X069/701

NATIONAL
QUALIFICATIONS
2003

MONDAY, 19 MAY
1.00 PM – 3.30 PM

PHYSICS
ADVANCED HIGHER

Answer **all** questions.

Any necessary data may be found in the Data Sheet on page two.

Care should be taken to give an appropriate number of significant figures in the final answers to calculations.

Square-ruled paper (if used) should be placed inside the front cover of the answer book for return to the Scottish Qualifications Authority.

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DATA SHEET

COMMON PHYSICAL QUANTITIES

Quantity	*Symbol*	*Value*	*Quantity*	*Symbol*	*Value*
Gravitational acceleration on Earth	g	$9{\cdot}8\ \mathrm{m\ s^{-2}}$	Mass of electron	m_e	$9{\cdot}11 \times 10^{-31}\ \mathrm{kg}$
Radius of Earth	R_E	$6{\cdot}4 \times 10^{6}\ \mathrm{m}$	Charge on electron	e	$-1{\cdot}60 \times 10^{-19}\ \mathrm{C}$
Mass of Earth	M_E	$6{\cdot}0 \times 10^{24}\ \mathrm{kg}$	Mass of neutron	m_n	$1{\cdot}675 \times 10^{-27}\ \mathrm{kg}$
Mass of Moon	M_M	$7{\cdot}3 \times 10^{22}\ \mathrm{kg}$	Mass of proton	m_p	$1{\cdot}673 \times 10^{-27}\ \mathrm{kg}$
Mean Radius of Moon Orbit		$3{\cdot}84 \times 10^{8}\mathrm{m}$	Planck's constant	h	$6{\cdot}63 \times 10^{-34}\ \mathrm{J\ s}$
Universal constant of gravitation	G	$6{\cdot}67 \times 10^{-11}\ \mathrm{m^3\ kg^{-1}\ s^{-2}}$	Permittivity of free space	ε_0	$8{\cdot}85 \times 10^{-12}\ \mathrm{F\ m^{-1}}$
Speed of light in vacuum	c	$3{\cdot}0 \times 10^{8}\ \mathrm{m\ s^{-1}}$	Permeability of free space	μ_0	$4\pi \times 10^{-7}\ \mathrm{H\ m^{-1}}$
Speed of sound in air	v	$3{\cdot}4 \times 10^{2}\ \mathrm{m\ s^{-1}}$			

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*
Hydrogen	656	Red
	486	Blue-green
	434	Blue-violet
	410	Violet
	397	Ultraviolet
	389	Ultraviolet
Sodium	589	Yellow

Element	*Wavelength*/nm	*Colour*
Cadmium	644	Red
	509	Green
	480	Blue

Lasers

Element	*Wavelength*/nm	*Colour*
Carbon dioxide	9550, 10590	Infrared
Helium-neon	633	Red

PROPERTIES OF SELECTED MATERIALS

Substance	*Density*/ $\mathrm{kg\ m^{-3}}$	*Melting Point*/ K	*Boiling Point*/ K	*Specific Heat Capacity*/ $\mathrm{J\ kg^{-1}\ K^{-1}}$	*Specific Latent Heat of Fusion*/ $\mathrm{J\ kg^{-1}}$	*Specific Latent Heat of Vaporisation*/ $\mathrm{J\ kg^{-1}}$
Aluminium	$2{\cdot}70 \times 10^{3}$	933	2623	$9{\cdot}02 \times 10^{2}$	$3{\cdot}95 \times 10^{5}$	....
Copper	$8{\cdot}96 \times 10^{3}$	1357	2853	$3{\cdot}86 \times 10^{2}$	$2{\cdot}05 \times 10^{5}$	....
Glass	$2{\cdot}60 \times 10^{3}$	1400	....	$6{\cdot}70 \times 10^{2}$	....	....
Ice	$9{\cdot}20 \times 10^{2}$	273	....	$2{\cdot}10 \times 10^{3}$	$3{\cdot}34 \times 10^{5}$	....
Glycerol	$1{\cdot}26 \times 10^{3}$	291	563	$2{\cdot}43 \times 10^{3}$	$1{\cdot}81 \times 10^{5}$	$8{\cdot}30 \times 10^{5}$
Methanol	$7{\cdot}91 \times 10^{2}$	175	338	$2{\cdot}52 \times 10^{3}$	$9{\cdot}9 \times 10^{4}$	$1{\cdot}12 \times 10^{6}$
Sea Water	$1{\cdot}02 \times 10^{3}$	264	377	$3{\cdot}93 \times 10^{3}$	....	....
Water	$1{\cdot}00 \times 10^{3}$	273	373	$4{\cdot}19 \times 10^{3}$	$3{\cdot}34 \times 10^{5}$	$2{\cdot}26 \times 10^{6}$
Air	1·29	....	....	....	....	....
Hydrogen	$9{\cdot}0 \times 10^{-2}$	14	20	$1{\cdot}43 \times 10^{4}$	....	$4{\cdot}50 \times 10^{5}$
Nitrogen	1·25	63	77	$1{\cdot}04 \times 10^{3}$	....	$2{\cdot}00 \times 10^{5}$
Oxygen	1·43	55	90	$9{\cdot}18 \times 10^{2}$	....	$2{\cdot}40 \times 10^{5}$

The gas densities refer to a temperature of 273 K and a pressure of $1{\cdot}01 \times 10^{5}$ Pa.

[Turn over for Question 1 on *Page four*]

1. (*a*) The average acceleration of a radio controlled car is investigated by a student.

She marks distance AB on a straight track, as shown in Figure 1 and measures this distance using a measuring tape.

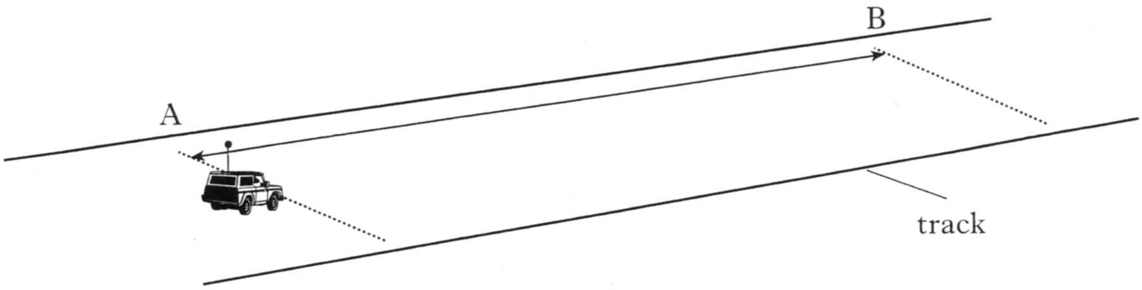

Figure 1

She places the car at A and uses the radio control to accelerate the car.

The car starts from rest and accelerates in a straight line along the track to B.

Using a stopwatch, the student measures the time for the car to travel the distance AB.

She repeats this several times and obtains the following results.

Distance AB = (3·54 ± 0·01) m.

Stopwatch readings: 2·53 s; 2·29 s; 2·34 s; 2·36 s; 2·65 s; 2·53 s.

(i) Starting with the appropriate equation of motion, show that the acceleration of the car is given by

$$a = \frac{2s}{t^2}$$

where the symbols have their usual meanings.

(ii) Calculate the average value of the car's acceleration.

(iii) Calculate the random uncertainty in the time measurement.

(iv) Calculate the percentage uncertainty in the average acceleration.

(v) Express the numerical result of her investigation in the form

final value ± absolute uncertainty. **7**

1. (continued)

(*b*) The student now places the car, which has a mass of 2·5 kg, on a horizontal circular track as shown in Figure 2.

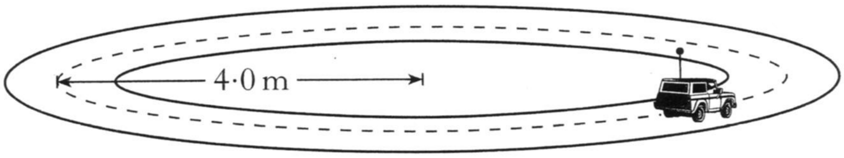

Figure 2

She uses the radio control to make the car travel with a constant speed of $6{\cdot}0\,\mathrm{m\,s^{-1}}$ around a circular path of radius 4·0 m.

(i) Calculate the car's radial acceleration.

(ii) The radial friction between the car's tyres and the track has a maximum value of 23 N.

Show that this force is sufficient to prevent the car skidding off the track. **4**

(*c*) The student now places the car on a banked track as shown in Figure 3.

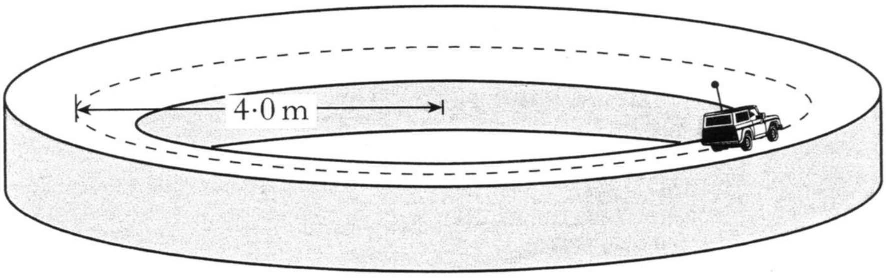

Figure 3

She again uses the radio control to make the car follow a circular path of radius 4·0 m.

Explain why the car can now travel much faster than $6{\cdot}0\,\mathrm{m\,s^{-1}}$ without skidding off the track. **2**

(13)

[Turn over

Marks

2. (*a*) A mass m rotates at a distance r from a fixed axis.

State the expression for its moment of inertia. **1**

(*b*) A toy gyroscope consists of an axle, a narrow ring and spokes as shown in Figure 4.

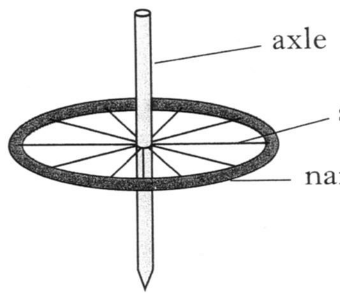

Figure 4

The mass of the axle and spokes is negligible compared to the mass of the narrow ring.

The narrow ring has a mass of 1·5 kg and an average radius of 0·20 m. Show that the moment of inertia of the gyroscope is 0·060 kg m^2. **1**

(*c*) The axle of the gyroscope has a radius of 4·0 mm.

The gyroscope is made to spin using a thin cord. A 0·50 m length of thin cord is wound round the axle, as shown in Figure 5.

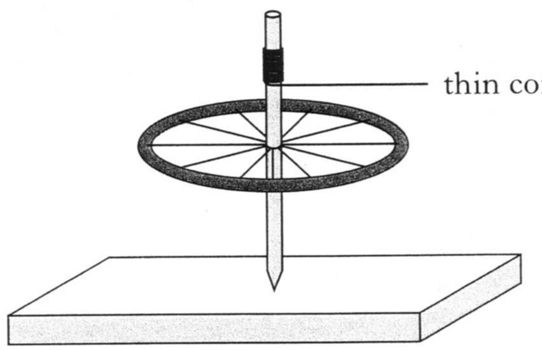

Figure 5

The cord is pulled with a steady horizontal force of 25 N.

A constant frictional torque of 0·070 N m opposes the motion of the gyroscope.

(i) Calculate the resultant torque acting on the gyroscope.

(ii) Calculate the angular acceleration of the gyroscope.

(iii) Show that the angular displacement of the gyroscope is 125 radians just as the cord fully unwinds.

(iv) Calculate the maximum angular velocity of the gyroscope.

(v) After the cord has fully unwound, the frictional torque remains constant. How long does it take for the angular velocity of the gyroscope to decrease to 4·2 rad s^{-1}? **11**

 (13)

3. (*a*) Figure 6 shows the Earth and the Moon, not drawn to scale.

Copy and complete the diagram to show the shape of the gravitational field lines between the Earth and the Moon. **2**

Figure 6

(*b*) Near the Moon the gravitational field can be considered to be radial.

Following a meteorite impact, a rock of mass 15 kg is ejected vertically from the Moon's surface. The rock just reaches a point P, which is $5{\cdot}0 \times 10^5$ m above the surface of the Moon.

The radius of the Moon is $1{\cdot}7 \times 10^6$ m.

(i) Calculate the potential energy of the rock:

(A) on the surface of the Moon;

(B) at point P.

(ii) Hence calculate the kinetic energy of the rock as it leaves the surface of the Moon.

(iii) Calculate the speed at which the rock is ejected from the surface of the Moon. **6**

(8)

[Turn over

Marks

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

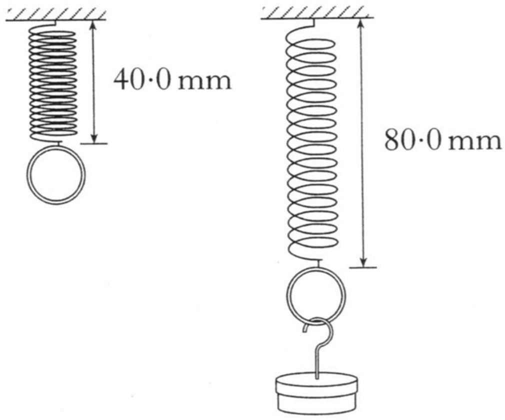

Figure 7

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. **1**

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

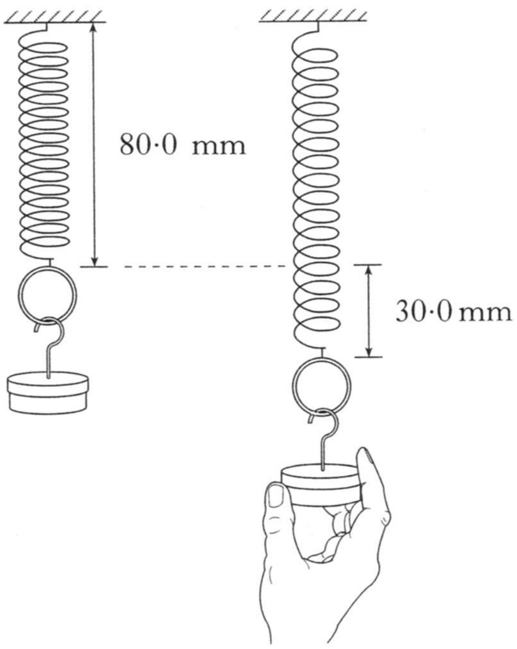

Figure 8

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.

(ii) Calculate the period of oscillation of the mass. **5**

(6)

Marks

5. (*a*) State what is meant by the electric field strength at a point. 1

(*b*) An arrangement for an electron gun is shown in Figure 9.

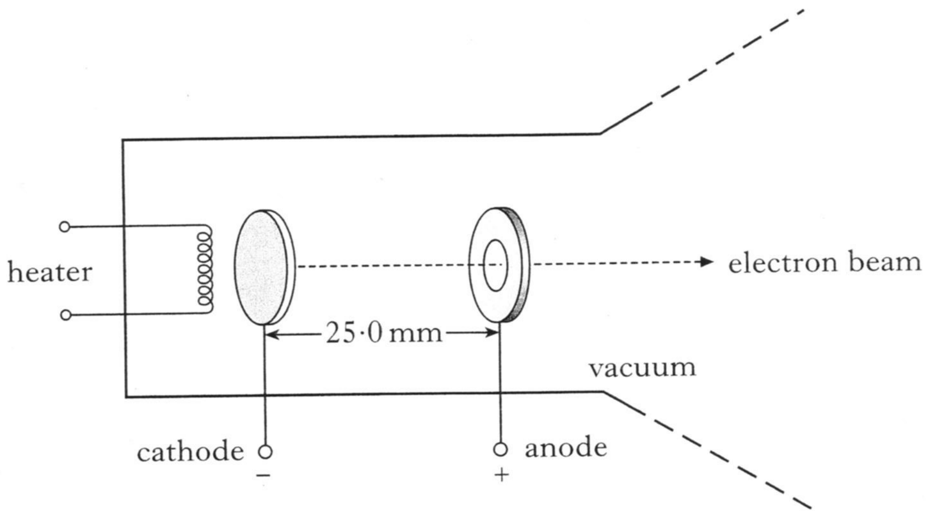

Figure 9

The electric field strength between the cathode and the anode has a constant value of $750\,N\,C^{-1}$. The distance between the anode and the cathode is 25·0 mm.

(i) Show that the acceleration of an electron between the cathode and the anode is $1{\cdot}32 \times 10^{14}\,m\,s^{-2}$.

(ii) Assuming that the electrons have negligible velocity at the cathode, calculate the speed of the electrons as they emerge from the anode. 4

(*c*) The relativistic mass of a particle is given by

$$m = \frac{m_0}{\sqrt{(1 - \frac{v^2}{c^2})}}$$

where the symbols have their usual meanings.

An electron is moving with velocity $1{\cdot}5 \times 10^8\,m\,s^{-1}$.

(i) Calculate the relativistic mass of this electron.

(ii) Calculate its relativistic energy. 4

(*d*) In a scattering experiment, a beam of alpha particles is fired at a tungsten target.

The kinetic energy of an alpha particle is $1{\cdot}17 \times 10^{-12}\,J$.

A tungsten nucleus has a charge of $+74e$.

Calculate the distance of closest approach between the alpha particle and the nucleus.

Relativistic effects can be ignored. 3

(12)

6. A single rectangular loop of wire is arranged vertically in the uniform magnetic field between the poles of a magnet as shown in Figure 10. The loop is free to spin about axis XY.

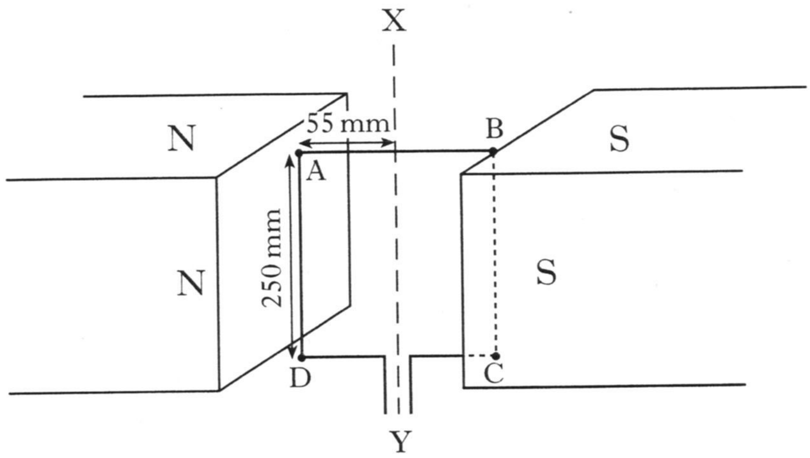

Figure 10

Sides AD and BC of the rectangle are 250 mm in length and each is 55 mm from the axis of rotation.

The loop of wire carries a current of 0·40 A.

The magnetic induction of the field is 0·60 T.

(*a*) Calculate the size of the magnetic force acting on side AD. **2**

(*b*) Figure 11 shows the loop when **viewed from above**.

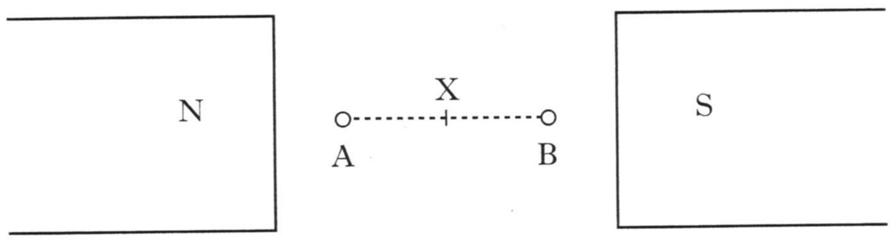

Figure 11

Calculate the magnitude of the torque acting on the loop. **2**

(*c*) The loop is turned through 30 ° to the position shown in Figure 12.

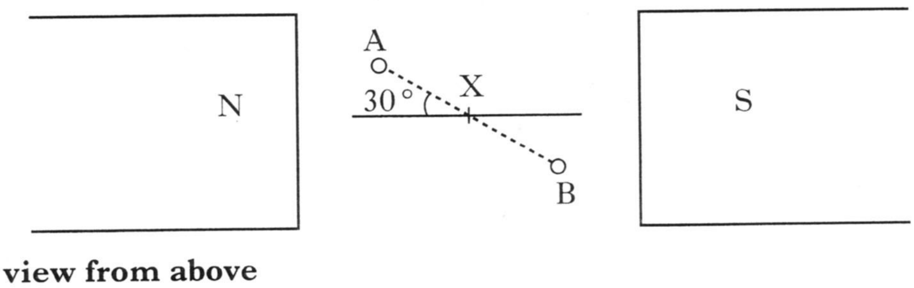

Figure 12

Calculate the magnitude of the torque now acting on the loop. **2**

6. (continued)

(*d*) The magnet is replaced by another magnet with the poles shaped as shown in Figure 13.

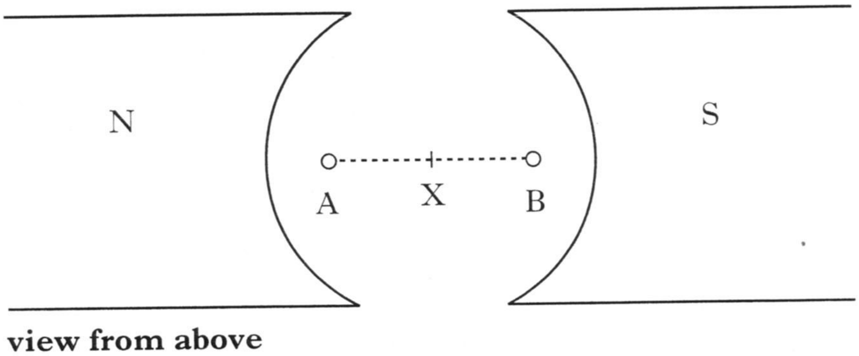

Figure 13

Explain how this arrangement reduces variation in the torque as the loop turns. **1**

(7)

[Turn over

Marks

7. (*a*) A long straight conductor PQ carries a current of 0·50 A.

Calculate the magnetic induction at a point 120 mm from the conductor. **2**

(*b*) A second long straight conductor RS is placed 120 mm from PQ. The conductors are parallel as shown in Figure 14.

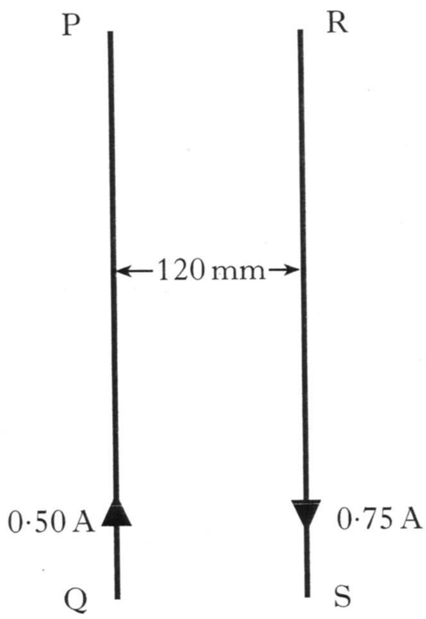

Figure 14

Conductor RS carries a current of 0·75 A in the opposite direction to the current in PQ.

Determine the magnitude and **direction** of the force per unit length exerted on conductor RS by conductor PQ. **3**

(5)

Marks

8. Electrons are fired through a vacuum containing a region of uniform electric and magnetic fields. The fields are at right angles to each other.

The initial direction of travel of the electrons is shown in Figure 15.

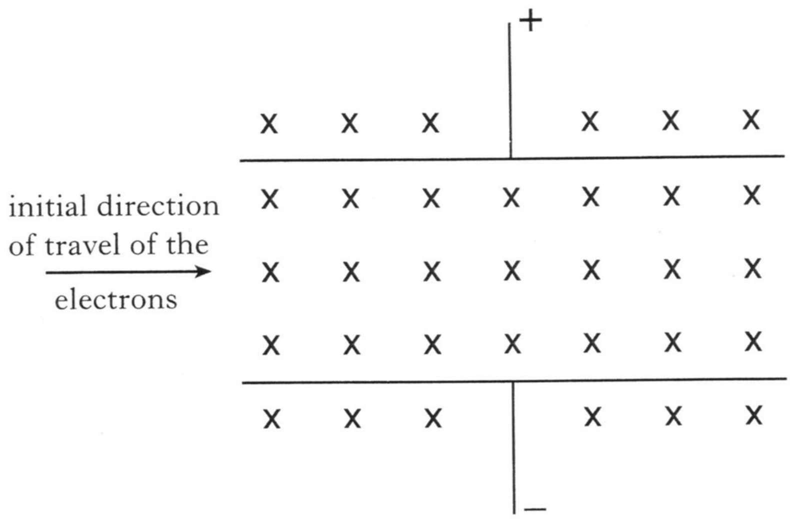

Figure 15

The field strengths are adjusted until the path of the electrons is a straight line.

(*a*) (i) In terms of electric and magnetic forces, explain why the path of an electron is a straight line.

(ii) The electric field strength is $4{\cdot}2 \times 10^3\,N\,C^{-1}$ and the magnetic field has a magnetic induction of $2{\cdot}8 \times 10^{-3}\,T$.

Calculate the speed of the electrons. **3**

(*b*) Alpha particles are now fired in the same direction through the above electric and magnetic fields.

The alpha particles are also found to travel in a straight line. How does the speed of the alpha particles compare to the speed of the electrons in part (*a*)?

You must justify your answer. **2**

(*c*) The electric field is switched off leaving only the magnetic field. Alpha particles and then electrons with the same velocity are fired, in the same direction as before, into this region.

Sketch the approximate paths followed by the alpha particles and electrons. **2**

(7)

[Turn over

9. (*a*) The circuit shown in Figure 16 contains an inductor, a resistor and a switch connected in series with a cell of e.m.f. 2·0 V.

The cell has negligible internal resistance and the resistance of the inductor is negligible.

The current in the circuit is measured using a computer interface.

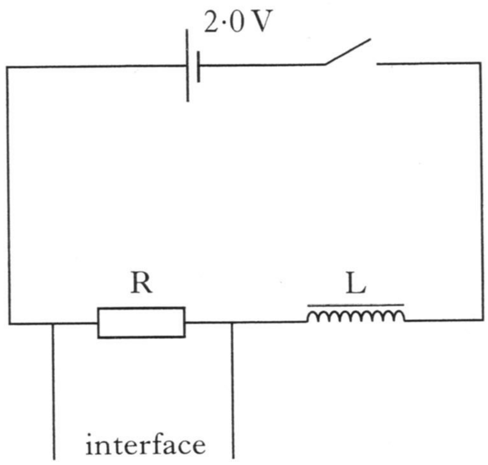

Figure 16

The switch is closed and the graph shown in Figure 17 is displayed on the computer screen.

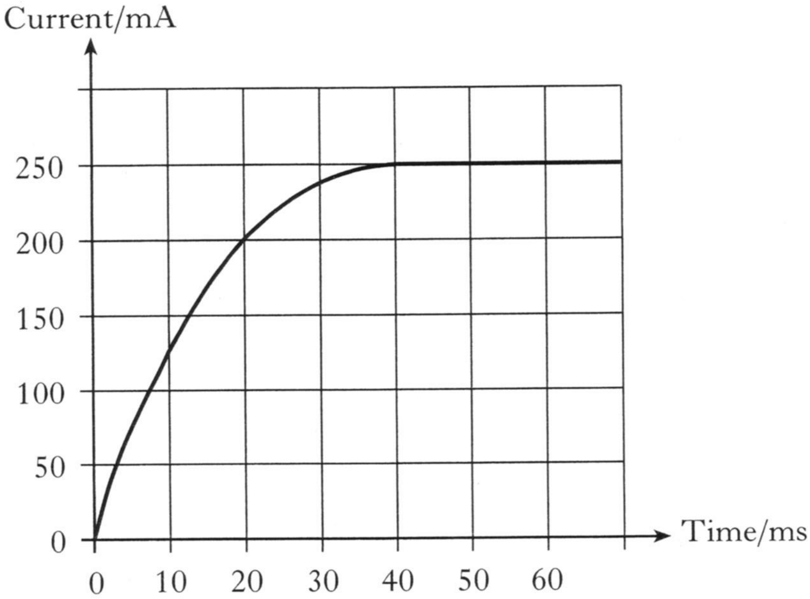

Figure 17

(i) Explain why there is a time delay in the current reaching its steady value.

(ii) Calculate the resistance of the circuit.

(iii) From the graph, the initial rate of change of current is estimated to be $20\ \text{A s}^{-1}$.

Calculate the self inductance of the coil.

(iv) Calculate the maximum energy stored in the inductor. **7**

9. (continued)

(*b*) A resistor and an inductor are connected in series to a variable frequency supply as shown in Figure 18.

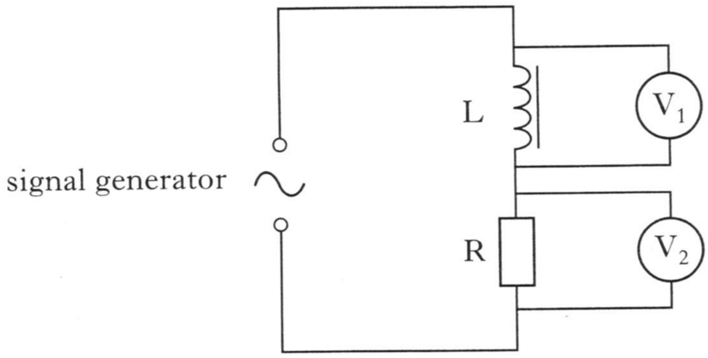

Figure 18

The supply voltage is kept constant as the frequency of the supply is increased.

State and **explain** the changes in the readings on voltmeters V_1 and V_2. **3**

(10)

[Turn over

Marks

10. 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. **3**

(*c*) Two points on the string are separated by a horizontal distance of 24 mm. Calculate the phase difference between these points. **2**

(*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**

(7)

Marks

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

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

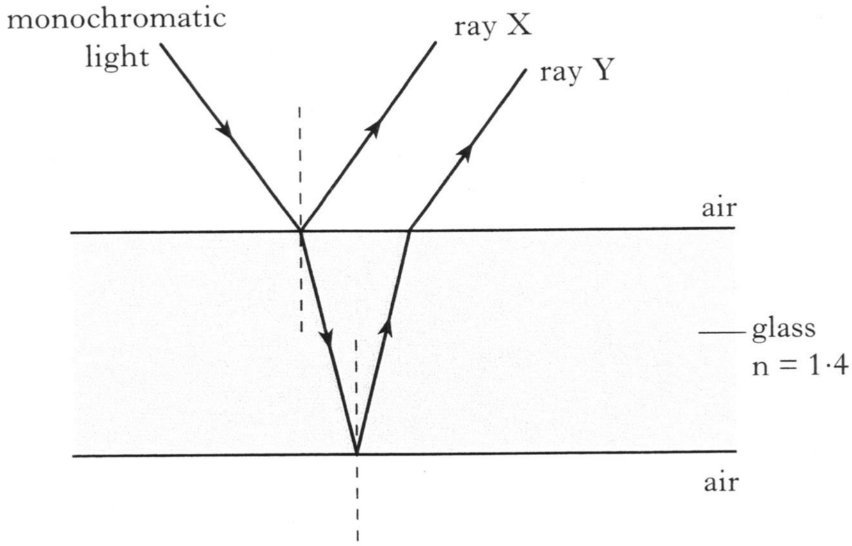

Figure 19

Ray Y has travelled further than ray X.

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

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

(A) constructive interference of rays X and Y;

(B) destructive interference of rays X and Y.

(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. **4**

(*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.

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

(7)

[Turn over

Marks

12. (*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.

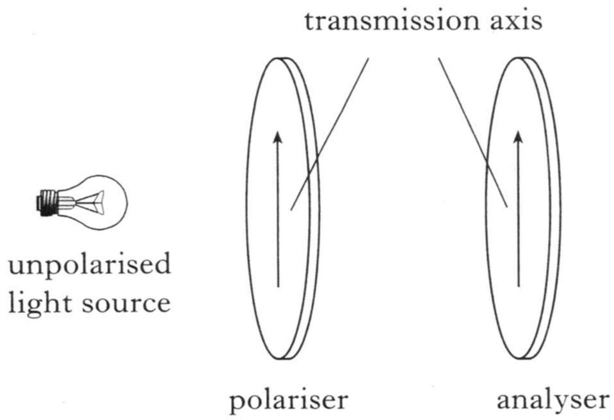

Figure 20

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. **2**

12. (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.

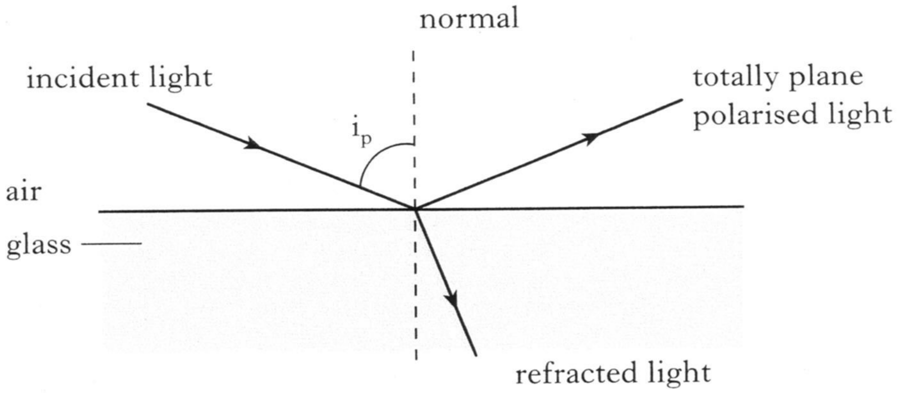

Figure 22

Show that,

$$\tan i_p = n$$

where n is the refractive index of the glass. **2**

(5)

[*END OF QUESTION PAPER*]

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