FOR OFFICIAL USE

AH

National Qualifications

Mark

X857/77/01 Physics

Duration — 3 hours

X8577701

Fill in these boxes and read what is printed below.

Full name of centre

Town

Forename(s)

Surname

Number of seat

Date of birth

Day

Month

Year

Scottish candidate number

Total marks — 155

Attempt ALL questions.

Reference may be made to the Physics Relationships Sheet X857/77/11 and the Data Sheet on *page 02*.

Write your answers clearly in the spaces provided in this booklet. Additional space for answers and rough work is provided at the end of this booklet. If you use this space you must clearly identify the question number you are attempting. Any rough work must be written in this booklet. You should score through your rough work when you have written your final copy.

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

Use **blue** or **black** ink.

Before leaving the examination room you must give this booklet to the Invigilator; if you do not, you may lose all the marks for this paper.

DATA SHEET

COMMON PHYSICAL QUANTITIES

Quantity	Symbol	Value	Quantity	Symbol	Value
Gravitational acceleration on Earth	g	$9{\cdot}8\ \text{m s}^{-2}$	Mass of electron	m_e	$9{\cdot}11 \times 10^{-31}$ kg
Radius of Earth	R_E	$6{\cdot}4 \times 10^{6}$ m	Charge on electron	e	$-1{\cdot}60 \times 10^{-19}$ C
Mass of Earth	M_E	$6{\cdot}0 \times 10^{24}$ kg	Mass of neutron	m_n	$1{\cdot}675 \times 10^{-27}$ kg
Mass of Jupiter	M_J	$1{\cdot}90 \times 10^{27}$ kg	Mass of proton	m_p	$1{\cdot}673 \times 10^{-27}$ kg
Radius of Jupiter	R_J	$7{\cdot}15 \times 10^{7}$ m	Mass of alpha particle	m_α	$6{\cdot}645 \times 10^{-27}$ kg
Mean Radius of Jupiter Orbit		$7{\cdot}79 \times 10^{11}$ m	Charge on alpha particle		$3{\cdot}20 \times 10^{-19}$ C
Solar radius		$6{\cdot}955 \times 10^{8}$ m	Charge on copper nucleus		$4{\cdot}64 \times 10^{-18}$ C
Mass of Sun		$2{\cdot}0 \times 10^{30}$ kg	Planck's constant	h	$6{\cdot}63 \times 10^{-34}$ J s
1 AU		$1{\cdot}5 \times 10^{11}$ m	Permittivity of free space	ε_0	$8{\cdot}85 \times 10^{-12}\ \text{F m}^{-1}$
Stefan-Boltzmann constant	σ	$5{\cdot}67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$	Permeability of free space	μ_0	$4\pi \times 10^{-7}\ \text{H m}^{-1}$
Universal constant of gravitation	G	$6{\cdot}67 \times 10^{-11}\ \text{m}^3\ \text{kg}^{-1}\ \text{s}^{-2}$	Speed of light in vacuum	c	$3{\cdot}00 \times 10^{8}\ \text{m s}^{-1}$
			Speed of sound in air	v	$3{\cdot}4 \times 10^{2}\ \text{m s}^{-1}$

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
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 } 10 590 }	Infrared
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	$2{\cdot}70 \times 10^{3}$	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	$4{\cdot}18 \times 10^{3}$	$3{\cdot}34 \times 10^{5}$	$2{\cdot}26 \times 10^{6}$
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	$9{\cdot}18 \times 10^{2}$	....	$2{\cdot}40 \times 10^{4}$

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

X857770102

Total marks —155

Attempt ALL questions

MARKS DO NOT WRITE IN THIS MARGIN

1. During a rollercoaster ride, a train is moving along a track as shown in **Figure 1A**.

Figure 1A

At time $t = 0$, the train reaches a straight section of track. It takes 4·0 seconds to move over this section of track.

The horizontal velocity v_h of the train, over this section of track, is given by the relationship

$$v_h = 8 + 4t^2 - \frac{2}{3}t^3$$

where v_h is in m s^{-1} and t is in s.

Using calculus methods

(a) determine the horizontal acceleration of the train at $t = 4{\cdot}0$ s **3**

Space for working and answer

(b) determine the horizontal displacement of the train at $t = 4{\cdot}0$ s. **3**

Space for working and answer

[Turn over

2. A cyclist is using an exercise bicycle.

A large flywheel forms part of the exercise bicycle, as shown in **Figure 2A**.

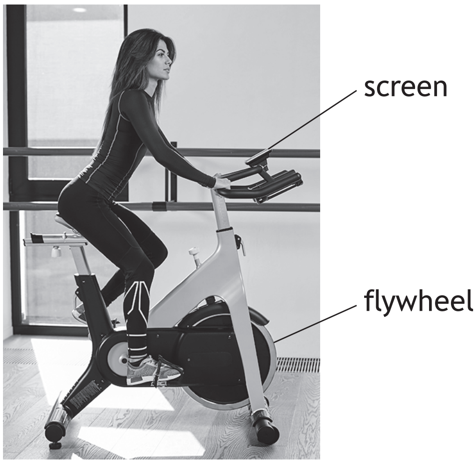

Figure 2A

The rotational motion of the flywheel is monitored by sensors at its outer edge.

Data from the sensors is used to calculate equivalent linear speeds, which are displayed on the screen.

(a) The cyclist is pedalling steadily.

A constant linear speed of $6{\cdot}7\ \mathrm{m\,s^{-1}}$ is displayed on the screen.

(i) The flywheel has a radius of 0·35 m.

Calculate the angular velocity of the flywheel. **3**

Space for working and answer

2. (a) (continued) MARKS | DO NOT WRITE IN THIS MARGIN

(ii) The cyclist now stops pedalling for 5·5 seconds and the flywheel slows down due to a constant frictional torque.

The flywheel has a constant angular acceleration of $-2{\cdot}4\ \text{rad s}^{-2}$.

Determine the number of revolutions made by the flywheel in this time. **4**

Space for working and answer

(iii) The cyclist reduces the frictional torque acting on the flywheel.

The cyclist resumes pedalling until the screen again displays a linear speed of $6{\cdot}7\ \text{m s}^{-1}$.

The cyclist then stops pedalling for another 5·5 seconds.

State how the number of revolutions made by the flywheel in this 5·5 seconds compares with your answer to (a) (ii).

Justify your answer. **2**

[Turn over

MARKS DO NOT WRITE IN THIS MARGIN

2. (continued)

(b) The frictional torque is produced by a brake pad in contact with the flywheel.

Figure 2B shows four possible positions A, B, C, and D at which the brake pad could come into contact with the flywheel.

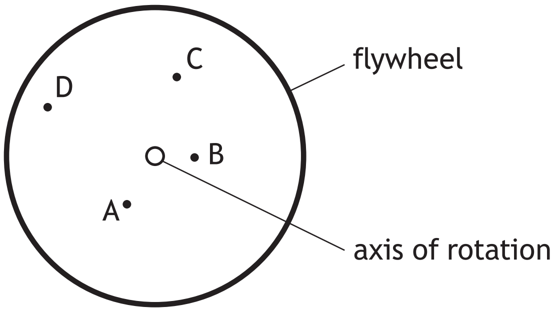

Figure 2B

The brake pad would apply the same force in each of these positions.

State which of **these** positions would allow the brake pad to produce the greatest frictional torque on the flywheel.

Justify your answer. **2**

MARKS DO NOT WRITE IN THIS MARGIN

3. The apparatus shown in **Figure 3A** is used to investigate conservation of angular momentum.

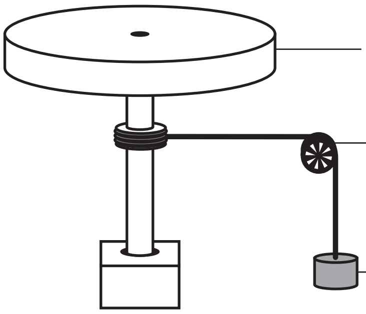

Figure 3A

A sensor in the smart pulley is used to determine the angular velocity and angular acceleration of the rotating disc.

(a) During one experiment, the torque applied to the rotating disc is $6{\cdot}30 \times 10^{-3}$ N m. This torque produces an angular acceleration of $0{\cdot}618$ rad s^{-2}.

Show that the moment of inertia of the rotating disc is $1{\cdot}02 \times 10^{-2}$ kg m^2. **2**

Space for working and answer

(b) (i) State the principle of conservation of angular momentum. **1**

3. (b) (continued)

(ii) In another experiment, the rotating disc has a constant angular velocity of 7·75 rad s^{-1}.

A small cube is dropped onto the rotating disc close to the axis of rotation. The cube remains at a constant distance from the axis of rotation.

The angular velocity of the rotating disc decreases to 5·74 rad s^{-1}.

Determine the moment of inertia of the cube at this position. **3**

Space for working and answer

(iii) The small cube is removed and the disc is again set to rotate at a constant angular velocity of 7·75 rad s^{-1}.

A small cube of greater mass is now dropped onto the rotating disc. This cube remains at the same distance from the axis of rotation as the cube in (b) (ii).

State whether the resulting angular velocity of the rotating disc is more than, equal to or less than 5·74 rad s^{-1}.

You must justify your answer. **2**

[Turn over

4. A space probe is travelling through the region of space known as the Kuiper Belt. The Kuiper Belt lies beyond the orbit of Neptune and contains a large number of small asteroids.

As the probe passes through the Kuiper Belt, it travels close to two asteroids. Both asteroids can be approximated as spherical masses.

This is shown in **Figure 4A**.

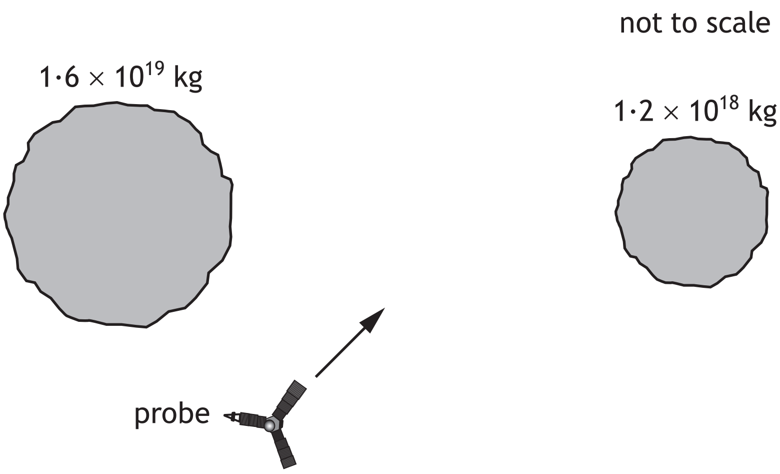

Figure 4A

(a) (i) State what is meant by the term *gravitational field strength*. **1**

(ii) On **Figure 4B**, sketch the gravitational field lines in the region between the asteroids. Gravitational effects from other objects can be ignored. **2**

Figure 4B

(An additional diagram, if required, can be found on *page 51*.)

4. (a) (continued)

MARKS DO NOT WRITE IN THIS MARGIN

(iii) The probe must reach point P. Two possible paths to this point are shown on **Figure 4C**.

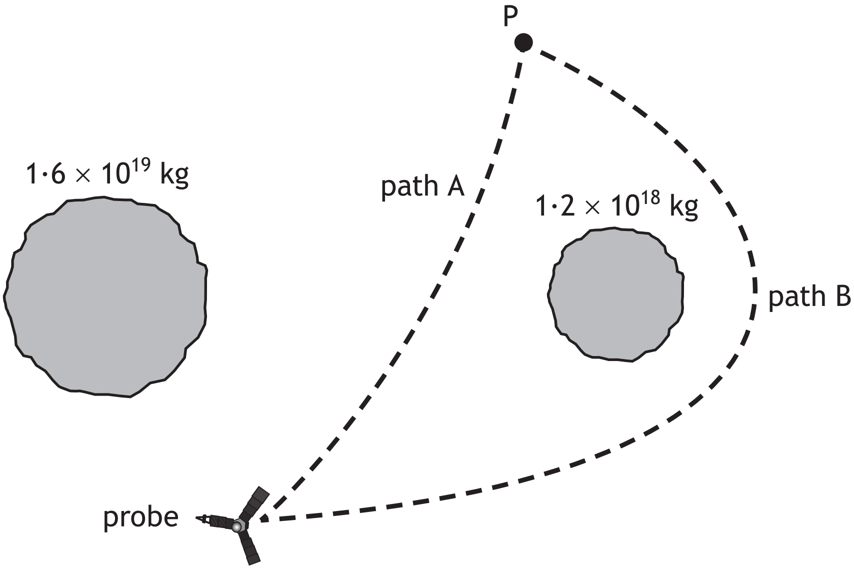

Figure 4C

State whether the energy required to move the probe to point P via path A will be more than, equal to or less than the energy required to move the probe to point P via path B.

Justify your answer. **2**

[Turn over

4. (continued) **MARKS** DO NOT WRITE IN THIS MARGIN

(b) As the probe travels further from Earth, its on-board clock becomes increasingly desynchronised from clocks on Earth.

State whether the clock on board the probe runs faster or slower than clocks on Earth.

You must justify your answer. **2**

(c) Another asteroid in the Kuiper Belt is at a distance of 49·8 AU from the Sun.

Calculate the minimum velocity for this asteroid to escape the gravitational field of the Sun. **4**

Space for working and answer

5. A 'coin vortex donation box' used for charitable donations is shown in **Figure 5A**.

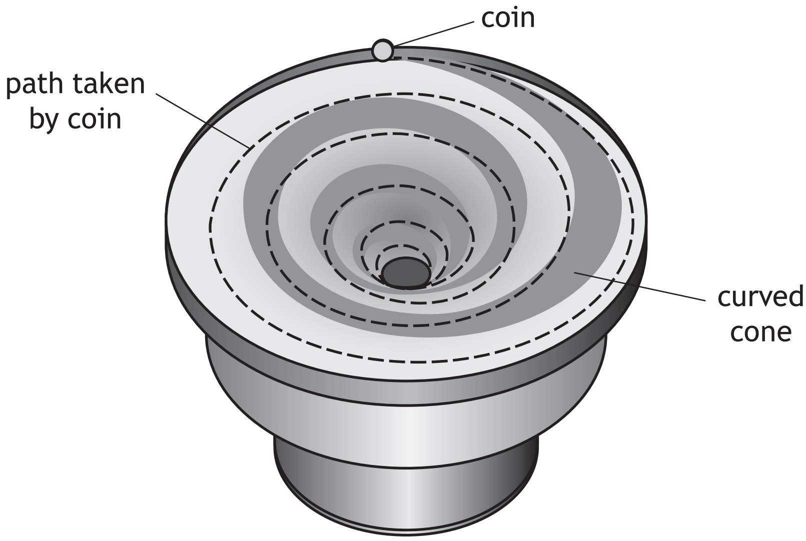

Figure 5A

The donation box has a curved cone. Coins will roll round the curved cone in a spiral path before falling into the centre.

A physics teacher watching a coin roll as it falls into the centre, makes the following observation.

> *'This is an excellent model for visualising how a small object follows the curvature of spacetime around a larger object.*
>
> *However, the model isn't perfect.'*

Using your knowledge of physics, comment on this observation. **3**

MARKS | DO NOT WRITE IN THIS MARGIN

6. The star HD 209458, in the constellation Pegasus, has similar properties to the Sun.

(a) State the name given to the series of fusion reactions that converts hydrogen to helium inside the core of stars such as HD 209458. **1**

(b) The surface temperature of HD 209458 is 6070 K and its radius is $8{\cdot}35 \times 10^8$ m.

(i) Calculate the luminosity of HD 209458. **3**

Space for working and answer

(ii) HD 209458 is 159 light-years from Earth.

Determine the apparent brightness of HD 209458 when viewed from Earth. **4**

Space for working and answer

[Turn over

DO NOT WRITE IN THIS MARGIN

6. (continued)

(c) Observations made of HD 209458 from Earth found that its apparent brightness varies periodically.

These variations are shown in **Figure 6A**.

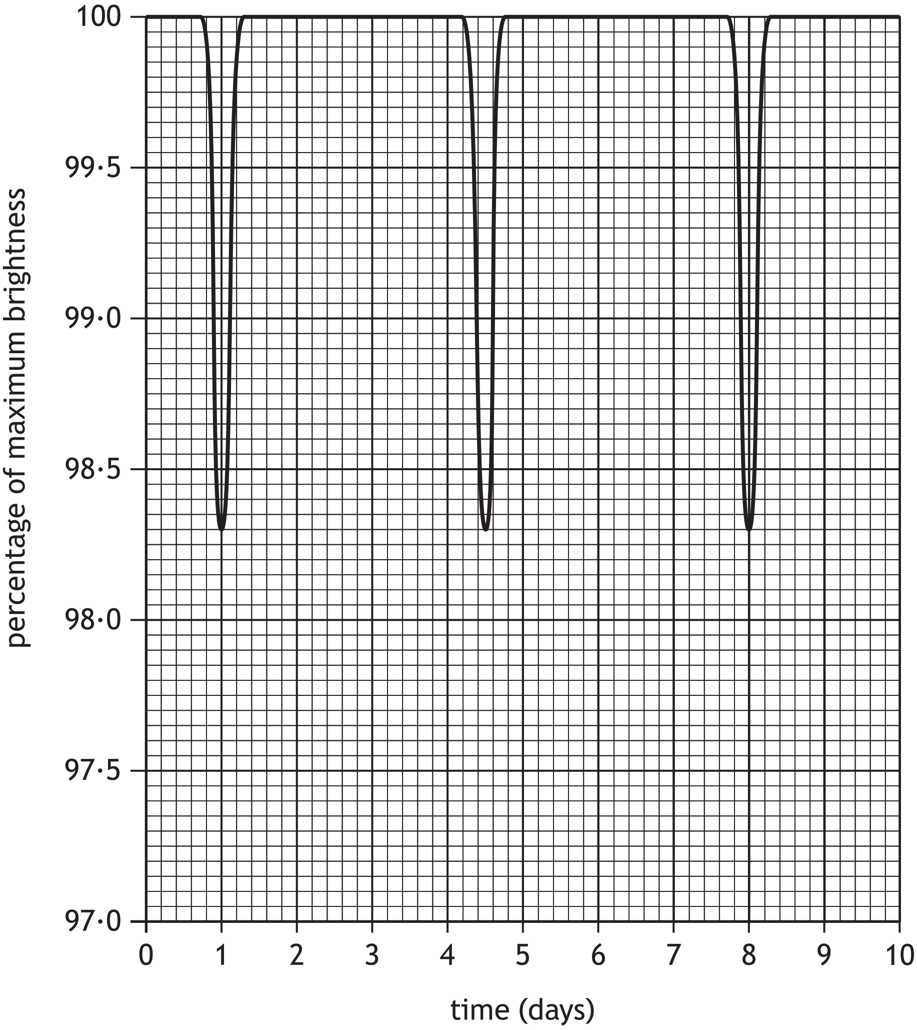

Figure 6A

An explanation for this variation is that a planet is in a circular orbit around HD 209458 and periodically passes between the star and Earth.

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6. (c) (continued)

(i) Using data from the graph, determine the angular velocity, in $rad\,s^{-1}$, of this planet. **4**

Space for working and answer

(ii) The mass of HD 209458 is estimated to be $2{\cdot}5 \times 10^{30}$ kg.

By considering the gravitational force acting on the planet orbiting HD 209458, calculate the distance between the star and this planet. **3**

Space for working and answer

[Turn over

MARKS DO NOT WRITE IN THIS MARGIN

7. (a) The existence of line spectra is evidence for the wave-like behaviour of particles.

State one piece of experimental evidence for the particle-like behaviour of waves. **1**

(b) In the Bohr model of the hydrogen atom, an electron is considered to orbit a proton in one of a number of discrete orbits.

The orbits are identified by a principal quantum number n.

This model is shown in **Figure 7A**.

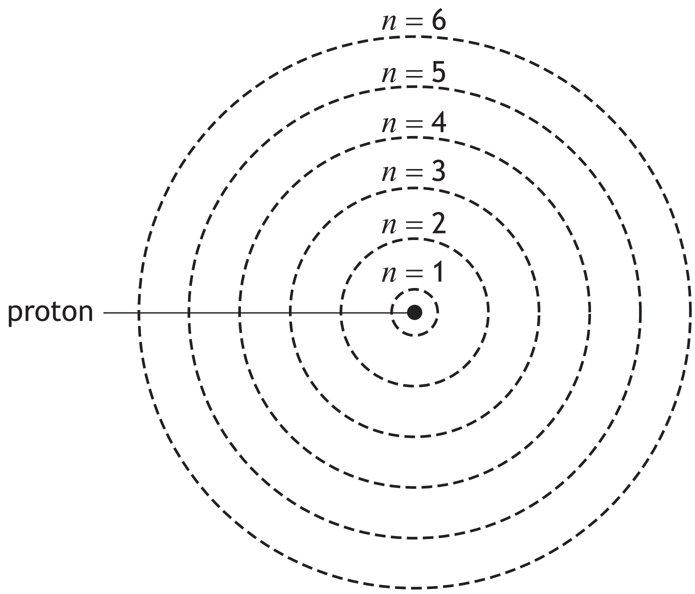

Figure 7A

These discrete orbits can be explained in terms of the quantisation of angular momentum of the electron.

MARKS | DO NOT WRITE IN THIS MARGIN

7. (b) (continued)

(i) The radius of the second orbit, where $n = 2$, is $2{\cdot}12 \times 10^{-10}$ m.

Show that the speed of an electron in this orbit is $1{\cdot}09 \times 10^{6}$ m s^{-1}. **2**

Space for working and answer

(ii) By calculating the de Broglie wavelength of an electron in the second orbit, explain why the electron can be considered as a wave. **4**

Space for working and answer

[Turn over

7. (continued)

(c) The visible spectral lines of hydrogen are shown in **Figure 7B**.

Figure 7B

Spectral lines are produced by electron transitions.

The transitions that produce each visible line in the hydrogen spectrum are represented in **Figure 7C**.

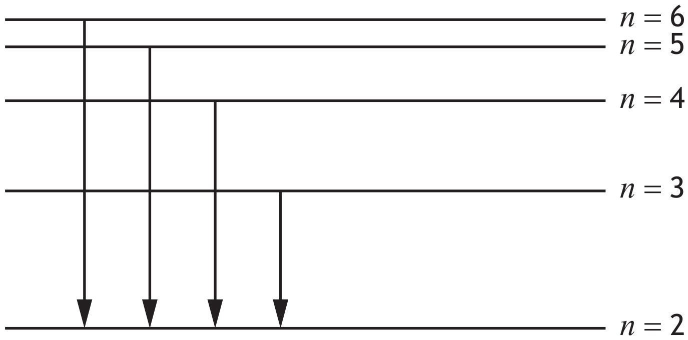

Figure 7C

The wavelengths of **these spectral lines** can be calculated using the relationship

$$\frac{1}{\lambda} = RZ^2\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

where R is the Rydberg constant
Z is the atomic number of hydrogen
n_i is the principal quantum number of the initial orbit
n_f is the principal quantum number of the final orbit.

Electrons making the transition from $n = 6$ to $n = 2$ produce the **violet** line in the hydrogen spectrum.

Determine the Rydberg constant. **2**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

8. Polonium-212 (Po-212) undergoes nuclear decay by emitting alpha particles.

(a) Alpha particle emission from Po-212 can be explained using the concept of quantum tunnelling.

State what is meant by *quantum tunnelling*. **1**

(b) The diameter of the nucleus of Po-212 is taken to be 54 femtometres.

When a Po-212 nucleus emits an alpha particle there is a minimum uncertainty in the position of the alpha particle equal to the diameter of the nucleus.

Calculate the minimum uncertainty $\Delta p_{x_{\min}}$ in the momentum of the alpha particle as it is emitted from the nucleus. **3**

Space for working and answer

[Turn over

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8. **(continued)**

MARKS | DO NOT WRITE IN THIS MARGIN

(c) Alpha particles with a specific speed are used to probe the nuclei of copper atoms in a target.

A sample of Po-212 emits alpha particles with a range of speeds.

A velocity selector is a device that will allow only alpha particles with a specific speed to pass straight through to the target.

This is shown in **Figure 8A**.

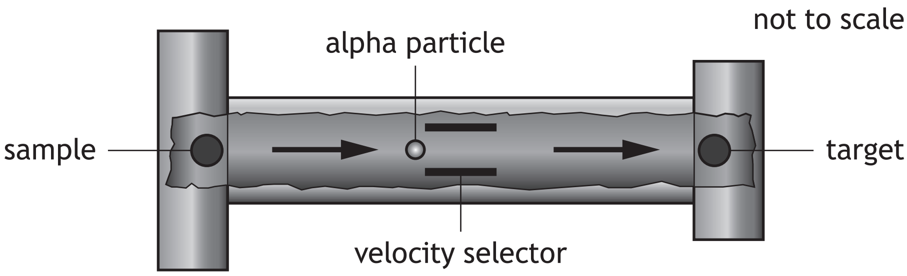

Figure 8A

(i) The velocity selector has a region in which there is a uniform electric field and a uniform magnetic field. These fields are perpendicular to each other and also perpendicular to the initial velocity v of the alpha particles, as shown in **Figure 8B**.

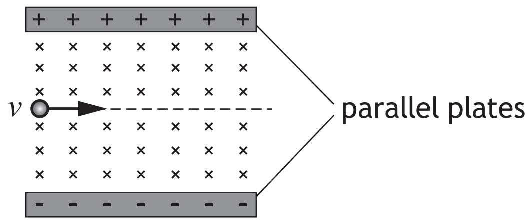

Figure 8B

(A) Calculate the speed of an alpha particle with kinetic energy 8·8 MeV. **4**

Space for working and answer

8. (c) (i) (continued)

(B) By considering the forces acting on an alpha particle in the velocity selector, show that the speed v of the particle travelling straight through is given by

$$v = \frac{E}{B}$$ 2

Space for working and answer

(C) The potential difference between the parallel plates is 27 kV.

The plate separation is 15 mm.

Determine the magnetic induction that allows alpha particles with kinetic energy 8·8 MeV to pass straight through the velocity selector. 3

Space for working and answer

[Turn over

MARKS | DO NOT WRITE IN THIS MARGIN

8. (c) (continued)

(ii) An alpha particle with kinetic energy 8·8 MeV approaches a copper nucleus head-on as shown in **Figure 8C**.

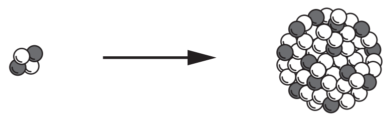

Figure 8C

The distance of closest approach r of the alpha particle to the copper nucleus is given by

$$r = \frac{qQ}{2\pi\varepsilon_0 m v^2}$$

where q is the charge on the alpha particle
Q is the charge on the copper nucleus
m is the mass of the alpha particle
v is the speed of the alpha particle.

Calculate the distance of closest approach of the alpha particle to the copper nucleus. **2**

Space for working and answer

8. (continued)

(d) A second alpha particle with kinetic energy greater than 8·8 MeV enters the velocity selector.

On **Figure 8D**, draw the path taken by this alpha particle in the velocity selector. **1**

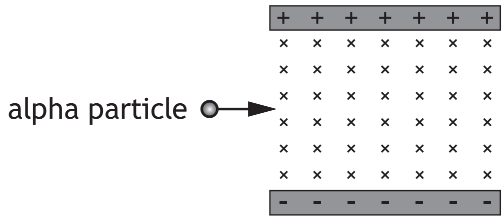

Figure 8D

(An additional diagram, if required, can be found on *page 51*.)

[Turn over

9. Bungee jumping involves a person jumping from a high structure while attached to an elastic cord. A bungee jumper is shown in **Figure 9A**.

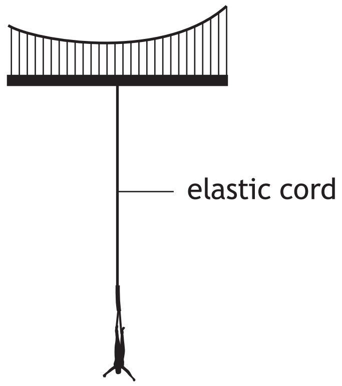

Figure 9A

The subsequent motion of the bungee jumper can be modelled as simple harmonic motion (SHM).

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

(b) The displacement of a mass undergoing SHM is represented by the relationship

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

Show that this relationship is a solution to the equation

$$F = -m\omega^2 y$$

where the symbols have their usual meaning. **3**

9. **(continued)** **MARKS**

DO NOT WRITE IN THIS MARGIN

(c) (i) The spring constant k for the elastic cord is $1{\cdot}5 \times 10^2\ \text{N m}^{-1}$. The bungee jumper has a mass of 77 kg.

Show that the angular frequency of the bungee jumper is $1{\cdot}4\ \text{rad s}^{-1}$. **3**

Space for working and answer

(ii) The maximum speed of the bungee jumper during SHM is $18\ \text{m s}^{-1}$.

Calculate the amplitude of the motion of the bungee jumper during SHM. **3**

Space for working and answer

(iii) Calculate the maximum potential energy stored in the elastic cord. **3**

Space for working and answer

[Turn over

9. (continued)

(d) The motion of the bungee jumper is better modelled as underdamped SHM.

On **Figure 9B**, sketch a graph showing the variation of displacement of the bungee jumper from the equilibrium position with time.

Your sketch should show **two** oscillations from the moment that the bungee jumper first passes through the equilibrium position at $t = 0$.

Numerical values are **not** required on either axis. **2**

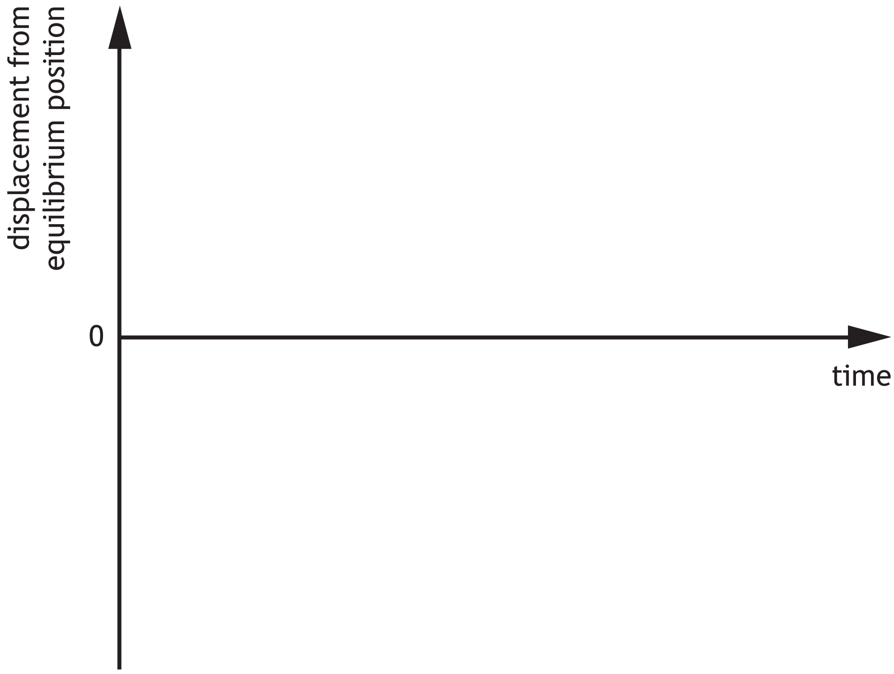

Figure 9B

(An additional graph, if required, can be found on *page 52*.)

(e) The bungee jumper now performs a second jump using a shorter elastic cord, which has the same spring constant as the original cord.

State how the angular frequency of the motion of the bungee jumper during the second jump compares to the value given in (c)(i).

Justify your answer. **2**

MARKS DO NOT WRITE IN THIS MARGIN

10. Zinc oxide is increasingly being used as an anti-reflection coating on optoelectronic devices. This coating is shown in **Figure 10A**.

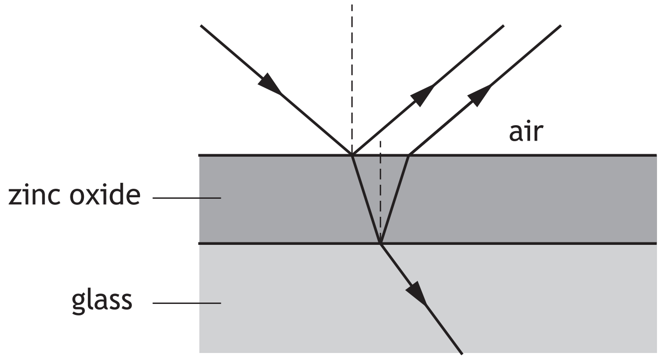

Figure 10A

The refractive index of zinc oxide n_z is greater than both the refractive index of the glass and the refractive index of air.

This coating is non-reflecting for a specific wavelength of light to maximise the transmission of light into the optoelectronic device.

(a) Explain briefly why a particular thickness of zinc oxide coating is non-reflecting for a specific wavelength of light. **1**

(b) (i) State the phase change experienced by a light wave travelling in air when it is reflected from an interface with zinc oxide. **1**

(ii) State the phase change experienced by a light wave travelling in zinc oxide when it is reflected from an interface with glass. **1**

[Turn over

MARKS | DO NOT WRITE IN THIS MARGIN

10. (continued)

(c) The minimum film thickness d for maximum transmission of light into the optoelectronic device is given by

$$d = \frac{\lambda}{2n_z}$$

where λ is the specific wavelength of the light for which the coating is non-reflecting.

(i) The refractive index of zinc oxide is dependent upon the wavelength of the incident light. The relationship between wavelength of light λ in air and refractive index n_z of zinc oxide is shown in **Figure 10B**.

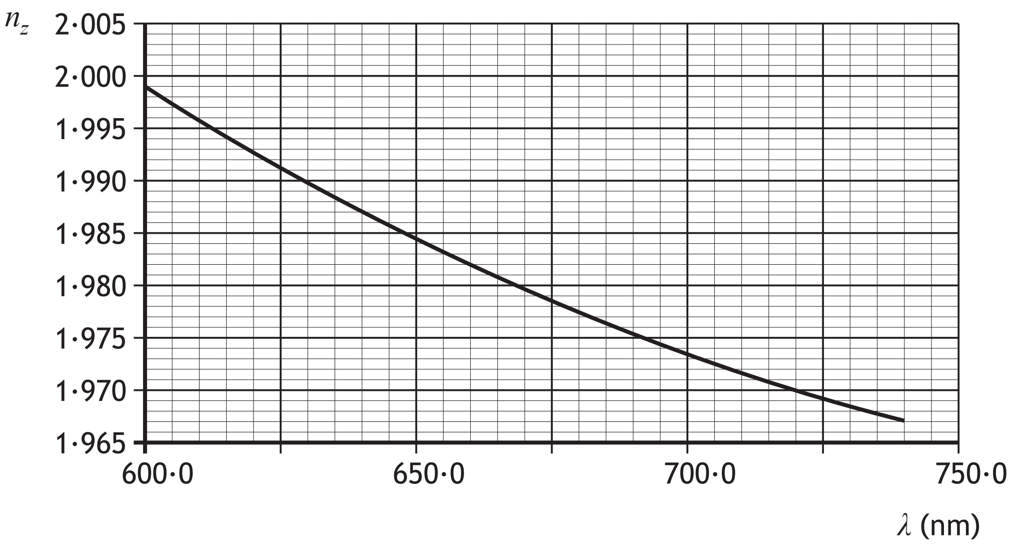

Figure 10B

Determine the minimum film thickness required to make the coating non-reflecting for light of wavelength 660·0 nm. **2**

Space for working and answer

10. (c) (continued) MARKS DO NOT WRITE IN THIS MARGIN

(ii) When viewed under white light this zinc oxide coating appears blue-green in colour.

Explain this observation. **2**

(d) The wave equation for light that has passed through the film into the glass is given by

$$y = 1{\cdot}60 \times 10^{3} \sin 2\pi \left(4{\cdot}55 \times 10^{14} t - \frac{x}{4{\cdot}37 \times 10^{-7}} \right)$$

where y is the electric field strength of the light wave in $\mathbf{V\,m^{-1}}$.

(i) Using data from the wave equation, determine the speed of this light in the glass. **3**

Space for working and answer

(ii) The light wave loses energy as it travels through the glass. At one point in the glass the energy of the light wave would reduce to 90% of its original value.

Determine the amplitude of the electric field strength of the light wave at this point. **3**

Space for working and answer

[Turn over

MARKS | DO NOT WRITE IN THIS MARGIN

11. A teacher sets up an experiment to determine Brewster's angle for Perspex.

The experimental set-up is shown in **Figure 11A**.

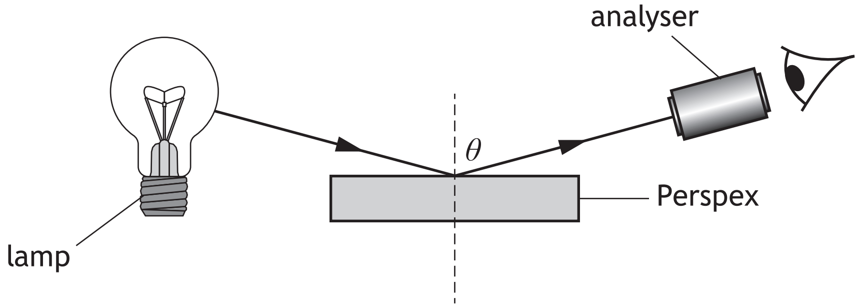

Figure 11A

The lamp produces unpolarised light.

Light from the lamp is reflected from the surface of the Perspex and is viewed through the analyser.

The position of the analyser is set so that angle θ is equal to Brewster's angle i_p.

The transmission axis of the analyser is at right angles to the plane of polarisation of light reflected from the surface of the Perspex at Brewster's angle.

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

(b) (i) Complete **Figure 11B** to show the path of the ray of light that is refracted into the Perspex. **1**

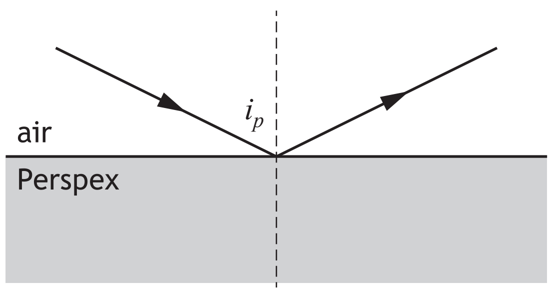

Figure 11B

(An additional diagram, if required, can be found on *page 52*.)

MARKS DO NOT WRITE IN THIS MARGIN

11. (b) (continued)

(ii) Calculate Brewster's angle for Perspex. **3**

Space for working and answer

(c) Using the same apparatus, the analyser is gradually moved as shown in **Figure 11C**.

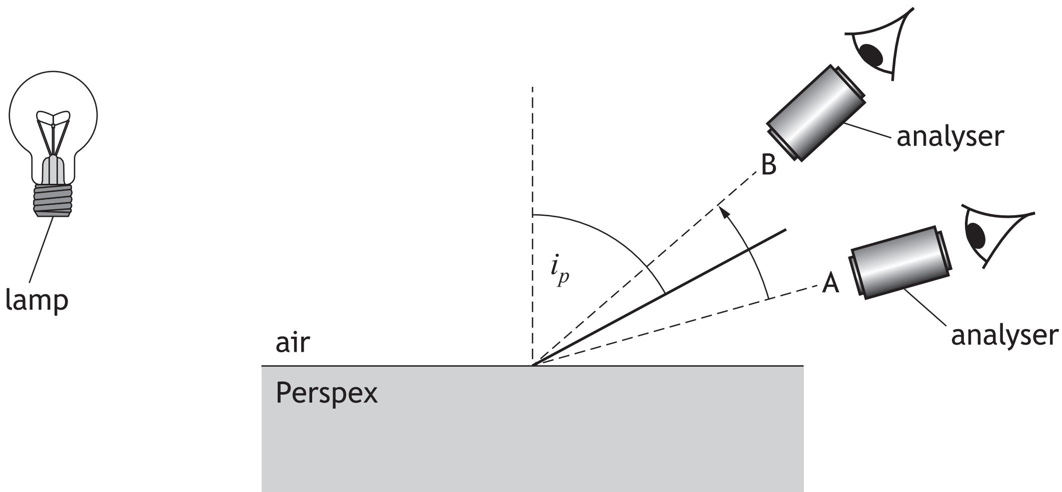

Figure 11C

Describe how the brightness of the reflected light, viewed through the analyser, changes when the analyser is gradually moved from position A, through Brewster's angle, to position B. **2**

[Turn over

* X 8 5 7 7 7 0 1 3 5 *

12. A student makes the following evaluative statements about an experiment.

- *The experiment could be made more accurate by repeating the measurements more times.*
- *More accuracy could be obtained by using a better meter with more decimal places.*
- *Some of the meters were old and so they had probably lost precision over the years.*
- *The random uncertainty was very high so more repeated measurements would help.*

Using your knowledge of experimental physics, comment on these evaluative statements. **3**

13. Q_1 is a point charge. The distance r between Q_1 and position Y is 0·400 m. This is shown in **Figure 13A**.

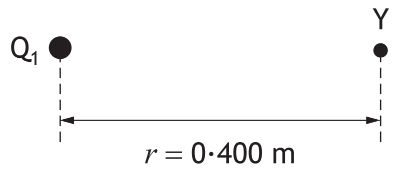

Figure 13A

(a) The electric field strength at position Y is $+144\ \text{N C}^{-1}$.

Calculate the charge Q_1. **3**

Space for working and answer

(b) Calculate the electrical potential at position Y. **3**

Space for working and answer

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13. (continued)

(c) Position X is further away from Q_1 than position Y, as shown in **Figure 13B**.

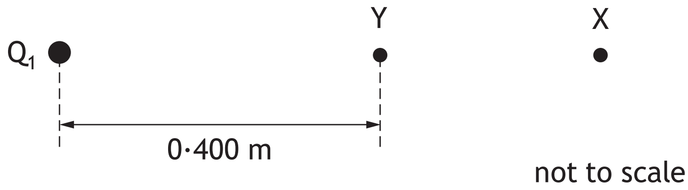

Figure 13B

The electrical potential at position X is +19·2 V.

Determine the work done in moving a point charge of $+2{\cdot}00 \times 10^{-12}$ C from position X to position Y. **4**

Space for working and answer

[Turn over

14. Proton beam therapy is a medical treatment. Protons are accelerated to specific velocities using a cyclotron.

A cyclotron is a particle accelerator that consists of two D-shaped hollow structures, called Dees, placed in a vacuum. The Dees are separated by a gap.

This is shown in **Figure 14A**.

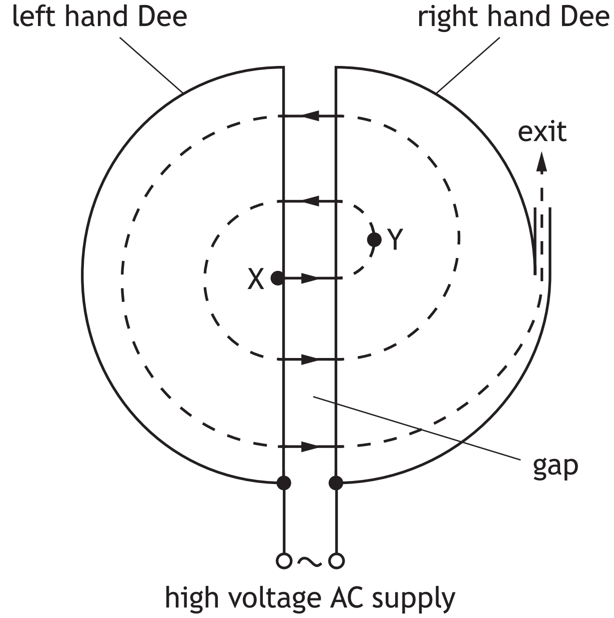

Figure 14A

During testing, protons are introduced to the cyclotron at point X.

The protons are accelerated from rest across the gap by an electric field.

Inside the Dees there is a uniform magnetic field B.

This field acts on the protons causing them to move in semi-circular paths within the Dees.

(a) Determine the direction of the magnetic field B. **1**

14. (continued) MARKS DO NOT WRITE IN THIS MARGIN

(b) (i) By considering the force acting on a proton as it moves in a semi-circular path, show that its speed at point Y is

$$v = \frac{qBr}{m}$$

where the symbols have their usual meaning. **2**

(ii) The magnetic induction is 0·714 T. The radius of the semi-circular path at Y is 0·105 m.

Calculate the speed of a proton at point Y. **2**

Space for working and answer

(c) Explain why an AC supply must be used to provide the electric field. **1**

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15. A student sets up the circuit shown in **Figure 15A**.

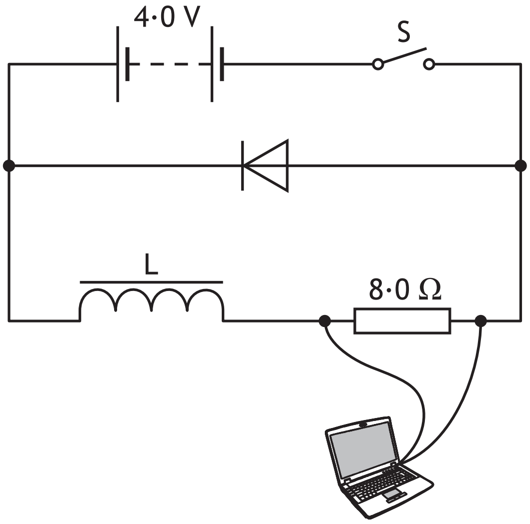

Figure 15A

The resistance of both the battery and inductor can be considered negligible.

The switch is closed and the laptop records data.

The student uses the data to produce a graph of current I against time t.

This is shown in **Figure 15B**.

The dashed line is the tangent to the curve at the origin.

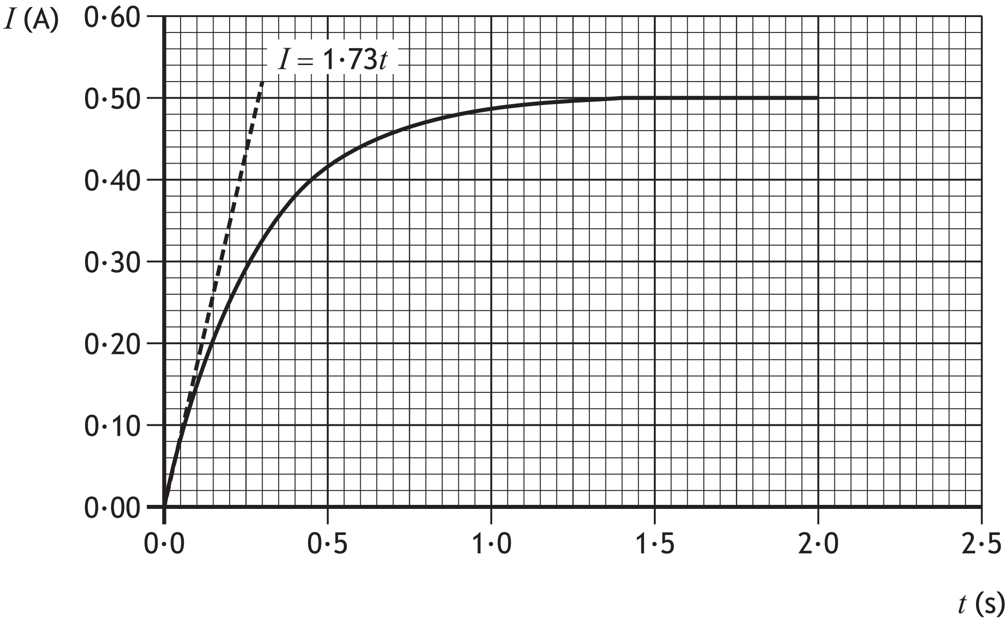

Figure 15B

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15. **(continued)** **MARKS** DO NOT WRITE IN THIS MARGIN

(a) (i) There is a delay in the current reaching a steady value due to a back EMF being produced across the inductor.

Explain how the back EMF is produced. **1**

(ii) Using data from **Figures 15A** and **15B**, determine the self-inductance of inductor L. **4**

Space for working and answer

(iii) Determine the energy stored in the inductor when the potential difference across the **resistor** is 3·2 V. **4**

Space for working and answer

[Turn over

MARKS | DO NOT WRITE IN THIS MARGIN

15. (continued)

(b) The switch is now opened and inductor L is replaced by a second inductor.

The second inductor has smaller self-inductance and negligible resistance.

The switch is now closed.

Figure 15C shows how current in the first inductor varies with time.

On **Figure 15C** draw a line to show how current in the second inductor varies with time from $t = 0{\cdot}0$ s to $t = 2{\cdot}0$ s. **2**

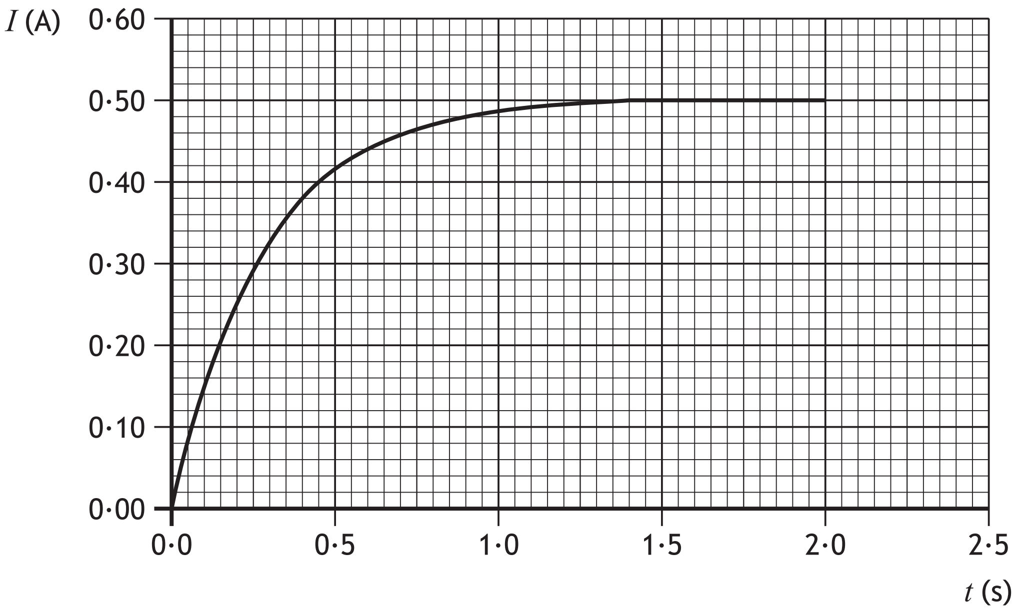

Figure 15C

(An additional graph, if required, can be found on *page 53*.)

16. A student carries out an experiment using a simple pendulum to determine the gravitational field strength g.

A simplified diagram of the apparatus is shown in **Figure 16A**.

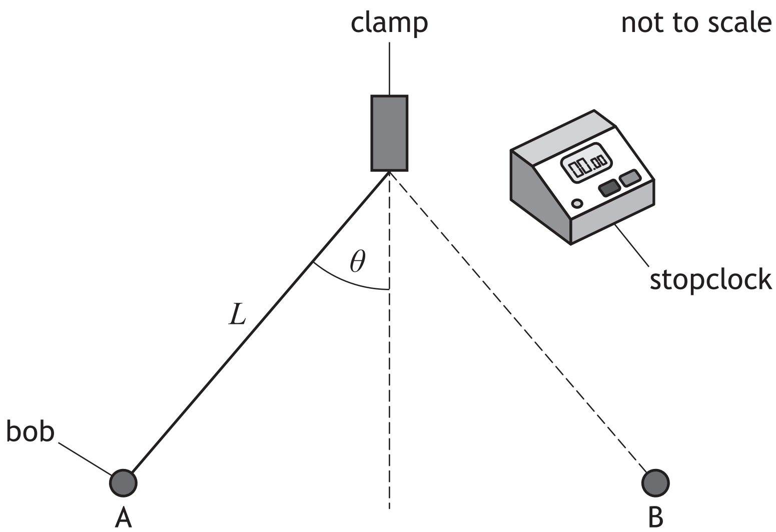

Figure 16A

The student measures the length of the pendulum string L using a metre stick.

The bob is released from point A and swings freely. The student measures the period T by timing how long it takes for the bob to swing from point A to point B and back again.

The student measures the period for a range of lengths.

The relationship between period and length is

$$T^2 = \frac{4\pi^2}{g}L$$

The student uses graphing software to produce the graph shown in **Figure 16B**.

16. (continued)

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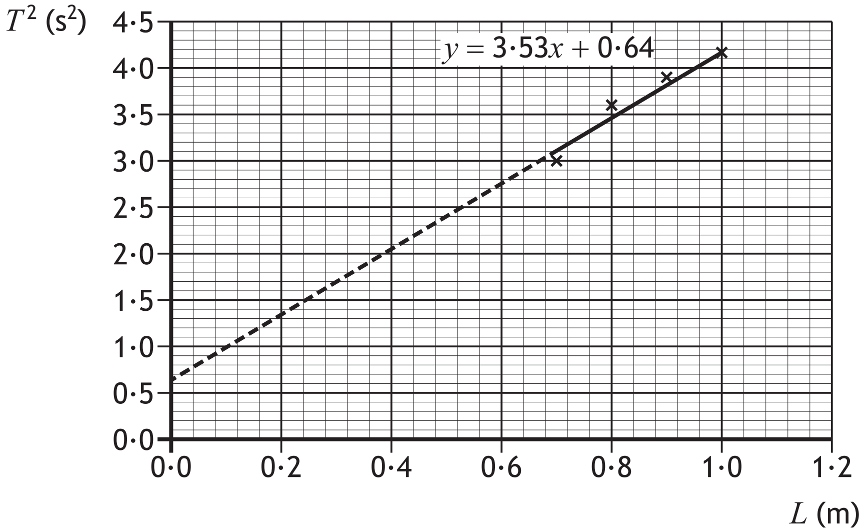

Figure 16B

(a) (i) Using data from the graph, determine the gravitational field strength. **3**

Space for working and answer

(ii) Data from the graphing software is shown below.

gradient	3·53	y-intercept	0·64
uncertainty in gradient	0·69	uncertainty in y-intercept	0·59

Determine the absolute uncertainty in the value of the gravitational field strength obtained from the graph. **2**

Space for working and answer

16. (a) (continued)

(iii) A second student suggests that the uncertainties in the measurement of length and period should have been combined with the uncertainty in the gradient of the line on the graph.

Explain why this is **not** an appropriate method to determine the absolute uncertainty in the value of the gravitational field strength. 1

(b) Suggest two possible changes to the experimental procedure that could improve the **accuracy** of the value obtained for gravitational field strength. 2

(c) Theory predicts that the line of best fit should pass through the origin.

The line of best fit in **Figure 16B** does not pass through the origin. This is due to a systematic uncertainty.

Suggest a possible source for this systematic uncertainty. 1

[END OF QUESTION PAPER]