St Ninian's High School

Advanced Higher Physics

Unit 2 Homework

Waves

Schrödinger's Cat

MEEEEEOW

SHE'S HUNGRY
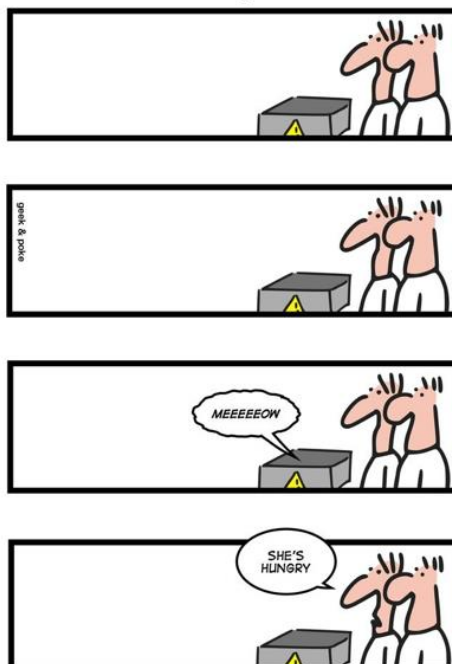
DATA SHEET
COMMON PHYSICAL QUANTITIES

Quantity	Symbol	Value	Quantity	Symbol	Value
Gravitational acceleration on Earth	g	$9.8\,\text{m s}^{-2}$	Mass of electron	m_e	$9.11 \times 10^{-31}\,\text{kg}$
Radius of Earth	R_E	$6.4 \times 10^6\,\text{m}$	Charge on electron	e	$-1.60 \times 10^{-19}\,\text{C}$
Mass of Earth	M_E	$6.0 \times 10^{24}\,\text{kg}$	Mass of neutron	m_n	$1.675 \times 10^{-27}\,\text{kg}$
Mass of Moon	M_M	$7.3 \times 10^{22}\,\text{kg}$	Mass of proton	m_p	$1.673 \times 10^{-27}\,\text{kg}$
Radius of Moon	R_M	$1.7 \times 10^6\,\text{m}$	Mass of alpha particle	m_α	$6.645 \times 10^{-27}\,\text{kg}$
Mean Radius of Moon Orbit		$3.84 \times 10^8\,\text{m}$	Charge on alpha particle		$3.20 \times 10^{-19}\,\text{C}$
Solar radius		$6.955 \times 10^8\,\text{m}$	Planck's constant	h	$6.63 \times 10^{-34}\,\text{J s}$
Mass of Sun		$2.0 \times 10^{30}\,\text{kg}$	Permittivity of free space	ε_0	$8.85 \times 10^{-12}\,\text{F m}^{-1}$
1 AU		$1.5 \times 10^{11}\,\text{m}$	Permeability of free space	μ_0	$4\pi \times 10^{-7}\,\text{H m}^{-1}$
Stefan-Boltzmann constant	σ	$5.67 \times 10^{-8}\,\text{W m}^{-2}\,\text{K}^{-4}$	Speed of light in vacuum	c	$3.0 \times 10^8\,\text{m s}^{-1}$
Universal constant of gravitation	G	$6.67 \times 10^{-11}\,\text{m}^3\,\text{kg}^{-1}\,\text{s}^{-2}$	Speed of sound in air	v	$3.4 \times 10^2\,\text{m s}^{-1}$

REFRACTIVE INDICES
The refractive indices refer to sodium light of wavelength 589 nm and to substances at a temperature of 273 K.

Substance	Refractive index	Substance	Refractive index
Diamond	2·42	Glycerol	1·47
Glass	1·51	Water	1·33
Ice	1·31	Air	1·00
Perspex	1·49	Magnesium Fluoride	1·38

SPECTRAL LINES

Element	Wavelength/nm	Colour	Element	Wavelength/nm	Colour
Hydrogen	656	Red	Cadmium	644	Red
	486	Blue-green		509	Green
	434	Blue-violet		480	Blue
	410	Violet			
	397	Ultraviolet		Lasers	
	389	Ultraviolet	Element	Wavelength/nm	Colour
			Carbon dioxide	9550 } 10590 }	Infrared
Sodium	589	Yellow	Helium-neon	633	Red

PROPERTIES OF SELECTED MATERIALS

Substance	Density/ kg m^{-3}	Melting Point/ K	Boiling Point/K	Specific Heat Capacity/ $\text{J kg}^{-1}\,\text{K}^{-1}$	Specific Latent Heat of Fusion/ J kg^{-1}	Specific Latent Heat of Vaporisation/ J kg^{-1}
Aluminium	2.70×10^3	933	2623	9.02×10^2	3.95×10^5	. . . .
Copper	8.96×10^3	1357	2853	3.86×10^2	2.05×10^5	. . . .
Glass	2.60×10^3	1400	. . . .	6.70×10^2	. . . .	. . . .
Ice	9.20×10^2	273	. . . .	2.10×10^3	3.34×10^5	. . . .
Glycerol	1.26×10^3	291	563	2.43×10^3	1.81×10^5	8.30×10^5
Methanol	7.91×10^2	175	338	2.52×10^3	9.9×10^4	1.12×10^6
Sea Water	1.02×10^3	264	377	3.93×10^3	. . . .	. . . .
Water	1.00×10^3	273	373	4.19×10^3	3.34×10^5	2.26×10^6
Air	1·29	. . . .	. . . .	. . . .	. . . .	. . . .
Hydrogen	9.0×10^{-2}	14	20	1.43×10^4	. . . .	4.50×10^5
Nitrogen	1·25	63	77	1.04×10^3	. . . .	2.00×10^5
Oxygen	1·43	55	90	9.18×10^2	. . . .	2.40×10^4

The gas densities refer to a temperature of 273 K and a pressure of 1.01×10^5 Pa.

2.3 Simple-Harmonic-Motion

1.

(a) A mass is suspended from a spring and is at rest.

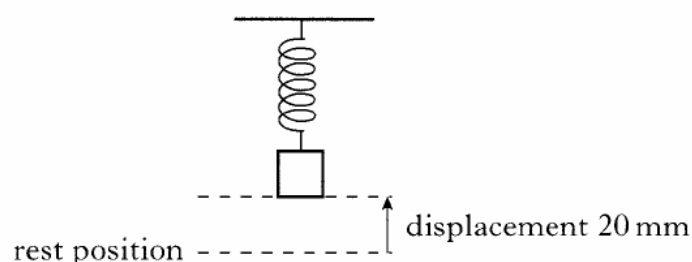The mass is displaced 20 mm from its rest position, as shown in Figure 7.

Figure 7

The mass is released.

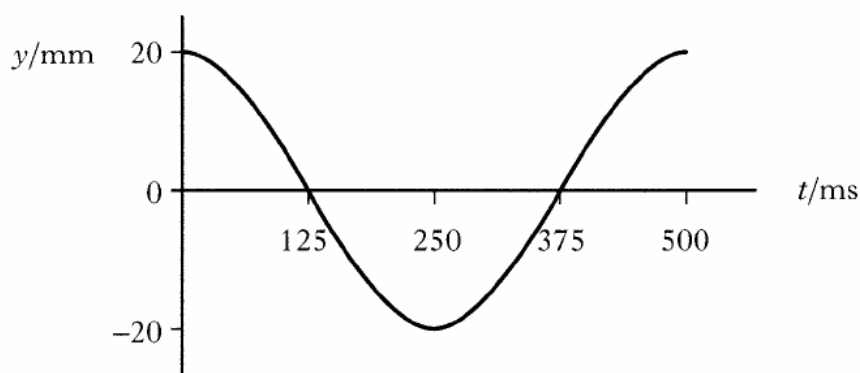A graph of the displacement y of the mass against time t is shown in Figure 8.

Figure 8

(i) Show, by calculation, that

$$\frac{d^2 y}{dt^2} = -158y.$$

3

(ii) Sketch a graph of the velocity of the mass against time for the first period of the oscillation. Numerical values are required on both axes.

4

(b) An object has a periodic motion and oscillates between A and B as shown in Figure 9.

object

A   X   Y   B
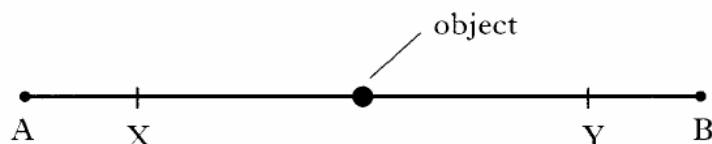
Figure 9

Between points X and Y the object moves with constant speed. Explain **fully** why the motion of the object cannot be described as simple harmonic.

2

(9)

2.

A mass of 0·50 kg is suspended from a spring of negligible mass, as shown in Figure 5(*a*).
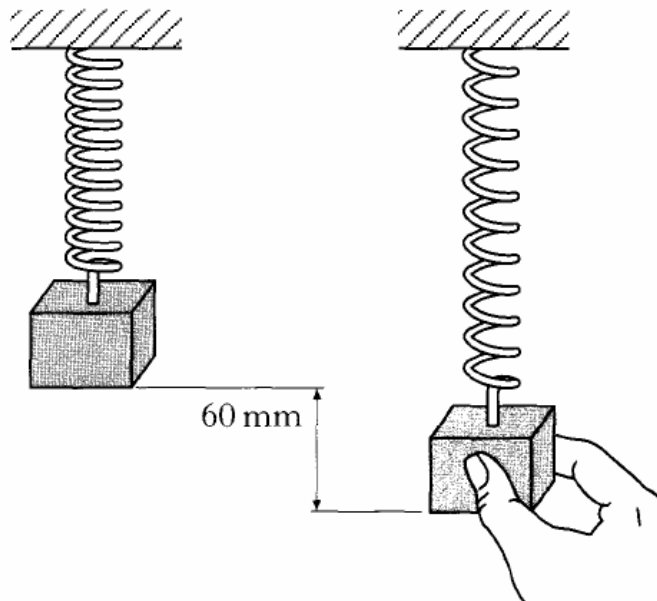
Figure 5(*a*)   Figure 5(*b*)

A student pulls the mass down a distance of 60 mm and holds it in the position shown in Figure 5(*b*).

The tension in the spring is now 7·0 N.

(*a*) By considering the vertical forces acting on the mass, calculate the force applied by the student to hold the mass in this position.   2

(*b*) The student releases the mass, which performs simple harmonic motion.

    (i) State the relationship between the unbalanced force acting on the mass and the displacement of the mass.   1

    (ii) Calculate the acceleration of the mass immediately after its release.   3

    (iii) State the initial amplitude of the oscillations.   1

(*c*) The oscillations of the mass are described by the equation

$$\frac{d^2 y}{dt^2} = -\omega^2 y.$$

    (i) Name the physical quantity represented by the term $\frac{d^2 y}{dt^2}$.   1

    (ii) Calculate the frequency of the oscillations.   3

                                                      (11)

3.

A mass of 0·40 kg is suspended from a spring as shown in Figure 2. The mass is then displaced vertically and released. Its subsequent motion is recorded using a motion sensor linked to a computer.
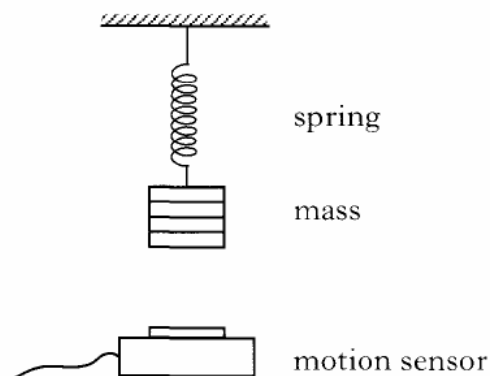

spring

mass

motion sensor

Figure 2

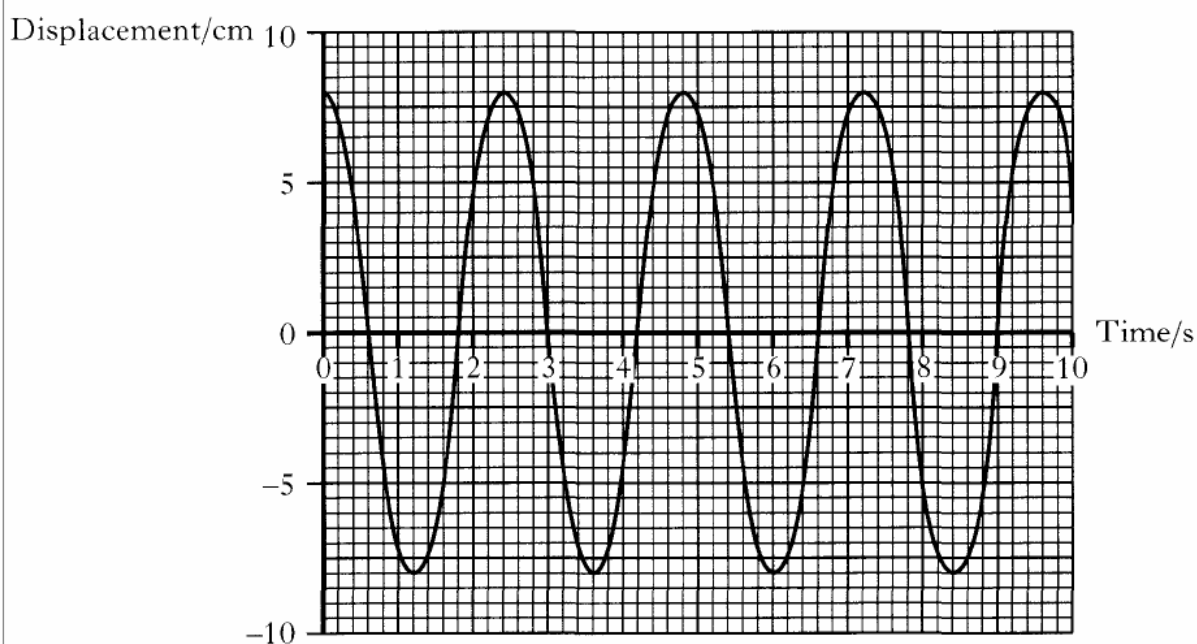The mass moves with simple harmonic motion. The displacement-time graph of the mass is shown in Figure 3.

Figure 3

(a) Find:

    (i) the amplitude of the oscillation;

    (ii) the period of the oscillation.   2

(b) Using the values from part (a), obtain an expression, in the form $y = A \cos \omega t$, for the vertical displacement y of the mass.   3

(c) (i) Using the solution to part (b), derive an expression which gives the relationship between the acceleration a of the mass and time t.   3

    (ii) Calculate the maximum kinetic energy of the mass.   4

                                                                   (12)

4.

The flexible paper cone of a loudspeaker vibrates, producing a sound. The loudspeaker has a small cap at the centre of the cone as shown in Figure 5.
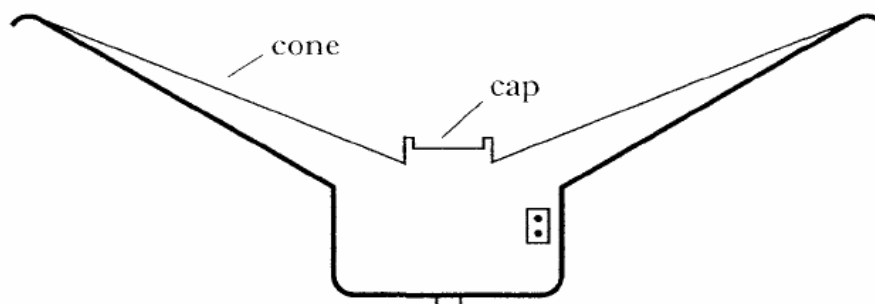
Figure 5

The cone and cap vibrate with simple harmonic motion when the loudspeaker is connected to a signal generator.

(a) State what is meant by *simple harmonic motion*. **1**

(b) At a particular frequency, the velocity of the cap, in $m\,s^{-1}$, is given by the expression

$$v = 0{\cdot}50 \cos 625t.$$

   (i) Calculate the frequency of the sound emitted by the loudspeaker. **3**

   (ii) Calculate the amplitude of vibration of the loudspeaker cap. **2**

(c) A small polystyrene sphere is placed on the cap of the loudspeaker as shown in Figure 6.
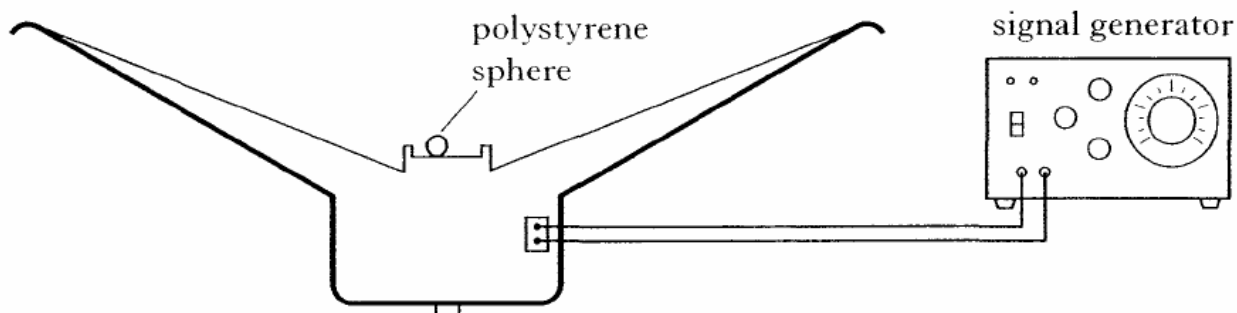
Figure 6

The frequency of the signal generator is slowly increased from zero. At low frequencies the polystyrene sphere stays in contact with the cap. At one particular frequency the sphere just loses contact with the cap. State the maximum acceleration of the cap when this occurs. Justify your answer. **2**

(8)

5.

A test tube contains lead shot. The combined mass of the test tube and the lead shot is $0.250\,\text{kg}$.

The test tube is gently dropped into a container of water and oscillates above and below its equilibrium position with simple harmonic motion as shown in Figure 7.
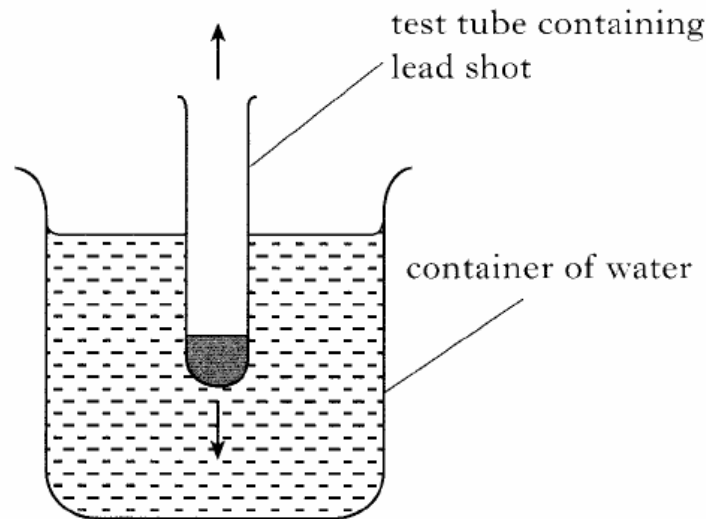

Figure 7

The displacement y of the test tube from its equilibrium position is described by the equation

$$y = 0.05 \cos 6t$$

where y is in metres and t is in seconds.

(a) Show that the kinetic energy of the test tube, in joules, is given by the equation

$$E_k = 4.5\,(2.5 \times 10^{-3} - y^2).$$

2

(b) Calculate the maximum value of the kinetic energy of the test tube.

1

(c) Calculate the potential energy of the test tube when it is $40\,\text{mm}$ above its equilibrium position.

3

(6)

6.

A motorised mixer in a DIY store is used to mix different coloured paints.

Paints are placed in a tin and the tin is clamped to the base as shown in Figure 8A.

Figure 8A

The oscillation of the tin in the vertical plane closely approximates to simple harmonic motion.

(a) State what is meant by *simple harmonic motion*.   1

6.

(continued)

(b) The amplitude of the oscillation is 0·012 m.
The mass of the tin of paint is 1·4 kg.

Figure 8B shows the graph of the acceleration against displacement for the tin of paint.

Acceleration/ms^2
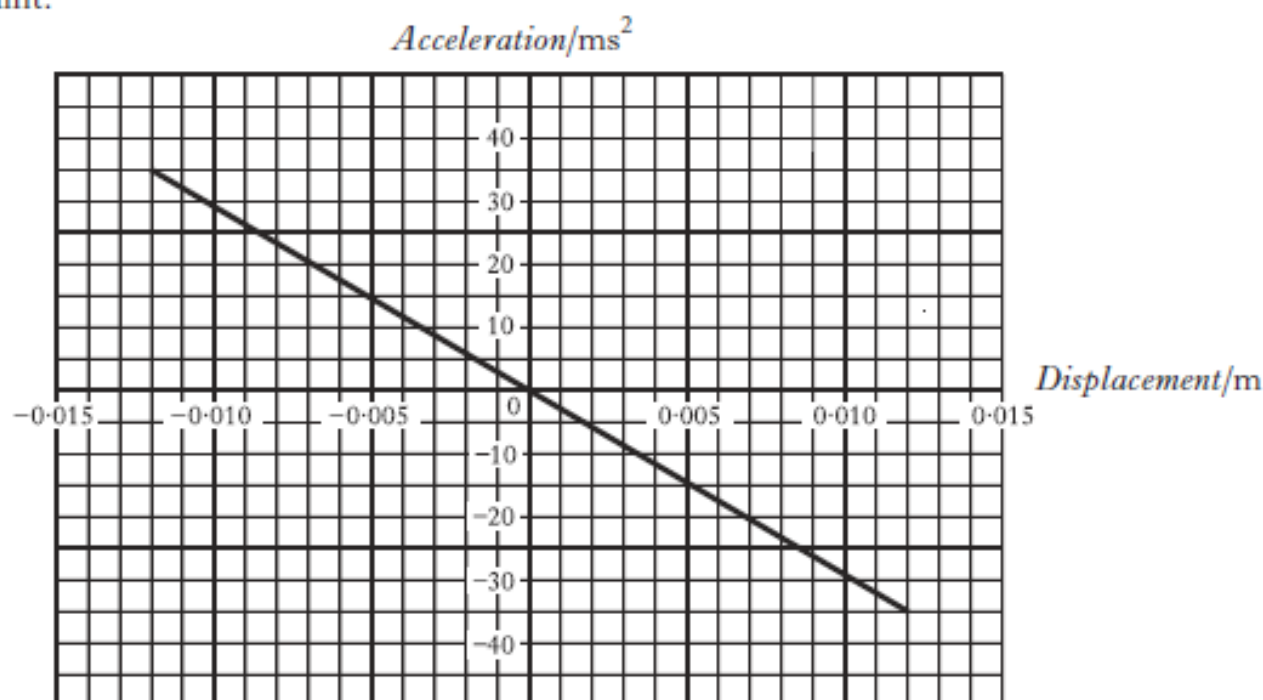
Displacement/m

Figure 8B

(i) Show that the angular frequency ω of the oscillation is 54 rad s^{-1}.   2

(ii) Write an expression for the displacement y of the tin as a function of time. Include appropriate numerical values.   2

(iii) Derive an expression for the velocity v of the tin as a function of time. Numerical values should again be included.   3

(iv) Calculate the maximum kinetic energy of the tin as it oscillates.   3

(v) Sketch a graph of the potential energy of the oscillating tin against displacement from the tin's central position.

Maximum and minimum numerical values are required on both axes.   3

(14)

7.

(a) (i) State what is meant by *simple harmonic motion*.   **1**

(ii) The displacement of an oscillating mass can be described by the expression

$$y = A\sin\omega t$$

where the symbols have their usual meanings.

Show that this mass exhibits simple harmonic motion (SHM).   **3**

(iii) The displacement of an object exhibiting SHM can also be written as

$$y = A\cos\omega t$$

Identify the initial condition for which this equation would be used.   **1**

(b) A mass attached to a spring is displaced from its equilibrium position and allowed to oscillate vertically. A motion sensor, connected to a computer, is placed below the mass as shown in Figure 6A.

motion sensor
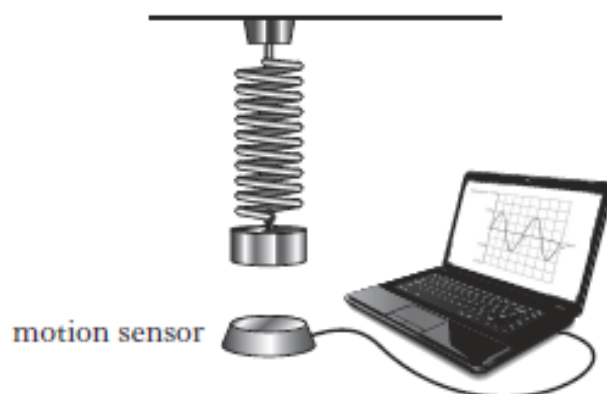
Figure 6A

Figure 6B shows the graph of the displacement from equilibrium position against time for the mass.
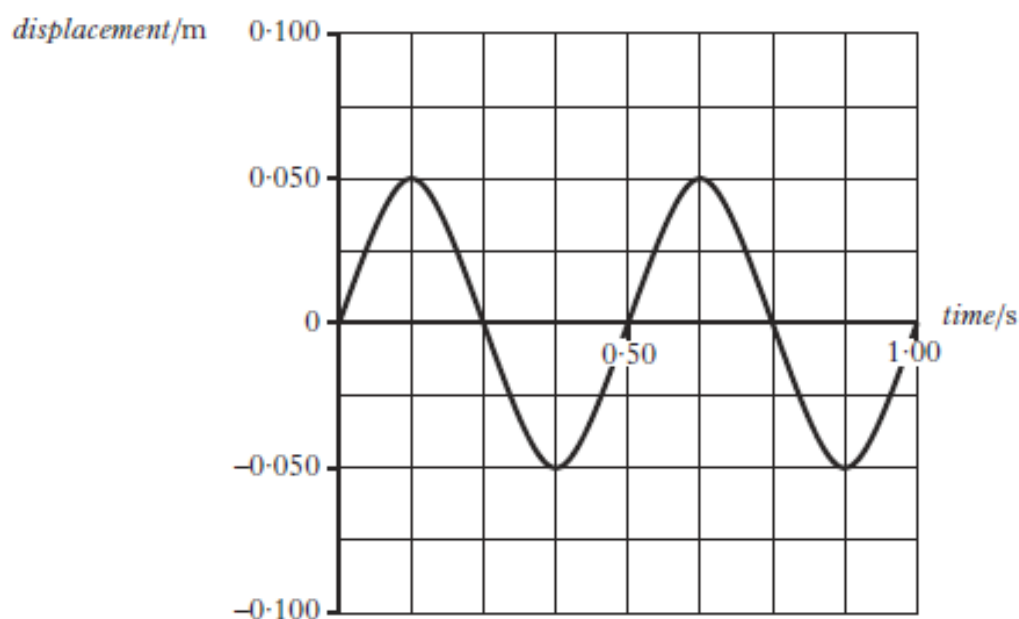
Figure 6B

7.

(b) (continued)

    (i) Using data from the graph, determine the velocity of the mass at 0·50 s.   4

    (ii) Calculate the maximum acceleration of the mass.   3

  (c) The system is modified by attaching a rigid card of negligible mass as shown in Figure 6C.
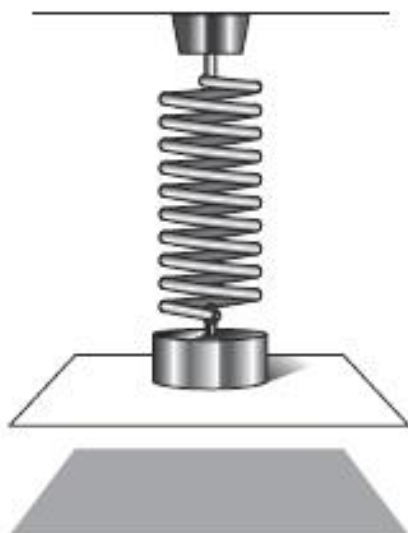

Figure 6C

The mass is displaced from its equilibrium position and allowed to oscillate vertically.

Sketch a displacement time graph of this motion.   1

        (13)

8.

A "saucer" swing consists of a bowl shaped seat of mass 1·2 kg suspended by four ropes of negligible mass as shown in Figure 7A.

Figure 7A

When the empty seat is pulled back slightly from its rest position and released its motion approximates to simple harmonic motion.

(a) Define the term *simple harmonic motion*. 1

(b) The acceleration-time graph for the seat with no energy loss is shown in Figure 7B.
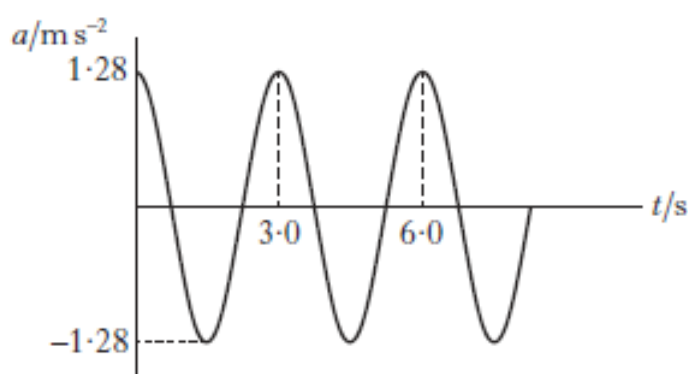
Figure 7B

   (i) Show that the amplitude of the motion is 0·29 m. 4

   (ii) Calculate the velocity of the seat when its displacement is 0·10 m. 3

(c) Calculate the displacement of the seat when the kinetic energy and potential energy are equal. 4

(12)

9.

Car engines use the ignition of fuel to release energy which moves the pistons up and down, causing the crankshaft to rotate.

The vertical motion of the piston approximates to simple harmonic motion.

Figure 8 shows different positions of a piston in a car engine.
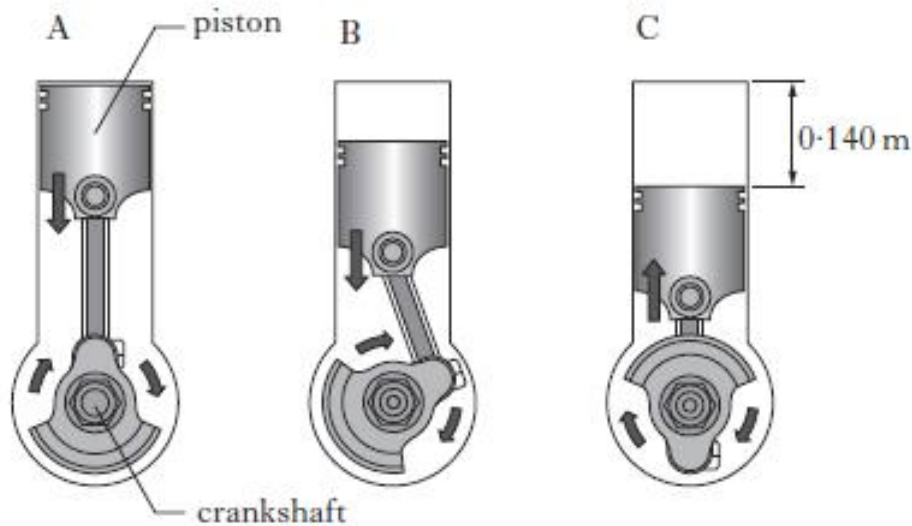
Figure 8

(a) Define *simple harmonic motion*. 1

(b) Determine the amplitude of the motion. 1

(c) In this engine the crankshaft rotates at 1500 revolutions per minute and the piston has a total mass of 1·40 kg.

    (i) Calculate the maximum acceleration of the piston. 4

    (ii) Calculate the maximum kinetic energy of the piston. 3

(9)

10.

(a) State what is meant by *simple harmonic motion*.   1

(b) The motion of a piston in a car engine closely approximates to simple harmonic motion.

In a typical engine, the top of a piston moves up and down between points A and B, a distance of 0·10 m, as shown in Figure 4.
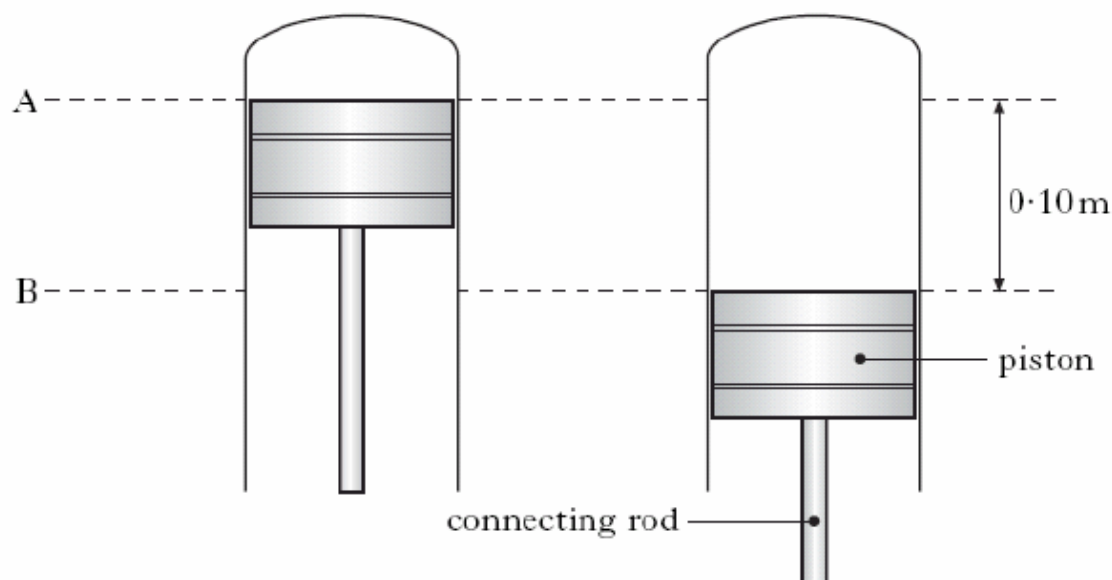

Figure 4

The frequency of the piston's motion is 100 Hz.

Write down an equation which describes how the displacement of the piston from its central position varies with time. Numerical values are required.   3

(c) Calculate the maximum acceleration of the piston.   3

(d) The mass of the piston is 0·48 kg.

Calculate the maximum force applied to the piston by the connecting rod.   3

(e) Calculate the maximum kinetic energy of the piston.   3

(13)

11.

A simple pendulum consists of a lead ball on the end of a long string as shown in Figure 5.

Figure 5

The ball moves with simple harmonic motion. At time t the displacement s of the ball is given by the expression

$$s = 2 \cdot 0 \times 10^{-2} \cos 4 \cdot 3t$$

where s is in metres and t in seconds.

(a) (i)   State the definition of *simple harmonic motion*.   1

    (ii) Calculate the period of the pendulum.   3

(b) Calculate the maximum speed of the ball.   3

(c) The mass of the ball is $5 \cdot 0 \times 10^{-2}$ kg and the string has negligible mass.

    Calculate the total energy of the pendulum.   3

(d) The period T of a pendulum is given by the expression

$$T = 2\pi\sqrt{\frac{L}{g}}$$

    where L is the length of the pendulum.

    Calculate the length of this pendulum.   3

(e) In the above case, the assumption has been made that the motion is not subject to *damping*.

    State what is meant by *damping*.   1

(14)

12.

A mass of 1·5 kg is suspended from a spring as shown in Figure 7.

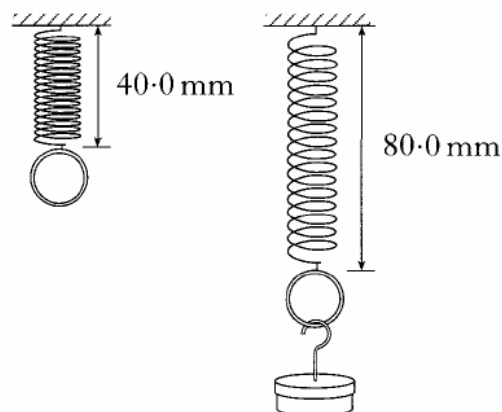

Figure 7

This extends the length of the spring from 40·0 mm to 80·0 mm. The mass is at rest.

(a) Calculate the force exerted by the spring on the mass.   2

(b) The mass is now pulled down, extending the spring a further 30·0 mm as shown in Figure 8.
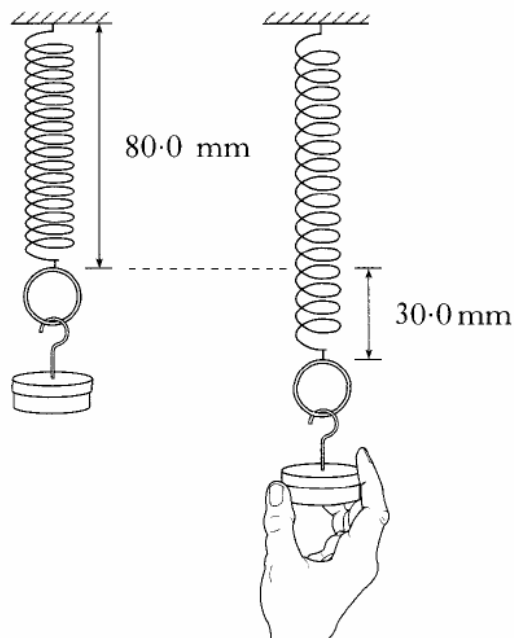

Figure 8

The mass is released and the subsequent motion is simple harmonic.

The force exerted by the spring is directly proportional to its extension.

(i) Calculate the unbalanced force acting on the mass just after its release.   3

(ii) Calculate the period of oscillation of the mass.   4

(9)

2.4 Waves

1.

(a) A travelling wave is represented by the expression

$$y = 2 \cdot 0 \times 10^{-4} \sin (1570t - 4 \cdot 6x)$$

where x and y are in metres and t is in seconds.

    (i) Calculate the frequency of the wave.   **2**

    (ii) A wave with the same frequency and four times the intensity travels in the opposite direction.

    Write down the equation which represents this wave.   **2**

                                           (4)

2.

A transverse wave travels along a string as shown in Figure 9A.
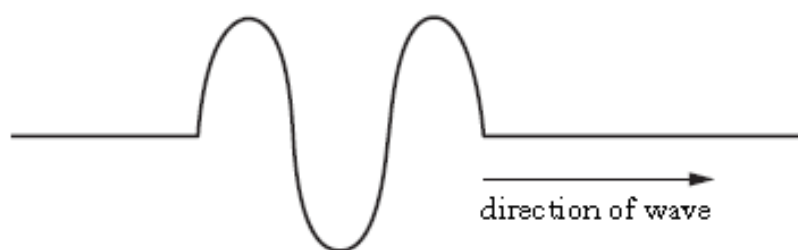
Figure 9A

The equation representing the travelling wave on the string is

$$y = 8 \cdot 6 \times 10^{-2} \sin 2\pi (2 \cdot 4t - 2 \cdot 0x)$$

where x and y are in metres and t is in seconds.

(a) State the frequency of the wave.   **1**

(b) Calculate the velocity of the wave.   **3**

(c) Attached to the end of the string is a very light ring. The ring is free to move up and down a fixed vertical rod.

Figure 9B shows the string after the wave reflects from the vertical rod.
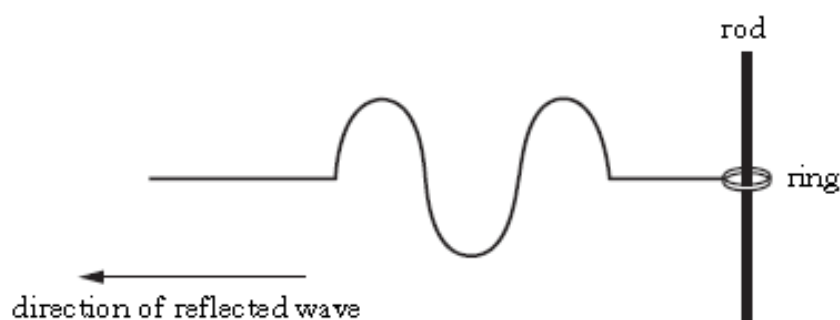
Figure 9B

When the wave reflects, its intensity falls to one quarter of its original value. The frequency and wavelength are constant.

Write the equation that represents this reflected wave.   **2**

(6)

3.

A water wave of frequency 2·5 Hz travels from left to right.

Figure 9 represents the displacement y of the water at one instant in time.

Figure 9

Points S and T are separated by a horizontal distance of 0·28 m.

The phase difference between these two points is 3·5 radians.

(a) Calculate the wavelength of this wave.   3

(b) A second wave with double the frequency travels in the same direction through the water. This wave transfers five times the energy of the wave in part (a).

Calculate:

  (i)   the speed of this wave;   3

  (ii)   the amplitude of this wave.   2

(8)

3

4.

A wave travelling along a horizontal string is represented by the equation

$$y = 25 \sin 2\pi(55t - \frac{x}{16})$$

where x and y are in millimetres and t in seconds.

(a) State the amplitude of the wave.   **1**

(b) Calculate the speed of the wave.   **4**

(c) Two points on the string are separated by a horizontal distance of 24 mm. Calculate the phase difference between these points.   **3**

(d) Another two points on the wave are described as being in phase.

State a possible value for the horizontal distance between these points.   **1**

    (9)

5.

A transverse wave is described by the expression

$$y = 8 \cdot 0 \sin (12t - 0 \cdot 50x)$$

where t is in seconds and x and y are in metres.

(a) For this wave, calculate the:
   (i) frequency;   **1**
   (ii) wavelength.   **1**

(b)   (i) Calculate the phase difference, in radians, between the point at $x = 3 \cdot 0$ m and the point at $x = 4 \cdot 0$ m.   **3**

   (ii) Calculate the time for the wave to travel between these two points.   **2**

(c) The wave is reflected and loses some energy.

State a possible equation for the reflected wave.   **2**

    (9)

6.

(a) A water wave travels with a speed of $0.060 \, \mathrm{m\,s^{-1}}$ in the positive x direction. Figure 14 represents the water wave at one instant in time.

y/m

0·05

0

0·01   0·02   0·03   0·04   0·05   x/m

−0·05
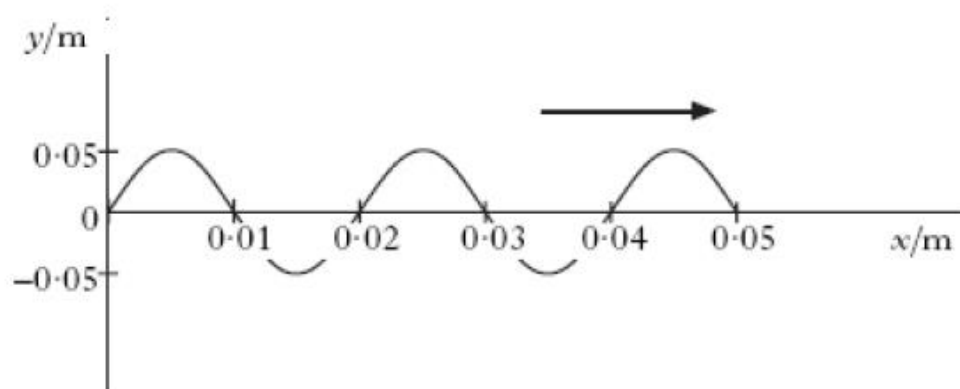
Figure 14

Write down an equation for the vertical displacement y of a point on the water surface in terms of the horizontal displacement x and time t.

Numerical values are required.　　　　　　　　　　　　　　　　　　　　　　2

(b) Write down an equation for an identical wave travelling in the opposite direction.　　　　　　　　　　　　　　　　　　　　　　　　　　　　　1

(c) The amplitude of the wave gradually decreases.

Calculate the amplitude of the water wave when the intensity of the wave has decreased by 50%.　　　　　　　　　　　　　　　　　　　　　　2

(5)

7.

A water wave of frequency 2·5 Hz travels from left to right.

Figure 9 represents the displacement y of the water at one instant in time.
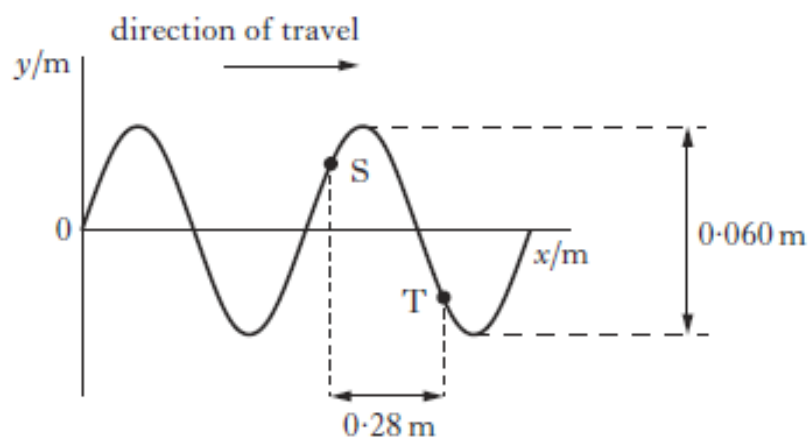
Figure 9

Points S and T are separated by a horizontal distance of 0·28 m.

The phase difference between these two points is 3·5 radians.

(a) Calculate the wavelength of this wave.　　　　　　　　　　　　　　　3

(b) A second wave with double the frequency travels in the same direction through the water. This wave transfers five times the energy of the wave in part (a).

Calculate:

　(i)　the speed of this wave;　　　　　　　　　　　　　　　　　　　1

　(ii)　the amplitude of this wave.　　　　　　　　　　　　　　　　　2

(6)

8.

In an experiment to measure the speed of sound in air, a loudspeaker, a signal generator and a reflector are set up as shown in Figure 14.
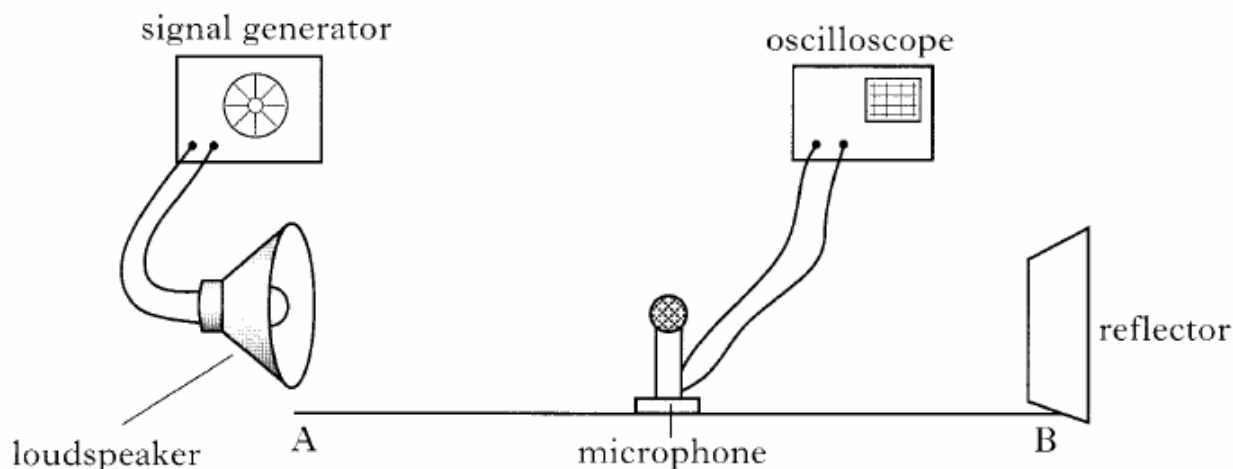
Figure 14

A stationary wave pattern is produced between the loudspeaker and the reflector. The intensity of the sound is monitored using a microphone connected to an oscilloscope. The microphone is moved steadily along line AB and the oscilloscope indicates alternate maximum and minimum values of sound intensity.

(a) What name is given to the points in the stationary wave pattern at which **minimum** values of sound intensity occur? **1**

(b) The signal generator is adjusted until the frequency of the sound produced is 2000 Hz. The distance between two successive points of minimum sound intensity is measured as 88 mm.

    (i)   Use this data to calculate the speed of sound in air. **4**

    (ii) Suggest **one** improvement to the experiment which would result in a more accurate value for the speed of sound in air.

    Justify your answer. **2**

(c) The microphone is placed at a position of minimum sound intensity. Without moving the microphone, the reflector is moved away from the loudspeaker until a minimum is again detected.

The intensity of sound at this minimum is found to be **greater** than the intensity of sound before the reflector was moved.

Explain this observation. **2**

(9)

9.

The apparatus shown in Figure 17 is set up to measure the speed of transverse waves on a stretched string.
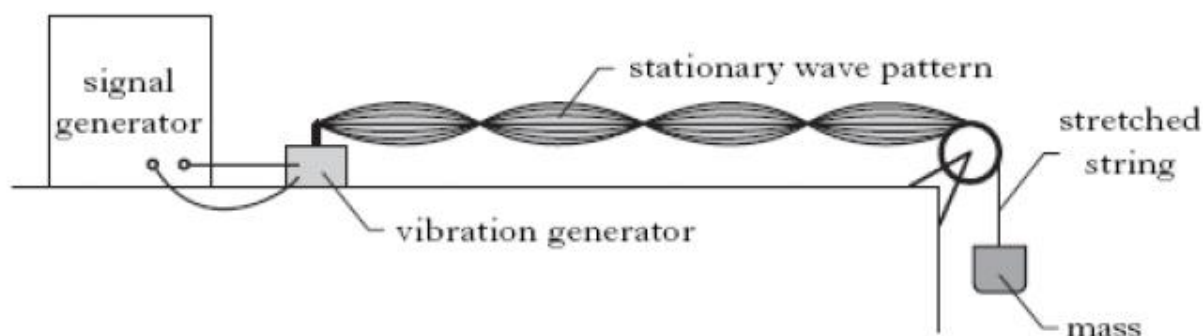
Figure 17

The following data are obtained.

    Distance between adjacent nodes = (0.150 ± 0.005) m
    Frequency of signal generator   = (250 ± 10) Hz

(a) Show that the wave speed is $75\ \mathrm{m\,s^{-1}}$.   3

(b) Calculate the absolute uncertainty in this value for the wave speed. Express your answer in the form $(75 \pm\ \ )\ \mathrm{m\,s^{-1}}$.   4

(c) (i) In an attempt to reduce the absolute uncertainty, the frequency of the signal generator is increased to (500 ± 10) Hz. Explain why this will **not** result in a reduced absolute uncertainty.   1

    (ii) State how the absolute uncertainty in wave speed could be reduced.   1

                                                     (9)

2.5 Interference

1.

(a) (i) Explain, **with the aid of a diagram**, how a thin coating on the surface of a camera lens can make it non-reflecting for monochromatic light at near normal incidence.   3

(ii) Calculate the thickness of a layer of magnesium fluoride required to make the surface of a lens non-reflecting for light of wavelength 500 nm.   3

(iii) When white light is incident upon a lens with this coating, a purple hue is observed in the reflected light. Explain how this colour effect is produced.   2

(b) Light from a red laser is incident upon a double slit which has a slit separation of $5 \cdot 0 \times 10^{-5}$ m. A screen is placed $2 \cdot 0$ m beyond the double slit as shown in Figure 9.

double
slit

screen

laser light

$2 \cdot 0$ m
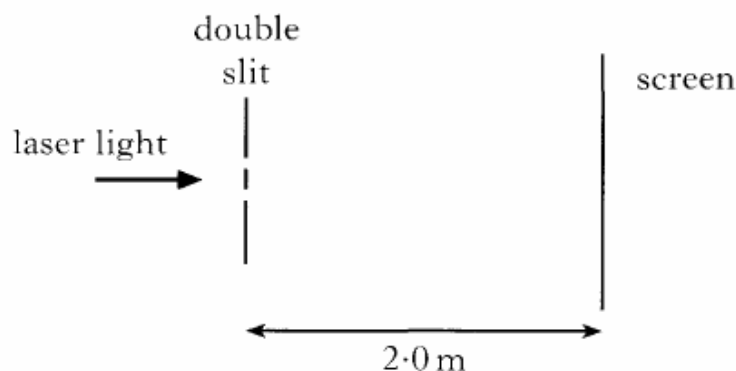
Figure 9

A pattern of light and dark fringes, as shown in Figure 10, is observed on the screen.

100 mm
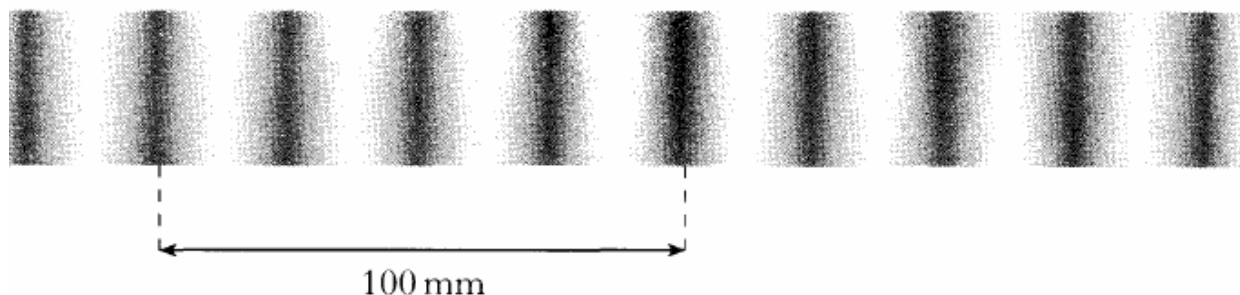
Figure 10

Calculate the wavelength of the laser light.   4

(12)

2.

A thin air wedge is formed between two flat glass plates which are in contact at one end and separated by a thin copper wire at the other end.

The experimental arrangement in Figure 16 shows how interference fringes can be observed using a travelling microscope.

4
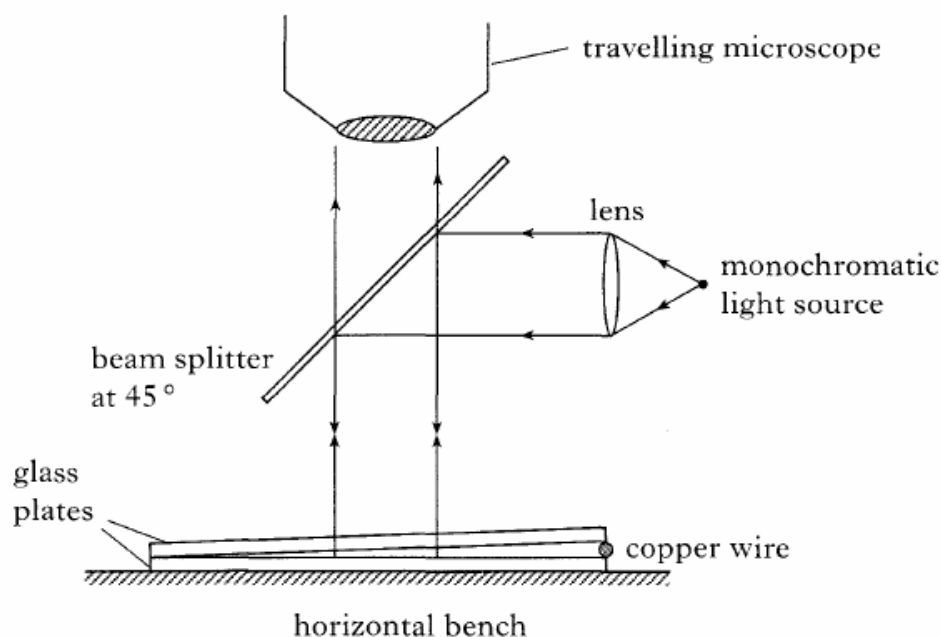
Figure 16

(a) In this arrangement, state whether the interference fringes are produced by division of amplitude or by division of wavefront.

1

(b) Measurements are taken as follows:

separation of fringes = 0·080 mm
length of each glass plate = 75·0 mm
wavelength of monochromatic light = 589 nm.

The separation of thin air wedge fringes is given by the expression

$$\Delta x = \frac{\lambda}{2 \tan \theta}$$

where the symbols have their usual meanings.

Calculate the diameter of the copper wire.

3

(c) Water enters the wedge and replaces all the air, as shown in Figure 17.
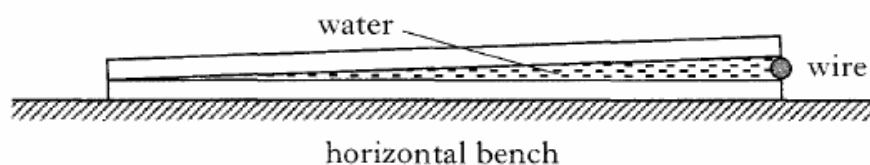
Figure 17

(i) Describe the change that occurs in the interference pattern.

1

(ii) Explain this change.

2

(7)

3.

(a) (i) State the condition for two light sources to be coherent.   1

(ii) Monochromatic light is directed towards a glass slide as shown in Figure 19. The glass has a refractive index of 1·4.
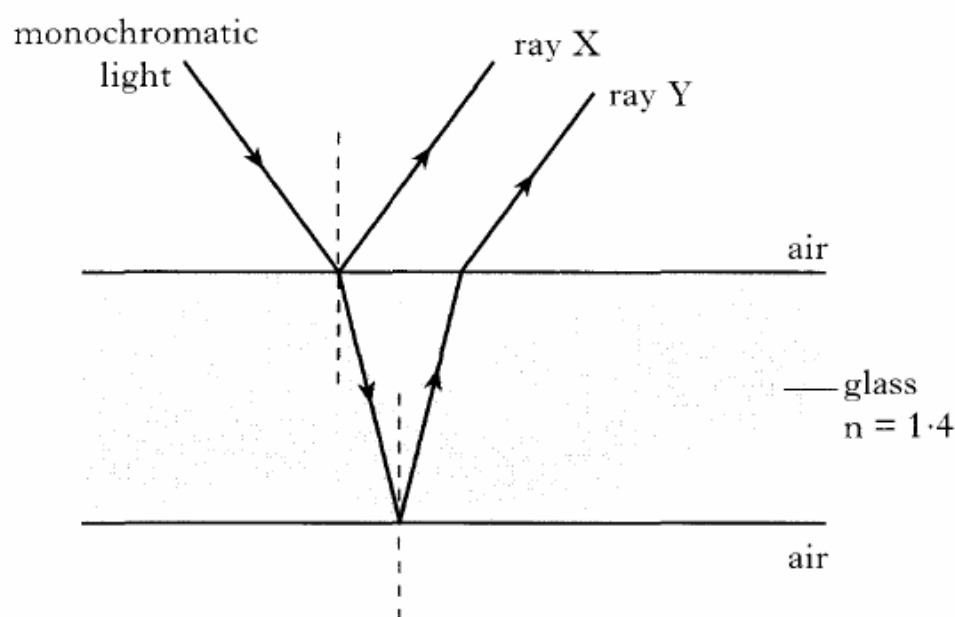
Figure 19

Ray Y has travelled further than ray X.

State the relationship between the path difference and the **optical** path difference between the rays.   1

(iii) In terms of optical path difference, state the conditions for:

(A) constructive interference of rays X and Y;   1

(B) destructive interference of rays X and Y.   1

(iv) A glass slide, set up as shown in Figure 19, is observed at near normal incidence. Constructive interference is observed.

The glass slide is now placed on the surface of a liquid of refractive index greater than 1·4. Destructive interference is now observed at near normal incidence.

Explain this observed change.   1

(b) Good quality lenses reflect very little light.

A thin coating of magnesium fluoride on the surface of a lens reduces reflection.

(i) Explain briefly why this coating reduces reflection.   1

(ii) Calculate the thickness of magnesium fluoride that minimises reflection for light of wavelength 550 nm.   3

(9)

4.

(a) The speed of an electron is measured to be $5 \cdot 00 \times 10^3 \, m \, s^{-1}$.

    (i)   Calculate the momentum of the electron.   3

    (ii)   Calculate the de Broglie wavelength of the electron.   3

(b) The uncertainty in the speed of the electron is $\pm \, 0 \cdot 0030\%$.

Calculate the uncertainty in determining the position of the electron.   5

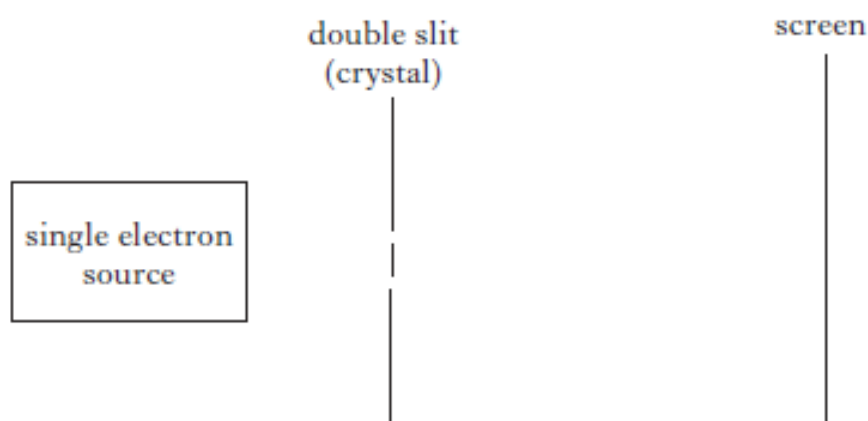(c) Electrons are fired one at a time towards a crystal which behaves like a double slit, as shown in Figure 7.

Figure 7

Classical physics predicts that each electron will go through one or the other slit. In practice, an interference pattern is observed on the screen. It can be concluded that each electron goes through both slits simultaneously.

State what would be observed on the screen if an attempt was made to observe an electron going through either slit. Justify your answer.   2

(13)

5.

High quality *optical flats* made from glass are often used to test components of optical instruments. A high quality optical flat has a very smooth and flat surface.

(a) During the manufacture of an optical flat, the quality of the surface is tested by placing it on top of a high quality flat. This results in a thin air wedge between the flats as shown in Figure 8A.

monochromatic light

flat being tested

thin air wedge

d

high quality flat

50 mm

not to scale
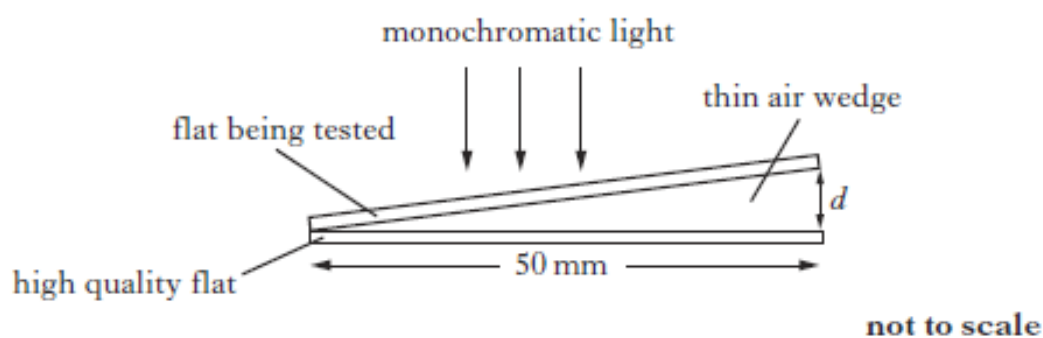
Figure 8A

The thickness d of the air wedge is 6.2×10^{-5} m.

Monochromatic light is used to illuminate the flats from above. When viewed from above using a travelling microscope, a series of interference fringes is observed as shown in Figure 8B.

1.2×10^{-3} m
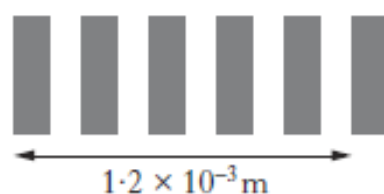
Figure 8B

Calculate the wavelength of the monochromatic light.　　　　　4

(b) A second flat is tested using the same method as in part (a). This flat is slightly curved as shown in Figure 8C.

Figure 8C

Draw the fringe pattern observed.　　　　　1

5.

(continued)

(c) Good quality optical flats often have a non-reflecting coating of magnesium fluoride applied to the surface as shown in Figure 8D.

magnesium fluoride

optical flat
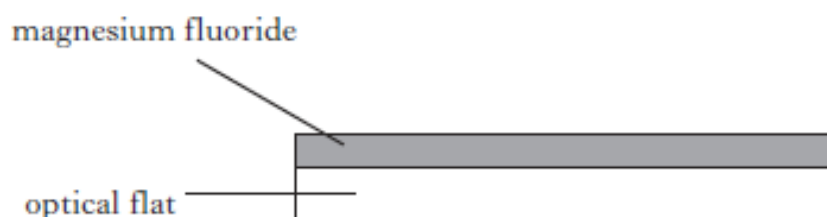
Figure 8D

   (i) With the aid of a diagram explain fully how the coating reduces reflections from the flat for monochromatic light.   2

  (ii) Calculate the minimum thickness of magnesium fluoride required to make the flat non-reflecting for yellow light from a sodium lamp.   3

(10)

6.

(a) When sunlight hits a thin film of oil floating on the surface of water, a complex pattern of coloured fringes is observed.

light of wavelength, λ

oil

water
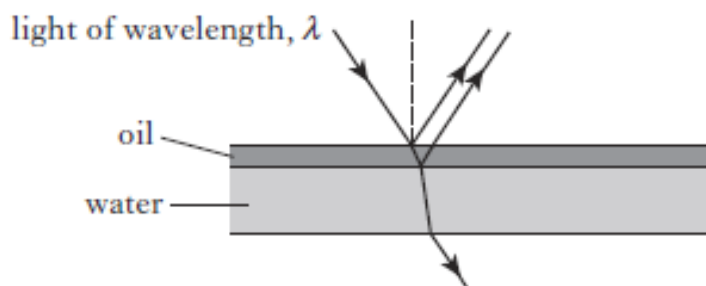
Figure 10

Explain how these fringes are formed.   2

(b) The surface of a lens is coated with a thin film of magnesium fluoride.

Calculate the minimum thickness required to make the lens non-reflecting at a wavelength of 555 nm.   3

(c) The lens of a digital camera appears to be purple in white light.

Explain this observation.   2

(7)

7.

A student sets up a "Young's double slit" experiment, as shown in Figure 9, to measure the wavelength of laser light.
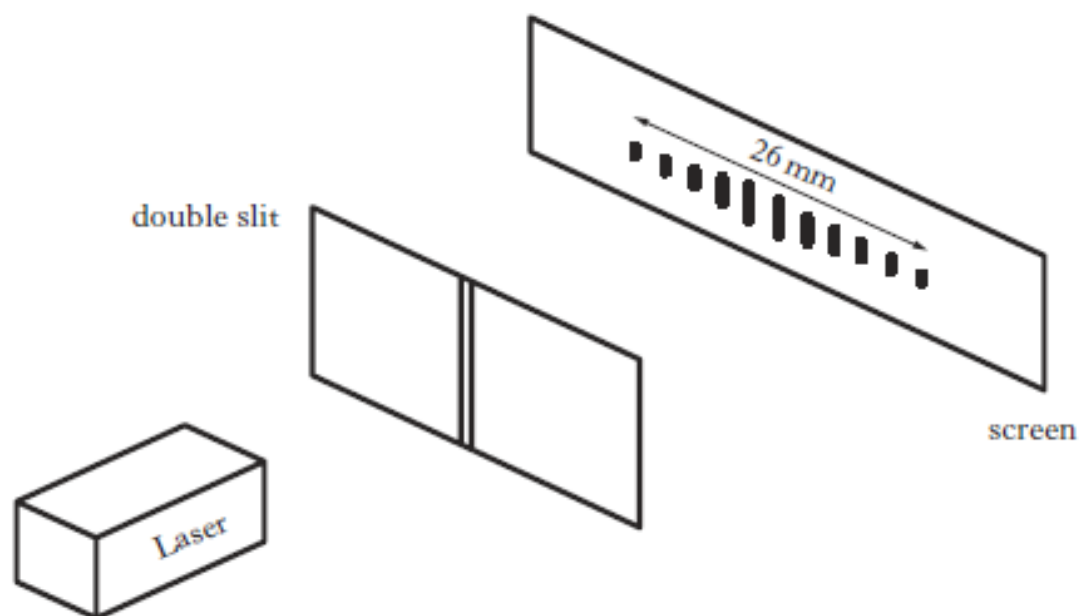
Figure 9

The student obtains the following results.

Separation of 11 fringes	$(26 \pm 2)\,mm$
Distance to screen from slits	$(1\cdot94 \pm 0\cdot01)\,m$
Separation of slits	$(0\cdot38 \pm 0\cdot02)\,mm$

(a) Which principle does this experiment illustrate, interference by division of wavefront or by division of amplitude?　　1

(b) Calculate the wavelength of the laser light.　　4

(c) Calculate the absolute uncertainty in this wavelength.　　5

(d) Using the same equipment, suggest an improvement to the experiment that would reduce the uncertainty in the calculated value of the wavelength.

You must justify your answer.　　2

(e) The experiment is now set up under water using the same laser and double slit. The distance to the screen from the slits is kept the same as before at 1·94 m

　(i)　Calculate the wavelength of the laser light in water.　　3

　(ii)　Calculate the separation of 11 fringes as they appear on the screen under water.　　4

(19)

8.

A series of coloured LEDs are used in the Young's slit experiment as shown in Figure 9. The distance from the slits to the screen is $(2 \cdot 50 \pm 0 \cdot 05)$m. The slit separation is $(3 \cdot 0 \pm 0 \cdot 1) \times 10^{-4}$ m.
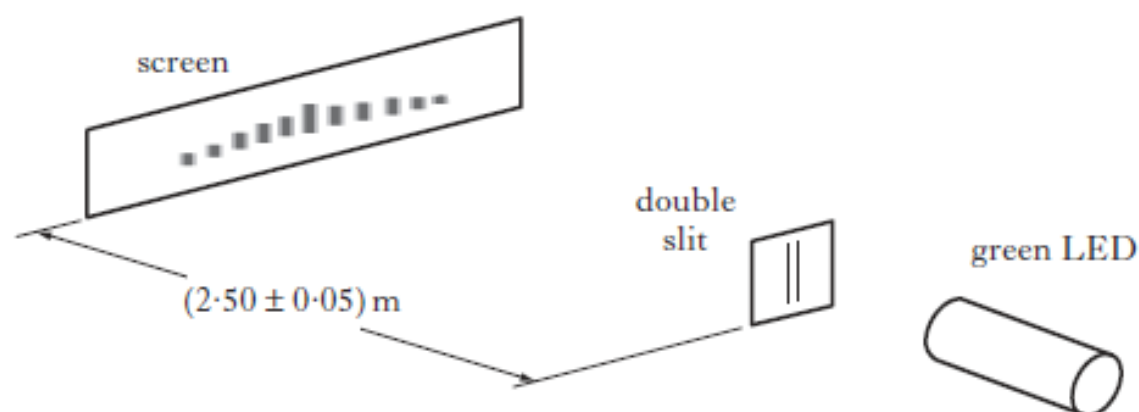
Figure 9

Colour of LED	Wavelength (nm)
Red	650 ± 2
Green	510 ± 2
Blue	470 ± 2

(a) State whether the pattern on the screen is caused by the division of wavefront or the division of amplitude. 1

(b) (i) Calculate the fringe separation observed on the screen when the green LED is used. 3

(ii) Calculate the absolute uncertainty in the fringe separation. 5

(9)

9.

A student carries out a Young's double slit experiment in order to determine the wavelength of monochromatic red light.

The student uses the apparatus shown in Figure 8 to produce an interference pattern on the screen.
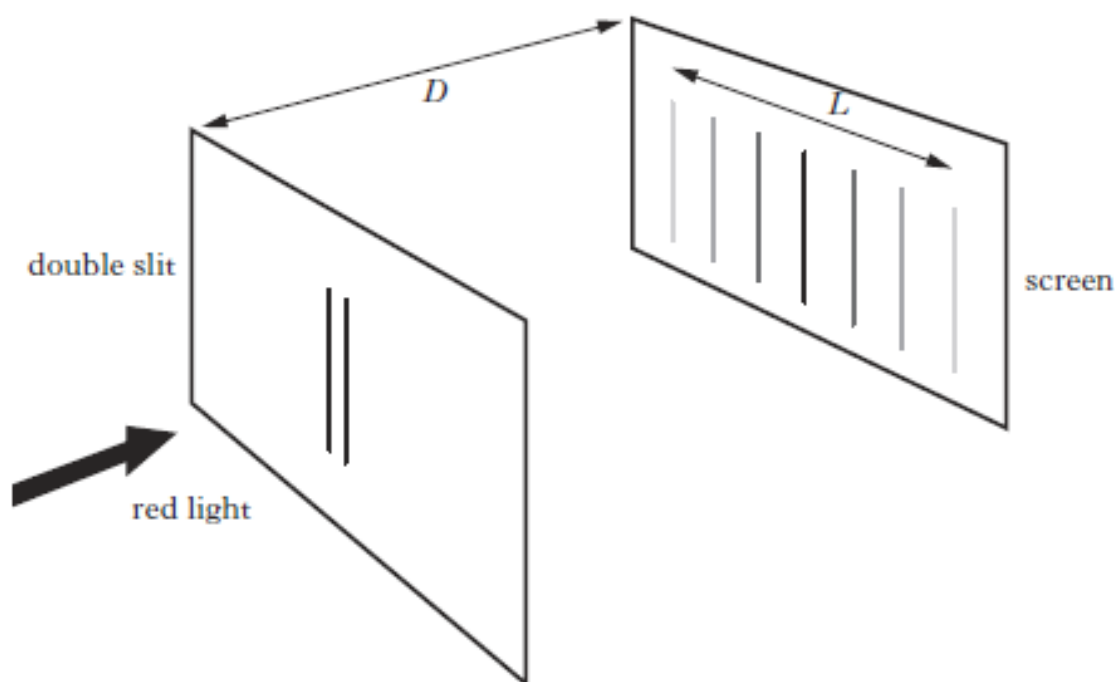
Figure 8

The double slit separation d is measured using a travelling microscope. The distance D between the double slit and the screen is measured using a steel measuring tape. The length L of the interference pattern is measured using a plastic ruler.

The student records the following data.

$$D = (4\cdot250 \pm 0\cdot005)\,\text{m}$$
$$L = (67 \pm 2)\,\text{mm}$$
$$d = (0\cdot25 \pm 0\cdot01)\,\text{mm}$$

(a)   (i) State why it is possible to produce an interference pattern using only a single light source.   **1**

    (ii) Calculate the wavelength of the light from the source.   **4**

    (iii) Calculate the absolute uncertainty in the wavelength.   **5**

(b) The student repeats the experiment with the same apparatus but uses a monochromatic blue light source. D remains fixed.

  State the effect this will have on the percentage uncertainty in the calculated value for the wavelength of the blue light.

  You must justify your answer.   **2**

           (12)

10.

Light from a helium-neon laser is incident on a double slit. A pattern of light and dark fringes is observed on a screen 3·50 m beyond the slits as shown in Figure 20.
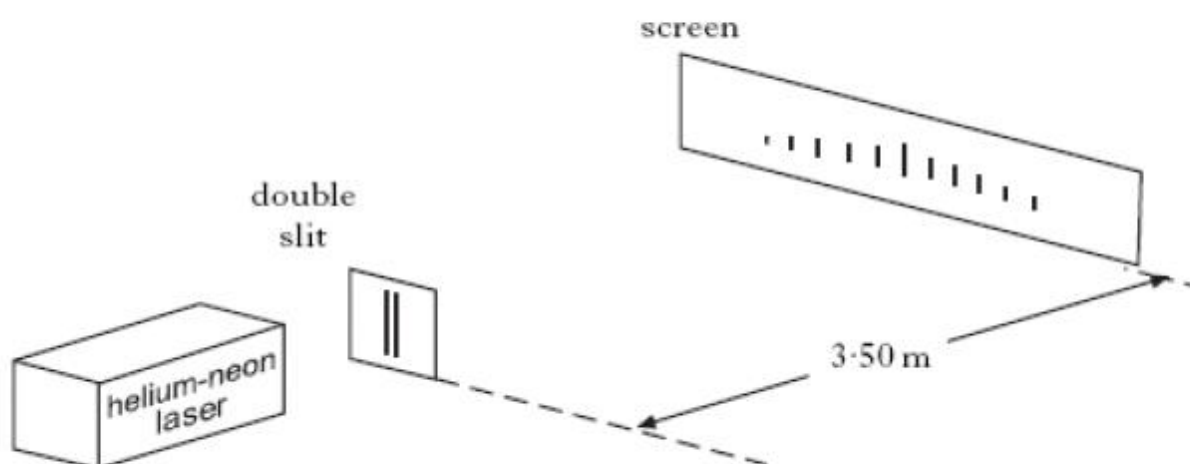
Figure 20

(a) State whether these fringes are caused by division of amplitude or division of wavefront.

1

(b) The distance between two adjacent bright fringes on the screen is 7·20 mm. Calculate the separation of the two slits.

3

(c) The distance between the double slit and screen is increased to 5·50 m. The distance between the fringes is remeasured and the calculation of the slit separation is repeated.

(i) Explain **one** advantage of moving the screen further away from the double slit.

2

(ii) State **one** disadvantage of moving the screen further away from the double slit.

1

(7)

11.

(a) An air wedge is formed between two flat glass plates of length l, which are in contact at one end. They are separated by a human hair of diameter d at the other end, as shown in Figure 15.

Figure 15

The air wedge is illuminated from above by a monochromatic light source of wavelength λ. When viewed from above a series of interference fringes of separation Δx is observed.

  (i) Use this information to derive an expression for the diameter of the human hair.   **3**

  (ii) The wavelength of the monochromatic light is 589 nm, the length of the glass plates is 75 mm and the separation between two adjacent dark fringes is $3\cdot4 \times 10^{-4}$ m.

     Calculate the diameter of the hair.   **2**

(b) A camera lens can be made non-reflecting by coating it with a thin layer of magnesium fluoride.

  (i) Calculate the thickness of magnesium fluoride required to make the lens non-reflecting for light of wavelength 548 nm.   **3**

  (ii) The lens has a thin film of transparent liquid placed on its surface as shown in Figure 16. The refractive index of the liquid is 1·45.

Figure 16

Explain why the coating is no longer non-reflective.   **2**

(c) Explain why coloured fringes can be observed when a thin film of oil forms on a puddle of water.   **1**

    (11)

12.

(a) A thin coating of magnesium fluoride is applied to the surface of a camera lens.

Figure 15 shows an expanded view of this coating on the glass lens.
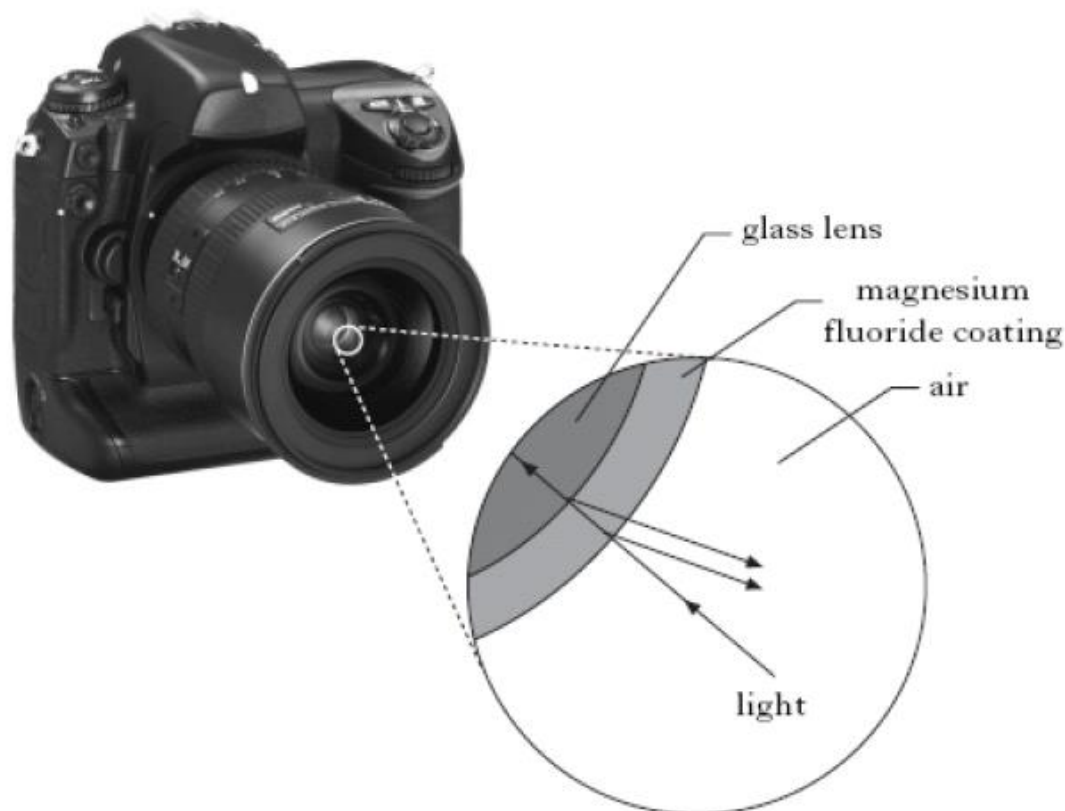
Figure 15

Monochromatic light is incident on the lens and some light reflects from the front and rear surfaces of the coating as shown in Figure 15.

   (i) State the phase change undergone by the light reflected from:

      (A) the front surface of the coating;   **1**

      (B) the rear surface of the coating.   **1**

   (ii) Explain, in terms of optical path difference, why this coating can make the lens non-reflecting for a particular wavelength of light.   **2**

   (iii) Why is it desirable that camera lenses should reflect very little light?   **1**

   (iv) A particular lens has a magnesium fluoride coating of thickness $1 \cdot 05 \times 10^{-7}$m.

      Calculate the wavelength of light for which this lens is non-reflecting.   **3**

12.

(continued)

(b) A thin air wedge is formed between two glass plates which are in contact at
one end and separated by a thin metal wire at the other end.

Figure 16 shows sodium light being reflected down onto the air wedge. A
travelling microscope is used to view the resulting interference pattern.
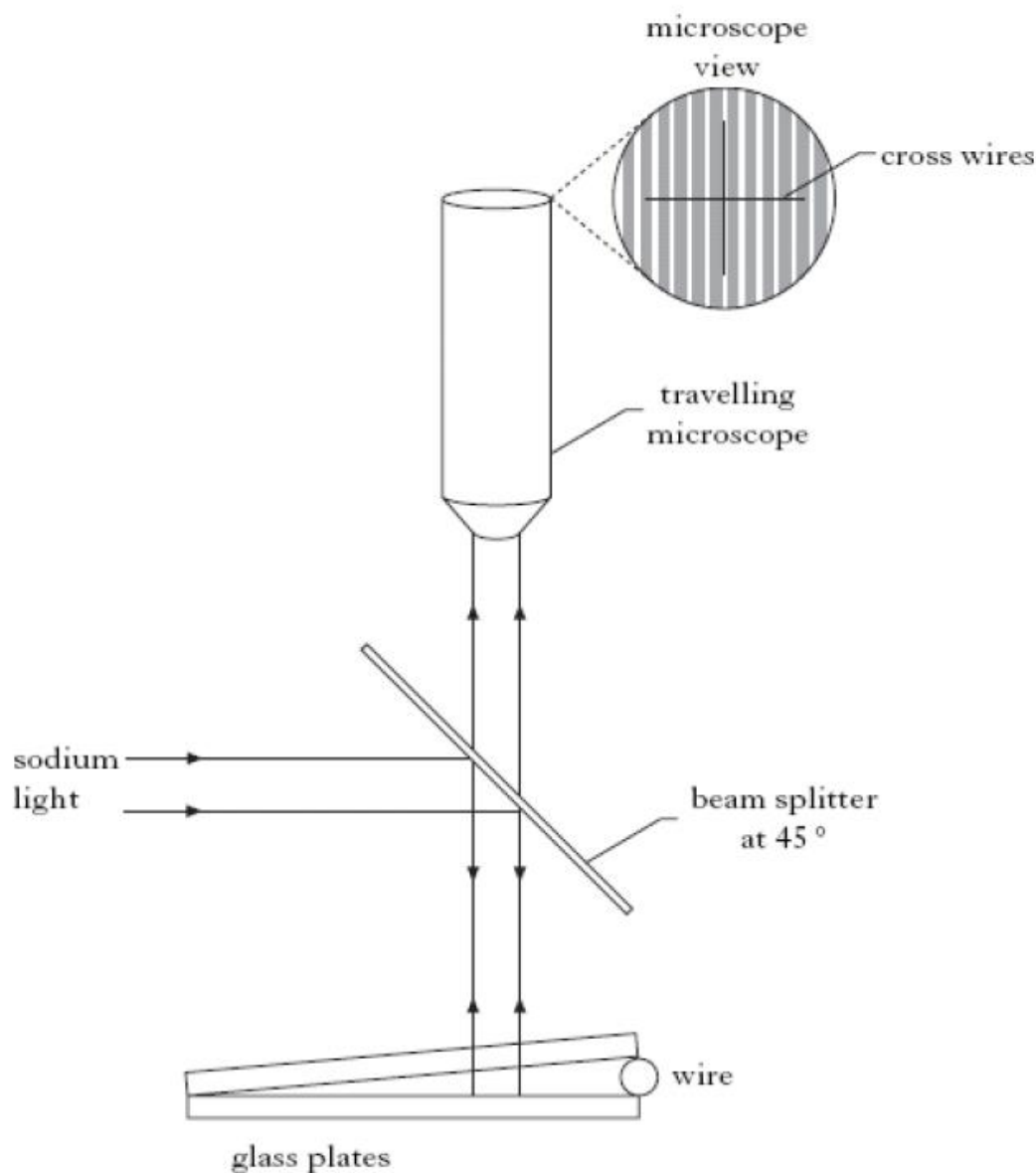
Figure 16

Explain how the diameter of the wire is determined using measurements
obtained with this apparatus.

Assume the sodium light is monochromatic.

Your answer should include:

• the measurements required
• any data required
• the equation used.

2

(10)

2.6 Polarisation

1.

A student, wearing polarising sunglasses, is using a tablet computer outdoors. The orientation of the tablet seems to affect the image observed by the student.

Two orientations are shown in Figure 11A.

Landscape mode   Portrait mode
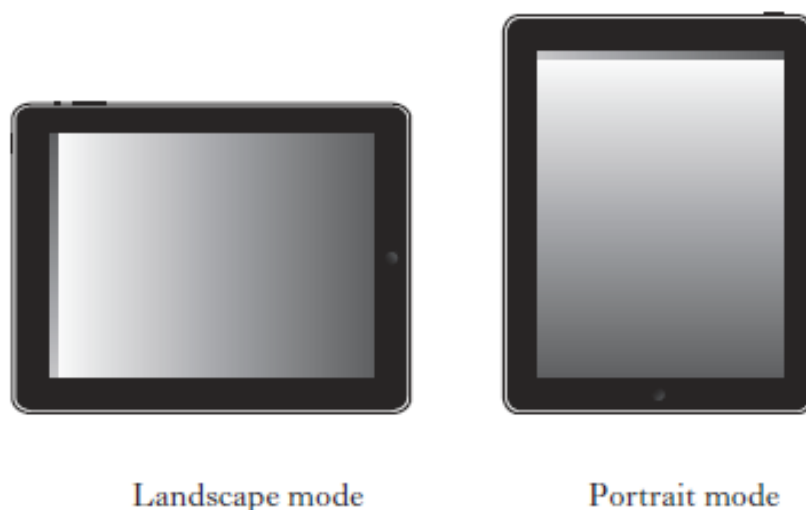
Figure 11A

(a) In landscape mode the image appears bright and in portrait mode it appears dark.

  (i) What may be concluded about the light emitted from the tablet screen?   **1**

  (ii) The student slowly rotates the tablet. Describe the change in brightness observed by the student as it is rotated through 180°.   **2**

(b) Unpolarised sunlight is incident on a water surface a shown in Figure 11B.
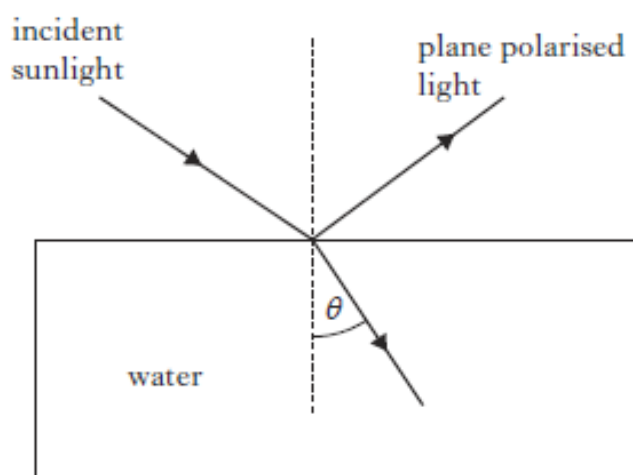
Figure 11B

The light is 100% plane polarised on reflection.

Calculate the angle of refraction θ.   **4**

      (7)

2.

(a) (i) State what is meant by the term *plane polarised light*.   **1**

(ii) Figure 16 shows the refraction of red light at a water-air interface.
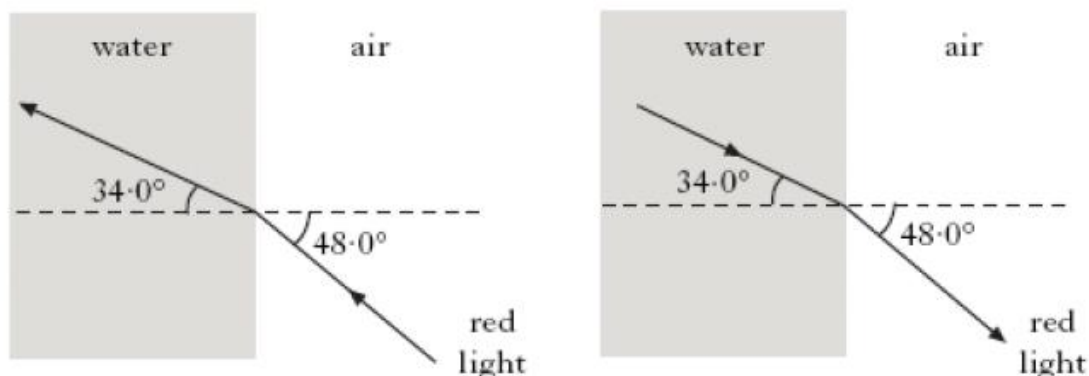
Figure 16

The refractive index n for red light travelling from air to water is 1·33. Show that the refractive index μ for red light travelling from **water** to **air** is 0·752.   **2**

(iii) Figure 17 shows a ray of unpolarised red light incident on a water-air interface.
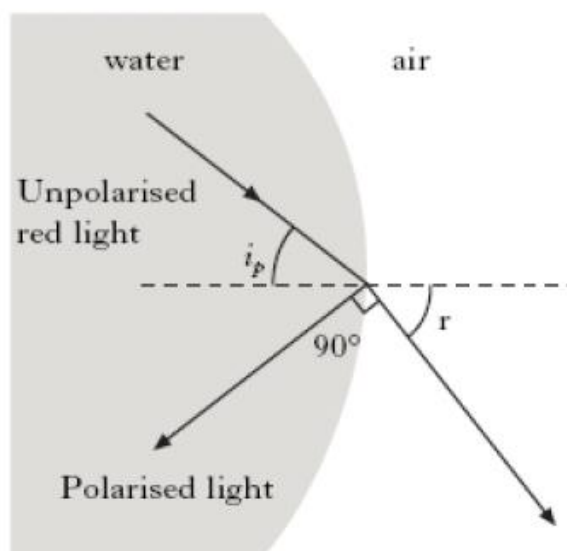
Figure 17

For light travelling from water to air,

$$\mu = \tan i_p$$

where i_p is the Brewster angle.

Calculate the Brewster angle for red light at this water-air interface.   **2**

2.

(b) A rainbow is produced when light follows the path in a raindrop as shown in Figure 18.
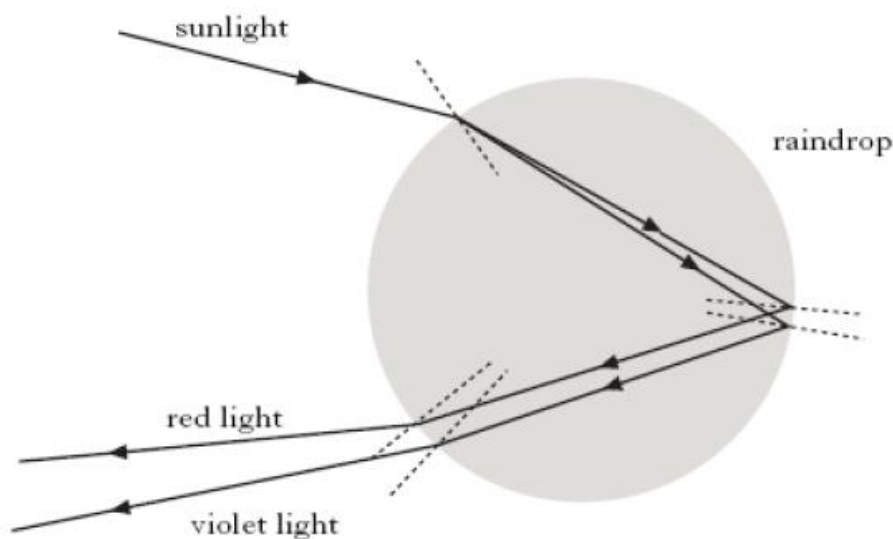
Figure 18

The light emerging from the raindrop is polarised.

The refractive index, μ, at a water to air interface is $0\cdot752$ for red light and $0\cdot745$ for violet light.

Calculate the difference in Brewster's angle for these two colours. 3

(c) Rainbows produce light that is 96% polarised. A photographer plans to take a photograph of a rainbow. Her camera has a polarising filter in front of the lens as shown in Figure 19.

Figure 19

She directs her camera at the rainbow and slowly rotates the filter to see which is the best image to take.

Describe what happens to the image of the rainbow as she slowly rotates her filter through $180°$. 2

(10)

3.

(a) State the difference between polarised and unpolarised light.   1

(b) Unpolarised monochromatic light is incident on a glass block of refractive index n at an angle i_p, as shown in Figure 18.
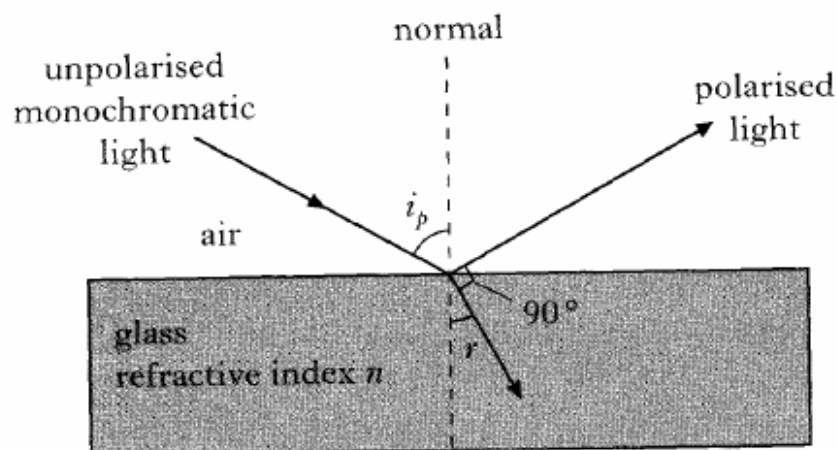
Figure 18

Light is refracted by the glass at angle r and polarised light is reflected by the glass.

Derive the expression

$$n = \tan i_p \qquad \text{where } i_p \text{ is known as Brewster's angle.}$$ 3

(c) Sunlight is reflected from the surface of a loch as shown in Figure 19.
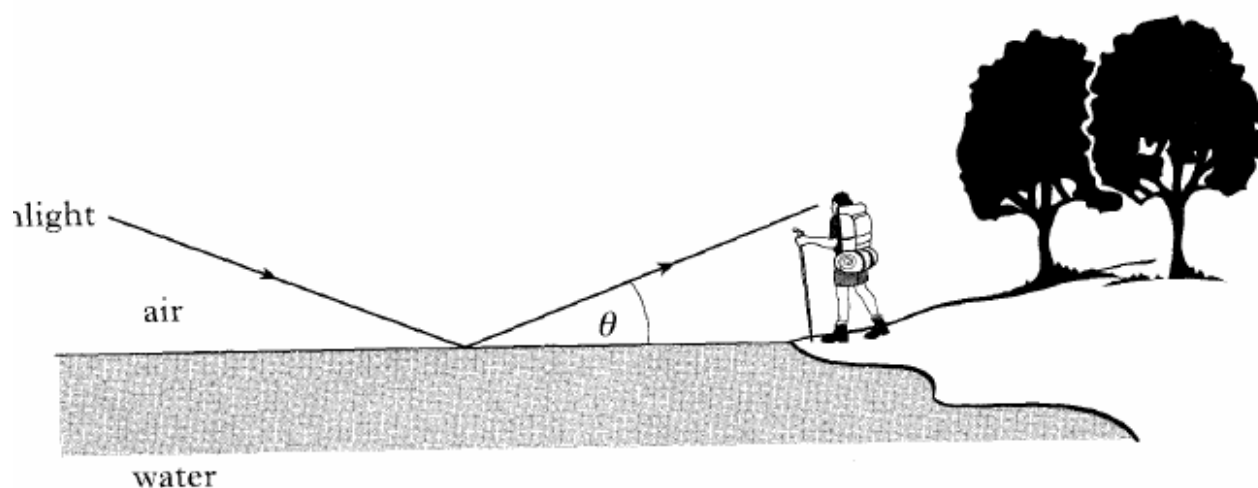
Figure 19

Calculate the angle θ at which the water reflects plane polarised light to the observer on the shore.   3

(7)

4.

(a) State the difference between plane polarised light and unpolarised light.   **1**

(b) Figure 20 shows two polarising filters.

The first filter is called the polariser and the second the analyser.

The direction of the transmission axis is shown for each filter.

transmission axis

unpolarised
light source

polariser   analyser
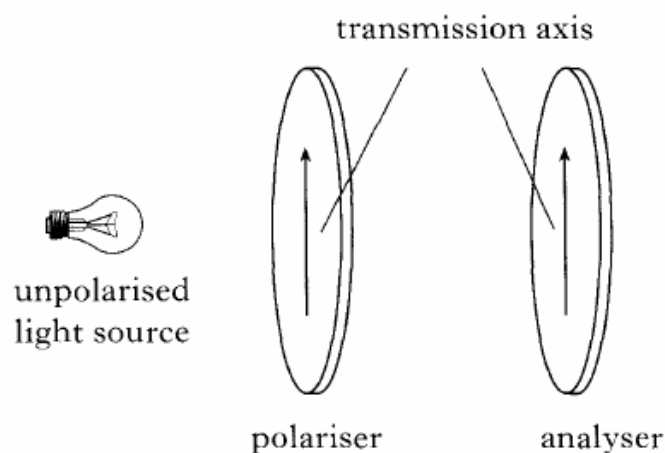
Figure 20

Unpolarised light is passed through the two filters.

The transmission axis of the analyser is now turned to different positions as shown in Figure 21.

Analyser setting	Position of analyser's transmission axis	Intensity of transmitted light/W m^{-2}
A	↑	5·0
B	↗	
C	→	
D	↘	
E	↓	

Figure 21

The intensity of transmitted light when the analyser is at setting A is 5·0 W m^{-2}.

State possible values for the intensity of the transmitted light when the transmission axis of the analyser is at settings B, C, D and E.   **4**

4.

(continued)

(c) Light can be polarised by reflection from a sheet of glass.

For a particular angle of incidence i_p, the reflected ray is totally plane polarised. This situation is represented in Figure 22.
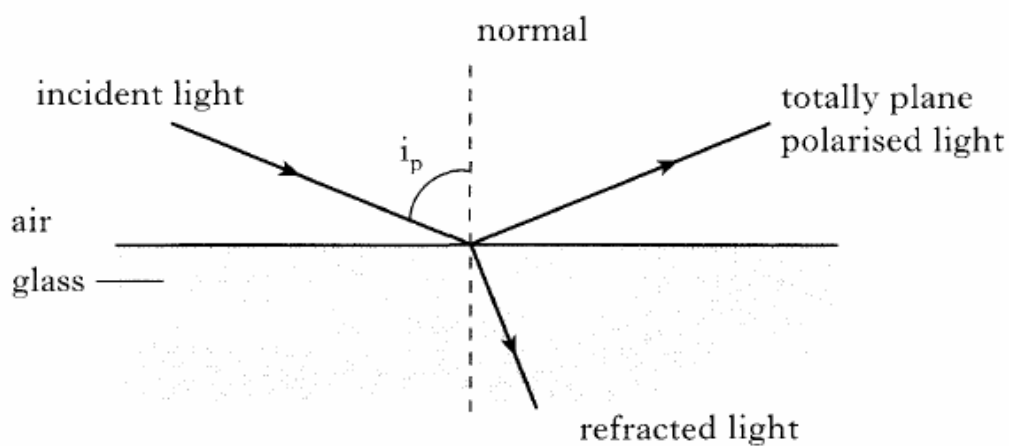

Figure 22

Show that,

$$\tan i_p = n$$

where n is the refractive index of the glass.

3

(8)

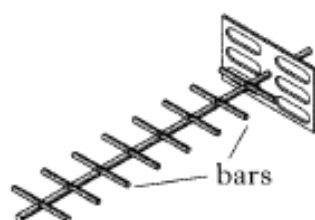5.

A television aerial is shown in Figure 15.

Figure 15

(a) Instructions for installing the aerial state

"*The television waves received are plane polarised. The aerial does not pick up a strong signal unless the plane of the bars is the same as the plane of polarisation of the television waves.*"

(i) Explain the term *plane polarised*. 1

(ii) The aerial is installed and connected to a television.

The television has a clear picture when the bars of the aerial are horizontal as shown in Figure 15.

The aerial is now slowly rotated until the bars are vertical as shown in Figure 16.

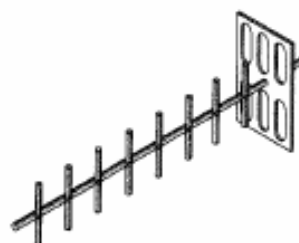Describe what happens to the television picture during this rotation. 1

Figure 16

(b) Unpolarised light strikes the surface of a transparent material at the Brewster angle i_p, as shown in Figure 17. The reflected light is plane polarised.
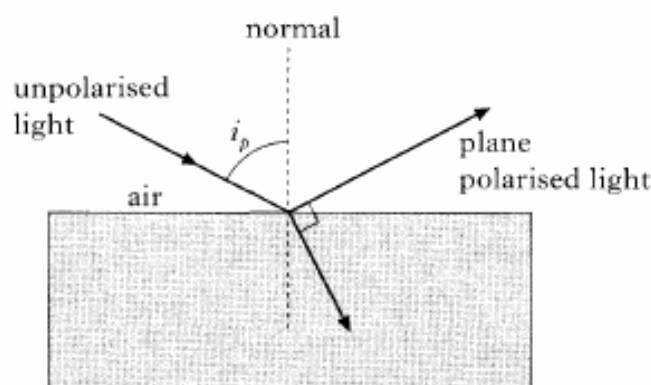

Figure 17

(i) Derive the expression

$$n = \tan i_p$$

where n is the refractive index of the transparent material. 3

(ii) Calculate the Brewster angle for perspex. 3

(8)

20. (*a*) State the difference between plane polarised light and unpolarised light.   **1**

(*b*) The digital display on a calculator consists of many small segments of liquid crystal material.

A "0" changes to an "8" when the middle segment switches from light to dark as shown in Figure 20.
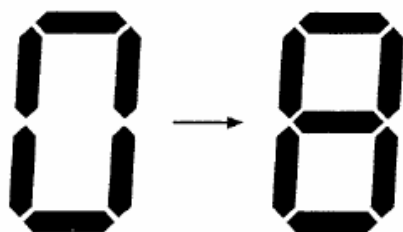

Figure 20

To make one segment of a 7-segment display, a slice of liquid crystal is placed between a piece of polarising material and a mirror. Figure 21 shows this arrangement for the **middle segment only**.
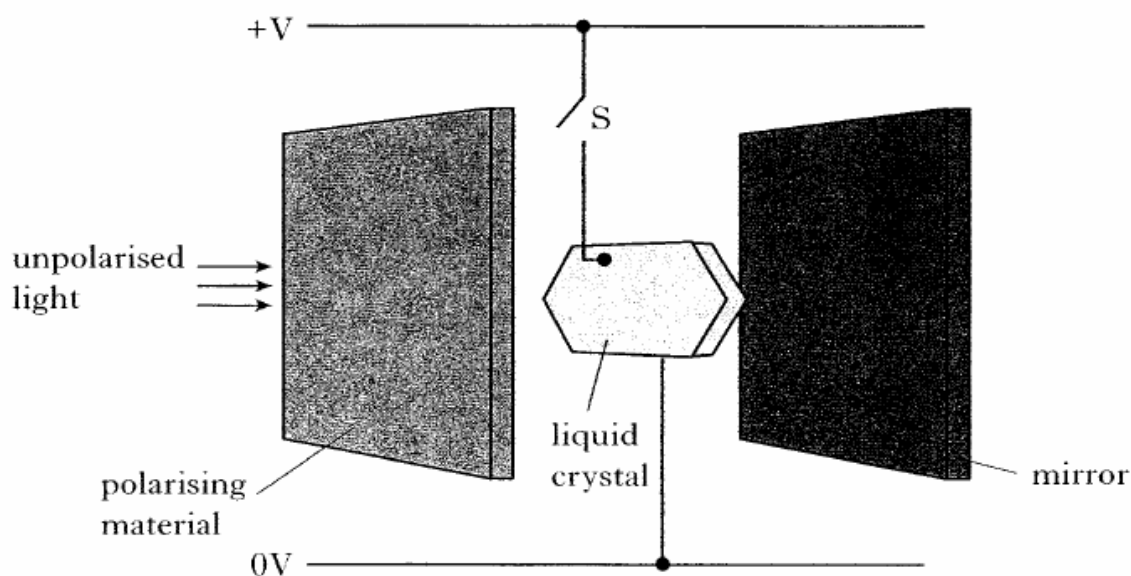

Figure 21

The following table summarises the effect of switch S.

Switch S	Response of liquid crystal
open	transmits polarised light
closed	does not transmit polarised light

  (i) Explain why the liquid crystal appears dark when switch S is closed.   **2**

(ii) State what happens to the switch when an "8" is changed to a "0".   **1**

6.

(continued)

(c) A student sees a row of numbers displayed on a calculator through a separate piece of polarising material as shown in Figure 22.
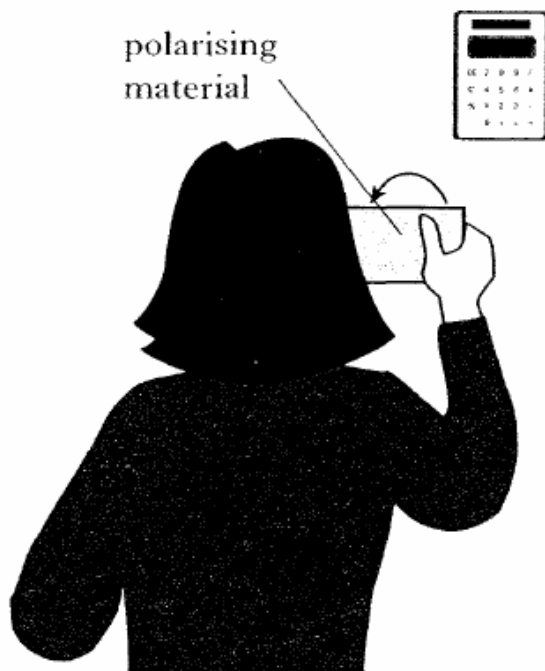

Figure 22

The student rotates the piece of polarising material through 180°. Explain what is seen as the polarising material is rotated.

2

(6)

7.

A student is investigating polarisation of waves.

(a) State what is meant by *plane polarised light*.

1

(b) While doing some background reading the student discovers that the Brewster angle i_p for the liquid solvent triethylamine is given as 54·5°. Explain, using a diagram, what is meant by the Brewster angle.

2

(3)

[END OF QUESTION PAPER]