed at a distance of 8 m from the double slit. What do these figures give for the wavelength of the incident light?

(d) In the practical determination of this wavelength three distances have to be measured. By considering each measurement in turn, explain which one would be the most critical in obtaining a reasonably accurate result.

7 A beam of yellow light from a single slit falls on a double slit, which is mounted on the end of a cardboard tube as shown below.



The interference pattern formed is recorded on a piece of photographic film placed over the end of the tube. When the film is developed a series of black lines can be seen. One such film is shown below.



(a) In one experiment a student obtains the following results:

distance between dark lines	= 7 $\pm$ 1 mm
separation of double slit	= 0.20 $\pm$ 0.01 mm
distance from double slit to film	= 2.40 $\pm$ 0.01 m

From these measurements, calculate:

(i) the wavelength of yellow light;

(ii) the uncertainty in this value.

(b) (i) Describe one method of measuring the double slit separation to the stated degree of accuracy.

(ii) Give one way in which the uncertainty in the measurement of the separation of the black lines on the film could be reduced.

(c) In each case, state and explain the effect on the film pattern, when:

(i) the double slits are closer together;

(ii) blue light is used instead of yellow light;

(iii) one of the slits is covered.

Tutorial 5.0

Polarisation

1. (a) Explain the difference between linearly polarised and unpolarised waves.
   (b) Describe how an unpolarised wave can be linearly polarised using a polaroid filter.
   (c) Describe how a ‘polariser’ and ‘analyser’ can prevent the transmission of light.

2. Monochromatic light is incident at a boundary between air and another medium.
   The reflected light is found to be polarised.
   (a) What information does this provide about the nature of the medium?
   (b) Derive the expression relating the polarising angle and the refractive index of the medium for this light.
   (c) State the other common name for the polarising angle.

3. Light is incident on a rectangular block of perspex
   (a) Draw a sketch to show the position of the polarising angle for perspex.
   (b) Mark on your sketch for part (a) the value of the polarising angle.

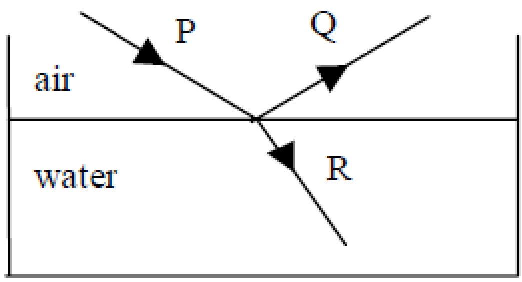
4. Explain how sunglasses can remove glare.

5. The refractive index of a liquid is 1.45.
   (a) Calculate the polarising angle for this liquid.
   (b) Determine the value of the angle of refraction for this polarising angle.

6. The critical angle in a certain glass is 40.5°.
   What is the polarising angle for this glass?

7. A spectrum can be produced by a prism because the refractive index changes with the frequency of light.
   What effect will an increase in the frequency of light have on the polarising angle?
   You must justify your answer.

8. Light is incident on a water surface as shown below.



   The angle between the ray Q and R is 90°.

   (a) The ray Q is observed through a sheet of polaroid. The polaroid is rotated.
   Describe and explain what is observed.
   (b) Calculate the polarising angle for water.
   (c) Copy the diagram and label in the correct places the values of the angle of incidence and angle of refraction.

Tutorial 5.1

Polarisation

1 Light is reflected from a smooth glass surface at an angle which produces plane polarised light. The refractive index of the glass is 1.52.

(a) Calculate the angles of incidence and refraction.

(b) Describe how you would prove that the reflected light was plane polarised.

2 A student investigates the glare from a smooth water surface using a polaroid filter as an analyser. She finds that the angle of incidence required to produce plane polarised light is 52°.

(a) State the angle of refraction.

(b) Calculate the refractive index of water given by these figures.

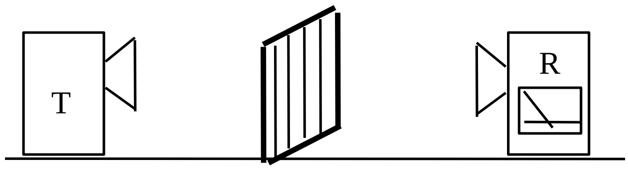
3 A beam of white light is reflected from the flat surface of a sample of crown glass. The information below gives the variation of refractive index with wavelength for crown glass.

refractive index	wavelength / nm
1.52	650 - red
1.53	510 - green
1.54	400 - violet

(a) Calculate the range of polarising angle for incident white light.

(b) Calculate the maximum angle of refraction.

4 A student sets up the following microwave apparatus.



The transmitter, T, sends out microwaves of wavelength 0.028 m.

As the metal grid is rotated through 360°, the reading on the receiver, R, becomes a maximum and then a minimum and then a maximum again.

(a) Calculate the frequency of the microwaves.

(b) Explain fully the behaviour of the reading on the receiver as the metal grid is rotated.

(c) Another student sets up a small portable television in front of the window in his new flat. He finds that unless he raises the metal venetian blind at the window the reception on the television is very poor.
Explain why the reception is so poor in this situation.

5. Monochromatic light is travelling into a medium and is reflected at the boundary with air. The critical angle for this light in the medium is 38°.
Calculate the polarising angle?

6 (a) What is meant by the polarising angle i_p?

(b) State another name for this angle i_p

(c) Derive the relationship between the polarising angle and the refractive index.

(d) A beam of white light is incident on a flat glass surface at an angle of 56°. The reflected beam is plane polarised.

(i) Calculate the angle of refraction in the glass

(ii) Calculate the refractive index of the glass.

7 (a) Sunlight is reflected off the smooth water surface of an unoccupied swimming pool. The refractive index of water is 1.33.

(i) At what angle of reflection is the sunlight completely plane polarised?

(ii) What is the corresponding angle of refraction for the sunlight that is refracted into the water.

(b) At night an underwater floodlight is turned on the pool.

(i) At what angle of reflection is the floodlight completely plane polarised?

(ii) What is the corresponding angle of refraction for the light that is refracted into the air?