Advanced Higher Physics Past Papers

Mr Davie

September 2025 Update (Mr White)

1 Intro

This document was created in order to make it easier to find past paper questions, both for teachers and students. I will do my best to keep this document up to date and include new past paper questions as they become available. If you spot any mistakes, or want to suggest any improvements, send me an email at MrDaviePhysics@gmail.com. I am more than happy to send you the Tex file used to produce the document so that you can modify it as you wish.

2 How to Use

The table on the next page contains links to questions sorted by topic and year. Clicking on a link will take you to that question. The marking instructions follow directly after each question. I have not included the marking instructions for open ended questions as they do not contain enough information for you to mark your own work. Instead ask your teacher to have a look at what you have written. To return to the table click on **Question Table** at the top or bottom of any page. Trying to navigate the document without doing this is tedious.

Before starting any past paper questions I recommend that you have paper copies of the Relationships Sheet and Data Sheet to avoid wasting time. If you don't have them then they are linked at the top of each page allow you to print them or open them in a separate tab.

3 September 2025 Update

Full credit for the creation of this document goes to Mr Davie. This has been an invaluable resource for Physics teachers and students across Scotland, who I know are very grateful for his work. In March 2025, the original document was updated by Mr White, adding the 2023 and 2024 papers (maintaining the same style as the original) along with links to the Data Sheet and Relationship Sheet. I have also added links to the answers in the bottom corner of each multiple-choice question page to make them easier to find. The 2025 paper was added in September 2025.

By clicking the Data Sheet and Relationship Sheet links with the middle mouse button or by right-clicking on the links, you can open them in another tab. If there are any issues with the papers after 2023, please send me an email at twhite@lenzieacademy.e-dunbarton.sch.uk and I will try to fix them. I will also do my best to keep the document updated and add new past paper questions every year.

	2016	2017	2018	2019	2020	2022	2023	2024	2025
Kinematic relationships	1	1	1	1	1	1	1	1	1
Angular motion	2	2	2	2,4	2a, 6c(i)	2	2	2,3b(i),c(i),5c(i),10b	2a(i),c,3a
Rotational dynamics	16	3	3	3	2b,3	3	3,13c(ii)	3a,b(ii),c(ii),d	2a(ii),b,3b,c,9a
Gravitation	3	4,5	4	5	4,6c(ii)	4	4	4	4a,b
General relativity	5		5	6	4b,5		5	5	4c
Stellar physics	4	6	6,8	7	6a,b	5	6	6	3d, 5, 6b
Introduction to quantum theory	6,7,8	7	7	8, 9	7,8a,b	6,7,8	7,8,9b	7	6a,6c,7c(ii),8
Particles from space			8d	10	8c(i)(B), 8d	9	9a	8	7a,b
Simple harmonic motion	10	8	9	11	9	10	10a,b,f	9	9b,c
Waves	11	9	10	12a	10d	11	10d,e	10a	10a,b
Interference		10	11	13	10a-c	12	11	11a,b(i),c(i)	11
Polarisation	12		12		11	13a	12	12	12
Fields	9,13,14	11,12	13,14	14,15	8,13,14	14,15	8b(i),10c,13a-c(i),14a,b(i)	13,14,15	7c(i),13,14
Circuits		13,14	15	16	15	16	15	16	10c,15
Electromagnetic radiation	15a(ii)								
Graph work & Experimental methods	15,16				16	13		17b,c	16a
Uncertainties	14b,c	10c(ii)	14b(ii),d	12b,c	12,16	12	14b(ii-iv),16	11b(ii),c(ii),17a	16b

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	9.11×10^{-31} kg
Radius of Earth	R_E	6.4×10^{6} m	Charge on electron	e	-1.60×10^{-19} C
Mass of Earth	M_E	6.0×10^{24} kg	Mass of neutron	m_n	1.675×10^{-27} kg
Mass of Moon	M_M	7.3×10^{22} kg	Mass of proton	m_p	1.673×10^{-27} kg
Radius of Moon	R_M	1.7×10^{6} m	Mass of positron	m_{e^+}	9.11×10^{-31} kg
Mean Radius of Moon Orbit		3.84×10^{8} m	Charge on positron	e^+	1.60×10^{-19} C
Solar radius		6.955×10^{8} m	Charge on copper nucleus		4.64×10^{-18} C
Mass of Sun		2.0×10^{30} kg	Planck's constant	h	6.63×10^{-34} J s
Mass of Mars	M_{Mars}	6.42×10^{23} kg	Permittivity of free space	ε_0	$8.85 \times 10^{-12}\ \text{F m}^{-1}$
Radius of Mars	R_{Mars}	3.39×10^{6} m	Permeability of free space	μ_0	$4\pi \times 10^{-7}\ \text{H m}^{-1}$
1 AU		1.5×10^{11} m	Speed of light in vacuum	c	$3.00 \times 10^{8}\ \text{m s}^{-1}$
Stefan-Boltzmann constant	σ	$5.67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$	Speed of sound in air	v	$3.4 \times 10^{2}\ \text{m s}^{-1}$
Universal constant of gravitation	G	$6.67 \times 10^{-11}\ \text{m}^3\ \text{kg}^{-1}\ \text{s}^{-2}$			

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	2.70×10^{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	4.18×10^{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.

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FOR OFFICIAL USE

AH

National Qualifications 2016

Mark

X757/77/01 Physics

TUESDAY, 24 MAY

9:00 AM – 11:30 AM

* X 7 5 7 7 7 0 1 *

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 — 140

Attempt ALL questions.

Reference may be made to the Physics Relationships Sheet X757/77/11 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.

Total marks — 140 marks

Attempt ALL questions

MARKS DO NOT WRITE IN THIS MARGIN

1.

Calvin Chan/shutterstock.com

A car on a long straight track accelerates from rest. The car's run begins at time $t = 0$.

Its velocity v at time t is given by the equation

$$v = 0{\cdot}135t^2 + 1{\cdot}26t$$

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

Using **calculus** methods:

(a) determine the acceleration of the car at $t = 15{\cdot}0$ s; **3**

Space for working and answer

(b) determine the displacement of the car from its original position at this time. **3**

Space for working and answer

Detailed Marking Instructions for each question

Question			Answer	Max Mark	Additional Guidance
1.	(a)		$v = 0\cdot135t^2 + 1\cdot26t$ $a = \frac{dv}{dt} = 0\cdot135 \times 2t + 1\cdot26$ **1** $a = (0\cdot135 \times 2 \times 15\cdot0) + 1\cdot26$ **1** $a = 5\cdot31\ \text{m s}^{-2}$ **1**	3	Accept $5\cdot3\ \text{m s}^{-2}$, $5\cdot310\ \text{m s}^{-2}$, $5\cdot3100\ \text{m s}^{-2}$
	(b)		$v = 0\cdot135t^2 + 1\cdot26t$ $s = \int_0^{15\cdot0} v.dt = \left[0\cdot045t^3 + 0\cdot63t^2\right]_0^{15\cdot0}$ **1** $s = (0\cdot045 \times 15\cdot0^3) + (0\cdot63 \times 15\cdot0^2)$ **1** $s = 294\ \text{m}$ **1**	3	Accept 290 m, 293·6 m, 293·63 m Constant of integration method acceptable.

MARKS DO NOT WRITE IN THIS MARGIN

2. (a) An ideal conical pendulum consists of a mass moving with constant speed in a circular path, as shown in Figure 2A.

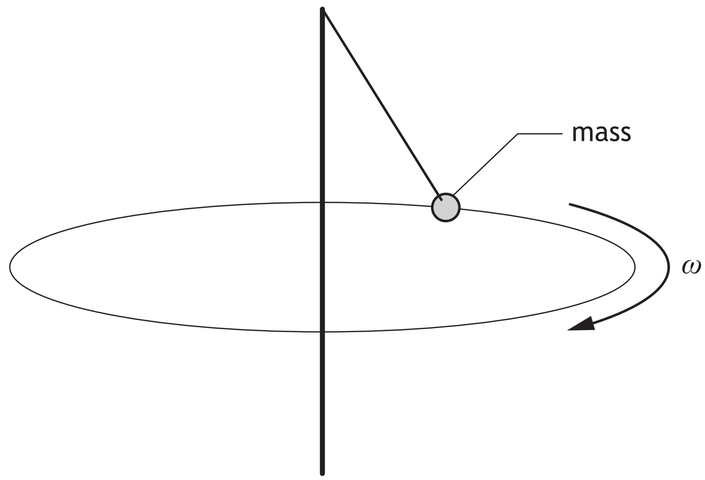


Figure 2A

(i) Explain why the mass is accelerating despite moving with constant speed. **1**

(ii) State the direction of this acceleration. **1**

2. (continued)

MARKS DO NOT WRITE IN THIS MARGIN

(b) Swingball is a garden game in which a ball is attached to a light string connected to a vertical pole as shown in Figure 2B.

The motion of the ball can be modelled as a conical pendulum.

The ball has a mass of 0·059 kg.

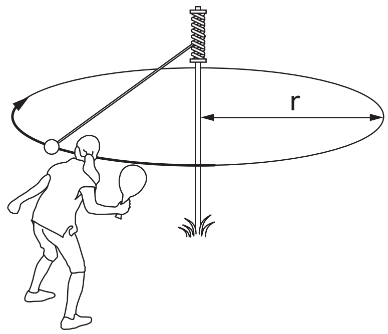


Figure 2B

(i) The ball is hit such that it moves with constant speed in a horizontal circle of radius 0·48 m.

The ball completes 1·5 revolutions in 2·69 s.

(A) Show that the angular velocity of the ball is 3·5 rad s^{-1}. **2**

Space for working and answer

(B) Calculate the magnitude of the centripetal force acting on the ball. **3**

Space for working and answer

2. (b) (i) (continued) MARKS

DO NOT WRITE IN THIS MARGIN

(C) The horizontal component of the tension in the string provides this centripetal force and the vertical component balances the weight of the ball.

Calculate the magnitude of the tension in the string. **3**

Space for working and answer

(ii) The string breaks whilst the ball is at the position shown in Figure 2C.

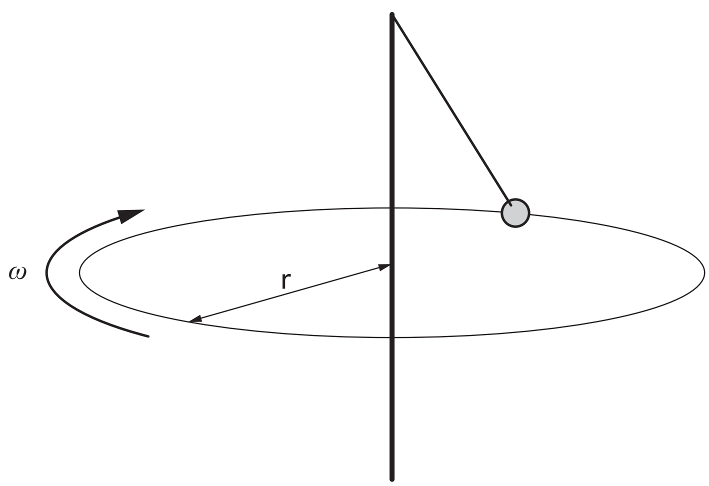


Figure 2C

On Figure 2C, draw the direction of the ball's velocity **immediately** after the string breaks. **1**

(An additional diagram, if required, can be found on *Page 39*.)

Question			Answer	Max Mark	Additional Guidance
2.	(a)	(i)	velocity changing or changing direction or an unbalanced force is acting or a centripetal/central/radial force is acting	1	
		(ii)	towards the centre	1	towards the axis/pole
	(b)	(i) (A)	SHOW QUESTION $\omega = \frac{d\theta}{dt}$ OR $\omega = \frac{\theta}{t}$ 1 $\omega = \frac{1\cdot5\times2\pi}{2\cdot69}$ 1 $\omega = 3\cdot5$ rad s^{-1}	2	$\omega = \frac{v}{r}$ and $v = \frac{d}{t}$ 1 $\omega = \frac{1\cdot5\times2\times\pi\times0\cdot48}{2\cdot69\times0\cdot48}$ 1 $\omega = 3\cdot5$ rad s^{-1} If final answer not stated, max 1 mark
		(B)	$F = mr\omega^2$ 1 $F = 0\cdot059\times0\cdot48\times3\cdot5^2$ 1 $F = 0\cdot35$ N 1	3	Accept 0·3, 0·347, 0·3469 $F = \frac{mv^2}{r}$ 1 $F = \frac{0\cdot059\times\left(\frac{1\cdot5\times2\times\pi\times0\cdot48}{2\cdot69}\right)^2}{0\cdot48}$ 1 $F = 0\cdot35$ N 1
		(C)	$W = mg$ $W = 0\cdot059\times9\cdot8$ 1 $T^2 = 0\cdot35^2 + (0\cdot059\times9\cdot8)^2$ 1 $T = 0\cdot68$ N 1 1 mark for calculating weight 1 mark for Pythagorean relationship 1 mark for final answer	3	Accept 0·7, 0·676, 0·6759 $W = mg$ $W = 0\cdot059\times9.8$ 1 $\theta = \tan^{-1}\left(\frac{0\cdot35}{0\cdot059\times9\cdot8}\right)$ $\sin\theta = \frac{0\cdot35}{T}$ 1 for both $T = 0\cdot68$ N 1
		(ii)	In a straight line at a tangent to the circle	1	Any parabolic path is not acceptable.

MARKS | DO NOT WRITE IN THIS MARGIN

3. A spacecraft is orbiting a comet as shown in Figure 3.

The comet can be considered as a sphere with a radius of $2{\cdot}1 \times 10^3$ m and a mass of $9{\cdot}5 \times 10^{12}$ kg.

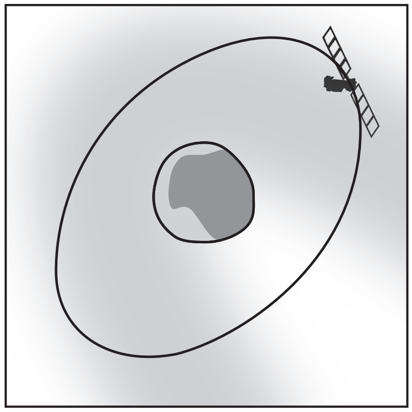


Figure 3 (not to scale)

(a) A lander was released by the spacecraft to land on the surface of the comet. After impact with the comet, the lander bounced back from the surface with an initial upward vertical velocity of $0{\cdot}38\ \mathrm{m\,s^{-1}}$.

By calculating the escape velocity of the comet, show that the lander returned to the surface for a second time. **4**

Space for working and answer

[Turn over

MARKS DO NOT WRITE IN THIS MARGIN

3. (continued)

(b) (i) Show that the gravitational field strength at the surface of the comet is $1{\cdot}4 \times 10^{-4}\ \text{N kg}^{-1}$. **3**

Space for working and answer

(ii) Using the data from the space mission, a student tries to calculate the maximum height reached by the lander after its first bounce.

The student's working is shown below

$$v^2 = u^2 + 2as$$

$$0 = 0{\cdot}38^2 + 2 \times \left(-1{\cdot}4 \times 10^{-4}\right) \times s$$

$$s = 515{\cdot}7\ \text{m}$$

The actual maximum height reached by the lander was **not** as calculated by the student.

State whether the actual maximum height reached would be greater or smaller than calculated by the student.

You must justify your answer. **3**

Question			Answer	Max Mark	Additional Guidance
3.	(a)		$v=\sqrt{\frac{2GM}{r}}$ **1** $v=\sqrt{\frac{2\times 6\cdot 67\times 10^{-11}\times 9\cdot 5\times 10^{12}}{2\cdot 1\times 10^{3}}}$ **1** $v=\sqrt{0\cdot 603}$ $v=0\cdot 78\ (\text{m s}^{-1})$ **1** (lander returns to surface as) lander v less than escape velocity of comet **1**	4	
	(b)	(i)	SHOW QUESTION $(F_g=W)$ $\frac{GMm}{r^2}=mg$ **1** for both eqns, **1** for equating $g=\frac{GM}{r^2}$ $g=\frac{6\cdot 67\times 10^{-11}\times 9\cdot 5\times 10^{12}}{\left(2\cdot 1\times 10^{3}\right)^2}$ **1** $g=1\cdot 4\times 10^{-4}\ \text{N kg}^{-1}$	3	Show question, if final line is missing then a maximum of two marks. If the 2nd line is missing then 1 mark maximum for $F_g = W$ $\frac{F}{m}=\frac{GM}{r^2}$ or $g=\frac{GM}{r^2}$ As a starting point, zero marks
		(ii)	Height will be greater **1** Because 'a' reduces **1** with height **1**	3	'Must justify' question Alternative: Assumption that 'a' is constant is invalid 1 The value for 'a' is too large 1

MARKS DO NOT WRITE IN THIS MARGIN

4. Epsilon Eridani is a star $9{\cdot}94 \times 10^{16}$ m from Earth. It has a diameter of $1{\cdot}02 \times 10^{9}$ m. The apparent brightness of Epsilon Eridani is measured on Earth to be $1{\cdot}05 \times 10^{-9}\,\mathrm{W\,m^{-2}}$.

(a) Calculate the luminosity of Epsilon Eridani. **3**

Space for working and answer

(b) Calculate the surface temperature of Epsilon Eridani. **3**

Space for working and answer

(c) State an assumption made in your calculation in (b). **1**

Question			Answer	Max Mark	Additional Guidance
4.	(a)		$b=\frac{L}{4\pi r^2}$ **1** $1\cdot05\times10^{-9}=\frac{L}{4\pi\left(9\cdot94\times10^{16}\right)^2}$ **1** $L = 1\cdot30 \times 10^{26}$ W **1**	**3**	Accept 1·3, 1·304,1·3037
	(b)		$L=4\pi r^2\sigma T^4$ **1** $1\cdot30\times10^{26}=4\pi\left(5\cdot10\times10^{8}\right)^2\times$ $5\cdot67\times10^{-8}\times T^4$ **1** $T=5150$ K **1**	**3**	Or consistent with (a) Accept 5100, 5146, 5146·4
	(c)		That the star is a black body (emitter/radiator) **OR** the star is spherical/constant radius **OR** the surface temperature of the star is constant/uniform **OR** no energy absorbed between star and Earth	**1**	

MARKS | DO NOT WRITE IN THIS MARGIN

5. Einstein's theory of general relativity can be used to describe the motion of objects in non-inertial frames of reference. The equivalence principle is a key assumption of general relativity.

(a) Explain what is meant by the terms:

(i) *non-inertial frames of reference*; **1**

(ii) *the equivalence principle*. **1**

(b) Two astronauts are on board a spacecraft in deep space far away from any large masses. When the spacecraft is accelerating one astronaut throws a ball towards the other.

(i) On Figure 5A sketch the path that the ball would follow in the astronauts' frame of reference. **1**

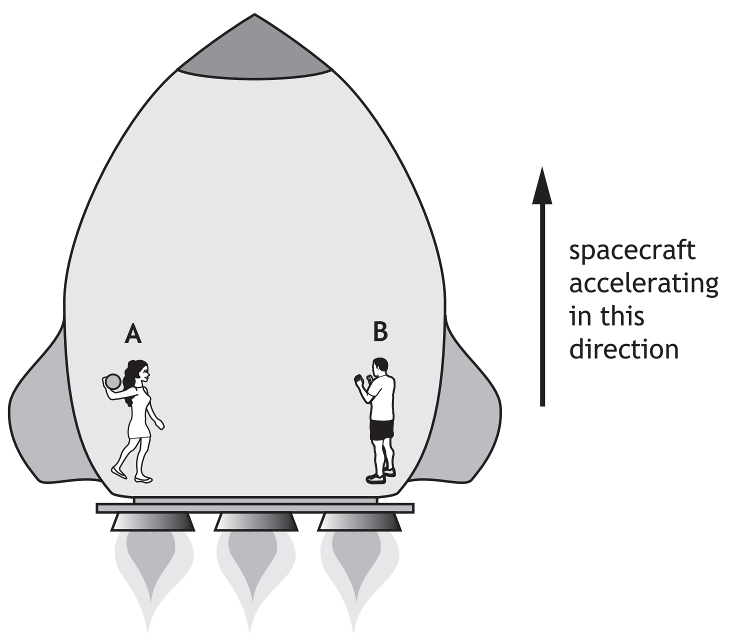


Figure 5A

(An additional diagram, if required, can be found on *Page 39*.)

MARKS DO NOT WRITE IN THIS MARGIN

5. (b) (continued)

(ii) The experiment is repeated when the spacecraft is travelling at constant speed.

On Figure 5B sketch the path that the ball would follow in the astronauts' frame of reference. **1**

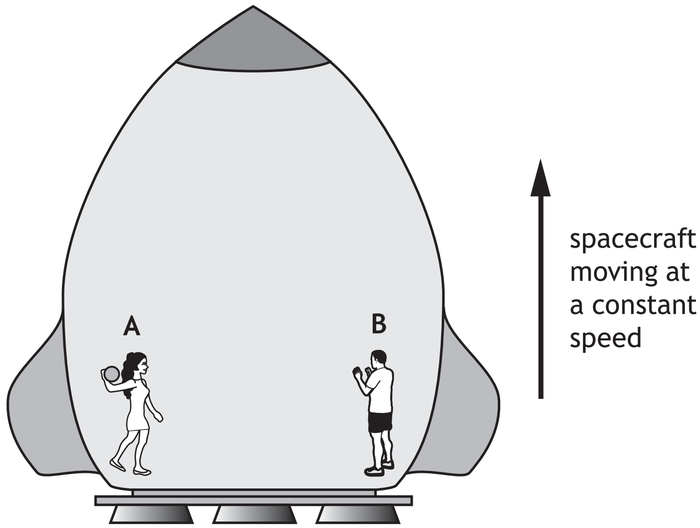


Figure 5B

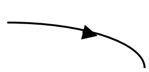
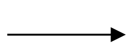
(An additional diagram, if required, can be found on *Page 40*.)

(c) A clock is on the surface of the Earth and an identical clock is on board a spacecraft which is accelerating in deep space at $8\,m\,s^{-2}$.

State which clock runs slower.

Justify your answer in terms of the equivalence principle. **2**

[Turn over

Question			Answer	Max Mark	Additional Guidance
5.	(a)	(i)	Frames of reference that are accelerating (with respect to an inertial frame)	**1**	
		(ii)	It is impossible to tell the difference between the effects of gravity and acceleration.	**1**	
	(b)	(i)		**1**	Any convex upward parabola.
		(ii)		**1**	Any straight line.
	(c)		The clock on the surface of the Earth would run more slowly. 1 The (effective) gravitational field for the spacecraft is smaller. 1 Or vice versa.	**2**	

MARKS | DO NOT WRITE IN THIS MARGIN

6. A student makes the following statement.

"Quantum theory — I don't understand it. I don't really know what it is. I believe that classical physics can explain everything."

Use your knowledge of physics to comment on the statement. **3**

MARKS DO NOT WRITE IN THIS MARGIN

7. (a) The Earth can be modelled as a black body radiator.

The average surface temperature of the Earth can be estimated using the relationship

$$T = \frac{b}{\lambda_{\text{peak}}}$$

where

T is the average surface temperature of the Earth in kelvin;

b is Wien's Displacement Constant equal to $2{\cdot}89 \times 10^{-3}$ K m;

λ_{peak} is the peak wavelength of the radiation emitted by a black body radiator.

The average surface temperature of Earth is 15 °C.

(i) Estimate the peak wavelength of the radiation emitted by Earth. **3**

Space for working and answer

(ii) To which part of the electromagnetic spectrum does this peak wavelength correspond? **1**

[Turn over

7. (continued)

MARKS DO NOT WRITE IN THIS MARGIN

(b) In order to investigate the properties of black body radiators a student makes measurements from the spectra produced by a filament lamp. Measurements are made when the lamp is operated at its rated voltage and when it is operated at a lower voltage.

The filament lamp can be considered to be a black body radiator.

A graph of the results obtained is shown in Figure 7.

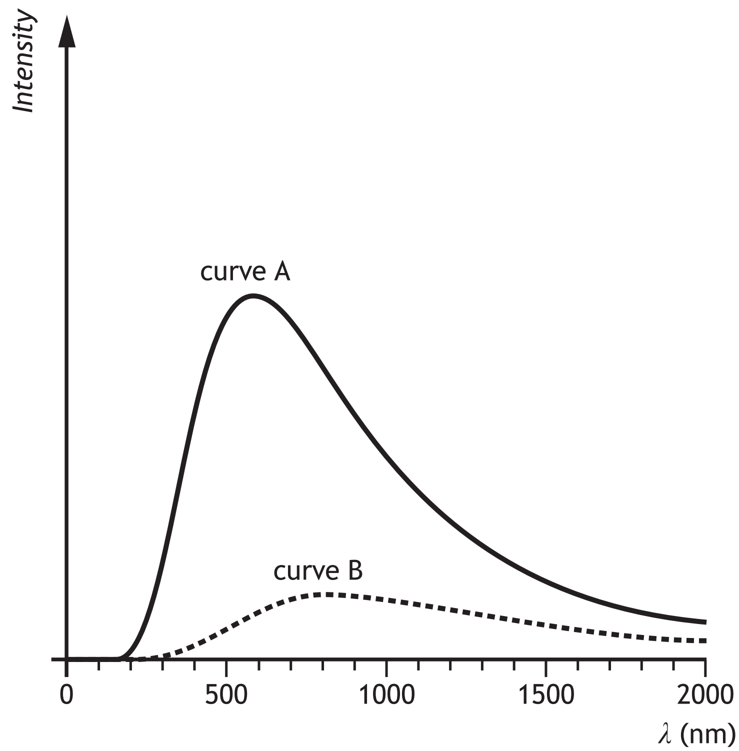


Figure 7

(i) State which curve corresponds to the radiation emitted when the filament lamp is operating at its rated voltage.

You must justify your answer. **2**

(ii) The shape of the curves on the graph on Figure 7 is not as predicted by classical physics.

On Figure 7, sketch a curve to show the result predicted by classical physics. **1**

(An additional graph, if required, can be found on *Page 40*.)

Question			Answer	Max Mark	Additional Guidance
7.	(a)	(i)	$T_K = 15 + 273$ **1** $T_{kelvin} = \frac{b}{\lambda_{peak}}$ $288 = \frac{2 \cdot 89x10^{-3}}{\lambda_{peak}}$ **1** $\lambda_{peak} = 1 \cdot 0 \times 10^{-5}$ m **1**	**3**	Accept 1, 1·00, 1·003 Also accept 1·0035 Incorrect/no conversion to kelvin - zero marks
		(ii)	Infrared	**1**	Consistent with answer to a(i).
	(b)	(i)	(curve) A **1** Peak at shorter wavelength/higher frequency (as Temperature is higher) **1** **OR** Higher/greater (peak) intensity (as greater energy) **1**	**2**	
		(ii)	curve (approximately) asymptotic to y-axis and decreasing with increased wavelength	**1**	Intercept of y-axis – zero marks

MARKS DO NOT WRITE IN THIS MARGIN

8. Werner Heisenberg is considered to be one of the pioneers of quantum mechanics.

He is most famous for his uncertainty principle which can be expressed in the equation

$$\Delta x \Delta p_x \geq \frac{h}{4\pi}$$

(a) (i) State what quantity is represented by the term Δp_x. **1**

(ii) Explain the implications of the Heisenberg uncertainty principle for experimental measurements. **1**

[Turn over

8. (continued)

MARKS DO NOT WRITE IN THIS MARGIN

(b) In an experiment to investigate the nature of particles, individual electrons were fired one at a time from an electron gun through a narrow double slit. The position where each electron struck the detector was recorded and displayed on a computer screen.

The experiment continued until a clear pattern emerged on the screen as shown in Figure 8.

The momentum of each electron at the double slit is $6{\cdot}5 \times 10^{-24}$ kg m s^{-1}.

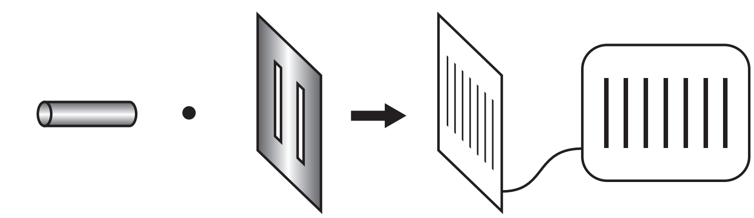


Figure 8 not to scale

(i) The experimenter had three different double slits with slit separations 0·1 mm, 0·1 µm and 0·1 nm.

State which double slit was used to produce the image on the screen.

You must justify your answer by calculation of the de Broglie wavelength. **4**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

8. (b) (continued)

(ii) The uncertainty in the momentum of an electron at the double slit is $6{\cdot}5 \times 10^{-26}$ kg m s^{-1}.

Calculate the minimum absolute uncertainty in the position of the electron. **3**

Space for working and answer

(iii) Explain fully how the experimental result shown in Figure 8 can be interpreted. **3**

[Turn over

Question			Answer	Max Mark	Additional Guidance
8.	(a)	(i)	$\Delta p_x =$ the uncertainty in the momentum (in the x-direction.)	1	
		(ii)	The precise position of a particle/ system and its momentum cannot both be known at the same instant. **1** **OR** If the uncertainty in the location of the particle is reduced, the minimum uncertainty in the momentum of the particle will increase (or vice-versa). **1** **OR** The precise energy and lifetime of a particle cannot both be known at the same instant. **1** **OR** If the uncertainty in the energy of the particle is reduced, the minimum uncertainty in the lifetime of the particle will increase (or vice-versa). **1**	1	"At the same instant/ simultaneously" required Confusion of accuracy with precision award zero marks.
	(b)	(i)	$\lambda = \frac{h}{p}$ **1** $\lambda = \frac{6 \cdot 63 \times 10^{-34}}{6 \cdot 5 \times 10^{-24}}$ **1** $\lambda = 1 \cdot 0 \times 10^{-10}$ (m) **1** slit width $0 \cdot 1$ nm used **1**	4	
		(ii)	$\Delta x \Delta p_x \geq \frac{h}{4\pi}$ **1** $\Delta x \times 6 \cdot 5 \times 10^{-26} \geq \frac{6 \cdot 63 \times 10^{-34}}{4\pi}$ **1** $\Delta x \geq 8 \cdot 1 \times 10^{-10}$ min uncertainty $= 8 \cdot 1 \times 10^{-10}$ m **1**	3	Accept 8, 8·12, 8·117
		(iii)	Electron behaves like a wave "Interference" Uncertainty in position is greater than slit separation Electron passes through both slits	3	Any three of the statements can be awarded 1 mark each.

MARKS DO NOT WRITE IN THIS MARGIN

9. A particle with charge q and mass m is travelling with constant speed v. The particle enters a uniform magnetic field at 90° and is forced to move in a circle of radius r as shown in Figure 9.

The magnetic induction of the field is B.

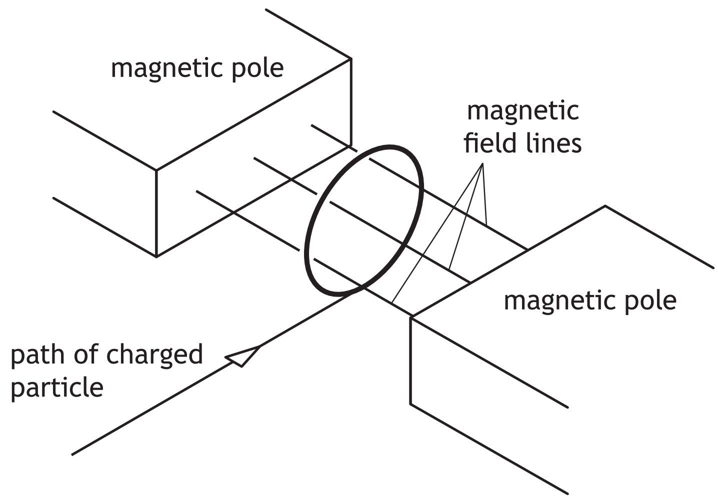


Figure 9

(a) Show that the radius of the circular path of the particle is given by

$$r = \frac{mv}{Bq}$$

2

9. (continued)

MARKS DO NOT WRITE IN THIS MARGIN

(b) In an experimental nuclear reactor, charged particles are contained in a magnetic field. One such particle is a deuteron consisting of one proton and one neutron.

The kinetic energy of each deuteron is 1·50 MeV.

The mass of the deuteron is $3{\cdot}34 \times 10^{-27}$ kg.

Relativistic effects can be ignored.

(i) Calculate the speed of the deuteron. **4**

Space for working and answer

(ii) Calculate the magnetic induction required to keep the deuteron moving in a circular path of radius 2·50 m. **2**

Space for working and answer

[Turn over

9. (b) (continued) MARKS DO NOT WRITE IN THIS MARGIN

(iii) Deuterons are fused together in the reactor to produce isotopes of helium.

$^{3}_{2}He$ nuclei, each comprising 2 protons and 1 neutron, are present in the reactor.

A $^{3}_{2}He$ nucleus also moves in a circular path in the same magnetic field.

The $^{3}_{2}He$ nucleus moves at the same speed as the deuteron.

State whether the radius of the circular path of the $^{3}_{2}He$ nucleus is greater than, equal to or less than 2·50 m.

You must justify your answer. **2**

Question			Answer	Max Mark	Additional Guidance
9.	(a)		SHOW QUESTION $m\frac{v^2}{r} = Bqv(\sin\theta)$ 1 for both relationships 1 for equating $r = \frac{mv}{Bq}$	2	If the final line is missing then a maximum of 1 mark can be awarded
	(b)	(i)	$1{\cdot}50\ (\text{MeV}) = 1{\cdot}50 \times 10^6 \times 1{\cdot}60 \times 10^{-19}$ $= 2{\cdot}40 \times 10^{-13}\ (\text{J})$ **1** $E_k = \frac{1}{2}mv^2$ **1** $2{\cdot}40\times10^{-13} = 0{\cdot}5\times3{\cdot}34\times10^{-27}\times v^2$ **1** $v = 1{\cdot}20\times10^7\ \text{m s}^{-1}$ **1**	4	Accept 1·2, 1·199, 1·1988 No conversion to J - Max 1 mark Calculation of deuteron mass by adding mass of proton and neutron is incorrect - max 2
		(ii)	$r = \frac{mv}{Bq}$ $2{\cdot}50 = \frac{3{\cdot}34\times10^{-27}\times1{\cdot}20\times10^7}{B\times1{\cdot}60\times10^{-19}}$ **1** $B = 0{\cdot}100\ \text{T}$ **1**	2	Final answer consistent with b(i) Suspend the significant figure rule and accept $0{\cdot}1$
		(iii)	r will be less **1** $r \propto \frac{m}{q}$ **and** q increases more than m does **1** or q doubles but m × 1·5	2	Justification involving an increase in charge without mentioning mass - max 1

MARKS DO NOT WRITE IN THIS MARGIN

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

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

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

where the symbols have their usual meaning.

Show that this expression is a solution to the equation

$$\frac{d^2y}{dt^2} + \omega^2 y = 0$$

2

[Turn over

10. (continued)

MARKS DO NOT WRITE IN THIS MARGIN

(b) A mass of 1·5 kg is suspended from a spring of negligible mass as shown in Figure 10. The mass is displaced downwards 0·040 m from its equilibrium position.

The mass is then released from this position and begins to oscillate. The mass completes ten oscillations in a time of 12 s.

Frictional forces can be considered to be negligible.

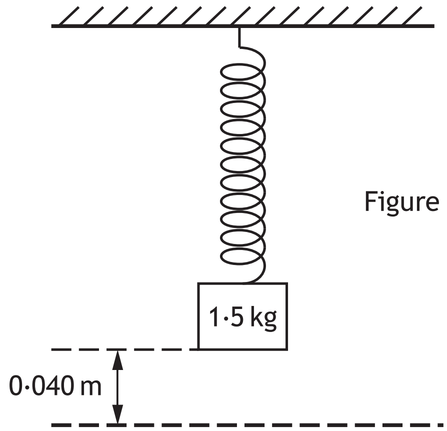


Figure 10

(i) Show that the angular frequency ω of the mass is 5·2 rad s^{-1}. **3**

Space for working and answer

(ii) Calculate the maximum velocity of the mass. **3**

Space for working and answer

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

(iii) Determine the potential energy stored in the spring when the mass is at its maximum displacement. **3**

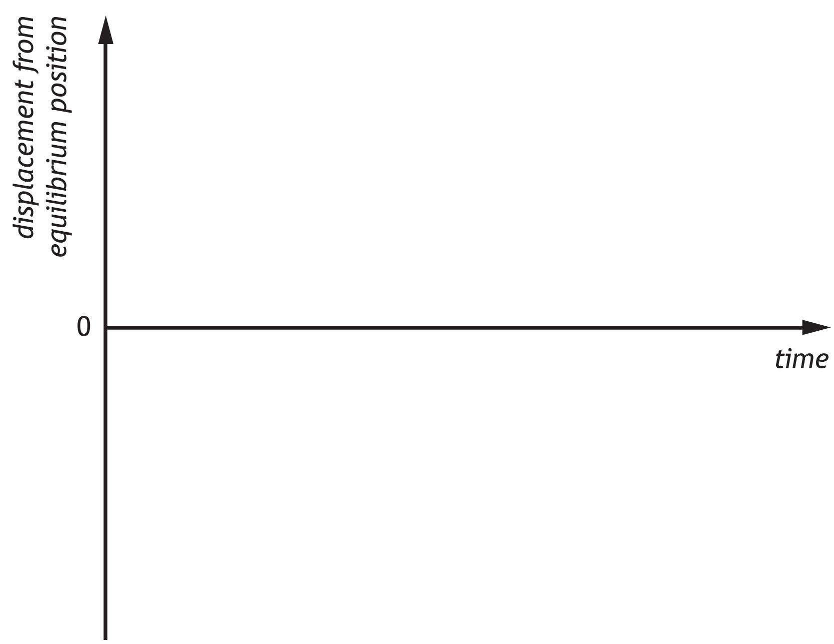
Space for working and answer

(c) The system is now modified so that a damping force acts on the oscillating mass.

(i) Describe how this modification may be achieved. **1**

(ii) Using the axes below sketch a graph showing, for the modified system, how the displacement of the mass varies with time after release.

Numerical values are **not** required on the axes. **1**



(An additional graph, if required, can be found on *Page 41*.)

Question			Answer	Max Mark	Additional Guidance
10.	(a)	(i)	displacement is proportional to and in the opposite direction to the acceleration	1	$F = -ky$ or equivalent
		(ii)	SHOW QUESTION $y = A\cos\omega t$ $\frac{dy}{dt} = -\omega A\sin\omega t$ $\frac{d^2y}{dt^2} = -\omega^2 A\cos\omega t$ **1** $\frac{d^2y}{dt^2} = -\omega^2 y$ **1** $\frac{d^2y}{dt^2} + \omega^2 y = 0$	2	If final line not shown then max 1 mark can be awarded Award zero marks if: $\frac{dy}{dt} = \omega A\sin\omega t$ appears First mark can only be awarded if both the first and second differentiations are included.
	(b)	(i)	$T = \frac{12\cdot0}{10}$ **1** $\omega = \frac{2\pi}{T}$ **1** $\omega = \frac{2\pi\times10}{12}$ **1** $\omega = 5\cdot2\ \text{rad s}^{-1}$	3	If final line not shown maximum 2 marks $f = \frac{10}{12}$ 1 $\omega = 2\pi f$ 1 $\omega = \frac{2\pi\times10}{12}$ 1 $\omega = 5\cdot2\ \text{rad s}^{-1}$ **OR** $\theta = 2\pi\times10$ 1 $\omega = \frac{\theta}{t}$ 1 $\omega = \frac{2\pi\times10}{12}$ 1 $\omega = 5\cdot2\ \text{rad s}^{-1}$
		(ii)	$v = (\pm)\omega\sqrt{A^2 - y^2}$ **1** $v = 5\cdot2\times0\cdot04$ **1** $v = 0\cdot21\ \text{m s}^{-1}$ **1**	3	Accept $v_{max} = \omega A$ Accept 0·2, 0·208, 0·2080

Question			Answer	Max Mark	Additional Guidance
		(iii)	$E_P = \frac{1}{2} m\omega^2 y^2$ **1** $E_P = \frac{1}{2} \times 1\cdot 5 \times 5\cdot 2^2 \times 0\cdot 04^2$ **1** $E_P = 0\cdot 032$ J **1**	**3**	Accept 0·03, 0·0324. 0·03245 $E_K = \frac{1}{2} mv^2$ **1** $= 0\cdot 5 \times 1\cdot 5 \times 0\cdot 21^2$ **1** $= 0\cdot 033$ J **1** Accept 0·03, 0·0331, 0·03308
	(c)	(i)	Any valid method of damping.	**1**	A practical method must be described. For example, place mass in a more viscous medium, increase the surface area of the mass.
		(ii)	amplitude of harmonic wave reducing.	**1**	Graph must show positive and negative amplitude.

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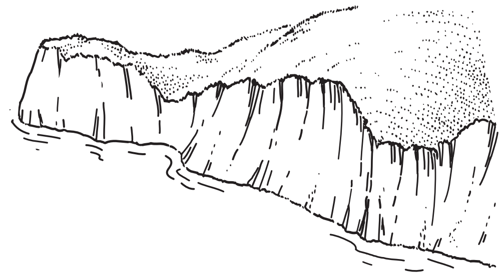
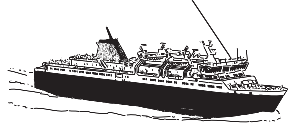
11.





A ship emits a blast of sound from its foghorn. The sound wave is described by the equation

$$y = 0{\cdot}250 \sin 2\pi(118t - 0{\cdot}357x)$$

where the symbols have their usual meaning.

(a) Determine the speed of the sound wave. **4**

Space for working and answer

11. (continued)

MARKS DO NOT WRITE IN THIS MARGIN

(b) The sound from the ship's foghorn reflects from a cliff. When it reaches the ship this reflected sound has half the energy of the original sound.

Write an equation describing the reflected sound wave at this point. **4**

[Turn over

Question			Answer	Max Mark	Additional Guidance
11	(a)		$\frac{1}{\lambda} = 0 \cdot 357$ **1** $\lambda = \frac{1}{0 \cdot 357}$ $v = f\lambda$ **1** $v = 118 \times \frac{1}{0 \cdot 357}$ **1** $v = 331 \text{ m s}^{-1}$ **1**	4	Accept 330, 330·5, 330·53
	(b)		$E = kA^2$ **1** $\frac{E_1}{A_1^2} = \frac{E_2}{A_2^2}$ $\frac{1}{0 \cdot 250^2} = \frac{0 \cdot 5}{A_2^2}$ **1** $A_2 = 0 \cdot 177 \text{ (m)}$ **1** $y = 0 \cdot 177 \sin 2\pi(118t + 0 \cdot 357x)$ **1**	4	$A_1 = \sqrt{2} \times A_2$ acceptable method Accept 0·18, 0·1768, 0·17678 Final mark is independent and for: $\sin 2\pi(118t + 0 \cdot 357x)$ $y = 0 \cdot 177 \sin(744t + 2 \cdot 24x)$

12. Some early 3D video cameras recorded two separate images at the same time to create two almost identical movies.

Cinemas showed 3D films by projecting these two images simultaneously onto the same screen using two projectors. Each projector had a polarising filter through which the light passed as shown in Figure 12.

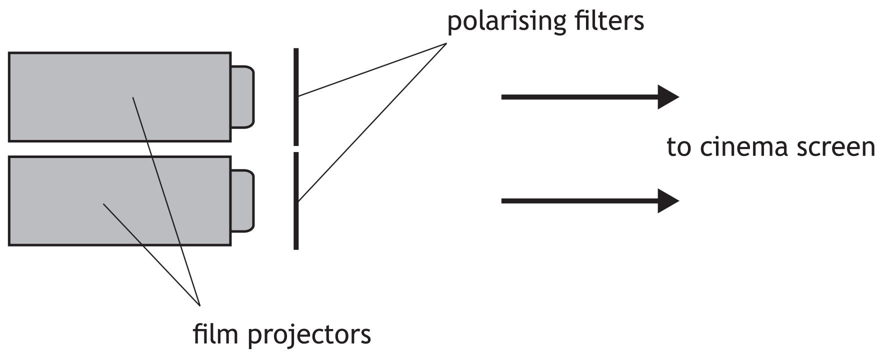


Figure 12

(a) Describe how the transmission axes of the two polarising filters should be arranged so that the two images on the screen do not interfere with each other. **1**

(b) A student watches a 3D movie using a pair of glasses which contains two polarising filters, one for each eye.

Explain how this arrangement enables a different image to be seen by each eye. **2**

12. (continued)

MARKS DO NOT WRITE IN THIS MARGIN

(c) Before the film starts, the student looks at a ceiling lamp through one of the filters in the glasses. While looking at the lamp, the student then rotates the filter through 90°.

State what effect, if any, this rotation will have on the observed brightness of the lamp.

Justify your answer. **2**

(d) During the film, the student looks at the screen through only one of the filters in the glasses. The student then rotates the filter through 90° and does not observe any change in brightness.

Explain this observation. **1**

[Turn over

Question			Answer	Max Mark	Additional Guidance
12.	(a)		(The axes should be arranged) at 90° to each other (eg horizontal and vertical.)	**1**	Perpendicular to each other.
	(b)		The filter for each eye will allow light from one projected image to pass through. **1** while blocking the light from the other projector. **1**	**2**	'only one projected image to pass through to each eye' **2** **OR** 'Light from one projector gets through to one eye. Light from the other projector gets through to the other eye' **2**
	(c)		There will be no change to the brightness. **1** Light from the lamp is unpolarised. **1**	**2**	
	(d)		(As the student rotates the filter,) the image from one projector will decrease in brightness, while the image from the other projector will increase in brightness. (The two images are almost identical). **1**	**1**	

MARKS | DO NOT WRITE IN THIS MARGIN

13. (a) Q_1 is a point charge of +12 nC. Point Y is 0·30 m from Q_1 as shown in Figure 13A.

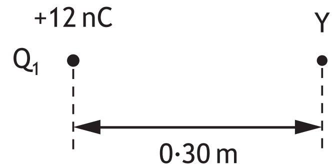


Figure 13A

Show that the electrical potential at point Y is +360 V. **2**

Space for working and answer

(b) A second point charge Q_2 is placed at a distance of 0·40 m from point Y as shown in Figure 13B . The electrical potential at point Y is now zero.

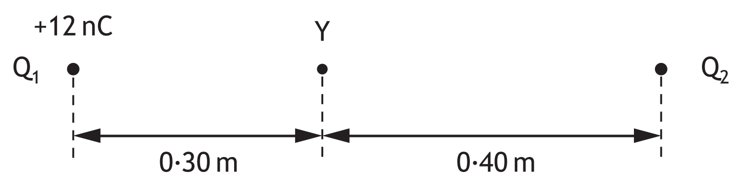


Figure 13B

(i) Determine the charge of Q_2. **3**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

13. (b) (continued)

(ii) Determine the electric field strength at point Y. **4**

Space for working and answer

(iii) On Figure 13C, sketch the electric field pattern for this system of charges. **2**

Figure 13C

(An additional diagram, if required, can be found on *Page 41*)

[Turn over

Question			Answer	Max Mark	Additional Guidance
13	(a)		SHOW QUESTION $V=\frac{1}{4\pi\varepsilon_o}\frac{Q_1}{r}$ **1** $V=\frac{1}{4\pi\times8\cdot85\times10^{-12}}\frac{12\times10^{-9}}{0\cdot30}$ **1** $V=(+)360\text{ V}$	2	$V=k\frac{Q_1}{r}$ **1** $V=\frac{9\times10^9\times12\times10^{-9}}{0\cdot30}$ **1** **OR** $V=\frac{12\times10^{-9}}{1\cdot1\times10^{-10}\times0\cdot30}$ $V=(+)360\text{ V}$ If either a value for k or ε_0 is not given, then a maximum of 1 mark can be awarded. If the final line is missing then a maximum of 1 mark can be awarded
	(b)	(i)	V = -360 (V) **1** $V=\frac{1}{4\pi\varepsilon_o}\frac{Q_2}{r}$ $-360=\frac{Q_2}{4\pi\times8\cdot85\times10^{-12}\times0\cdot40}$ **1** $Q_2=-1\cdot6\times10^{-8}\text{ C}$ **1**	3	Accept 2, 1·60, 1·601 Use of 9 × 10^9 acceptable Accept 2, 1·60, 1·600 Use of ratio method acceptable. Must start with $V_1 + V_2 = 0$ or equivalent. V = +360V – zero marks
		(ii)	$E_1=\frac{1}{4\pi\varepsilon_o}\frac{Q_1}{r^2}$ **1** $E_1=\frac{1}{4\pi\times8\cdot85\times10^{-12}}\frac{12\times10^{-9}}{0\cdot30^2}$ **1** $E_1=1200\ (\text{N C}^{-1}\ \textit{to right})$ $E_2=\frac{1}{4\pi\times8\cdot85\times10^{-12}}\frac{1\cdot6\times10^{-8}}{0\cdot40^2}$ **1** $E_2=900\ (\text{N C}^{-1}\text{ to right})$ $Total=2100\ \text{N C}^{-1}$ (to right) **1**	4	Accept 2000, 2098 Allow correct answer or consistent with b(i).
		(iii)	Shape of attractive field, including correct direction **1** Skew in correct position **1**	2	Field consistent with (b) (i)

MARKS DO NOT WRITE IN THIS MARGIN

14. A student measures the magnetic induction at a distance r from a long straight current carrying wire using the apparatus shown in Figure 14.

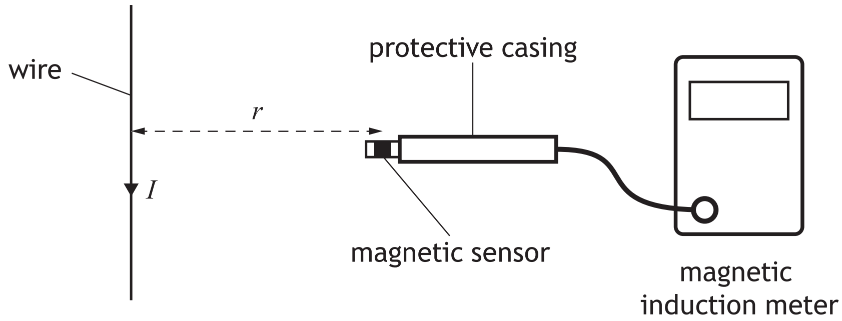


Figure 14

The following data are obtained.

Distance from wire $r = 0{\cdot}10\,\text{m}$
Magnetic induction $B = 5{\cdot}0\,\mu\text{T}$

(a) Use the data to calculate the current I in the wire. **3**

Space for working and answer

(b) The student estimates the following uncertainties in the measurements of B and r.

Uncertainties in r		Uncertainties in B	
reading	$\pm 0{\cdot}002\,\text{m}$	reading	$\pm 0{\cdot}1\,\mu\text{T}$
calibration	$\pm 0{\cdot}0005\,\text{m}$	calibration	$\pm 1{\cdot}5\%$ of reading

(i) Calculate the percentage uncertainty in the measurement of r. **1**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

14. (b) (continued)

(ii) Calculate the percentage uncertainty in the measurement of B. **3**

Space for working and answer

(iii) Calculate the absolute uncertainty in the value of the current in the wire. **2**

Space for working and answer

(c) The student measures distance r, as shown in Figure 14, using a metre stick. The smallest scale division on the metre stick is 1 mm.

Suggest a reason why the student's estimate of the reading uncertainty in r is not ±0·5 mm. **1**

[Turn over

Question			Answer	Max Mark	Additional Guidance
14.	(a)		$B = \frac{\mu_o I}{2\pi r}$ **1** $B = 5\times10^{-6} = \frac{4\pi\times10^{-7}\times I}{2\pi\times0\cdot1}$ **1** $I = 2\cdot5$ A **1**	**3**	Accept 3, 2·50, 2·500
	(b)	(i)	ignore calibration (less than 1/3) $\%\text{unc} = 0\cdot002/0\cdot1\times100 = 2\%$ **1**	**1**	Accept 2·1% if calibration not ignored. (Accept 2%, 2·06%, 2.062%)
		(ii)	reading $5 = 0\cdot1/5\times100 = 2\%$ **1** total%=√(reading%^{2}+calibration%^{2}) **1** total % = √($1\cdot5^2$ + 2^2) = 2·5% **1**	**3**	Accept 3%, 2·50%, 2·500%
		(iii)	total % = √(2^2 + $2\cdot5^2$)=√10·25% **1** abs u/c= $\frac{\sqrt{10\cdot25}}{100}$ × 2·5 = 0·08 A **1**	**2**	Accept 0·1, 0·080, 0·0800 Consistent with b(i) and (ii).
	(c)		Uncertainty in measuring exact distance from wire to position of sensor.	**1**	

15. A student constructs a simple air-insulated capacitor using two parallel metal plates, each of area A, separated by a distance d. The plates are separated using small insulating spacers as shown in Figure 15A.

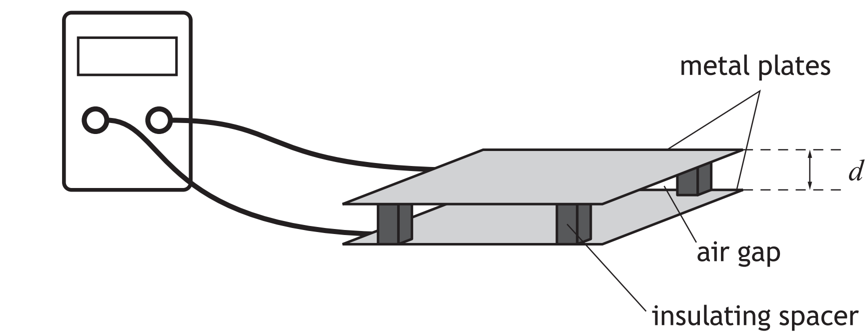


Figure 15A

The capacitance C of the capacitor is given by

$$C = \varepsilon_0 \frac{A}{d}$$

The student investigates how the capacitance depends on the separation of the plates. The student uses a capacitance meter to measure the capacitance for different plate separations. The plate separation is measured using a ruler.

The results are used to plot the graph shown in Figure 15B.

The area of each metal plate is $9{\cdot}0 \times 10^{-2}\ \text{m}^2$.

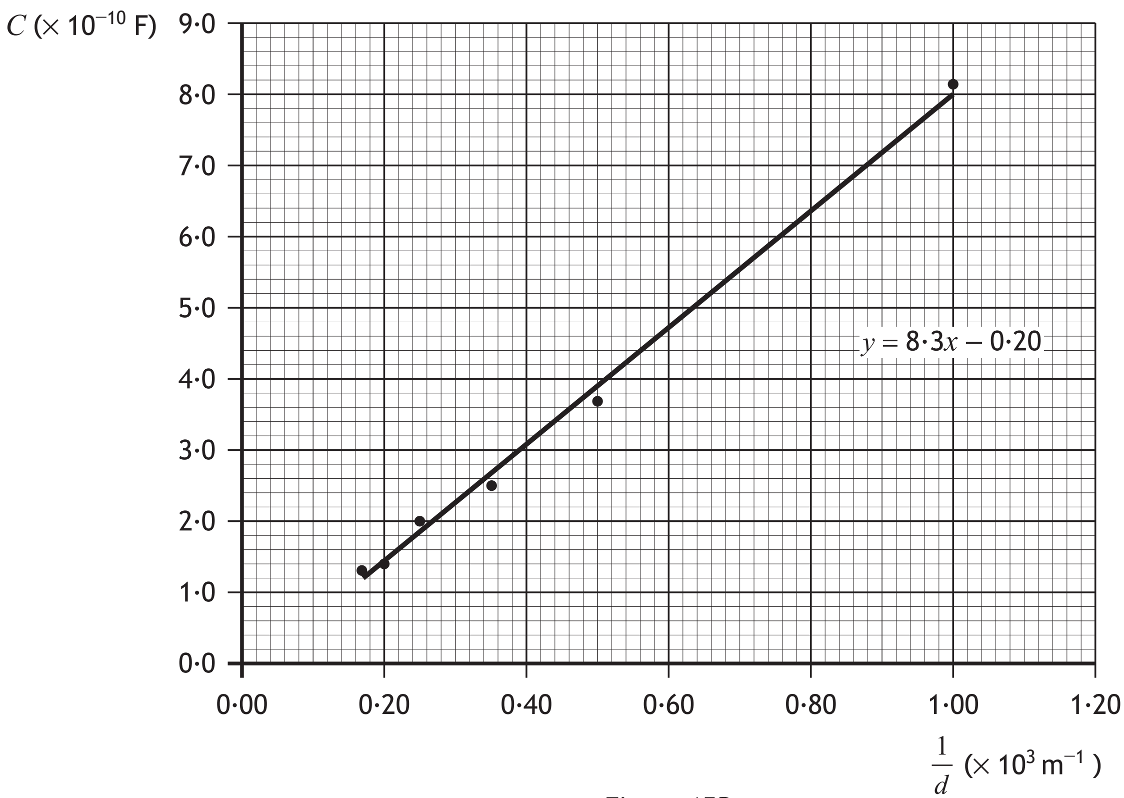


Figure 15B

MARKS DO NOT WRITE IN THIS MARGIN

15. (continued)

(a) (i) Use information from the graph to determine a value for ε_o, the permittivity of free space. **3**

Space for working and answer

(ii) Use your calculated value for the permittivity of free space to determine a value for the speed of light in air. **3**

Space for working and answer

(b) The best fit line on the graph does not pass through the origin as theory predicts.

Suggest a reason for this. **1**

[Turn over

Question			Answer	Max Mark	Additional Guidance
15.	(a)	(i)	$gradient = \frac{8\cdot3\times10^{-10}}{10^{3}}$ $= 8\cdot3\times10^{-13}$ **1** -------------------------------- $gradient = \varepsilon_0 A$ **1** $8\cdot3\times10^{-13} = \varepsilon_0 \times 9\cdot0\times10^{-2}$ $\varepsilon_0 = 9\cdot2\times10^{-12}$ F m^{-1} **1**	**3**	Accept 9, 9·22, 9·222 If gradient calculated using two points from best fit line, full credit possible.
		(ii)	$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$ **1** $c = \frac{1}{\sqrt{9\cdot2\times10^{-12}\times4\pi\times10^{-7}}}$ **1** $c = 2\cdot9\times10^{8}$ m s^{-1} **1**	**3**	Accept 3, 2·94, 2·941 Or consistent with (a)(i)
	(b)		Systematic uncertainty specific to capacitance or spacing measurement	**1**	Systematic uncertainty: Large % uncertainty in smallest values of d Stray capacitance Dip in plates/non uniform plate separation. Insufficient/poor choice of range. 'Systematic uncertainty' on its own – 0 marks

MARKS DO NOT WRITE IN THIS MARGIN

16. A student uses two methods to determine the moment of inertia of a solid sphere about an axis through its centre.

(a) In the first method the student measures the mass of the sphere to be 3·8 kg and the radius to be 0·053 m.

Calculate the moment of inertia of the sphere. **3**

Space for working and answer

(b) In the second method, the student uses conservation of energy to determine the moment of inertia of the sphere.

The following equation describes the conservation of energy as the sphere rolls down the slope

$$mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

where the symbols have their usual meanings.

The equation can be rearranged to give the following expression

$$2gh = \left(\frac{I}{mr^2} + 1\right)v^2$$

This expression is in the form of the equation of a straight line through the origin,

$$y = gradient \times x$$

[Turn over

16. (b) (continued) MARKS DO NOT WRITE IN THIS MARGIN

The student measures the height of the slope h. The student then allows the sphere to roll down the slope and measures the final speed of the sphere v at the bottom of the slope as shown in Figure 16.

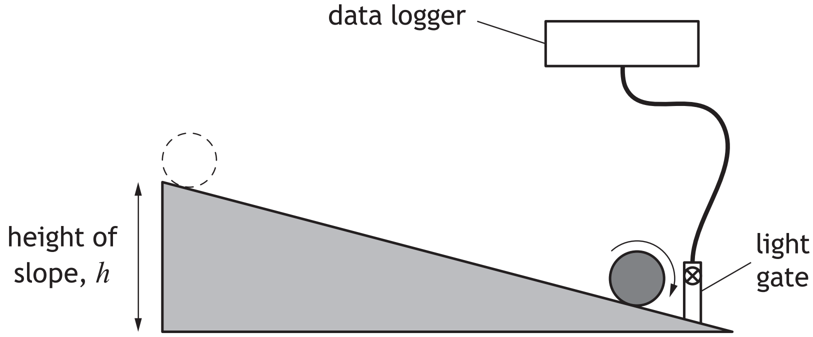


Figure 16

The following is an extract from the student's notebook.

h (m)	v ($m\,s^{-1}$)	$2gh$ ($m^2\,s^{-2}$)	v^2 ($m^2\,s^{-2}$)
0·020	0·42	0·39	0·18
0·040	0·63	0·78	0·40
0·060	0·68	1·18	0·46
0·080	0·95	1·57	0·90
0·100	1·05	1·96	1·10

$m = 3{\cdot}8$ kg $r = 0{\cdot}053$ m

(i) On the square-ruled paper on *Page 37*, draw a graph that would allow the student to determine the moment of inertia of the sphere. **3**

(ii) Use the gradient of your line to determine the moment of inertia of the sphere. **3**

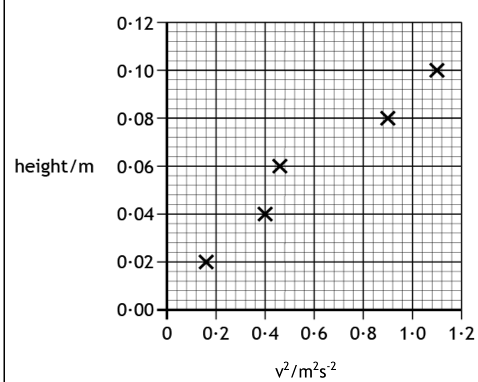
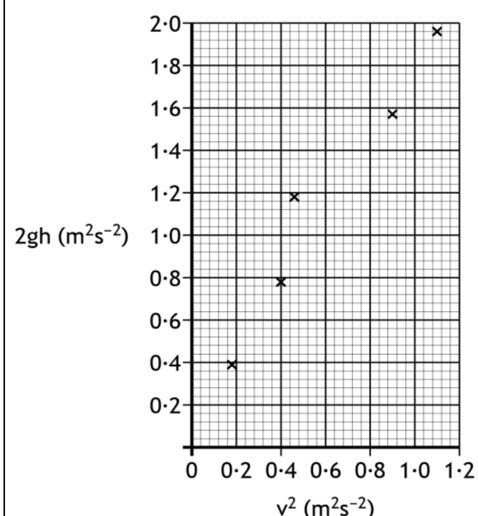
Space for working and answer

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

(c) The student states that more confidence should be placed in the value obtained for the moment of inertia in the second method.

Use your knowledge of experimental physics to comment on the student's statement. **3**

[END OF QUESTION PAPER]

Question			Answer	Max Mark	Additional Guidance
16.	(a)		$I=\frac{2}{5}mr^2$ **1** $I=\frac{2}{5}\times 3\cdot 8\times 0\cdot 053^2$ **1** $I=4\cdot 3\times 10^{-3}$ kg m^2 **1**	**3**	Accept 4, 4·27, 4·270
	(b)	(i)	Labelling & scales **1** Plotting **1** best fit line **1** ½ box tolerance applies for plotting	**3**	If rogue point not ignored, do not award the mark for best fit line, unless incorrect plotting does not expose a rogue point.  

Question			Answer	Max Mark	Additional Guidance
		(ii)	*gradient* = 1·73 or consistent with candidate's best fit line. **1** -- $2gh = \left(\frac{I}{mr^2}+1\right)v^2$ $\frac{2gh}{v^2} = \left(\frac{I}{mr^2}+1\right)$ $1\cdot73 = \left(\frac{I}{3\cdot8\times0\cdot053^2}+1\right)$ **1** $I = 7\cdot8\times10^{-3}\ \text{kg m}^2$ **1**	**3**	The gradient should be calculated using points from the candidate's best fit line to access the first mark. $\frac{h}{v^2} = \frac{1}{2g}\left(\frac{I}{mr^2}+1\right)$ $0\cdot088 = \frac{1}{2\times9\cdot8}\left(\frac{I}{3\cdot8\times0\cdot053^2}+1\right)$ **1** $I = 7\cdot74\times10^{-3}\ \text{kg m}^2$ 1

FOR OFFICIAL USE

AH

National Qualifications 2017

Mark

X757/77/01 Physics

WEDNESDAY, 17 MAY

9:00 AM – 11:30 AM

X757770 1

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 — 140

Attempt ALL questions.

Reference may be made to the Physics Relationship Sheet X757/77/11 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 Moon	M_M	$7{\cdot}3 \times 10^{22}$ kg	Mass of proton	m_p	$1{\cdot}673 \times 10^{-27}$ kg
Radius of Moon	R_M	$1{\cdot}7 \times 10^{6}$ m	Mass of alpha particle	m_α	$6{\cdot}645 \times 10^{-27}$ kg
Mean Radius of Moon Orbit		$3{\cdot}84 \times 10^{8}$ m	Charge on alpha particle		$3{\cdot}20 \times 10^{-19}$ C
Solar radius		$6{\cdot}955 \times 10^{8}$ m	Planck's constant	h	$6{\cdot}63 \times 10^{-34}$ J s
Mass of Sun		$2{\cdot}0 \times 10^{30}$ kg	Permittivity of free space	ε_0	$8{\cdot}85 \times 10^{-12}\ \text{F m}^{-1}$
1 AU		$1{\cdot}5 \times 10^{11}$ m	Permeability of free space	μ_0	$4\pi \times 10^{-7}\ \text{H m}^{-1}$
Stefan-Boltzmann constant	σ	$5{\cdot}67 \times 10^{-8}\ \text{W m}^{-2}\text{K}^{-4}$	Speed of light in vacuum	c	$3{\cdot}00 \times 10^{8}\ \text{m s}^{-1}$
Universal constant of gravitation	G	$6{\cdot}67 \times 10^{-11}\ \text{m}^3\ \text{kg}^{-1}\ \text{s}^{-2}$	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/* J kg^{-1} 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.

Total marks — 140 marks

Attempt ALL questions

MARKS DO NOT WRITE IN THIS MARGIN

1. An athlete competes in a one hundred metre race on a flat track, as shown in Figure 1A.

Figure 1A

Starting from rest, the athlete's speed for the first 3·10 seconds of the race can be modelled using the relationship

$$v = 0 \cdot 4t^2 + 2t$$

where the symbols have their usual meaning.

According to this model:

(a) determine the speed of the athlete at $t = 3 \cdot 10$ s; **2**

Space for working and answer

(b) determine, using **calculus** methods, the distance travelled by the athlete in this time. **3**

Space for working and answer

Detailed Marking Instructions for each question

Question			Answer	Max mark	Additional guidance
1.	(a)		$v = 0{\cdot}4t^2 + 2t$ $v = (0{\cdot}4 \times 3{\cdot}10^2) + (2 \times 3{\cdot}10)$ 1 $v = 10{\cdot}0\ \text{m s}^{-1}$ 1 Accept: 10, 10·04, 10·044	**2**	
	(b)		$s = \int (0{\cdot}4t^2 + 2t).dt$ $s = \frac{0{\cdot}4}{3}t^3 + t^2 (+c)$ 1 $s = 0$ when $t = 0,\ c = 0$ $s = \frac{0{\cdot}4}{3} \times (3{\cdot}10)^3 + 3{\cdot}10^2$ 1 $s = 13{\cdot}6\ \text{m}$ 1 Accept: 14, 13·58, 13·582	**3**	Solution with limits also acceptable. $s = \int_0^{3.10} (0{\cdot}4t^2 + 2\text{t}).dt$ $s = \left[\frac{0{\cdot}4 \times t^3}{3} + t^2\right]_{(0)}^{(3.10)}$ 1 $s = \left(\frac{0{\cdot}4 \times 3{\cdot}10^3}{3} + 3{\cdot}10^2\right) - 0$ 1 $s = 13{\cdot}6\ \text{m}$ 1

MARKS | DO NOT WRITE IN THIS MARGIN

2. (a) As part of a lesson, a teacher swings a sphere tied to a light string as shown in Figure 2A. The path of the sphere is a vertical circle as shown in Figure 2B.

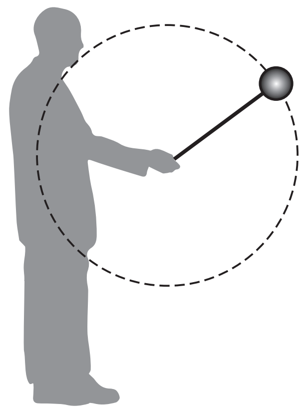


Figure 2A

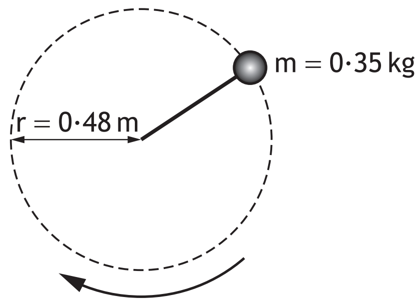


Figure 2B

(i) On Figure 2C, show the forces acting on the sphere as it passes through its highest point.

You must name these forces and show their directions. **1**

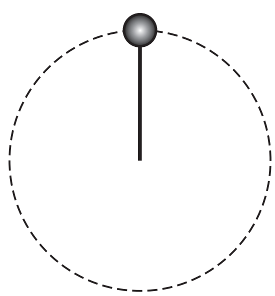


Figure 2C

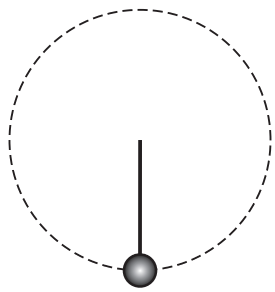
MARKS DO NOT WRITE IN THIS MARGIN

2. (a) (continued)

(ii) On Figure 2D, show the forces acting on the sphere as it passes through its lowest point.

You must name these forces and show their directions. **1**

Figure 2D



(iii) The sphere of mass 0·35 kg can be considered to be moving at a constant speed.

The centripetal force acting on the sphere is 4·0 N.

Determine the magnitude of the tension in the light string when the sphere is at:

(A) the highest position in its circular path; **2**

Space for working and answer

(B) the lowest position in its circular path. **1**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

2. (continued)

(b) The speed of the sphere is now gradually reduced until the sphere no longer travels in a circular path.

Explain why the sphere no longer travels in a circular path. **2**

(c) The teacher again swings the sphere with constant speed in a vertical circle. The student shown in Figure 2E observes the sphere moving up and down vertically with simple harmonic motion.

The period of this motion is 1·4 s.

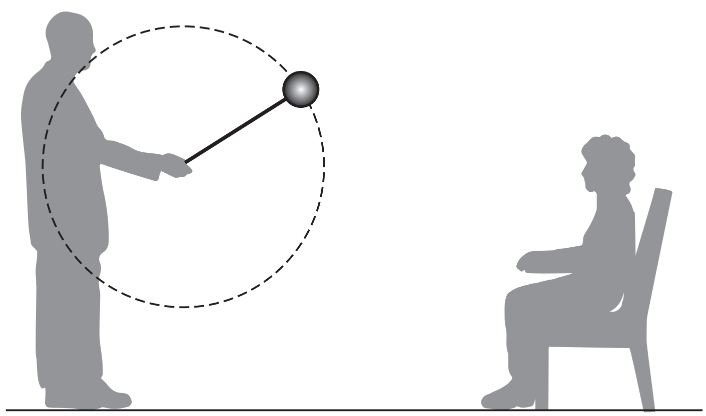


Figure 2E

Figure 2F represents the path of the sphere as observed by the student.

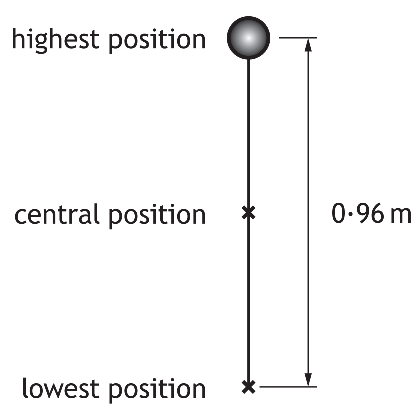


Figure 2F

MARKS DO NOT WRITE IN THIS MARGIN

2. (c) (continued)

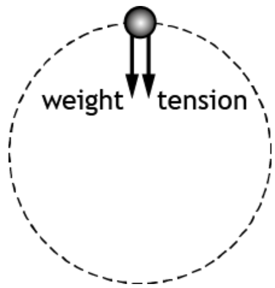
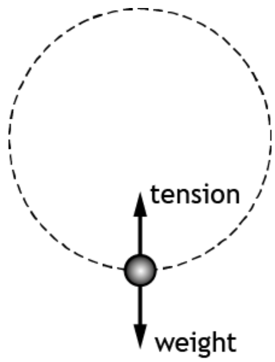
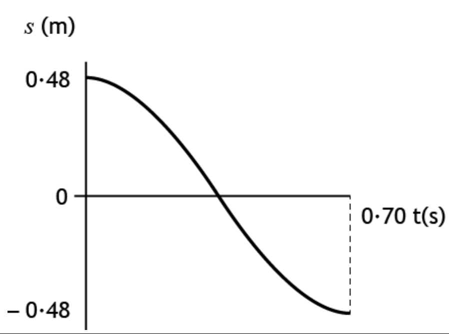
On Figure 2G, sketch a graph showing how the vertical displacement s of the sphere from its central position varies with time t, as it moves from its highest position to its lowest position.

Numerical values are required on both axes. **3**

Figure 2G

(An additional diagram, if required, can be found on *Page 42*.)

[Turn over

Question			Answer	Max mark	Additional guidance
2.	(a)	(i)		**1**	If centripetal force is included and in the downward direction – ignore If centripetal force is included and in any other direction – award 0 marks Any mention of centrifugal force - award 0 marks.
		(ii)		**1**	If centripetal force is included and in the upward direction – ignore. If centripetal force is included and in any other direction – award 0 marks Any mention of centrifugal force - award 0 marks.
		(iii) (A)	$T + (0{\cdot}35 \times 9{\cdot}8) = 4{\cdot}0$ 1 $T = 0{\cdot}57\ \text{N}$ 1 Accept: 0·6, 0·570, 0·5700	**2**	
		(B)	$T = 7{\cdot}4\ \text{N}$ 1 Accept: 7, 7·43, 7·430	**1**	
	(b)		the tension reduces (to zero) 1 weight is greater than the central force that would be required for circular motion. 1	**2**	Independent marks.
	(c)		Shape 1 0·48 and -0·48 for amplitude 1 0·7(0) time for half cycle 1 	**3**	Marks independent.

MARKS DO NOT WRITE IN THIS MARGIN

3. A student uses a solid, uniform circular disc of radius 290 mm and mass 0·40 kg as part of an investigation into rotational motion.

The disc is shown in Figure 3A.

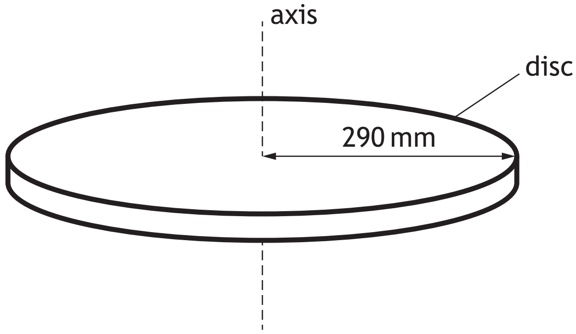


Figure 3A

(a) Calculate the moment of inertia of the disc about the axis shown in Figure 3A. **3**

Space for working and answer

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

(b) The disc is now mounted horizontally on the axle of a rotational motion sensor as shown in Figure 3B.

The axle is on a frictionless bearing. A thin cord is wound around a stationary pulley which is attached to the axle.

The moment of inertia of the pulley and axle can be considered negligible.

The pulley has a radius of 7·5 mm and a force of 8·0 N is applied to the free end of the cord.

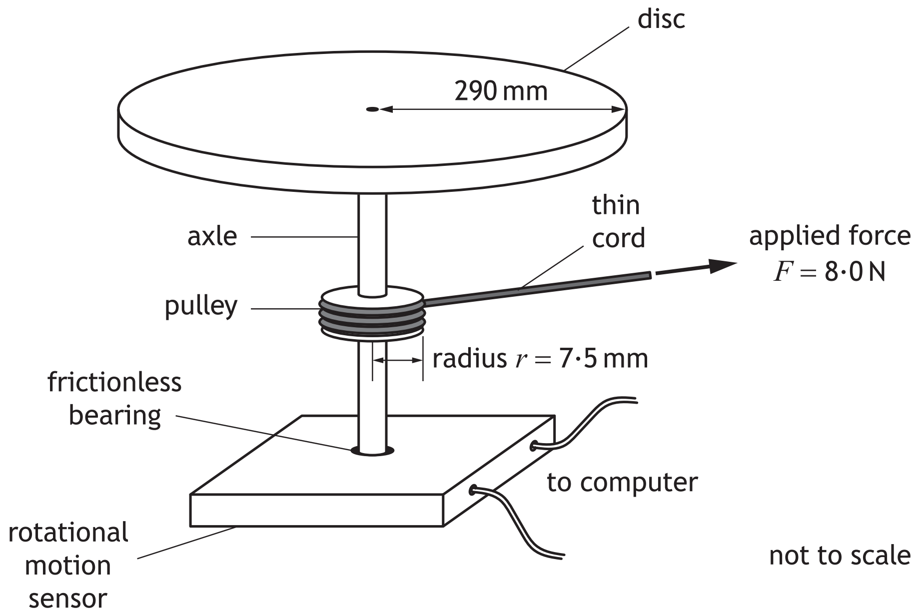


Figure 3B

(i) Calculate the torque applied to the pulley. **3**

Space for working and answer

(ii) Calculate the angular acceleration produced by this torque. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

3. (b) (continued)

(iii) The cord becomes detached from the pulley after 0·25 m has unwound.

By considering the angular displacement of the disc, determine its angular velocity when the cord becomes detached. **5**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

3. (continued)

(c) In a second experiment the disc has an angular velocity of $12\ \text{rad s}^{-1}$.

The student now drops a small 25 g cube vertically onto the disc. The cube sticks to the disc.

The centre of mass of the cube is 220 mm from the axis of rotation, as shown in Figure 3C.

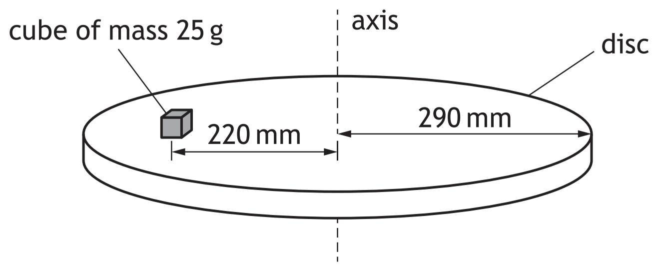


Figure 3C

Calculate the angular velocity of the system immediately after the cube was dropped onto the disc. **5**

Space for working and answer

Question			Answer	Max mark	Additional guidance
3.	(a)		$I = \frac{1}{2}mr^2$ 1 $I = \frac{1}{2} \times 0 \cdot 40 \times \left(290 \times 10^{-3}\right)^2$ 1 $I = 0 \cdot 017\ \text{kg m}^2$ 1 Accept: 0·02, 0·0168, 0·01682	3	
	(b)	(i)	$T = Fr$ 1 $T = 8 \cdot 0 \times 7 \cdot 5 \times 10^{-3}$ 1 $T = 0 \cdot 060\ \text{N m}$ 1 Accept: 0·06, 0·0600, 0·06000	3	
		(ii)	$T = I\alpha$ 1 $0 \cdot 060 = 0 \cdot 017 \times \alpha$ 1 $\alpha = 3 \cdot 5\ \text{rad s}^{-2}$ 1 Accept: 4, 3·53, 3·529	3	Or consistent with (a) and (b)(i)
		(iii)	$\theta = \frac{s}{r}$ 1 $\theta = \frac{0 \cdot 25}{7 \cdot 5 \times 10^{-3}}$ 1 $\omega^2 = \omega_0^2 + 2\alpha\theta$ 1 $\omega^2 = 0^2 + 2 \times 3 \cdot 5 \times \frac{0 \cdot 25}{7 \cdot 5 \times 10^{-3}}$ 1 $\omega = 15\ \text{rad s}^{-1}$ 1 Accept: 20, 15·3, 15·28	5	Or consistent with (a), (b)(i) and (b)(ii) $\theta = \omega_0 t + \frac{1}{2}\alpha t^2$ and $\alpha = \frac{\omega - \omega_0}{t}$ 1
	(c)		$I_{cube} = mr^2$ 1 $I_{cube} = 25 \times 10^{-3} \times (220 \times 10^{-3})^2$ 1 $I_1\omega_1 = (I_1 + I_{cube})\omega_2$ 1 $0 \cdot 017 \times 12 = (0 \cdot 017 +$ $(25 \times 10^{-3} \times (220 \times 10^{-3})^2))\omega_2$ 1 $\omega_2 = 11\ \text{rad s}^{-1}$ 1 Accept: 10, 11·2, 11·20	5	Or consistent with (a)

MARKS DO NOT WRITE IN THIS MARGIN

4. The NASA space probe Dawn has travelled to and orbited large asteroids in the solar system. Dawn has a mass of 1240 kg.

The table gives information about two large asteroids orbited by Dawn. Both asteroids can be considered to be spherical and remote from other large objects.

Name	*Mass* ($\times 10^{20}$ kg)	*Radius* (km)
Vesta	2·59	263
Ceres	9·39	473

(a) Dawn began orbiting Vesta, in a circular orbit, at a height of 680 km above the surface of the asteroid. The gravitational force acting on Dawn at this altitude was 24·1 N.

(i) Show that the tangential velocity of Dawn in this orbit is 135 m s^{-1}. **2**

Space for working and answer

(ii) Calculate the orbital period of Dawn. **3**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

4. (continued)

(b) Later in its mission, Dawn entered orbit around Ceres. It then moved from a high orbit to a lower orbit around the asteroid.

(i) State what is meant by the *gravitational potential of a point in space*. **1**

(ii) Dawn has a gravitational potential of $-1{\cdot}29 \times 10^4\,\text{J kg}^{-1}$ in the high orbit and a gravitational potential of $-3{\cdot}22 \times 10^4\,\text{J kg}^{-1}$ in the lower orbit.

Determine the change in the potential energy of Dawn as a result of this change in orbit. **4**

Space for working and answer

Question			Answer	Max mark	Additional guidance
4.	(a)	(i)	$F = \frac{mv^2}{r}$ 1 $24 \cdot 1 = \frac{1240 \times v^2}{(263 \times 10^3 + 680 \times 10^3)}$ 1 $v = 135 \text{ m s}^{-1}$	2	SHOW question $\frac{mv^2}{r} = \frac{GMm}{r^2}$ 1 $v = \sqrt{\frac{GM}{r}}$ $v = \sqrt{\frac{6 \cdot 67 \times 10^{-11} \times 2 \cdot 59 \times 10^{20}}{(263 + 680) \times 10^3}}$ 1 $v = 135 \text{ m s}^{-1}$ If final answer not shown a maximum of 1 mark can be awarded.
		(ii)	$v_c = \frac{2\pi r}{T}$ 1 $135 = \frac{2\pi(263 \times 10^3 + 680 \times 10^3)}{T}$ 1 $T = 4 \cdot 39 \times 10^4 \text{ s}$ 1 Accept: 4·4, 4·389, 4·3889	3	
	(b)	(i)	The work done in moving unit mass from infinity (to that point). 1	1	
		(ii)	$V_{low} - V_{high} = -3 \cdot 22 \times 10^4 - \left(-1 \cdot 29 \times 10^4\right)$ 1 $V_{low} - V_{high} = -1 \cdot 93 \times 10^4$ $(\Delta)E = (\Delta)Vm$ 1 $(\Delta)E = -1 \cdot 93 \times 10^4 \times 1240$ 1 $(\Delta)E = -2 \cdot 39 \times 10^7 \text{ J}$ 1 Accept: 2·4, 2·393, 2·3932	4	Can also be done by calculating potential energy in each orbit and subtracting. 1 for relationship 1 for all substitutions 1 for subtraction 1 for final answer including unit

MARKS DO NOT WRITE IN THIS MARGIN

5. Two students are discussing objects escaping from the gravitational pull of the Earth. They make the following statements:

Student 1: A rocket has to accelerate until it reaches the escape velocity of the Earth in order to escape its gravitational pull.

Student 2: The moon is travelling slower than the escape velocity of the Earth and yet it has escaped.

Use your knowledge of physics to comment on these statements. **3**

MARKS DO NOT WRITE IN THIS MARGIN

6. A Hertzsprung-Russell (H-R) diagram is shown in Figure 6A.

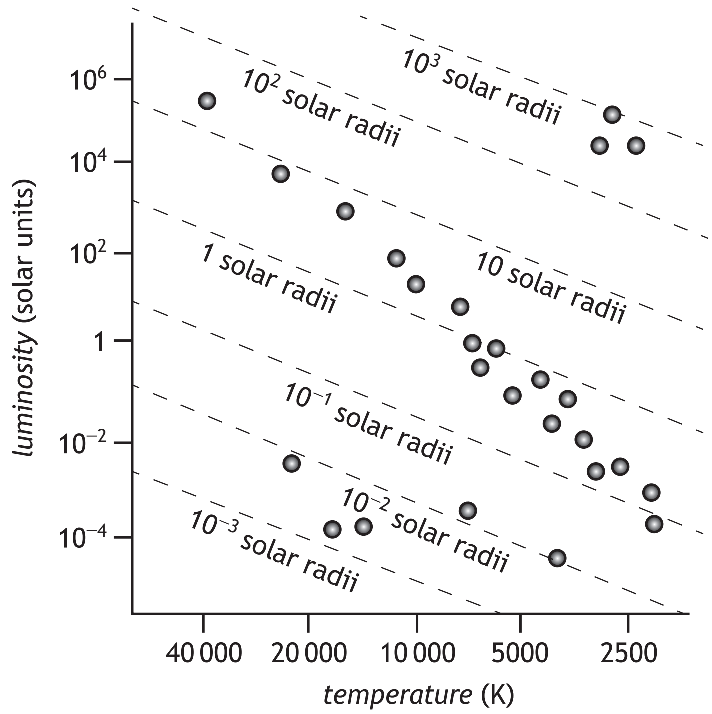


Figure 6A

(a) All stars on the main sequence release energy by converting hydrogen to helium. This process is known as the proton-proton (p-p) chain. One stage in the p-p chain is shown.

$$^1_1\text{H} + ^1_1\text{H} \rightarrow ^2_1\text{H} + \text{x} + \text{y}$$

Name particles x and y. **2**

(b) The luminosity of the Sun is $3{\cdot}9 \times 10^{26}$ W. The star Procyon B has a luminosity of $4{\cdot}9 \times 10^{-4}$ solar units and a radius of $1{\cdot}2 \times 10^{-2}$ solar radii.

(i) On the H-R diagram, circle the star at the position of Procyon B. **1**

(An additional diagram, if required, can be found on *Page 42*.)

(ii) What type of star is Procyon B? **1**

MARKS | DO NOT WRITE IN THIS MARGIN

6. (b) (continued)

(iii) The apparent brightness of Procyon B when viewed from Earth is $1{\cdot}3 \times 10^{-12}\ W\,m^{-2}$.

Calculate the distance of Procyon B from Earth. **4**

Space for working and answer

(c) The expression

$$\frac{L}{L_0} = 1{\cdot}5\left(\frac{M}{M_0}\right)^{3{\cdot}5}$$

can be used to approximate the relationship between a star's mass M and its luminosity L.

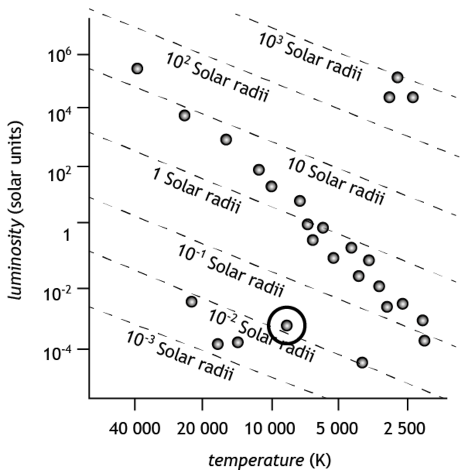
L_0 is the luminosity of the Sun (1 solar unit) and M_0 is the mass of the Sun.

This expression is valid for stars of mass between $2M_0$ and $20M_0$.

Spica is a star which has mass $10{\cdot}3M_0$.

Determine the approximate luminosity of Spica in solar units. **2**

Space for working and answer

Question			Answer	Max mark	Additional guidance
6.	(a)		(electron) neutrino (1) and positron (1)	2	e^+ and ν acceptable
	(b)	(i)	Correctly marked 1 	1	
		(ii)	(White) Dwarf 1	1	Or consistent with (b)(i)
		(iii)	$L = 4\cdot9\times10^{-4}\times3\cdot9\times10^{26}$ 1 $b = \frac{L}{4\pi r^2}$ 1 $1\cdot3\times10^{-12} = \frac{4\cdot9\times10^{-4}\times3\cdot9\times10^{26}}{4\pi r^2}$ 1 $r = 1\cdot1\times10^{17}$ m 1 Accept: 1, 1·08, 1·082	4	
	(c)		$\frac{L}{L_0} = 1\cdot5\left(\frac{M}{M_0}\right)^{3\cdot5}$ $\frac{L}{L_0} = 1\cdot5\left(\frac{10\cdot3}{1}\right)^{3\cdot5}$ 1 $L = 5260(L_0)$ 1 Accept: 5300, 5260·4	2	

MARKS DO NOT WRITE IN THIS MARGIN

7. Laser light is often described as having a single frequency. However, in practice a laser will emit photons with a range of frequencies.

Quantum physics links the frequency of a photon to its energy.

Therefore the photons emitted by a laser have a range of energies (ΔE). The range of photon energies is related to the lifetime (Δt) of the atom in the excited state.

A graph showing the variation of intensity with frequency for light from two types of laser is shown in Figure 7A.

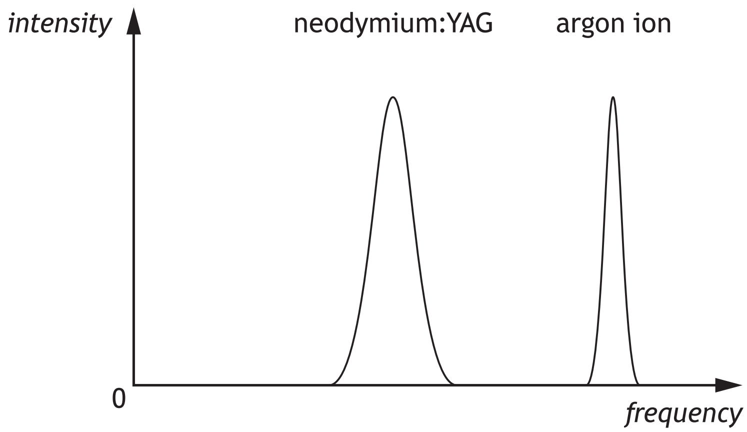


Figure 7A

(a) By considering the Heisenberg uncertainty principle, state how the lifetime of atoms in the excited state in the neodymium:YAG laser compares with the lifetime of atoms in the excited state in the argon ion laser.

Justify your answer. **2**

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7. **(continued)**

(b) In another type of laser, an atom is in the excited state for a time of $5 \cdot 0 \times 10^{-6}$ s.

(i) Calculate the minimum uncertainty in the energy (ΔE_{min}) of a photon emitted when the atom returns to its unexcited state. **3**

Space for working and answer

(ii) Determine a value for the range of frequencies (Δf) of the photons emitted by this laser. **3**

Space for working and answer

Question			Answer	Max mark	Additional guidance
7.	(a)		Atoms in the Nd:YAG have a shorter lifetime (in the excited state) OR Atoms in the Ar have a longer lifetime (in the excited state) 1 $\Delta f \propto \Delta E$ and $\Delta t \propto \frac{1}{\Delta E}$ or $\Delta t \propto \frac{1}{\Delta f}$ 1	**2**	
	(b)	(i)	$\Delta E \Delta t \geq \frac{h}{4\pi}$ 1 $\Delta E_{(min)} \times 5 \cdot 0 \times 10^{-6} = \frac{6 \cdot 63 \times 10^{-34}}{4\pi}$ 1 $\Delta E_{(min)} = 1 \cdot 1 \times 10^{-29}$ J 1 Accept: 1, 1·06, 1·055	**3**	
		(ii)	$(\Delta)E = h(\Delta)f$ 1 $1 \cdot 1 \times 10^{-29} = 6 \cdot 63 \times 10^{-34} \times (\Delta)f$ 1 $(\Delta)f = 1 \cdot 7 \times 10^{4}$ Hz 1 Accept: 2, 1·66, 1·659	**3**	Or consistent with (b)(i)

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8. A student is investigating simple harmonic motion. An oscillating mass on a spring, and a motion sensor connected to a computer, are used in the investigation. This is shown in Figure 8A.

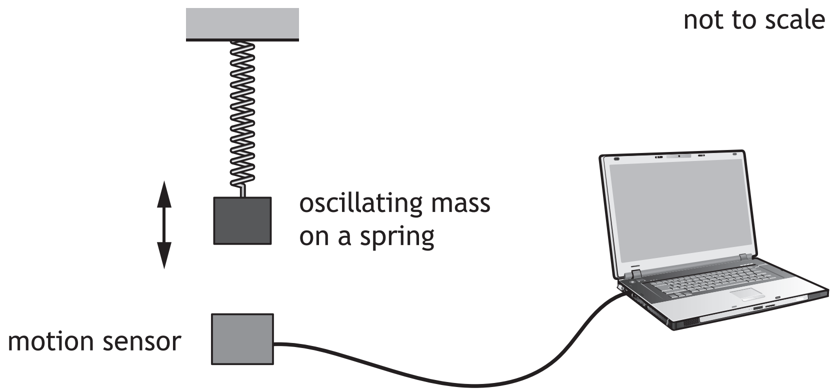


Figure 8A

The student raises the mass from its rest position and then releases it. The computer starts recording data when the mass is released.

(a) The student plans to model the displacement y of the mass from its rest position, using the expression

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

where the symbols have their usual meaning.

Explain why the student is incorrect. **1**

MARKS DO NOT WRITE IN THIS MARGIN

8. (continued)

(b) (i) The unbalanced force acting on the mass is given by the expression

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

Hooke's Law is given by the expression

$$F = -ky$$

where k is the spring constant.

By comparing these expressions, show that the frequency of the oscillation can be described by the relationship

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$ **2**

(ii) The student measures the mass to be 0·50 kg and the period of oscillation to be 0·80 s.

Determine a value for the spring constant k. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

8. (b) (continued)

(iii) The student plans to repeat the experiment using the same mass and a second spring, which has a spring constant twice the value of the original.

Determine the expected period of oscillation of the mass. **2**

(c) The student obtains graphs showing the variation of displacement with time, velocity with time and acceleration with time.

The student forgets to label the y-axis for each graph.

Complete the labelling of the y-axis of each graph in Figure 8B. **2**

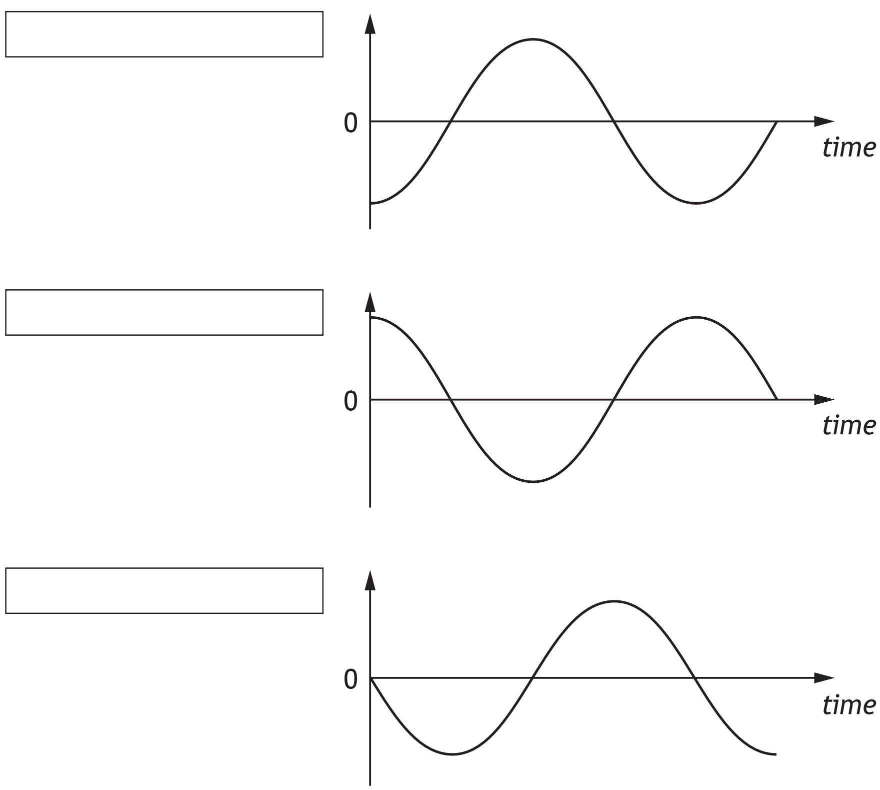
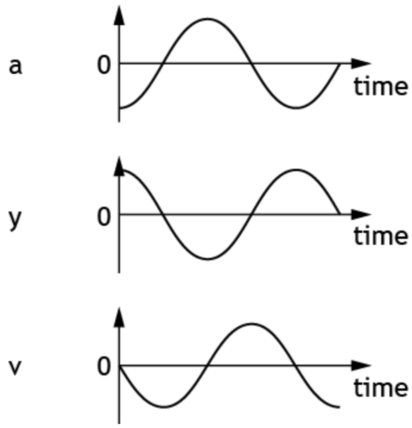


Figure 8B

Question			Answer	Max mark	Additional guidance
8.	(a)		At t=0 $\sin\omega t = 0$, which would mean that y=0. This is not the case in the example here, where y=A at t=0 1	1	Accept assumptions that no energy is lost
	(b)	(i)	$(F =)(-)m\omega^2 y = (-)ky$ 1 $\omega^2 = \frac{ky}{my}$ $\omega = \sqrt{\frac{k}{m}}$ $\omega = 2\pi f$ 1 $2\pi f = \sqrt{\frac{k}{m}}$ $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$	2	
		(ii)	$f = \frac{1}{T} = \left(\frac{1}{0\cdot 80}\right)$ 1 $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ $\frac{1}{0\cdot 80} = \frac{1}{2\pi}\sqrt{\frac{k}{0\cdot 50}}$ 1 $k = 31\ \text{N m}^{-1}$ 1 Accept: 30, 30·8, 30·84	3	
		(iii)	$T = \frac{0\cdot 80}{\sqrt{2}}$ 1 $T = 0\cdot 57\ \text{s}$ 1 Accept: 0·6, 0·566, 0·5657	2	$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ and $T = \frac{1}{f}$ $T = 2\times\pi\sqrt{\frac{0\cdot 50}{2\times 31}}$ 1 $T = 0\cdot 56\ \text{s}$ 1 Accept: 0·6, 0·564, 0·5642 Or consistent with (b)(ii)

Question			Answer	Max mark	Additional guidance
	(c)			**2**	(2) marks all three correct (1) mark for two correct

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9. A wave travelling along a string is represented by the relationship

$$y = 9 \cdot 50 \times 10^{-4} \sin\left(922t - 4 \cdot 50x\right)$$

(a) (i) Show that the frequency of the wave is 147 Hz. **1**

Space for working and answer

(ii) Determine the speed of the wave. **4**

Space for working and answer

(iii) The wave loses energy as it travels along the string.

At one point, the energy of the wave has decreased to one eighth of its original value.

Calculate the amplitude of the wave at this point. **3**

Space for working and answer

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9. (continued)

(b) The speed of a wave on a string can also be described by the relationship

$$v = \sqrt{\frac{T}{\mu}}$$

where v is the speed of the wave,

T is the tension in the string, and

μ is the mass per unit length of the string.

A string of length 0·69 m has a mass of $9{\cdot}0 \times 10^{-3}$ kg.

A wave is travelling along the string with a speed of 203 m s^{-1}.

Calculate the tension in the string. **3**

Space for working and answer

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9. **(continued)**

(c) When a string is fixed at both ends and plucked, a stationary wave is produced.

(i) Explain briefly, in terms of the superposition of waves, how the stationary wave is produced. **1**

(ii) The string is vibrating at its fundamental frequency of 270 Hz and produces the stationary wave pattern shown in Figure 9A.

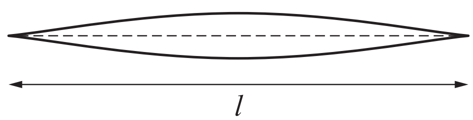

Figure 9A

Figure 9B shows the same string vibrating at a frequency called its third harmonic.

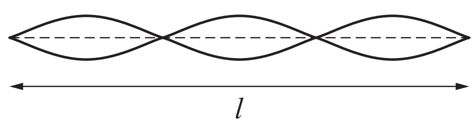

Figure 9B

Determine the frequency of the third harmonic. **1**

Question			Answer	Max mark	Additional guidance
9	(a)	(i)	$(\omega = 2\pi f)$ $922 = 2\pi f$ 1 $f = 147$ Hz	1	
		(ii)	$4 \cdot 50 = \left(\frac{2\pi}{\lambda}\right)$ 1 $v = f\lambda$ 1 $v = 147 \times \left(\frac{2\pi}{4 \cdot 50}\right)$ 1 $v = 205$ m s^{-1} 1 Accept:210, 205·3, 205·25	4	
		(iii)	$E = kA^2$ 1 $\frac{E}{(9 \cdot 50 \times 10^{-4})^2} = \frac{E}{8 \times A^2}$ 1 $A = 3 \cdot 36 \times 10^{-4}$ m 1 Accept: 3·4, 3·359, 3·3588	3	$\frac{E_1}{A_1^2} = \frac{E_2}{A_2^2}$ acceptable
	(b)		$\mu = \frac{9 \cdot 0 \times 10^{-3}}{0 \cdot 69}$ 1 $v = \sqrt{\frac{T}{\mu}}$ $203 = \sqrt{\frac{T}{\left(\frac{9 \cdot 0 \times 10^{-3}}{0 \cdot 69}\right)}}$ 1 $T = 540$ N 1 Accept: 500, 538, 537·5	3	
	(c)	(i)	Waves <u>reflected</u> from each end <u>interfere</u> (to create maxima and minima). 1	1	
		(ii)	$f_3 = (3 \times 270 =) 810$ Hz 1	1	

MARKS | DO NOT WRITE IN THIS MARGIN

10. The internal structure of some car windscreens produces an effect which can be likened to that obtained by slits in a grating.

A passenger in a car observes a distant red traffic light and notices that the red light is surrounded by a pattern of bright spots.

This is shown in Figure 10A.

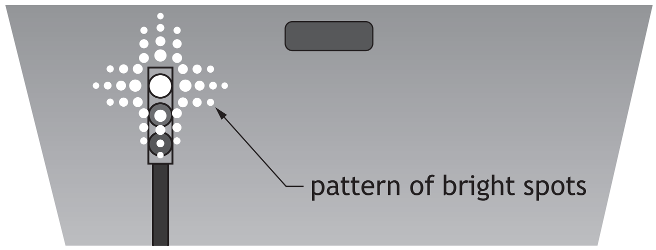

Figure 10A

(a) Explain how the **two-dimensional** pattern of bright spots shown in Figure 10A is produced. **2**

(b) The traffic light changes to green. Apart from colour, state a difference that would be observed in the pattern of bright spots.

Justify your answer. **2**

MARKS DO NOT WRITE IN THIS MARGIN

10. (continued)

(c) An LED from the traffic light is tested to determine the wavelength by shining its light through a set of Young's double slits, as shown in Figure 10B.

The fringe separation is (13·0 ± 0·5) mm and the double slit separation is (0·41 ± 0·01) mm.

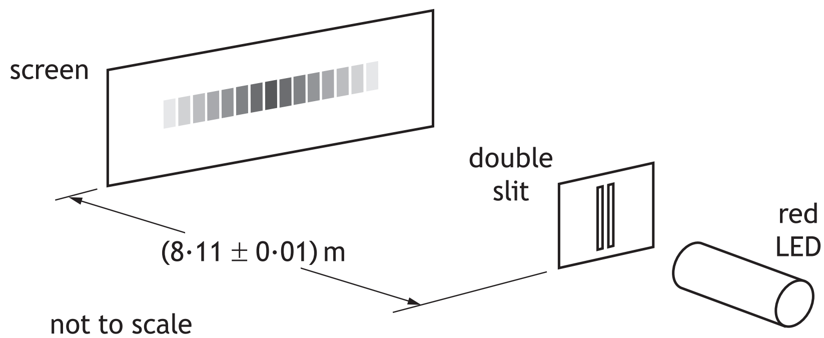

Figure 10B

(i) Calculate the wavelength of the light from the LED. **3**

Space for working and answer

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10. (c) (continued)

(ii) Determine the absolute uncertainty in this wavelength. **5**

Space for working and answer

(iii) The experiment is now repeated with the screen moved further away from the slits.

Explain why this is the most effective way of reducing the uncertainty in the calculated value of the wavelength. **1**

Question			Answer	Max mark	Additional guidance
10.	(a)		Pattern produced by interference. 1 Slits horizontal and vertical or at right angles 1	**2**	
	(b)		The spots are closer together. 1 The green light has a shorter wavelength and since $d\sin\theta = m\lambda$, d is fixed, $(\sin)\theta$ is smaller. 1	**2**	An argument quoting Young's slits is also acceptable. $\Delta x = \frac{\lambda D}{d}$ λ is less, D and d are fixed, so Δx is less

Question			Answer	Max mark	Additional guidance
	(c)	(i)	$\Delta x = \frac{\lambda D}{d}$ 1 $13 \cdot 0 \times 10^{-3} = \frac{\lambda \times 8 \cdot 11}{0 \cdot 41 \times 10^{-3}}$ 1 $\lambda = 6 \cdot 6 \times 10^{-7}$ m 1 Accept: 7, 6·57, 6·572	3	
		(ii)	% Uncertainty in fringe separation $= \left(\frac{0 \cdot 5}{13 \cdot 0}\right) \times 100$ 1 $= 3 \cdot 85\%$ % Uncertainty in slit separation $= \left(\frac{0 \cdot 01}{0 \cdot 41}\right) \times 100$ 1 $= 2 \cdot 44\%$ % Uncertainty in slit-screen separation $= \left(\frac{0 \cdot 01}{8 \cdot 11}\right) \times 100$ 1 $= 0 \cdot 123\%$ (can be ignored) % uncertainty in wavelength $= \sqrt{\left(\frac{0 \cdot 5}{13 \cdot 0}\right)^2 + \left(\frac{0 \cdot 01}{0 \cdot 41}\right)^2} \times 100\%$ 1 $= 4 \cdot 56\%$ $\Delta\lambda = \frac{4 \cdot 56}{100} \times 6 \cdot 6 \times 10^{-7}$ $\Delta\lambda = 0 \cdot 3 \times 10^{-7}$m 1	5	
		(iii)	Increasing the slit-screen distance spreads out the fringes, reducing the (percentage) uncertainty in the fringe separation (which is the dominant uncertainty). 1	1	

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11. (a) State what is meant by the term *electric field strength*. **1**

(b) A, B, C and D are the vertices of a square of side 0·12 m.

Two +4·0 nC point charges are placed at positions B and D as shown in Figure 11A.

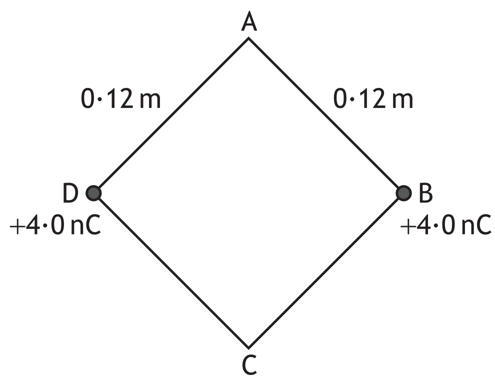


Figure 11A

(i) Show that the magnitude of the electric field strength at position A is $3{\cdot}5 \times 10^3\ \text{N C}^{-1}$. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

11. (b) (continued)

(ii) A +1·9 nC point charge is placed at position A.

Calculate the magnitude of the force acting on this charge. **3**

Space for working and answer

(iii) State the direction of the force acting on this charge. **1**

(iv) A fourth point charge is now placed at position C so that the resultant force on the charge at position A is zero.

Determine the magnitude of the charge placed at position C. **4**

Space for working and answer

Question			Answer	Max mark	Additional guidance
11	(a)		Force acting per unit positive charge (in an electric field)	**1**	
	(b)	(i)	$E = \frac{Q}{4\pi\varepsilon_0 r^2}$ 1 $E = \frac{4\cdot0\times10^{-9}}{4\pi\times8\cdot85\times10^{-12}\times0\cdot12^2}$ 1 $E_{total} = \sqrt{2\times\left[\frac{4\cdot0\times10^{-9}}{4\pi\times8\cdot85\times10^{-12}\times0\cdot12^2}\right]^2}$ 1 $E_{total} = 3\cdot5\times10^3\ \mathrm{N\,C^{-1}}$	**3**	If value for ε_0 not substituted, max 1 mark. third line can be done by trigonometry rather than Pythagoras. $E_{total} = 2\times\left[\frac{4\cdot0\times10^{-9}}{4\pi\times8\cdot85\times10^{-12}\times0\cdot12^2}\right]\times\sin45$ 1 If the final line is not shown then maximum 2 marks can be awarded.
		(ii)	$F = QE$ 1 $F = 1\cdot9\times10^{-9}\times3\cdot5\times10^3$ 1 $F = 6\cdot7\times10^{-6}\ \mathrm{N}$ 1 Accept: 7, 6·65, 6·650	**3**	$F_1 = \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$ and $F = \sqrt{F_1^2 + F_2^2}$ 1 $F = \sqrt{2\times\left(\frac{4\times10^{-9}\times1\cdot9\times10^{-9}}{4\pi\times8\cdot85\times10^{-12}\times0\cdot12^2}\right)^2}$ 1 $F = 6\cdot7\times10^{-6}N$ 1 Accept: 7, 6·71, 6·711 Accept: 6·718 for 9×10[9]
		(iii)	Towards top of page	**1**	
		(iv)	$r = \sqrt{(0\cdot12^2 + 0\cdot12^2)}$ 1 $F = \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$ 1 $6\cdot7\times10^{-6} = \frac{1\cdot9\times10^{-9}\times Q_2}{4\pi\times8\cdot85\times10^{-12}\times\sqrt{(0\cdot12^2+0\cdot12^2)}^2}$ 1 $Q_2 = 1\cdot1\times10^{-8}\mathrm{C}$ 1 Accept: 1, 1·13, 1·129	**4**	Or consistent with (b)(ii).

MARKS DO NOT WRITE IN THIS MARGIN

12. A velocity selector is used as the initial part of a larger apparatus that is designed to measure properties of ions of different elements.

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 ions.

This is shown in Figure 12A.

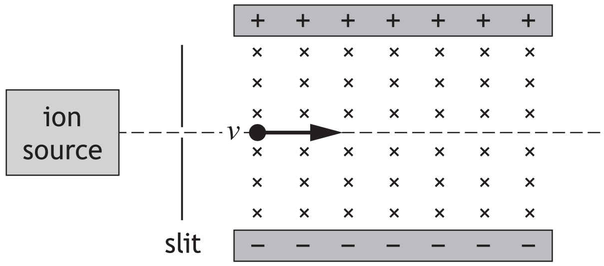


Figure 12A

A beam of chlorine ions consists of a number of isotopes including $^{35}Cl^{+}$.

The magnitude of the charge on a $^{35}Cl^{+}$ ion is $1{\cdot}60 \times 10^{-19}$ C.

The magnitude of electric force on a $^{35}Cl^{+}$ chlorine ion is $4{\cdot}00 \times 10^{-15}$ N.

The ions enter the apparatus with a range of speeds.

The magnetic induction is 115 mT.

(a) State the direction of the magnetic force on a $^{35}Cl^{+}$ ion. **1**

(b) By considering the electric and magnetic forces acting on a $^{35}Cl^{+}$ ion, determine the speed of the $^{35}Cl^{+}$ ions that will pass through the apparatus without being deflected. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

12. (continued)

(c) $^{35}Cl^{+}$ ions that are travelling at a velocity less than that determined in (b) are observed to follow the path shown in Figure 12B.

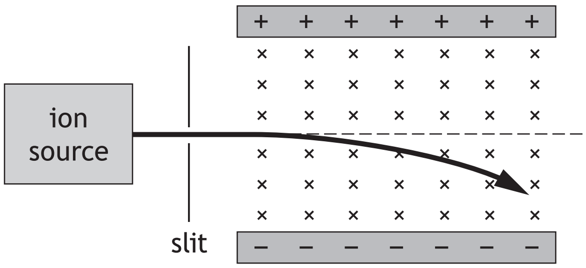


Figure 12B

Explain, in terms of their velocity, why these ions follow this path. **2**

(d) $^{37}Cl^{2+}$ ions are also present in the beam. $^{37}Cl^{2+}$ ions have a greater mass and a greater charge than $^{35}Cl^{+}$ ions. Some $^{37}Cl^{2+}$ ions also pass through the apparatus without being deflected.

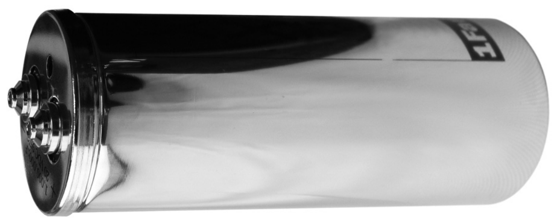
State the speed of these ions.

You must justify your answer. **2**

Question			Answer	Max mark	Additional guidance
12	(a)		Towards the top of the page.	**1**	
	(b)		$F = qvB$ 1 $4 \cdot 00 \times 10^{-15} = 1 \cdot 60 \times 10^{-19} \times v \times \ 115 \times 10^{-3}$ 1 $v = 2 \cdot 17 \times 10^{5}$ m s^{-1} 1 Accept: 2·2, 2·174, 2·1739	**3**	Starting with $v = \frac{E}{B}$ and $E = \frac{F}{Q}$ is acceptable
	(c)		(Since $F = Bqv$) At lower speeds the magnetic force is reduced. 1 Therefore unbalanced force (or acceleration) down Or The magnetic force is less than the electric force 1	**2**	Second mark dependant on the first.
	(d)		(All undeflected ions travel at) 2·17 x 10^{5} m s^{-1} 1 relative size of forces is independent of mass and of charge. 1	**2**	Or consistent with (b) Must justify $v = \frac{E}{B}$ as E & B remain constant v must also remain constant.

MARKS DO NOT WRITE IN THIS MARGIN

13. A student purchases a capacitor with capacitance 1·0 F. The capacitor, which has negligible resistance, is used to supply short bursts of energy to the audio system in a car when there is high energy demand on the car battery.



The instructions state that the capacitor must be fully charged from the 12 V d.c. car battery through a 1·0 kΩ series resistor.

(a) Show that the time constant for this charging circuit is $1{\cdot}0 \times 10^{3}$ s. **2**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

13. (continued)

(b) The student carries out an experiment to monitor the voltage across the capacitor while it is being charged.

(i) Draw a diagram of the circuit which would enable the student to carry out this experiment. **1**

(ii) The student draws the graph shown in Figure 13A.

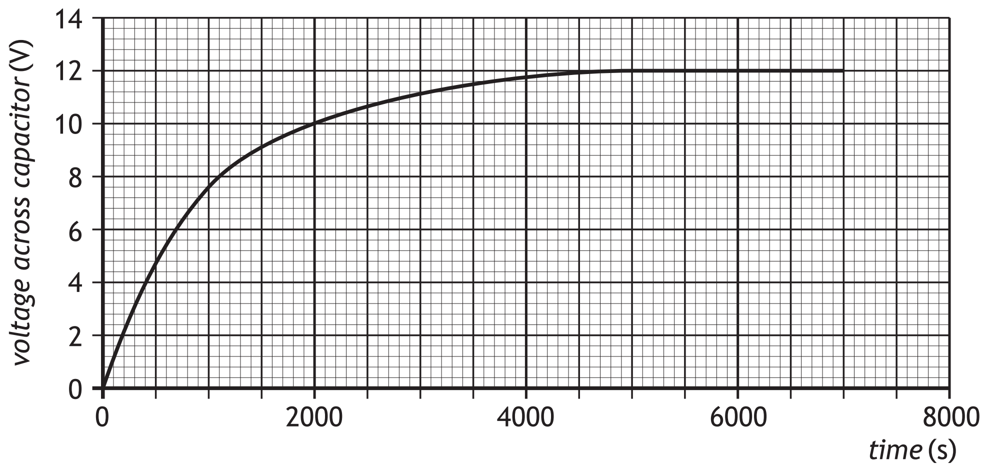


Figure 13A

(A) Use information from the graph to show that the capacitor is 63% charged after 1 time constant. **2**

Space for working and answer

(B) Use information from the graph to determine how many time constants are required for this capacitor to be considered fully charged **1**

MARKS DO NOT WRITE IN THIS MARGIN

13. (continued)

(c) The car audio system is rated at 12 V, 20 W.

Use your knowledge of physics to comment on the suitability of the capacitor as the only energy source for the audio system. **3**

Question			Answer	Max mark	Additional guidance
13.	(a)		$t = RC$ 1 $t = 1 \cdot 0 \times 10^3 \times 1 \cdot 0$ 1 $t = 1 \cdot 0 \times 10^3 \text{s}$	**2**	
	(b)	(i)	circuit diagram showing (12V) d.c. supply, resistor and capacitor all in series. Values not required. Voltmeter or CRO connected across the capacitor.	**1**	
		(ii) (A)	(After 1 time constant or 1000 s) V= 7·6 (V) 1 $\frac{V_c}{V_s} = \frac{7 \cdot 6}{12}$ 1 $\frac{V_c}{V_s} = 63\%$	**2**	
		(ii) (B)	4·5 – 5	**1**	

MARKS DO NOT WRITE IN THIS MARGIN

14. A student designs a loudspeaker circuit.

A capacitor and an inductor are used in the circuit so that high frequency signals are passed to a small "tweeter" loudspeaker and low frequency signals are passed to a large "woofer" loudspeaker.

Each loudspeaker has a resistance of 8·0 Ω.

The circuit diagram is shown in Figure 14A.

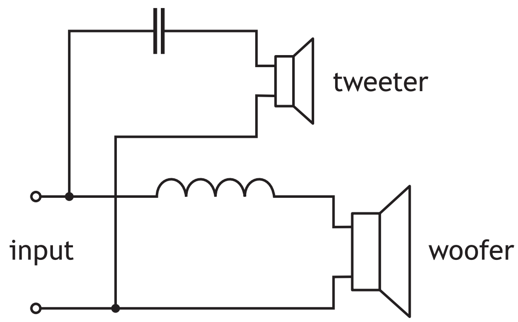


Figure 14A

The circuit is designed to have a "crossover" frequency of 3·0 kHz: at frequencies above 3·0 kHz there is a greater current in the tweeter and at frequencies below 3·0 kHz there is a greater current in the woofer.

(a) Explain how the use of a capacitor and an inductor allows:

(i) high frequency signals to be passed to the tweeter; **1**

(ii) low frequency signals to be passed to the woofer. **1**

MARKS DO NOT WRITE IN THIS MARGIN

14. (continued)

(b) At the crossover frequency, both the reactance of the capacitor and the reactance of the inductor are equal to the resistance of each loudspeaker.

Calculate the inductance required to provide an inductive reactance of $8 \cdot 0\,\Omega$ when the frequency of the signal is $3 \cdot 0\,\text{kHz}$. **3**

Space for working and answer

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14. (continued)

(c) In a box of components, the student finds an inductor and decides to determine its inductance. The student constructs the circuit shown in Figure 14B.

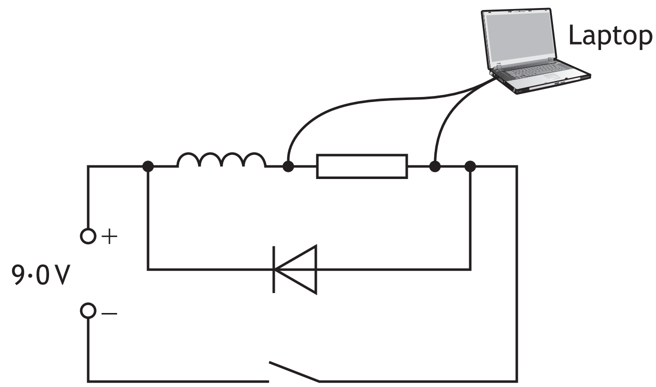

Figure 14B

The student obtains data from the experiment and presents the data on the graph shown in Figure 14C.

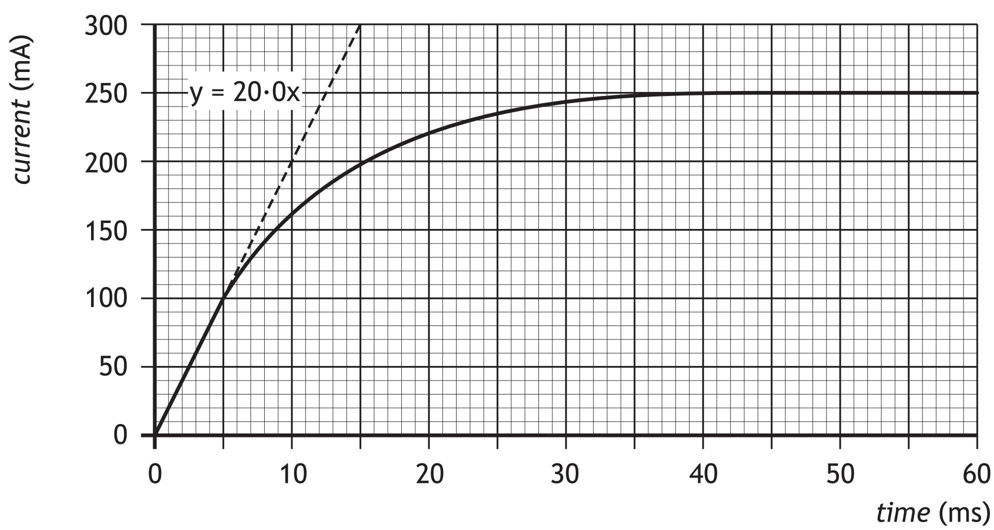

Figure 14C

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14. (c) (continued)

(i) Determine the inductance of the inductor. **4**

Space for working and answer

(ii) The student was advised to include a diode in the circuit to prevent damage to the laptop when the switch is opened.

Explain why this is necessary. **1**

[END OF QUESTION PAPER]

Question			Answer	Max Mark	Additional Guidance
14.	(a)	(i)	Capacitor has low reactance/impedance for high frequencies (therefore more current (and power) will be delivered to the tweeter at high frequencies). 1	**1**	
		(ii)	Inductor has low reactance/impedance for low frequencies (therefore more current (and power) will be delivered to the woofer at low frequencies). 1	**1**	
	(b)		$X_L = 2\pi fL$ 1 $8 \cdot 0 = 2 \times \pi \times 3 \cdot 0 \times 10^3 \times L$ 1 $L = 4 \cdot 2 \times 10^{-4}$ H 1 Accept: 4, 4·24, 4·244	**3**	
	(c)	(i)	$\frac{dI}{dt} = 20 \cdot 0$ 1 $E = -L\frac{dI}{dt}$ 1 $-9 \cdot 0 = -L \times 20 \cdot 0$ 1 $L = 0 \cdot 45$ H 1 Accept: 0·5, 0·450, 0·4500	**4**	
		(ii)	large (back) EMF.	**1**	(explanation of rapidly collapsing magnetic field) inducing high voltage Explanation in terms of energy released from inductor is acceptable.

[END OF MARKING INSTRUCTIONS]

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National Qualifications 2018

Mark

X757/77/01

Physics

TUESDAY, 8 MAY

9:00 AM – 11:30 AM

X757770 1

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 — 140

Attempt ALL questions.

Reference may be made to the Physics Relationships Sheet X757/77/11 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	$9{\cdot}8\,m\,s^{-2}$	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 Moon	M_M	$7{\cdot}3 \times 10^{22}\,kg$	Mass of proton	m_p	$1{\cdot}673 \times 10^{-27}\,kg$
Radius of Moon	R_M	$1{\cdot}7 \times 10^6\,m$	Mass of alpha particle	m_α	$6{\cdot}645 \times 10^{-27}\,kg$
Mean Radius of Moon Orbit		$3{\cdot}84 \times 10^8\,m$	Charge on alpha particle		$3{\cdot}20 \times 10^{-19}\,C$
Solar radius		$6{\cdot}955 \times 10^8\,m$	Planck's constant	h	$6{\cdot}63 \times 10^{-34}\,J\,s$
Mass of Sun		$2{\cdot}0 \times 10^{30}\,kg$	Permittivity of free space	ε_0	$8{\cdot}85 \times 10^{-12}\,F\,m^{-1}$
1 AU		$1{\cdot}5 \times 10^{11}\,m$	Permeability of free space	μ_0	$4\pi \times 10^{-7}\,H\,m^{-1}$
Stefan-Boltzmann constant	σ	$5{\cdot}67 \times 10^{-8}\,W\,m^{-2}\,K^{-4}$	Speed of light in vacuum	c	$3{\cdot}00 \times 10^8\,m\,s^{-1}$
Universal constant of gravitation	G	$6{\cdot}67 \times 10^{-11}\,m^3\,kg^{-1}\,s^{-2}$	Speed of sound in air	v	$3{\cdot}4 \times 10^2\,m\,s^{-1}$

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/* $J\,kg^{-1}\,K^{-1}$	*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.

Total marks — 140

Attempt ALL questions

1. Energy is stored in a clockwork toy car by winding-up an internal spring using a key. The car is shown in Figure 1A.

Figure 1A

The car is released on a horizontal surface and moves forward in a straight line. It eventually comes to rest.

The velocity v of the car, at time t after its release, is given by the relationship

$$v = 0{\cdot}0071t - 0{\cdot}00025t^2$$

where v is measured in $m\,s^{-1}$ and t is measured in s.

Using calculus methods:

(a) determine the acceleration of the car 20·0 s after its release; **3**

Space for working and answer

(b) determine the distance travelled by the car 20·0 s after its release. **3**

Space for working and answer

Detailed marking instructions for each question

Question			Answer	Max mark	Additional guidance
1.	(a)		$v = 0 \cdot 0071t - 0 \cdot 00025t^2$ $a\left(=\frac{dv}{dt}\right) = 0 \cdot 0071 - 0 \cdot 0005t$ **(1)** $a = 0 \cdot 0071 - (0 \cdot 0005 \times 20 \cdot 0)$ **(1)** $a = -0 \cdot 0029$ ms^{-2} **(1)**	**3**	Accept -0·003
	(b)		$v = 0 \cdot 0071t - 0 \cdot 00025t^2$ $s\left(=\int_0^{20 \cdot 0} v.dt\right) = \left[\frac{0 \cdot 0071}{2}t^2 - \frac{0 \cdot 00025}{3}t^3\right]_0^{20 \cdot 0}$ **(1)** $s = (\frac{0 \cdot 0071}{2} \times 20 \cdot 0^2) - (\frac{0 \cdot 00025}{3} \times 20 \cdot 0^3) - 0$ **(1)** $s = 0 \cdot 75$ m **(1)**	**3**	Accept 0·8, 0·753, 0·7533 Constant of integration method acceptable

MARKS | DO NOT WRITE IN THIS MARGIN

2. (a) A student places a radio-controlled car on a horizontal circular track, as shown in Figure 2A.

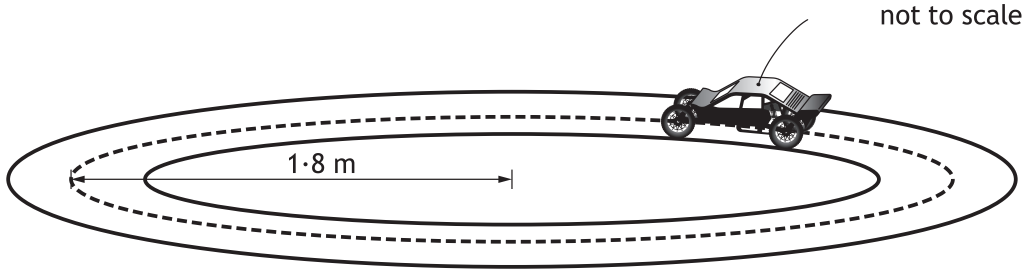


Figure 2A

The car travels around the track with a constant speed of $3\cdot5\,m\,s^{-1}$. The track has a radius of 1·8 m.

(i) Explain why the car is accelerating, even though it is travelling at a constant speed. **1**

(ii) Calculate the radial acceleration of the car. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

2. (a) (continued)

(iii) The car has a mass of 0·431 kg.

The student now increases the speed of the car to 5·5 m s^{-1}.

The total radial friction between the car and the track has a maximum value of 6·4 N.

Show by calculation that the car cannot continue to travel in a circular path. **3**

Space for working and answer

[Turn over

MARKS DO NOT WRITE IN THIS MARGIN

2. (continued)

(b) The car is now placed on a track, which includes a raised section. This is shown in Figure 2B.

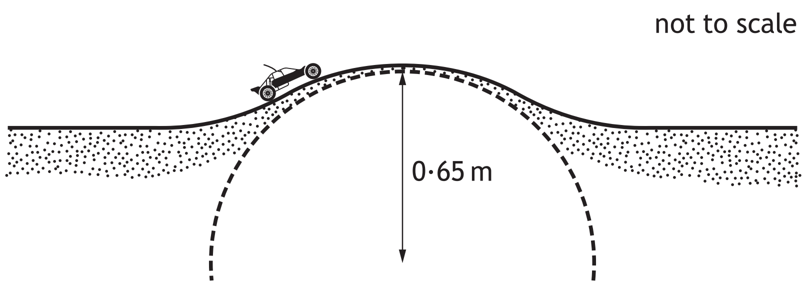


Figure 2B

The raised section of the track can be considered as the arc of a circle, which has radius r of 0·65 m.

(i) The car will lose contact with the raised section of track if its speed is greater than v_{max}.

Show that v_{max} is given by the relationship

$$v_{max} = \sqrt{gr}$$ **2**

(ii) Calculate the maximum speed v_{max} at which the car can cross the raised section without losing contact with the track. **2**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

2. (b) (continued)

(iii) A second car, with a smaller mass than the first car, approaches the raised section at the same speed as calculated in (b)(ii).

State whether the second car will lose contact with the track as it crosses the raised section.

Justify your answer in terms of forces acting on the car. **2**

[Turn over

Question			Answer	Max mark	Additional guidance
2.	(a)	(i)	The car's direction/velocity is changing. **OR** Unbalanced/centripetal/central force acting on the car	**1**	
		(ii)	$a_{(r)} = \frac{v^2}{r}$ **(1)** $a_{(r)} = \frac{3 \cdot 5^2}{1 \cdot 8}$ **(1)** $a_{(r)} = 6 \cdot 8 \text{ m s}^{-2}$ **(1)**	**3**	Accept: 7, 6·81, 6·806 $a_r = r\omega^2$ **(1)** $a_r = 1 \cdot 8 \times \left(\frac{3 \cdot 5}{1 \cdot 8}\right)^2$ **(1)** $a_r = 6 \cdot 8 \text{ m s}^{-2}$ **(1)**
		(iii)	$F = \frac{mv^2}{r}$ $F = \frac{0 \cdot 431 \times 5 \cdot 5^2}{1 \cdot 8}$ **(1)** $F = 7 \cdot 2\text{(N)}$ **(1)** Since 7·2(N)>6·4(N) **OR** There is insufficient friction and the car does not stay on the track. **(1)**	**3**	NOT A STANDARD 'SHOW' QUESTION Approach calculating minimum radius is acceptable.

Question			Answer	Max mark	Additional guidance
2.	(b)	(i)	$(F_{(centripetal)} = \frac{mv^2_{(max)}}{r}, W = mg)$ $\frac{mv^2_{(max)}}{r} = mg$ **(1), (1)** $\frac{v^2_{(max)}}{r} = g$ $v_{(max)} = \sqrt{gr}$	2	SHOW question both relationships **(1)** equating forces **(1)**
		(ii)	$v_{(max)} = \sqrt{gr}$ $v_{(max)} = \sqrt{9 \cdot 8 \times 0 \cdot 65}$ **(1)** $v_{(max)} = 2 \cdot 5$ ms^{-1} **(1)**	2	Accept: 3, 2·52, 2·524
		(iii)	The second car will not lose contact with the track. **(1)** A smaller centripetal force is supplied by a smaller weight. **(1)**	2	

MARKS DO NOT WRITE IN THIS MARGIN

3. Wheels on road vehicles can vibrate if the wheel is not 'balanced'. Garages can check that each wheel is balanced using a wheel balancing machine, as shown in Figure 3A.

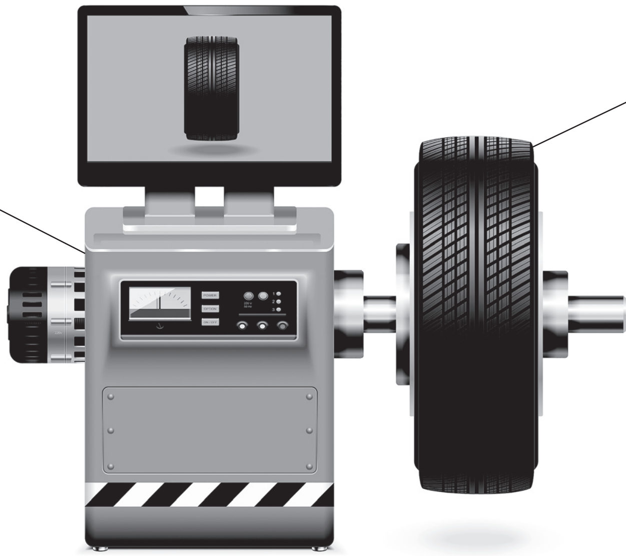


Figure 3A

The wheel is rotated about its axis by the wheel balancing machine.

The angular velocity of the wheel increases uniformly from rest with an angular acceleration of 6·7 rad s^{-2}.

(a) The wheel reaches its maximum angular velocity after 3·9 s.

Show that its maximum angular velocity is 26 rad s^{-1}. **2**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

3. (continued)

(b) After 3·9 s, the rotational kinetic energy of the wheel is 430 J.

Calculate the moment of inertia of the wheel. **3**

Space for working and answer

(c) A brake is applied which brings the wheel uniformly to rest from its maximum velocity.

The wheel completes 14 revolutions during the braking process.

(i) Calculate the angular acceleration of the wheel during the braking process. **4**

Space for working and answer

(ii) Calculate the braking torque applied by the wheel balancing machine. **3**

Space for working and answer

Question			Answer	Max mark	Additional guidance
3.	(a)		$\omega = \omega_o + \alpha t$ **(1)** $\omega = 0 + (6 \cdot 7 \times 3 \cdot 9)$ **(1)** $\omega = 26 \text{ rads}^{-1}$	**2**	SHOW question If final answer not shown 1 mark max
	(b)		$E_{(k)} = \frac{1}{2} I\omega^2$ **(1)** $430 = \frac{1}{2} \times I \times 26^2$ **(1)** $I = 1 \cdot 3 \text{ kg m}^2$ **(1)**	**3**	Accept: 1, 1·27, 1·272
	(c)	(i)	$\theta = 14 \times 2\pi$ **(1)** $\omega^2 = \omega_o^2 + 2\alpha\theta$ **(1)** $0^2 = 26^2 + (2 \times \alpha \times 14 \times 2\pi)$ **(1)** $\alpha = -3 \cdot 8 \text{ rad s}^{-2}$ **(1)**	**4**	Accept: -4, -3·84, -3·842 Alternative method: $\theta = 14 \times 2\pi$ **(1)** $\omega = \omega_o + \alpha t$ AND $\theta = \omega_o t + \frac{1}{2}\alpha t^2$ **(1)** all substitutions correct **(1)** $\alpha =$ $-3 \cdot 8 \text{ rad s}^{-2}$ **(1)**
		(ii)	$T = I\alpha$ **(1)** $T = 1 \cdot 3 \times (-)3 \cdot 8$ **(1)** $T = (-)4 \cdot 9 \text{ N m}$ **(1)**	**3**	Accept: 5, 4·94, 4·940 **OR** consistent with (b), (c)(i)

MARKS DO NOT WRITE IN THIS MARGIN

4. Astronomers have discovered another solar system in our galaxy. The main sequence star, HD 69830, lies at the centre of this solar system. This solar system also includes three exoplanets, b, c, and d and an asteroid belt.

This solar system is shown in Figure 4A.

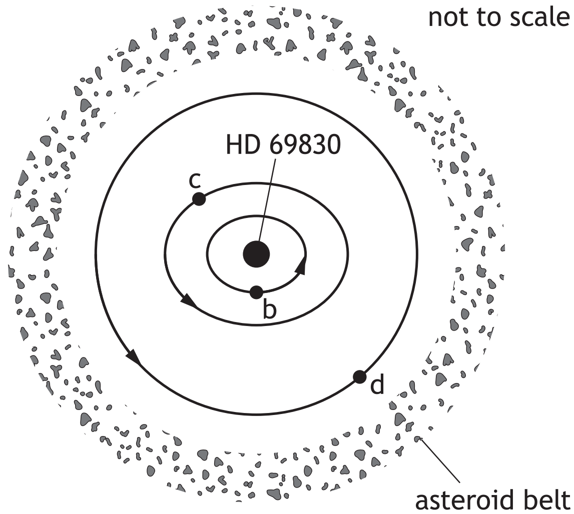


Figure 4A

(a) The orbit of exoplanet d can be considered circular.

To a reasonable approximation the centripetal force on exoplanet d is provided by the gravitational attraction of star HD 69830.

(i) Show that, for a circular orbit of radius r, the period T of a planet about a parent star of mass M, is given by

$$T^2 = \frac{4\pi^2}{GM}r^3$$

3

MARKS DO NOT WRITE IN THIS MARGIN

4. (a) (continued)

(ii) Some information about this solar system is shown in the table below.

Exoplanet	*Type of orbit*	*Mass in Earth masses*	*Mean orbital radius in Astronomical Units* (AU)	*Orbital period In Earth days*
b	Elliptical	10·2	-	8·67
c	Elliptical	11·8	0·186	-
d	Circular	18·1	0·63	197

Determine the mass, in kg, of star HD 69830. **3**

Space for working and answer

(b) Two asteroids collide at a distance of $1{\cdot}58 \times 10^{11}$ m from the centre of the star HD 69830. As a result of this collision, one of the asteroids escapes from this solar system.

Calculate the minimum speed which this asteroid must have immediately after the collision, in order to escape from this solar system. **3**

Space for working and answer

Question			Answer	Max mark	Additional guidance
4.	(a)	(i)	$(F_{centripetal} = F_{gravitational})$ **(1)** $mr\omega^2 = \frac{GMm}{r^2}$ **(1)** $\omega = \frac{2\pi}{T}$ *or* $\omega^2 = \left(\frac{2\pi}{T}\right)^2$ **(1)** $\frac{4\pi^2}{T^2} = \frac{GM}{r^3}$ $T^2 = \frac{4\pi^2}{GM}r^3$	3	SHOW question both relationships **(1)** equating **(1)** Alternative method acceptable $(F_{centripetal} = F_{gravitational})$ $\frac{mv^2}{r} = \frac{GMm}{r^2}$ **(1), (1)** $v = \frac{2\pi r}{T}$ or $v^2 = \left(\frac{2\pi r}{T}\right)^2$ **(1)** $\frac{4\pi^2}{T^2} = \frac{GM}{r^3}$ $T^2 = \frac{4\pi^2}{GM}r^3$
		(ii)	$T^2 = \frac{4\pi^2}{GM}r^3$ $\left\langle (197 \times 24 \times 60 \times 60)^2 = \frac{4\pi^2 \times (0 \cdot 63 \times 1 \cdot 5 \times 10^{11})^3}{6 \cdot 67 \times 10^{-11} \times M} \right\rangle$ **(1), (1)** $M = 1 \cdot 7 \times 10^{30}$ (kg) **(1)**	3	Accept: 2, 1·72,1·724 mark for converting AU to m independent. **(1)** complete substitution **(1)** final answer **(1)**
	(b)		$v = \sqrt{\frac{2GM}{r}}$ **(1)** $v = \sqrt{\frac{2 \times 6 \cdot 67 \times 10^{-11} \times 1 \cdot 7 \times 10^{30}}{1 \cdot 58 \times 10^{11}}}$ **(1)** $v = 3 \cdot 8 \times 10^4$ m s^{-1} **(1)**	3	**OR** consistent with (a)(ii) Accept 4, 3·79, 3·789

MARKS DO NOT WRITE IN THIS MARGIN

5. (a) Explain what is meant by the term *Schwarzschild radius*. **1**

(b) (i) Calculate the Schwarzschild radius of the Sun. **3**

Space for working and answer

(ii) Explain, with reference to its radius, why the Sun is not a black hole. **1**

(c) The point of closest approach of a planet to the Sun is called the perihelion of the planet. The perihelion of Mercury rotates slowly around the Sun, as shown in Figure 5A.

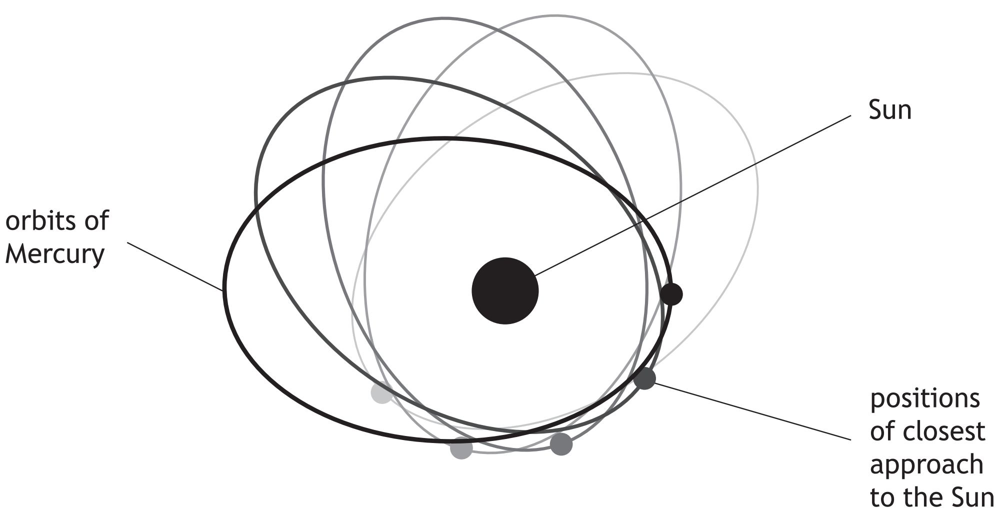


Figure 5A

MARKS DO NOT WRITE IN THIS MARGIN

5. (c) (continued)

This rotation of the perihelion is referred to as the precession of Mercury, and is due to the curvature of spacetime. This causes an angular change in the perihelion of Mercury.

The angular change **per orbit** is calculated using the relationship

$$\phi = 3\pi \frac{r_s}{a(1-e^2)}$$

where:

ϕ is the angular change **per orbit**, in radians;

r_s is the Schwarzschild radius of the Sun, in metres;

a is the semi-major axis of the orbit, for Mercury $a = 5{\cdot}805 \times 10^{10}$ m;

e is the eccentricity of the orbit, for Mercury $e = 0{\cdot}206$.

Mercury completes **four** orbits of the Sun in one Earth year.

Determine the angular change in the perihelion of Mercury **after one Earth year.** 3

Space for working and answer

Question			Answer	Max mark	Additional guidance
5.	(a)		The Schwarzschild radius is the distance from the centre of a mass such that, the escape velocity at that distance would equal the speed of light. **OR** The Schwarzschild radius is the distance from the centre of a mass to the event horizon.	1	Responses in terms of black hole acceptable
	(b)	(i)	$r_{(Schwarzschild)} = \frac{2GM}{c^2}$ **(1)** $r_{(Schwarzschild)} = \frac{2 \times 6 \cdot 67 \times 10^{-11} \times 2 \cdot 0 \times 10^{30}}{(3 \cdot 00 \times 10^8)^2}$ **(1)** $r_{(Schwarzschild)} = 3 \cdot 0 \times 10^3$ m **(1)**	3	Accept: 3×10^3, $2{\cdot}96 \times 10^3$, $2{\cdot}964 \times 10^3$
		(ii)	(Radius of Sun is $6 \cdot 955 \times 10^8$ m) This is greater than the Schwarzschild radius (the Sun is not a black hole.) **(1)**	1	There MUST be a comparison of solar radius with the Sun's Schwarzschild radius.
	(c)		$\phi = 3\pi \frac{r_s}{a(1-e^2)}$ $\phi = 3\pi \frac{3000}{5 \cdot 805 \times 10^{10} \times (1 - 0 \cdot 206^2)}$ **(1)** Angular change after one year = $4 \times \phi$ **(1)** Angular change $= 2 \cdot 0 \times 10^{-6}$ rad **(1)**	3	**OR** consistent with (b)(i) Second mark independent Accept 2, 2·03, 2·035 If 3·14 used, accept 2·034

MARKS | DO NOT WRITE IN THIS MARGIN

6. Bellatrix and Acrab are two stars which are similar in size. However, the apparent brightness of each is different.

Use your knowledge of stellar physics to comment on why there is a difference in the apparent brightness of the two stars. **3**

MARKS DO NOT WRITE IN THIS MARGIN

7. In a crystal lattice, atoms are arranged in planes with a small gap between each plane.

Neutron diffraction is a process which allows investigation of the structure of crystal lattices.

In this process there are three stages:
neutrons are accelerated;
the neutrons pass through the crystal lattice;
an interference pattern is produced.

(a) (i) In this process, neutrons exhibit wave-particle duality.

Identify the stage of the process which provides evidence for particle-like behaviour of neutrons. **1**

(ii) Neutrons, each with a measured momentum of $1{\cdot}29 \times 10^{-23}\,\text{kg m s}^{-1}$ produce an observable interference pattern from one type of crystal lattice.

Calculate the wavelength of a neutron travelling with this momentum. **3**

Space for working and answer

(iii) Explain the implication of the Heisenberg uncertainty principle for the precision of these experimental measurements. **1**

MARKS DO NOT WRITE IN THIS MARGIN

7. (a) (continued)

(iv) The momentum of a neutron is measured to be $1{\cdot}29 \times 10^{-23}$ kg m s^{-1} with a precision of $\pm$ 3·0%.

Determine the minimum **absolute** uncertainty in the position Δx_{min} of this neutron. **4**

Space for working and answer

(b) Some of the neutrons used to investigate the structure of crystal lattices will not produce an observed interference pattern. This may be due to a large uncertainty in their momentum.

Explain why a large uncertainty in their momentum would result in these neutrons being unsuitable for this diffraction process. **2**

Question			Answer	Max mark	Additional guidance
7.	(a)	(i)	Neutrons are accelerated.	1	
		(ii)	$\lambda = \frac{h}{p}$ **(1)** $\lambda = \frac{6\cdot63\times10^{-34}}{1\cdot29\times10^{-23}}$ **(1)** $\lambda = 5\cdot14\times10^{-11}$ m **(1)**	3	Accept 5·1, 5·140, 5·1395
		(iii)	The <u>precise/exact</u> position of a particle and its momentum cannot both be known <u>at the same instant</u>. **(1)** **OR** If the (minimum) uncertainty in the position of a particle is reduced, the uncertainty in the momentum of the particle will increase (or vice-versa). **(1)**	1	
		(iv)	$\Delta p_x = p \times \frac{\%p}{100}$ $\Delta p_x = 1\cdot29\times10^{-23}\times\frac{3}{100}$ **(1)** $\Delta x_{min}\Delta p_x = \frac{h}{4\pi}$ or $\Delta x\Delta p_x \geq \frac{h}{4\pi}$ **(1)** $\Delta x_{(min)} = \frac{6\cdot63\times10^{-34}}{4\pi\times1\cdot29\times10^{-23}\times0\cdot03}$ **(1)** $\Delta x_{(min)} = 1\cdot36\times10^{-10}$m **(1)**	4	Accept 1·4, 1·363, 1·3633 $\Delta x_{min} \geq 1\cdot36\times10^{-10}$ m do not award final mark
	(b)		The uncertainty in position will be (too) small. **(1)** Neutrons can be considered a particle/cannot be considered a wave, even on the length scale of the lattice spacing. **(1)**	2	Accept a de Broglie wavelength argument. A large uncertainty in p may result in a large uncertainty in the de Broglie wavelength. **(1)** This de Broglie wavelength may not be close to the lattice spacing. **(1)** Uncertainty in position less than gap between layers acceptable for both marks.

MARKS | DO NOT WRITE IN THIS MARGIN

8. (a) Inside the core of stars like the Sun, hydrogen nuclei fuse together to form heavier nuclei.

(i) State the region of the Hertzsprung-Russell diagram in which stars like the Sun are located. **1**

(ii) One type of fusion reaction is known as the proton-proton chain and is described below.

$$6\,{}^{1}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{X} + 2\,{}^{0}_{1}\mathrm{Z} + 2\,{}^{0}_{0}\nu + 2\,{}^{1}_{1}\mathrm{H} + 2\,{}^{0}_{0}\gamma$$

Identify the particles indicated by the letters X and Z. **2**

(b) High energy charged particles are ejected from the Sun.

State the name given to the constant stream of charged particles which the Sun ejects. **1**

8. (continued)

MARKS DO NOT WRITE IN THIS MARGIN

(c) The stream of particles being ejected from the Sun produces an outward pressure. This outward pressure depends on the number of particles being ejected from the Sun and the speed of these particles.

The pressure at a distance of one astronomical unit (AU) from the Sun is given by the relationship

$$p = 1{\cdot}6726 \times 10^{-6} \times n \times v^2$$

where:

p is the pressure in nanopascals;

n is the number of particles per cubic centimetre;

v is the speed of particles in kilometres per second.

(i) On one occasion, a pressure of $9{\cdot}56 \times 10^{-10}$ Pa was recorded when the particle speed was measured to be $6{\cdot}02 \times 10^{5}\,\text{m s}^{-1}$.

Calculate the number of particles per cubic centimetre. **2**

Space for working and answer

(ii) The pressure decreases as the particles stream further from the Sun.

This is because the number of particles per cubic centimetre decreases and the kinetic energy of the particles decreases.

(A) Explain why the number of particles per cubic centimetre decreases as the particles stream further from the Sun. **1**

(B) Explain why the kinetic energy of the particles decreases as the particles stream further from the Sun. **1**

MARKS DO NOT WRITE IN THIS MARGIN

8. (continued)

(d) When the charged particles approach the Earth, the magnetic field of the Earth causes them to follow a helical path, as shown in Figure 8A.

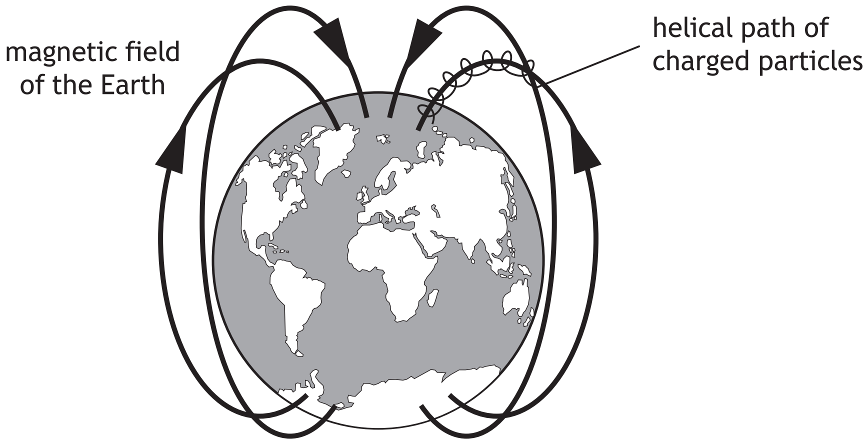


Figure 8A

Explain why the charged particles follow a helical path. **2**

Question			Answer	Max mark	Additional guidance
8.	(a)	(i)	Main sequence	1	
		(ii)	X: helium (nucleus) **(1)** Z: positron **(1)**	2	Accept alpha particle Accept anti-electron Accept He, e^+, β^+ Do not accept 'Helium atom'
	(b)		Solar wind	1	Do not accept cosmic rays.
	(c)	(i)	$p = 1{\cdot}6726 \times 10^{-6} \times n \times v^2$ $0{\cdot}956 = 1{\cdot}6726 \times 10^{-6} \times n \times 602^2$ **(1)** $n = 1{\cdot}58$ (particles per cm^3) **(1)**	2	Correct unit conversions must be made. Accept 1·6, 1·577, 1·5771
		(ii) (A)	(As the particles are ejected in all directions they will) spread out (as they get further from the Sun).	1	Accept density decreases with radius/Sun acts as a point source/constant number of particles over a larger area.
		(ii) (B)	(The particles lose kinetic energy and) gain (gravitational) potential (energy) (as they move further from the Sun.) **OR** Work is done against the Sun's gravitational field (for the particles to move away).	1	Accept reduction in velocity due to gravitational force and statement of $E_K = \frac{1}{2}mv^2$ Lose speed on its own not sufficient
	(d)		The charged particles have a component (of velocity) parallel to the (magnetic) field which moves them forwards in that direction. **(1)** The component (of velocity) perpendicular: to the (magnetic) field causes a central force on the charged particle **OR** it moves in a circle. **(1)**	2	Independent marks

MARKS | DO NOT WRITE IN THIS MARGIN

9. A ball-bearing is released from height h on a smooth curved track, as shown in Figure 9A.

The ball-bearing oscillates on the track about position P.

The motion of the ball-bearing can be modelled as Simple Harmonic Motion (SHM).

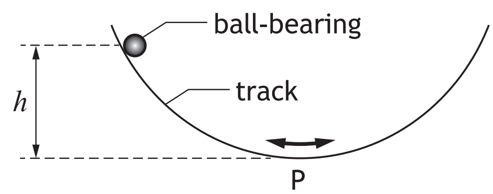


Figure 9A

(a) The ball-bearing makes 1·5 oscillations in 2·5 s.

(i) Show that the angular frequency of the ball-bearing is 3·8 rad s^{-1}. **2**

Space for working and answer

(ii) The horizontal displacement x of the ball-bearing from position P at time t can be predicted using the relationship

$$x = -0{\cdot}2\cos(3{\cdot}8t)$$

Using calculus methods, show that this relationship is consistent with SHM. **3**

MARKS DO NOT WRITE IN THIS MARGIN

9. (a) (continued)

(iii) Determine the maximum speed of the ball-bearing during its motion. **3**

Space for working and answer

(iv) Determine the height h from which the ball bearing was released. **3**

Space for working and answer

9. (continued)

MARKS DO NOT WRITE IN THIS MARGIN

(b) In practice, the maximum horizontal displacement of the ball-bearing decreases with time.

A graph showing the variation in the horizontal displacement of the ball-bearing from position P with time is shown in Figure 9B.

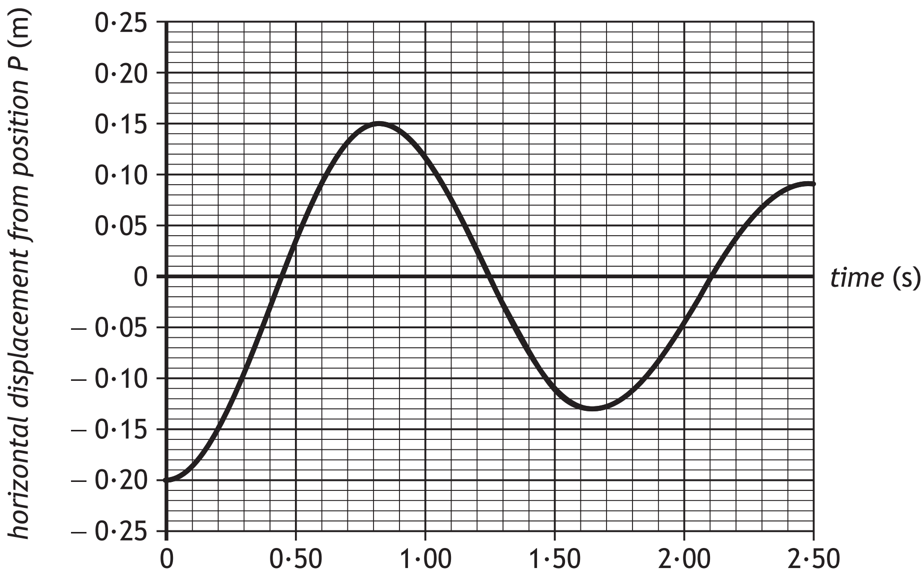
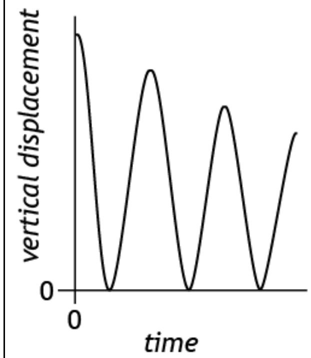


Figure 9B

Sketch a graph showing how the **vertical** displacement of the ball-bearing from position P changes over the same time period.

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

Question			Answer	Max mark	Additional guidance
9.	(a)	(i)	$\omega = \frac{d\theta}{dt}$ **(1)** $\omega = \frac{2\pi \times 1 \cdot 5}{2 \cdot 5}$ **(1)** $\omega = 3 \cdot 8 \text{ rad s}^{-1}$	2	SHOW question Accept $\omega = \frac{\theta}{t}$, $\omega = 2\pi f$ or $\omega = \frac{2\pi}{T}$ as a starting point. Final line must appear or max **(1 mark)**.
		(ii)	$(x = -0 \cdot 2\cos(3 \cdot 8t))$ $\frac{dx}{dt} = -3 \cdot 8 \times (-0 \cdot 2\sin(3 \cdot 8t))$ $\frac{d^2x}{dt^2} = -3 \cdot 8^2 \times (-0 \cdot 2\cos(3 \cdot 8t))$ **(1)** $\frac{d^2x}{dt^2} = -3 \cdot 8^2 x$ **(1)** (Since the equation is in the form) $a = -\omega^2 y$ or $a = -\omega^2 x$ (, the horizontal displacement is consistent with SHM). **(1)**	3	NOT A STANDARD SHOW QUESTION First mark for BOTH differentiations correct Second mark for correct substitution of *x* back into second differential (including correct treatment of negatives). Numerical constant may be evaluated without penalty (14·44). Statement regarding significance of equation required for third mark.
		(iii)	$v = (\pm)\omega\sqrt{(A^2 - y^2)}$ **(1)** $v = (\pm)3 \cdot 8 \times \sqrt{(0 \cdot 2^2 - 0^2)}$ **(1)** $v = (\pm)0 \cdot 76 \text{ m s}^{-1}$ **(1)**	3	Accept $v_{(max)} = (\pm)\omega A$ Accept A=0·2m or A=-0·2m Accept $\frac{dx}{dt} = -3 \cdot 8 \times (-0 \cdot 2\sin(3 \cdot 8t))$ as a starting point. Accept 0·8, 0·760, 0·7600
		(iv)	$\frac{1}{2}(m)v^2 = (m)gh$ **(1)** $h = \frac{0 \cdot 5 \times 0 \cdot 76^2}{9 \cdot 8}$ **(1)** $h = 2 \cdot 9 \times 10^{-2} \text{ m}$ **(1)**	3	Allow $\frac{1}{2}(m)\omega^2 A^2 = (m)gh$ as starting point. $\frac{1}{2}(m)\omega^2 y^2 = (m)gh$ zero marks unless statement that $y = A$ Accept 3, 2·95, 2·947

Question			Answer	Max mark	Additional guidance
9.	(b)		The shape of the line should resemble a sinusoidal wave with values either all positive or all negative and the minimum vertical displacement consistent. **(1)** Peak height should show a steady decline with each oscillation / decreasing amplitude, as shown in the graph in the additional guidance notes. **(1)**	**2**	 Marks independent

MARKS DO NOT WRITE IN THIS MARGIN

10. An electromagnetic wave is travelling along an optical fibre. Inside the fibre the electric field vectors oscillate, as shown in Figure 10A.

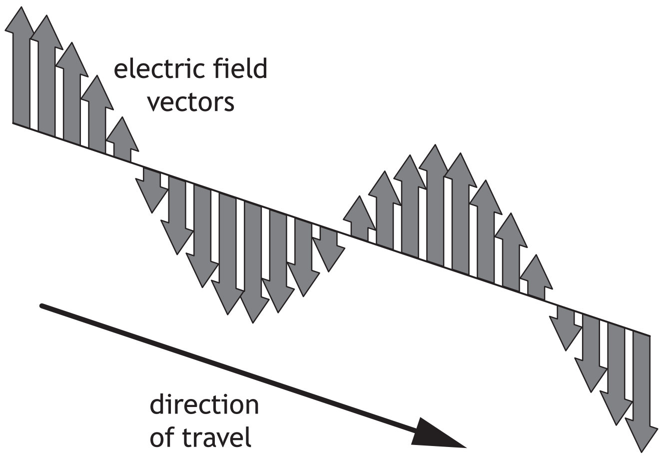


Figure 10A

The direction of travel of the wave is taken to be the x-direction.

The magnitude of the electric field vector E at any point x and time t is given by the relationship

$$E = 12 \times 10^{-6} \sin 2\pi \left(1{\cdot}31 \times 10^{14} t - \frac{x}{1{\cdot}55 \times 10^{-6}} \right)$$

(a) (i) Two points, A and B, along the wave are separated by a distance of $4{\cdot}25 \times 10^{-7}$ m in the x-direction.

Calculate the phase difference between points A and B. **3**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

10. (a) (continued)

(ii) Another two points on the wave, P and Q, have a phase difference of π radians.

State how the direction of the electric field vector at point P compares to the direction of the electric field vector at point Q. **1**

(b) (i) Show that the speed of the electromagnetic wave in this optical fibre is $2 \cdot 03 \times 10^8\ \mathrm{m\,s^{-1}}$. **2**

Space for working and answer

(ii) The speed v_m of an electromagnetic wave in a medium is given by the relationship

$$v_m = \frac{1}{\sqrt{\varepsilon_m \mu_m}}$$

The permeability μ_m of the optical fibre material can be considered to be equal to the permeability of free space.

By considering the speed of the electromagnetic wave in this fibre, determine the permittivity ε_m of the optical fibre material. **2**

Space for working and answer

Question			Answer	Max mark	Additional guidance
10.	(a)	(i)	$\phi = \frac{2\pi x}{\lambda}$ **(1)** $\phi = \frac{2\pi \times 4 \cdot 25 \times 10^{-7}}{1 \cdot 55 \times 10^{-6}}$ **(1)** $\phi = 1 \cdot 72$ rad **(1)**	**3**	Accept 1·7, 1·723, 1·7228
		(ii)	(The electric field vectors will be in) opposite (directions at positions P and Q).	**1**	
	(b)	(i)	$v = f\lambda$ **(1)** $v = 1 \cdot 31 \times 10^{14} \times 1 \cdot 55 \times 10^{-6}$ **(1)** $v = 2 \cdot 03 \times 10^{8}$ m s^{-1}	**2**	SHOW question Both equation and substitution must be shown. Final line must also be shown.
		(ii)	$v_m = \frac{1}{\sqrt{\varepsilon_m \mu_m}}$ $2 \cdot 03 \times 10^{8} = \frac{1}{\sqrt{\varepsilon_m \times 4\pi \times 10^{-7}}}$ **(1)** $\varepsilon_m = 1 \cdot 93 \times 10^{-11}$ F m^{-1} **(1)**	**2**	Accept 1·9, 1·931, 1·9311

DO NOT WRITE IN THIS MARGIN

11. A thin air wedge is formed between two glass plates of length 75 mm, which are in contact at one end and separated by a thin metal wire at the other end.

Figure 11A shows sodium light being reflected down onto the air wedge.

A travelling microscope is used to view the resulting interference pattern.

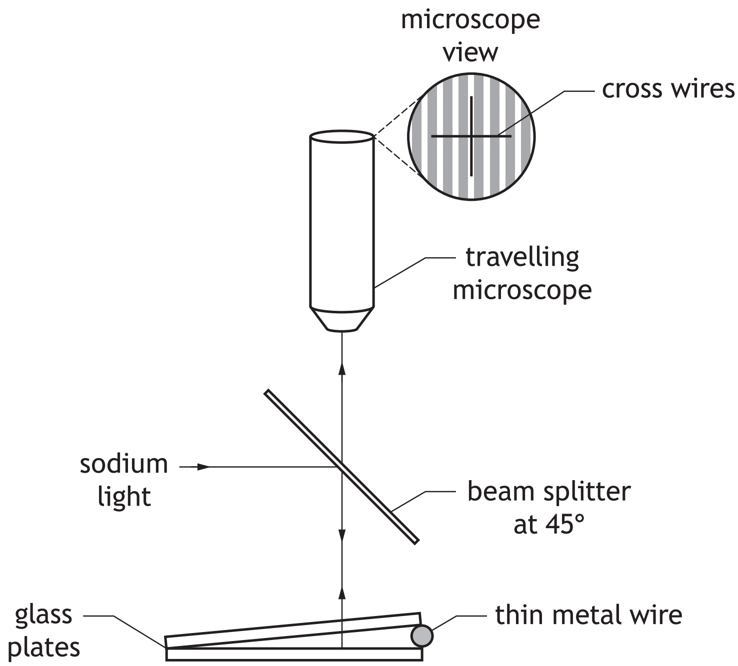


Figure 11A

A student observes the image shown in Figure 11B.

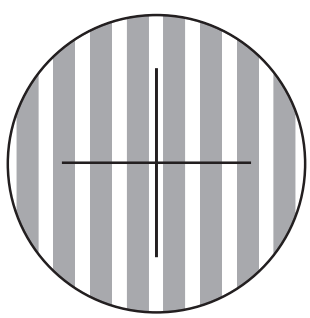


Figure 11B

The student aligns the cross-hairs to a bright fringe and then moves the travelling microscope until 20 further bright fringes have passed through the cross-hairs and notes that the travelling microscope has moved a distance of $9{\cdot}8 \times 10^{-4}$ m.

The student uses this data to determine the thickness of the thin metal wire between the glass plates.

11. (continued)

MARKS | DO NOT WRITE IN THIS MARGIN

(a) State whether the interference pattern is produced by division of amplitude or by division of wavefront. **1**

(b) Determine the diameter of the thin metal wire. **4**

Space for working and answer

(c) By measuring multiple fringe separations rather than just one, the student states that they have more confidence in the value of diameter of the wire which was obtained.

Suggest one reason why the student's statement is correct. **1**

(d) A current is now passed through the thin metal wire and its temperature increases.

The fringes are observed to get closer together.

Suggest a possible explanation for this observation. **2**

Question			Answer	Max mark	Additional guidance
11.	(a)		(Division of) amplitude	1	
	(b)		$\Delta x = \frac{9 \cdot 8 \times 10^{-4}}{20}$ **(1)** $\Delta x = \frac{\lambda l}{2d}$ **(1)** $d = \frac{589 \times 10^{-9} \times 75 \times 10^{-3} \times 20}{2 \times 9 \cdot 8 \times 10^{-4}}$ **(1)** $d = 4 \cdot 5 \times 10^{-4}$ m **(1)**	4	First mark independent Accept 5, 4·51, 4·508
	(c)		Reduces the uncertainty in the value of Δx or d obtained. **OR** Reduces the impact/significance of any uncertainty on the value obtained for Δx or d.	1	
	(d)		The wire expands/d increases **(1)** $\Delta x = \frac{\lambda l}{2d}$, (and since d increases) while l and λ remain constant, (Δx decreases). **OR** Since d increases and $\Delta x \propto 1/d$, Δx decreases. **(1)**	2	

MARKS DO NOT WRITE IN THIS MARGIN

12. A student is observing the effect of passing light through polarising filters.

Two polarising filters, the polariser and the analyser, are placed between a lamp and the student as shown in Figure 12A.

The polariser is held in a fixed position, and the analyser can be rotated. Angle θ is the angle between the transmission axes of the two filters.

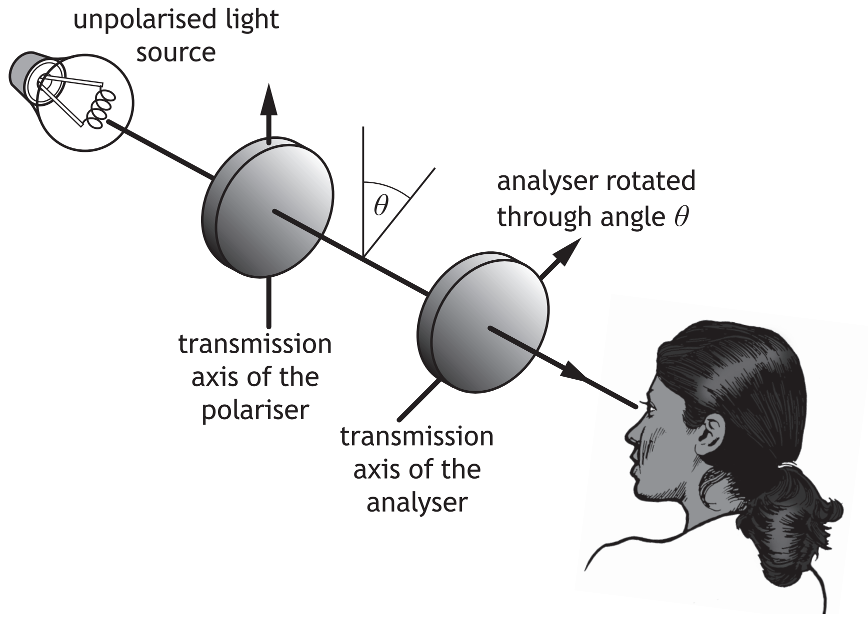


Figure 12A

When the transmission axes of the polariser and the analyser are parallel, θ is 0° and the student observes bright light from the lamp.

(a) (i) Describe, in terms of brightness, what the student observes as the analyser is slowly rotated from 0° to 180°. **2**

(ii) The polariser is now removed.

Describe, in terms of brightness, what the student observes as the analyser is again slowly rotated from 0° to 180° **1**

MARKS | DO NOT WRITE IN THIS MARGIN

12. (continued)

(b) Sunlight reflected from a wet road can cause glare, which is hazardous for drivers. This is shown in Figure 12B

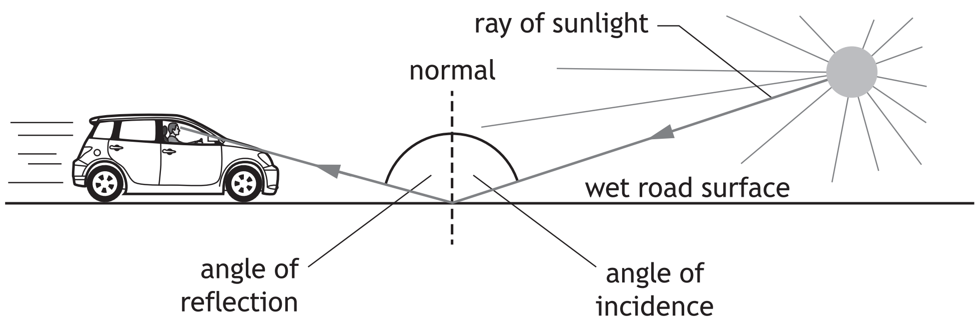


Figure 12B

Reflected sunlight is polarised when the light is incident on the wet road surface at the Brewster angle.

(i) Calculate the Brewster angle for light reflected from water. **3**

Space for working and answer

(ii) A driver is wearing polarising sunglasses.

Explain how wearing polarising sunglasses rather than non-polarising sunglasses will reduce the glare experienced by the driver. **1**

Question			Answer	Max mark	Additional guidance
12.	(a)	(i)	The brightness (starts at a maximum and) decreases to (a minimum at) 90°. **(1)** The brightness then increases (from the minimum back to the maximum at 180°). **(1)**	**2**	Response must indicate a gradual change as the analyser rotates.
		(ii)	The brightness remains constant (throughout).	**1**	
	(b)	(i)	$n = \tan i_p$ **(1)** $i_p = \tan^{-1}(1{\cdot}33)$ **(1)** $i_p = 53{\cdot}1^{\circ}$ **(1)**	**3**	Accept 53, 53·06, 53·061
		(ii)	The polarising sunglasses will act as an analyser/ absorb/block (some of) the glare.	**1**	

MARKS DO NOT WRITE IN THIS MARGIN

13. (a) State what is meant by *electric field strength*. **1**

(b) Two identical spheres, each with a charge of +22 nC, are suspended from point P by two equal lengths of light insulating thread.

The spheres repel and come to rest in the positions shown in Figure 13A.

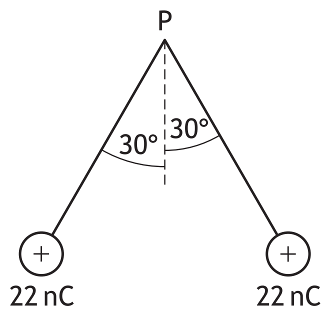


Figure 13A

(i) Each sphere has a weight of $9{\cdot}80 \times 10^{-4}$ N.

By considering the forces acting on one of the spheres, show that the electric force between the charges is $5{\cdot}66 \times 10^{-4}$ N. **2**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

13. (b) (continued)

(ii) By considering the electric force between the charges, calculate the distance between the centres of the spheres. **3**

Space for working and answer

(iii) Calculate the electrical potential at point P due to both charged spheres. **5**

Space for working and answer

Question			Answer	Max mark	Additional guidance
13.	(a)		Force per unit positive charge (at a point in an electric field)	**1**	
	(b)	(i)	$F_e = W \tan\theta$ **(1)** $F_e = 9\cdot80\times10^{-4}\times\tan 30$ **(1)** $F_e = 5\cdot66\times10^{-4}$ N	**2**	NOT A STANDARD SHOW QUESTION $\tan\theta = \frac{opposite}{adjacent}$ is an acceptable starting point
		(ii)	$F = \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$ **(1)** $5\cdot66\times10^{-4} = \frac{(22\times10^{-9})^2}{4\pi\times8\cdot85\times10^{-12}r^2}$ **(1)** $r = 0\cdot088$ m **(1)**	**3**	Accept 0·09, 0·0877, 0·08769 Accept 0·08773 if 9×10^9 used.
		(iii)	$V = \frac{Q}{4\pi\varepsilon_o r}$ **(1)** $r = 0\cdot088$ (m) **(1)** $V = \frac{22\times10^{-9}}{4\times\pi\times8\cdot85\times10^{-12}\times0\cdot088}$ **(1)** $V_{total} = 2\times\frac{22\times10^{-9}}{4\times\pi\times8\cdot85\times10^{-12}\times0\cdot088}$ **(1)** $V_{total} = 4\cdot5\times10^3$ V **(1)**	**5**	Or consistent with (b)(ii) Accept : 4000, 4496

DO NOT WRITE IN THIS MARGIN

14. A student carries out an experiment to determine the charge to mass ratio of the electron.

The apparatus is set up as shown in Figure 14A.

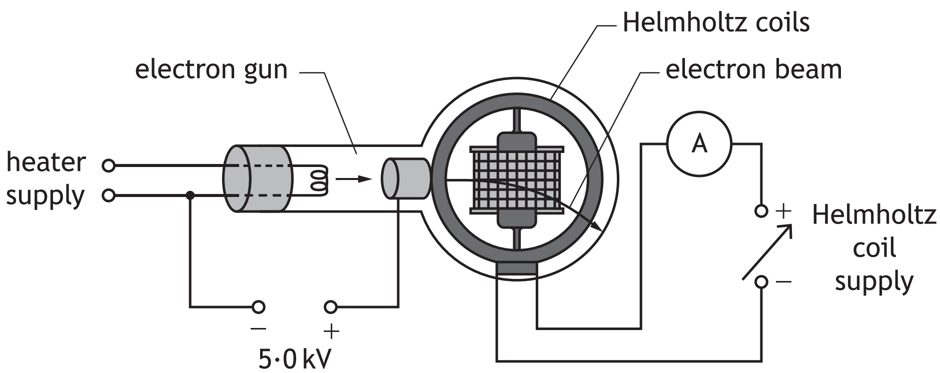


Figure 14A

An electron beam is produced using an electron gun connected to a 5·0 kV supply. A current I in the Helmholtz coils produces a uniform magnetic field.

The electron beam enters the magnetic field.

The path of the electron beam between points O and P can be considered to be an arc of a circle of constant radius r. This is shown in Figure 14B.

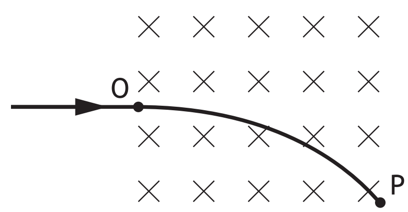


Figure 14B

The student records the following measurements:

Electron gun supply voltage, V	5·0 kV (±10%)
Current in the Helmholtz coils, I	0·22 A (±5%)
Radius of curvature of the path of the electron beam between O and P, r	0·28 m (±6%)

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

(a) The manufacturer's instruction sheet states that the magnetic field strength B at the centre of the apparatus is given by

$$B = 4{\cdot}20 \times 10^{-3} \times I$$

Calculate the magnitude of the magnetic field strength in the centre of the apparatus. **1**

Space for working and answer

(b) The charge to mass ratio of the electron is calculated using the following relationship

$$\frac{q}{m} = \frac{2V}{B^2 r^2}$$

(i) Using the measurements recorded by the student, calculate the charge to mass ratio of the electron. **2**

Space for working and answer

(ii) Determine the absolute uncertainty in the charge to mass ratio of the electron. **4**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

14. (continued)

(c) A second student uses the same equipment to find the charge to mass ratio of the electron and analyses their measurements differently.

The current in the Helmholtz coils is varied to give a range of values for magnetic field strength. This produces a corresponding range of measurements of the radius of curvature.

The student then draws a graph and uses the gradient of the line of best fit to determine the charge to mass ratio of the electron.

Suggest which quantities the student chose for the axes of the graph. **1**

MARKS DO NOT WRITE IN THIS MARGIN

14. (continued)

(d) The graphical method of analysis used by the second student should give a more reliable value for the charge to mass ratio of the electron than the value obtained by the first student.

Use your knowledge of experimental physics to explain why this is the case. **3**

Question			Answer	Max mark	Additional guidance
14.	(a)		$B = 4\cdot2\times10^{-3}\times0\cdot22$ $= 9\cdot2\times10^{-4}$ T **(1)**	**1**	Accept 9, 9·24, 9·240
	(b)	(i)	$\frac{q}{m} = \frac{2V}{B^2r^2}$ $\frac{q}{m} = \frac{2\times5\cdot0\times10^3}{(9\cdot2\times10^{-4})^2\times0\cdot28^2}$ **(1)** $\frac{q}{m} = 1\cdot5\times10^{11}$ C kg^{-1} **(1)**	**2**	Accept 2, 1·51, 1·507 **OR** consistent with (a)
		(ii)	%Uncertainty in B & r is doubled **(1)** $\%\Delta(w) = \sqrt{(\%\Delta x^2 + \%\Delta y^2 + \%\Delta z^2)}$ **(1)** $\%\Delta(\frac{q}{m}) = \sqrt{(10^2 + 10^2 + 12^2)}$ **(1)** $\Delta(\frac{q}{m}) = 0\cdot3\times10^{11}$ C kg^{-1} **(1)**	**4**	Suspend sig fig rule
	(c)		B^2 and $1/r^2$ *(r^2 and $1/B^2$)* **OR** B and $1/r$ *(r and 1/B)* **OR** I and $1/r$ *(r and 1/I)* OR I^2 and $1/r^2$ *(r^2 and $1/I^2$)* **(1)**	**1**	Also accept constants correctly included on the axes

DO NOT WRITE IN THIS MARGIN

15. A defibrillator is a device that gives an electric shock to a person whose heart has stopped beating normally.

This is shown in Figure 15A.

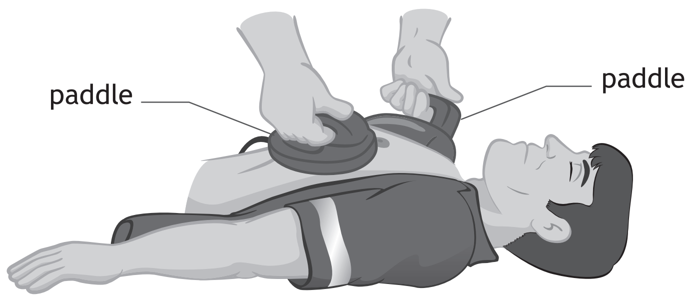


Figure 15A

Two paddles are initially placed in contact with the patient's chest.

A simplified defibrillator circuit is shown in Figure 15B.

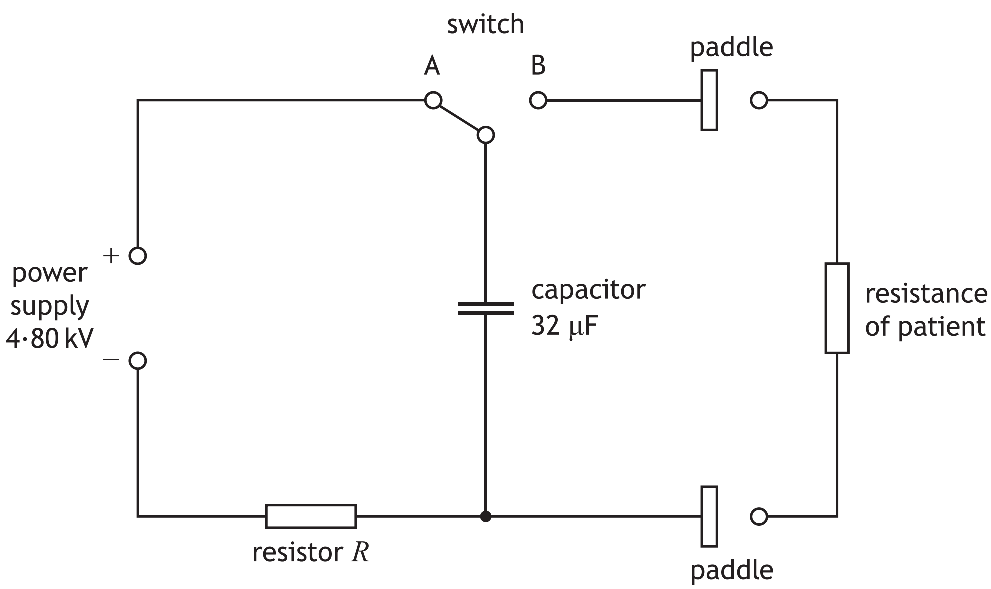


Figure 15B

When the switch is in position A, the capacitor is charged until there is a large potential difference across the capacitor.

MARKS DO NOT WRITE IN THIS MARGIN

15. (continued)

(a) The capacitor can be considered to be fully charged after 5 time constants.

The time taken for the capacitor to be considered to be fully charged is 10·0 s.

Determine the resistance of resistor R. **3**

Space for working and answer

(b) During a test, an 80·0 Ω resistor is used in place of the patient.

The switch is moved to position B, and the capacitor discharges through the 80·0 Ω resistor.

The initial discharge current is 60 A.

The current in the resistor will fall to half of its initial value after 0·7 time constants.

Show that the current falls to 30 A in 1·8 ms. **2**

Space for working and answer

15. (continued)

MARKS | DO NOT WRITE IN THIS MARGIN

(c) In practice a current greater than 30 A is required for a minimum of 5·0 ms to force the heart of a patient to beat normally.

An inductor, of negligible resistance, is included in the circuit to increase the discharge time of the capacitor to a minimum of 5·0 ms.

This is shown in Figure 15C.

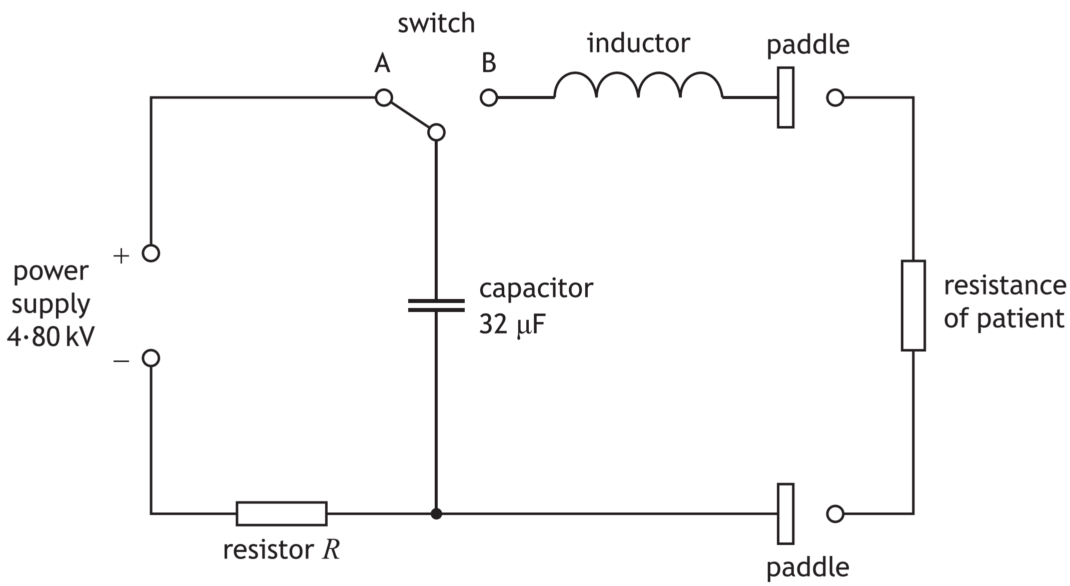


Figure 15C

(i) The inductor has an inductance of 50·3 mH.

The capacitor is again fully charged. The switch is then moved to position B.

Calculate the rate of change of current at the instant the switch is moved to position B. **3**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

15. (c) (continued)

(ii) It would be possible to increase the discharge time of the capacitor with an additional resistor connected in the circuit in place of the inductor. However, the use of an additional resistor would mean that maximum energy was not delivered to the patient.

Explain why it is more effective to use an inductor, rather than an additional resistor, to ensure that maximum energy is delivered to the patient. **2**

[END OF QUESTION PAPER]

Question			Answer	Max mark	Additional guidance
15.	(a)		$t = RC$ (1) $\frac{10.0}{5} = R \times 32 \times 10^{-6}$ (1) $R = 6 \cdot 3 \times 10^{4}\,\Omega$ (1)	3	Accept 6, 6·25, 6·250
	(b)		$t = RC$ (1) $t_{\left(\frac{1}{2}\right)} = 0 \cdot 7 \times 80 \cdot 0 \times 32 \times 10^{-6}$ (1) $t_{\left(\frac{1}{2}\right)} = 1 \cdot 8 \times 10^{-3}\,\mathrm{s}$	2	SHOW question
	(c)	(i)	$\varepsilon = -L\frac{dI}{dt}$ (1) $-4 \cdot 80 \times 10^{3} = -50 \cdot 3 \times 10^{-3} \times \frac{dI}{dt}$ (1) $\frac{dI}{dt} = 9 \cdot 54 \times 10^{4}\ \mathrm{A\,s^{-1}}$ (1)	3	Accept 9·5, 9·543, 9·5427
		(ii)	(Additional) resistor will dissipate energy. (1) Inductor will store energy (and then deliver it to the patient). (1)	2	No energy loss/dissipation in inductor acceptable for second mark.

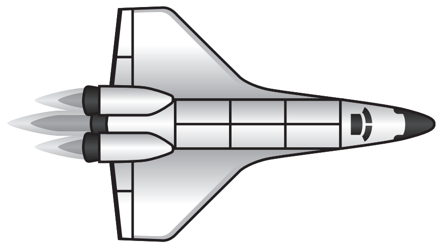
[END OF MARKING INSTRUCTIONS]

MARKS | DO NOT WRITE IN THIS MARGIN

Total marks — 140

Attempt ALL questions

1. A spacecraft accelerates from rest at time $t = 0$.



The velocity v of the spacecraft at time t is given by the relationship

$$v = 4\cdot2t^2 + 1\cdot6t$$

where v is measured in $m\,s^{-1}$ and t is measured in s.

Using calculus methods

(a) determine the time at which the acceleration of the spacecraft is $24\,m\,s^{-2}$ **3**

Space for working and answer

(b) determine the distance travelled by the spacecraft in this time. **3**

Space for working and answer

Marking instructions for each question

Question			Expected response	Max mark	Additional guidance
1.	(a)		$v = 4{\cdot}2t^2 + 1{\cdot}6t$ $a\left(=\frac{dv}{dt}\right) = 8{\cdot}4t + 1{\cdot}6$ **(1)** $24 = 8{\cdot}4t + 1{\cdot}6$ **(1)** $t = 2{\cdot}7\ s$ **(1)**	3	Accept: 3, 2·67, 2·667
	(b)		$s = \int (4{\cdot}2t^2 + 1{\cdot}6t).dt$ $s = \frac{4{\cdot}2t^3}{3} + \frac{1{\cdot}6t^2}{2}(+c)$ **(1)** (s=0 when t=0, so c=0) $s = \frac{4{\cdot}2 \times 2{\cdot}7^3}{3} + \frac{1{\cdot}6 \times 2{\cdot}7^2}{2}$ **(1)** $s = 33$ m **(1)**	3	Or consistent with (a) Accept: 30,33·4, 33·39 Solution with limits also acceptable $s = \int_0^{2{\cdot}7} \left(4{\cdot}2t^2 + 1{\cdot}6t\right).\ dt$ $s = \left[\frac{4{\cdot}2 \times t^3}{3} + \frac{1{\cdot}6 \times t^2}{2}\right]_0^{2{\cdot}7}$ **(1)** $s = \left(\frac{4{\cdot}2 \times 2{\cdot}7^3}{3} + \frac{1{\cdot}6 \times 2{\cdot}7^2}{2}\right)(-0)$ **(1)** $s = 33$ m **(1)**

MARKS | DO NOT WRITE IN THIS MARGIN

2. Riders on a theme park attraction sit in pods, which are suspended by wires.

This is shown in Figure 2A.

Figure 2A

(a) (i) During the ride, a pod travels at a constant speed of $8{\cdot}8\,\mathrm{m\,s^{-1}}$ in a horizontal circle.

The radius of the circle is $7{\cdot}6\,\mathrm{m}$.

When occupied, the pod has a mass of $380\,\mathrm{kg}$.

Calculate the centripetal force acting on the pod. **3**

Space for working and answer

(ii) State the direction of the centripetal force. **1**

MARKS DO NOT WRITE IN THIS MARGIN

2. (continued)

(b) (i) Figure 2B shows a simplified model of a pod following a horizontal circular path. The pod is suspended from a fixed point by a cord.

On Figure 2B, show the forces acting on the pod as it travels at a constant speed in a horizontal circle.

You must name these forces and show their directions. **2**

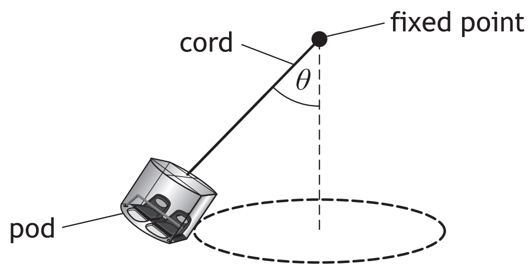
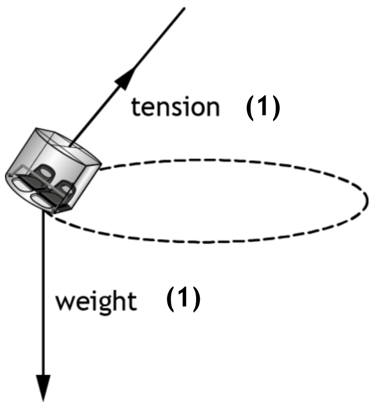


Figure 2B

(ii) The speed of the pod decreases.

State the effect this has on the angle θ.

You must justify your answer in terms of the forces acting on the pod. **2**

Question			Expected response	Max mark	Additional guidance
2.	(a)	(i)	$F = \frac{mv^2}{r}$ **(1)** $F = \frac{380 \times 8 \cdot 8^2}{7 \cdot 6}$ **(1)** $F = 3900$ N **(1)**	**3**	Accept: 4000, 3870, 3872 $F = mr\omega^2$ and $\omega = \frac{v}{r}$ **(1)** $F = 380 \times 7 \cdot 6 \times \left(\frac{8 \cdot 8}{7 \cdot 6}\right)^2$ **(1)** $F = 3900$ N **(1)**
	(a)	(ii)	Towards the <u>centre of the</u> (horizontal) <u>circle</u>	**1**	Along the radius **(0)** Along the radius towards the centre **(1)**
	(b)	(i)	 	**2**	
	(b)	(ii)	(θ) decreases **(1)** (Horizontal component of) tension decreases **and** weight unchanged **(1)**	**2**	MUST JUSTIFY Accept: centripetal force decreases.

MARKS DO NOT WRITE IN THIS MARGIN

3. A gymnast, in a straight position, rotates around a high bar.

This is shown in Figure 3A.

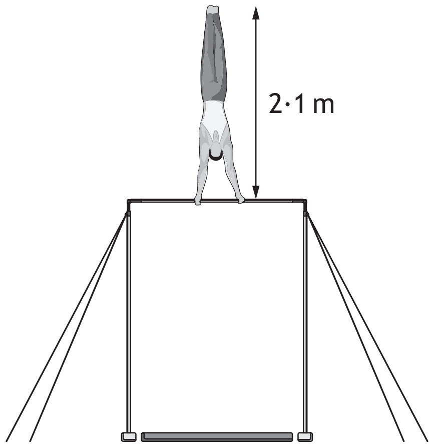


Figure 3A

The mass of the gymnast is 63 kg.

With arms extended, the total length of the gymnast is 2·1 m.

The gymnast is rotating with an angular velocity of 7·9 rad s^{-1}.

(a) With arms extended, the gymnast can be approximated as a uniform rod.

Using this approximation, show that the moment of inertia of the gymnast around the bar is 93 kg m^2. **2**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

3. (continued)

(b) The gymnast now makes a pike position, by bending at the waist.

This is shown in Figure 3B.

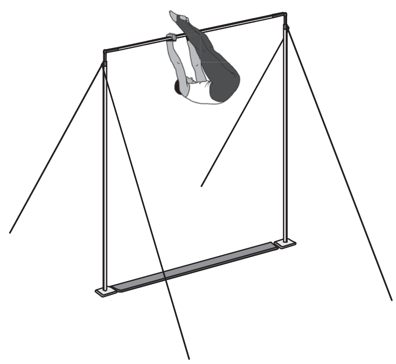


Figure 3B

This change of position causes the moment of inertia of the gymnast to decrease to 62 kg m^2.

(i) Explain why making a pike position results in a decrease in the moment of inertia of the gymnast. **1**

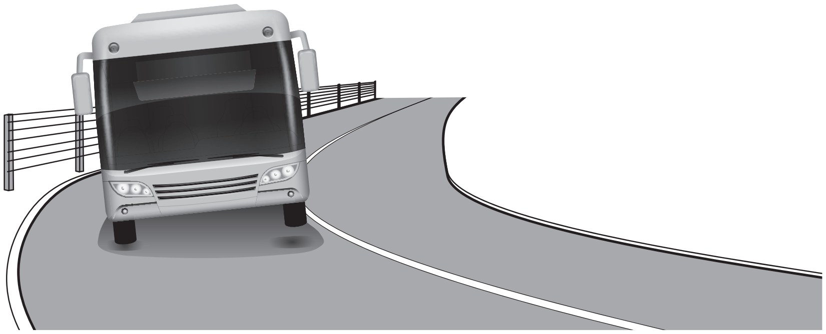
(ii) By considering the conservation of angular momentum, determine the angular velocity of the gymnast in the pike position. **3**

Space for working and answer

Question			Expected response	Max mark	Additional guidance
3.	(a)		$I = \frac{1}{3}ml^2$ **(1)** $I = \frac{1}{3} \times 63 \times 2{\cdot}1^2$ **(1)** $I = 93\ \text{kg}\,\text{m}^2$	2	SHOW QUESTION Final answer must be shown otherwise **(1 max)**
	(b)	(i)	Mass (is now distributed) closer to the axis of rotation	1	There must be some implication that the mass distribution/ gymnast/legs is closer to the axis.
		(ii)	$I_1\omega_1 = I_2\omega_2$ **(1)** $93 \times 7{\cdot}9 = 62 \times \omega_2$ **(1)** $\omega_2 = 12\ \text{rad}\,\text{s}^{-1}$ **(1)**	3	Accept 10, 11·9,11·85

MARKS | DO NOT WRITE IN THIS MARGIN

4. Passengers are sitting on a bus as it goes around a tight bend at speed.



The following conversation is overheard between two of the passengers after the journey.

Passenger one: 'Did you feel that centrifugal force? It nearly tipped the bus over!'

Passenger two: 'There is no such thing as centrifugal force. It's centripetal force that gets the bus around the bend.'

Passenger one: 'There is centrifugal force, it depends on your frame of reference.'

Passenger two: 'No, centrifugal force is just imaginary.'

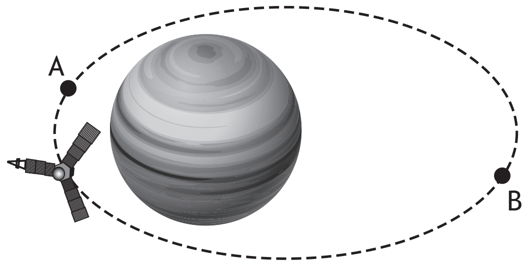
Use your knowledge of physics to comment on the overheard conversation. **3**

MARKS DO NOT WRITE IN THIS MARGIN

5. Juno is a spacecraft with a mission to survey Jupiter.

Juno is in an elliptical orbit around Jupiter.

This is shown in Figure 5A.



not to scale

Figure 5A

(a) The gravitational potential at point A in the orbit of Juno is $-1{\cdot}70 \times 10^{9}\,\mathrm{J\,kg^{-1}}$.

State what is meant by *a gravitational potential of* $-1{\cdot}70 \times 10^{9}\,J\,kg^{-1}$. **1**

(b) At point B, Juno is $1{\cdot}69 \times 10^{8}$ m from the centre of Jupiter.

Calculate the gravitational potential at point B. **3**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

5. (continued)

(c) The mass of Juno is $1{\cdot}6 \times 10^3$ kg.

Determine the change in gravitational potential energy of Juno when it has moved from point A to point B. **4**

Space for working and answer

Question			Expected response	Max mark	Additional guidance
5.	(a)		(-)$1{\cdot}70\times10^9$ joules (of energy) transferred in moving unit mass (or 1 kg) from infinity to that point	1	
	(b)		$V = -\frac{GM}{r}$ **(1)** $V = -\frac{6{\cdot}67\times10^{-11}\times1{\cdot}90\times10^{27}}{1{\cdot}69\times10^{8}}$ **(1)** $V = -7{\cdot}50\times10^{8}\ \text{Jkg}^{-1}$ **(1)**	3	Accept: 7·5, 7·499, 7·4988
	(c)		$\Delta V = -7{\cdot}50\times10^{8} - (-1{\cdot}70\times10^{9})$ **(1)** $(\Delta)E_p = (\Delta)Vm$ **(1)** $(\Delta)E_p = (-7{\cdot}50\times10^{8} - (-1{\cdot}70\times10^{9}))$ $\times1{\cdot}6\times10^{3}$ **(1)** $(\Delta)E_p = 1{\cdot}5\times10^{12}\ \text{J}$ **(1)**	4	Or consistent with (b) Accept: 2, 1·52, 1·520 Alternative method: $E_p = Vm$ **(1)** $E_{p(B)} = -7{\cdot}50\times10^{8}\times1{\cdot}6\times10^{3}$ $E_{p(A)} = -1{\cdot}70\times10^{9}\times1{\cdot}6\times10^{3}$ **(1)** $(\Delta)E_p = (-7{\cdot}50\times10^{8} - (-1{\cdot}70\times10^{9}))$ $\times1{\cdot}6\times10^{3}$ **(1)** $(\Delta)E_p = 1{\cdot}5\times10^{12}\ \text{J}$ **(1)**

MARKS | DO NOT WRITE IN THIS MARGIN

6. In 1915, Albert Einstein presented his general theory of relativity. The equivalence principle is a key part of this theory.

(a) State what is meant by *the equivalence principle*. **1**

(b) Spacetime diagrams are used to show the world line of objects.

A spacetime diagram representing the world lines of two objects, P and Q, is shown in Figure 6A.

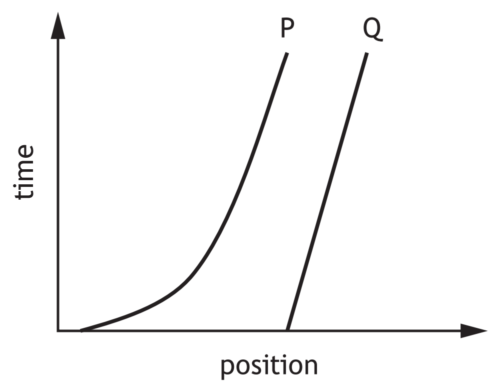


Figure 6A

(i) State which of these objects is accelerating. **1**

(ii) On Figure 6A, draw a world line that would represent a stationary object. **1**

MARKS DO NOT WRITE IN THIS MARGIN

6. (continued)

(c) General relativity explains the spacetime curvature caused by a black hole. This curvature causes a ray of light to appear to be deflected. This is known as gravitational lensing.

The angle of deflection θ, in radians, is given by the relationship

$$\theta = \frac{4GM}{rc^2}$$

where

G is the universal constant of gravitation

M is the mass of the black hole

r is the distance between the black hole and the ray of light

c is the speed of light in a vacuum.

(i) Imaging of the region around a black hole shows an angle of deflection of 0·0487 radians when a ray of light is $1{\cdot}54 \times 10^6$ m from the black hole.

Determine the mass of the black hole. **2**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

6. (c) (continued)

(ii) Gravitational lensing causes the deflection of light rays from background stars that appear close to the edge of the Sun. This phenomenon can be observed during a total solar eclipse.

It can be shown that the angle of deflection θ, in **radians**, of a ray of light by a star of mass M is related to the Schwarzschild radius of the star and the distance r between the ray of light and the centre of the star.

$$\theta = \frac{2r_{Schwarzschild}}{r}$$

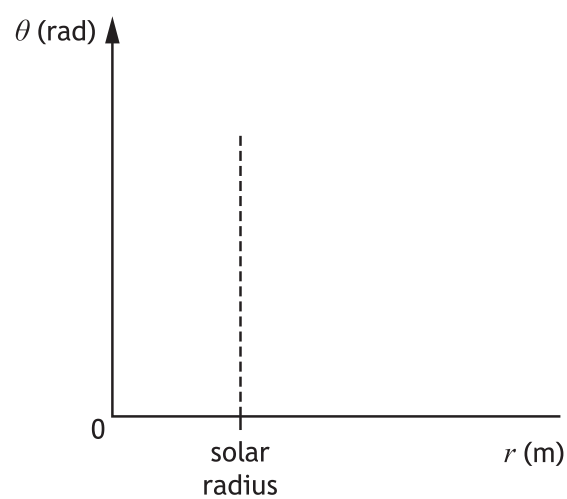
The Schwarzschild radius of the Sun is equal to $3{\cdot}0 \times 10^3$ m.

(A) Calculate the angle of deflection in radians of a ray of light that grazes the edge of the Sun. **2**

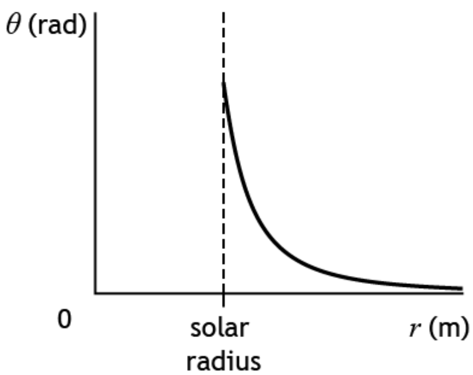
Space for working and answer

(B) On the axes below, sketch a graph showing the observed variation of the angle of deflection of a ray of light with its distance from the centre of the Sun. **2**

Numerical values are not required on either axis.



(An additional diagram, if required, can be found on *page 46*.)

Question			Expected response	Max mark	Additional guidance
6.	(a)		It is not possible to distinguish between the effects (on a body) of(uniform) acceleration and a (uniform) gravitational field	1	Effects must be implied.
	(b)	(i)	P	1	
		(ii)	vertical straight line	1	
	(c)	(i)	$\theta = \frac{4GM}{rc^2}$ $0\cdot0487 = \frac{4\times6\cdot67\times10^{-11}\times M}{1\cdot54\times10^{6}\times(3\cdot00\times10^{8})^2}$ (1) $M = 2\cdot53\times10^{31}$ kg (1)	2	Accept: 2·5, 2·530, 2·5299
		(ii) (A)	$\theta = \frac{2r_{Schwarzschild}}{r}$ $\theta = \frac{2\times3\cdot0\times10^{3}}{6\cdot955\times10^{8}}$ **(1)** $\theta = 8\cdot6\times10^{-6}$ (rad) **(1)**	2	Accept: 9, 8·63, 8·627
		(ii) (B)		2	Shape of line as an inverse curve asymptotic to x-axis **(1)** An inverse curve starting from and continuing to the right of the vertical dotted line. **(1)**

MARKS DO NOT WRITE IN THIS MARGIN

7. A Hertzsprung-Russell (H-R) diagram is shown in Figure 7A.

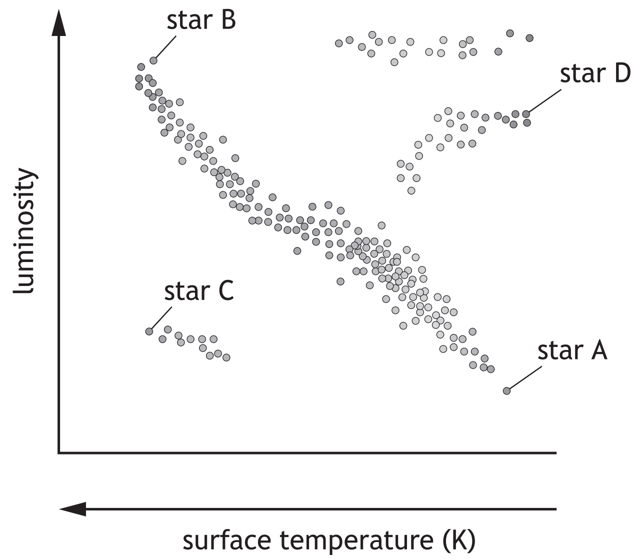


Figure 7A

(a) Stars are classified depending on their position on the H-R diagram.

(i) Four stars are labelled on the H-R diagram.

State which of these stars is a red giant. **1**

(ii) At present the Sun is a main sequence star. It is predicted that the Sun will eventually become a red giant.

(A) State the change that will occur in the fusion reactions within the core of the Sun at the point when it leaves the main sequence. **1**

(B) Explain, in terms of gravitational force and thermal pressure, why the diameter of the Sun will increase as it becomes a red giant. **1**

MARKS DO NOT WRITE IN THIS MARGIN

7. (continued)

(b) Betelgeuse is a red supergiant star in the constellation Orion.

It is $6{\cdot}1 \times 10^{18}$ m from Earth and has an apparent brightness of $1{\cdot}6 \times 10^{-7}$ W m^{-2}.

(i) Calculate the luminosity of Betelgeuse. **3**

Space for working and answer

(ii) The radius of Betelgeuse is $8{\cdot}3 \times 10^{11}$ m.

Calculate the surface temperature of Betelgeuse. **3**

Space for working and answer

(c) Ultimately, every main sequence star will become either a white dwarf, a neutron star or a black hole.

State the property of a star that determines which of these it will eventually become. **1**

Question			Expected response	Max mark	Additional guidance
7.	(a)	(i)	(Star) D	**1**	
		(ii) A	Fusion (of hydrogen) (in core) stops	**1**	
		(ii) B	(Outward forces caused by) thermal pressure exceed gravitational forces.	**1**	Must compare thermal pressure and gravitational forces.
	(b)	(i)	$b = \frac{L}{4\pi r^2}$ **(1)** $1{\cdot}6 \times 10^{-7} = \frac{L}{4\pi \times (6{\cdot}1 \times 10^{18})^2}$ **(1)** $L = 7{\cdot}5 \times 10^{31}$ W **(1)**	**3**	Accept: 7, 7·48, 7·482
		(ii)	$L = 4\pi r^2 \sigma T^4$ **(1)** $7{\cdot}5 \times 10^{31} = 4\pi(8{\cdot}3 \times 10^{11})^2 \times 5{\cdot}67 \times 10^{-8} \times T^4$ **(1)** $T = 3500$ K **(1)**	**3**	Accept:4000, 3520, 3516 **OR** Consistent with (b)(i)
	(c)		Mass	**1**	

MARKS DO NOT WRITE IN THIS MARGIN

8. Muons are created when cosmic rays enter the atmosphere of the Earth. This is shown in Figure 8A.

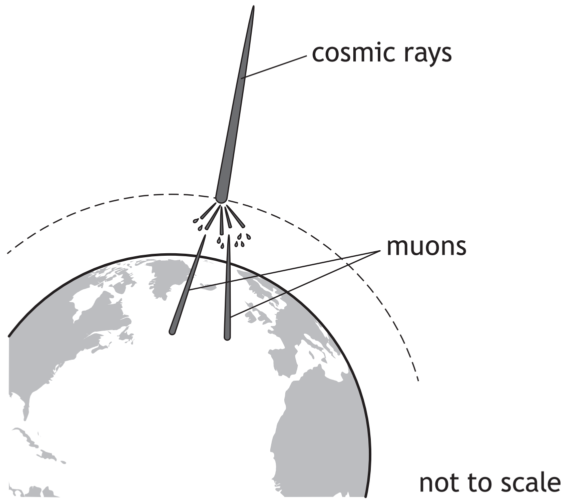


Figure 8A

To an observer on Earth the muons appear to have a lifetime of 8·5 μs.

Instruments on Earth can detect muons and measure muon energy E.

The precision of the muon energy measurement is limited by the lifetime Δt of the muon.

(a) By considering the Heisenberg uncertainty principle, calculate the minimum uncertainty in muon energy ΔE_{min}. **3**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

8. (continued)

(b) Some muons, detected at sea level, have an average energy of $4{\cdot}1 \times 10^{9}$ eV.

An instrument detects 10 000 such muons in one minute.

Determine the average total energy, in joules, measured per second. **3**

Space for working and answer

(c) At sea level, these muons have an average momentum of $4{\cdot}87 \times 10^{-19}\,\text{kg m s}^{-1}$.

By calculating the de Broglie wavelength of a muon with this momentum, explain why muons at sea level can be regarded as particles. **4**

Space for working and answer

Question			Expected response	Max mark	Additional guidance
8.	(a)		$\Delta E \Delta t \geq \frac{h}{4\pi}$ or $\Delta E_{min} \Delta t = \frac{h}{4\pi}$ **(1)** $\Delta E \times 8{\cdot}5 \times 10^{-6} \geq \frac{6{\cdot}63 \times 10^{-34}}{4\pi}$ **(1)** ($\Delta E \geq 6{\cdot}2 \times 10^{-30}$ J) $\Delta E_{(min)} = (\pm) 6{\cdot}2 \times 10^{-30}$ J **(1)**	3	Accept: 6, 6·21, 6·207 $\Delta E_{min} \Delta t \geq \frac{h}{4\pi}$ not acceptable for first line
	(b)		particle energy (J) = $4{\cdot}1 \times 10^{9} \times 1{\cdot}6 \times 10^{-19}$ **(1)** energy = $(4{\cdot}1 \times 10^{9} \times 1{\cdot}6 \times 10^{-19}) \times \frac{10\,000}{60}$ **(1)** energy $= 1{\cdot}1 \times 10^{-7}$ (J) **(1)**	3	Accept: 1, 1·09, 1·093 Independent mark for $10\,000 \div 60$
	(c)		$\lambda = \frac{h}{p}$ **(1)** $\lambda = \frac{6{\cdot}63 \times 10^{-34}}{4{\cdot}87 \times 10^{-19}}$ **(1)** $\lambda = 1{\cdot}36 \times 10^{-15}$ m **(1)** λ is too small for interference/diffraction to be observed **(1)**	4	Accept: 1·4, 1·361, 1·3614

MARKS DO NOT WRITE IN THIS MARGIN

9. An excerpt from a student's notes on fusion reactions is quoted below.

Electrostatic repulsion must be overcome before fusion can occur.

Two protons repel one another because of the electrostatic force between them.

If two protons can be brought close enough together, however, the electrostatic repulsion can be overcome by the quantum effect in which protons can tunnel through electrostatic forces.

The Heisenberg uncertainty principle suggests that protons can 'borrow' energy in order to overcome their electrostatic repulsion. This allows fusion to occur at lower temperatures than would otherwise be required.

Use your knowledge of physics to comment on this excerpt. **3**

MARKS DO NOT WRITE IN THIS MARGIN

10. (a) Alpha particles are accelerated to a speed of $5{\cdot}0 \times 10^6\,\mathrm{m\,s^{-1}}$.

The alpha particles are then injected into a magnetic field. The path of the alpha particles is perpendicular to the magnetic field lines.

The magnetic induction is $1{\cdot}7\,\mathrm{T}$.

The alpha particles follow the circular path shown in Figure 10A.

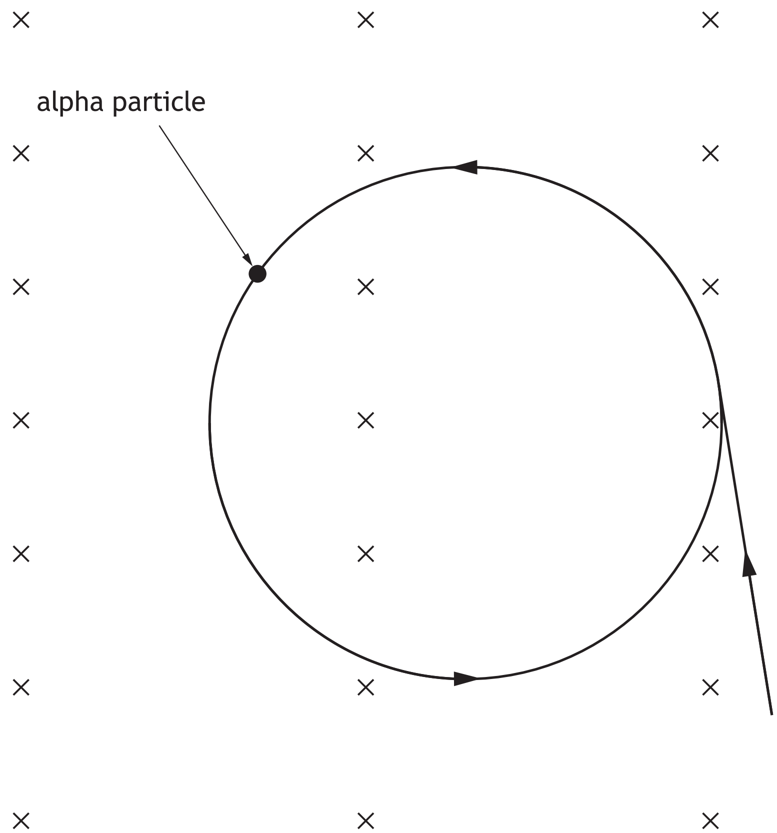


Figure 10A

(i) (A) Calculate the magnitude of the magnetic force acting on an alpha particle. **3**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

10. (a) (i) (continued)

(B) This magnetic force provides the centripetal force that causes the alpha particles to follow the circular path.

Calculate the radius of the circular path. **3**

Space for working and answer

(ii) The alpha particles are now replaced by protons.

The protons also travel at $5{\cdot}0 \times 10^6\,\text{m s}^{-1}$, and are injected into the magnetic field at the same point and in the same direction as the alpha particles.

On Figure 10A, sketch the path followed by the protons after they enter the magnetic field. **3**

(An additional diagram, if required, can be found on *page 46*)

MARKS | DO NOT WRITE IN THIS MARGIN

10. (continued)

(b) Cosmic rays travel through space towards Earth.

Approximately 9% of cosmic rays are alpha particles.

Alpha particles entering the magnetic field of the Earth follow a **helical**, rather than a **circular** path.

Explain why alpha particles travelling through the magnetic field of the Earth follow a helical path. **2**

MARKS | DO NOT WRITE IN THIS MARGIN

10. (continued)

(c) The Pierre Auger Observatory is a large cosmic ray observatory in Argentina. The location of this observatory is shown in Figure 10B.

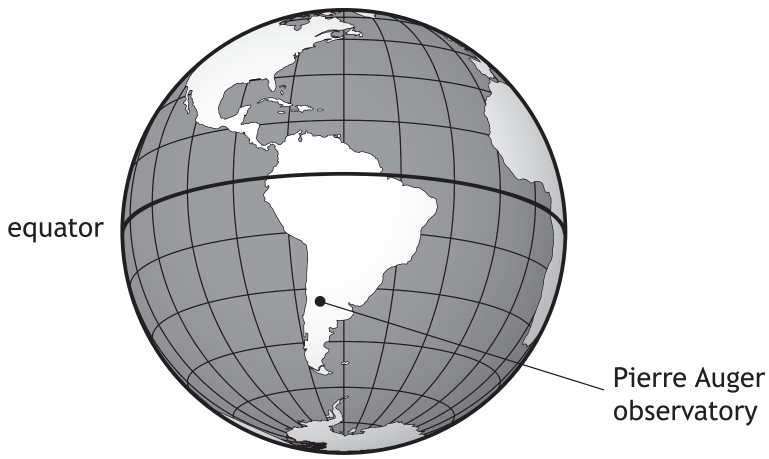
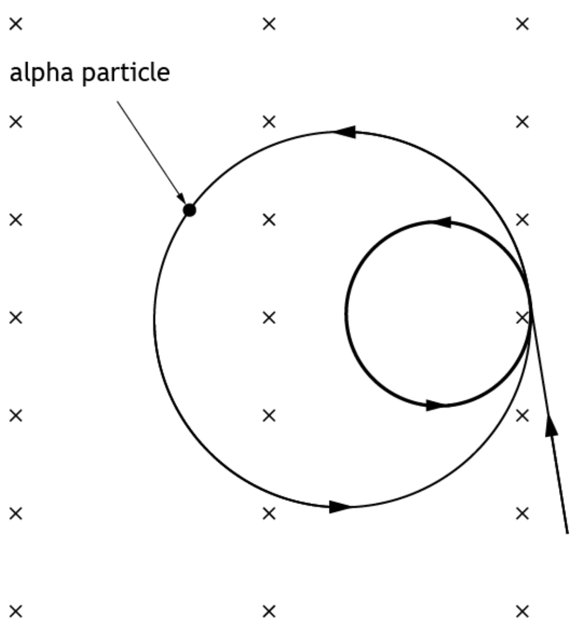


Figure 10B

The observatory is at an altitude of 1400 m.

Explain why this choice of location for the observatory was preferred to locations at lower altitude **and** to locations closer to the equator. **2**

Question			Expected response	Max mark	Additional guidance
10.	(a)	(i) A	$F = qvB$ **(1)** $F = 3{\cdot}20\times10^{-19}\times5{\cdot}0\times10^{6}\times1{\cdot}7$ **(1)** $F = 2{\cdot}7\times10^{-12}$ N **(1)**	3	Accept: 3, 2·72, 2·720
		(i) B	$F = \frac{mv^2}{r}$ **(1)** $2{\cdot}7\times10^{-12} = \frac{6{\cdot}645\times10^{-27}\times(5{\cdot}0\times10^{6})^2}{r}$ **(1)** $r = 6{\cdot}2\times10^{-2}$ m **(1)**	3	Or consistent with 10(a)(i)A Accept: 6,6·15,6·153 *If* $m = 6{\cdot}645 \times 10^{-27}$ not used then **(max 1)** Alternative method: $qvB = \frac{mv^2}{r}$ **(1)** $3{\cdot}20\times10^{-19}\times5{\cdot}0\times10^{6}\times1{\cdot}7 = \frac{6{\cdot}645\times10^{-27}\times(5{\cdot}0\times10^{6})^2}{r}$ **(1)** $r = 6{\cdot}1\times10^{-2}$ m **(1)** Accept: 6,6·11,6·108
		(ii)		3	Independent marks smaller circle **(1)** direction of arrow **(1)** position of circle **(1)**

Question			Expected response	Max mark	Additional guidance
10.	(b)		(Component of) velocity perpendicular to the (magnetic) field produces circular motion/central force. **(1)** (Component of) velocity parallel to the (magnetic) field is constant/results in no (unbalanced) force/is unaffected by the magnetic field. **(1)**	**2**	Independent marks 'Horizontal component', 'vertical component' not acceptable
	(c)		(The observatory is at a high altitude,) bringing it closer to (the path of) the cosmic rays/reduces interaction of rays with the atmosphere. **(1)** (The location is closer to the South Pole,) where the Earth's magnetic field is stronger/field lines are closer together/ higher particle density **(1)**	**2**	Independent marks

MARKS | DO NOT WRITE IN THIS MARGIN

11. A home improvement shop has a machine that can produce paint of any colour. Small amounts of pigment are added to paint in a tin. The tin is then shaken to produce a uniform colour of paint.

The machine is shown in Figure 11A.

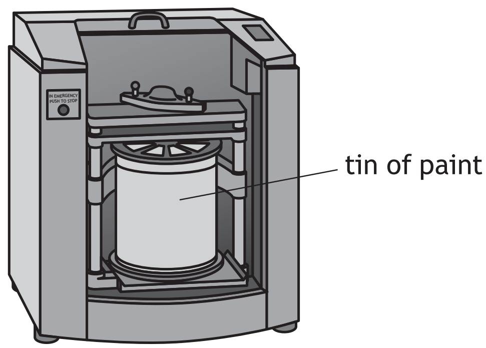


Figure 11A

The tin is placed in the machine and clamped securely. During shaking, the oscillation of the tin in the vertical plane can be modelled as simple harmonic motion.

The tin of paint has a mass of 3·67 kg.

The tin is shaken at a rate of 580 oscillations per minute.

The amplitude of its motion is 0·013 m.

(a) (i) Show that the angular frequency ω of the tin is 61 rad s^{-1}. **2**

Space for working and answer

(ii) Calculate the maximum kinetic energy of the tin. **3**

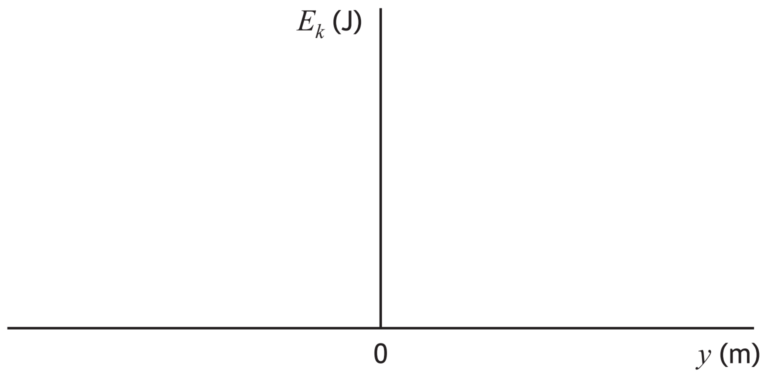
Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

11. (a) (continued)

(iii) On the axes below, sketch a graph showing the variation of the kinetic energy E_k of the tin with the vertical displacement y from its equilibrium position.

Numerical values are required on both axes. **3**



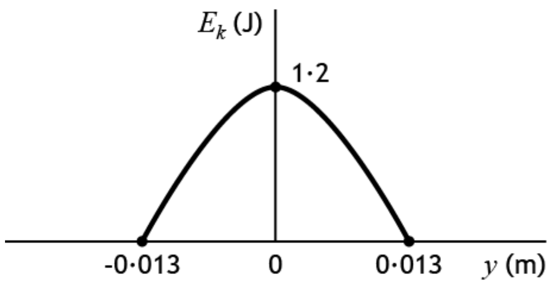
(An additional graph, if required, can be found on *page 47*.)

(b) A coin falls onto the lid of the tin of paint as it is being clamped into position. The coin loses contact with the lid during the first oscillation.

(i) State the magnitude and direction of the acceleration of the tin when the coin just loses contact with the lid. **1**

(ii) Determine the magnitude of the displacement of the tin from its equilibrium position when the coin just loses contact with the lid. **3**

Space for working and answer

Question			Expected response	Max mark	Additional guidance
11.	(a)	(i)	$\omega = 2\pi f$ **(1)** $\omega = 2\pi \times \frac{580}{60}$ **(1)** $\omega = 61\ \text{rad s}^{-1}$	2	SHOW QUESTION Accept: $\omega = \frac{\theta}{t}$ or $\omega = \frac{d\theta}{dt}$ or $\omega = \frac{2\pi}{T}$ as a starting point
		(ii)	$E_k = \frac{1}{2}m\omega^2(A^2 - y^2)$ **(1)** maximum E_k at $y = 0$ $E_k = \frac{1}{2} \times 3{\cdot}67 \times 61^2 \times (0{\cdot}013^2 - 0^2)$ **(1)** $E_k = 1{\cdot}2$ J **(1)**	3	$E_{k(max)} = \frac{1}{2}m\omega^2 A^2$ acceptable Accept: 1, 1·15, 1·154
		(iii)		3	independent marks shape (inverted curve) **(1)** Line reaches, but does not exceed ± 0·013 on horizontal axis **(1)** Line reaches, but does not exceed 1·2 on vertical axis **(1)** **OR** consistent with (a)(ii)
	(b)	(i)	9·8 m s^{-2} DOWNWARDS	1	magnitude AND direction required
		(ii)	$a = -\omega^2 y$ **(1)** $(-)9{\cdot}8 = (-)61^2 \times y$ **(1)** $y = (-)2{\cdot}6 \times 10^{-3}$ m **(1)**	3	**OR** consistent with (b)(i) Accept: 3, 2·63, 2·634

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12. A student is performing an experiment to determine the speed of sound in air.

The student uses the apparatus shown in Figure 12A.

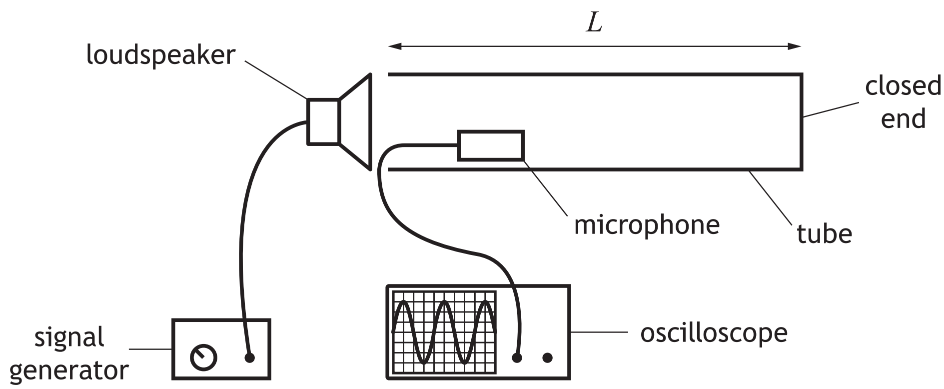

Figure 12A

The microphone is in a fixed position.

The signal generator is switched on.

A stationary wave is formed within the tube.

(a) (i) Explain how the stationary wave is formed. **1**

(ii) At one frequency the microphone detects a loud sound. The frequency produced by the signal generator is now increased gradually.

Describe what happens to the loudness of the sound detected by the microphone as the frequency is being increased to twice its original value. **2**

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12. (continued)

(b) At specific frequencies the air in the tube will resonate.

Frequencies that cause resonance can be determined by the relationship

$$f = \frac{nv}{4L}$$

where

v is the speed of sound in air

L is the length of the tube

n is the number of half-wavelengths of sound waves in the tube.

The student measures the length of the tube to be $(2\cdot00 \pm 0\cdot02)$ m.

The student notes that the resonant frequency is (510 ± 10) Hz when there are eleven half-wavelengths of sound waves in the tube.

(i) Use the data obtained by the student to calculate a value for the speed of sound in air. **2**

Space for working and answer.

(ii) Determine the absolute uncertainty in this value. **4**

Space for working and answer.

MARKS | DO NOT WRITE IN THIS MARGIN

12. (continued)

(c) The student now uses a graphical method to determine the speed of sound in air. Using a software graphing package, the student produces the graph shown in Figure 12B.

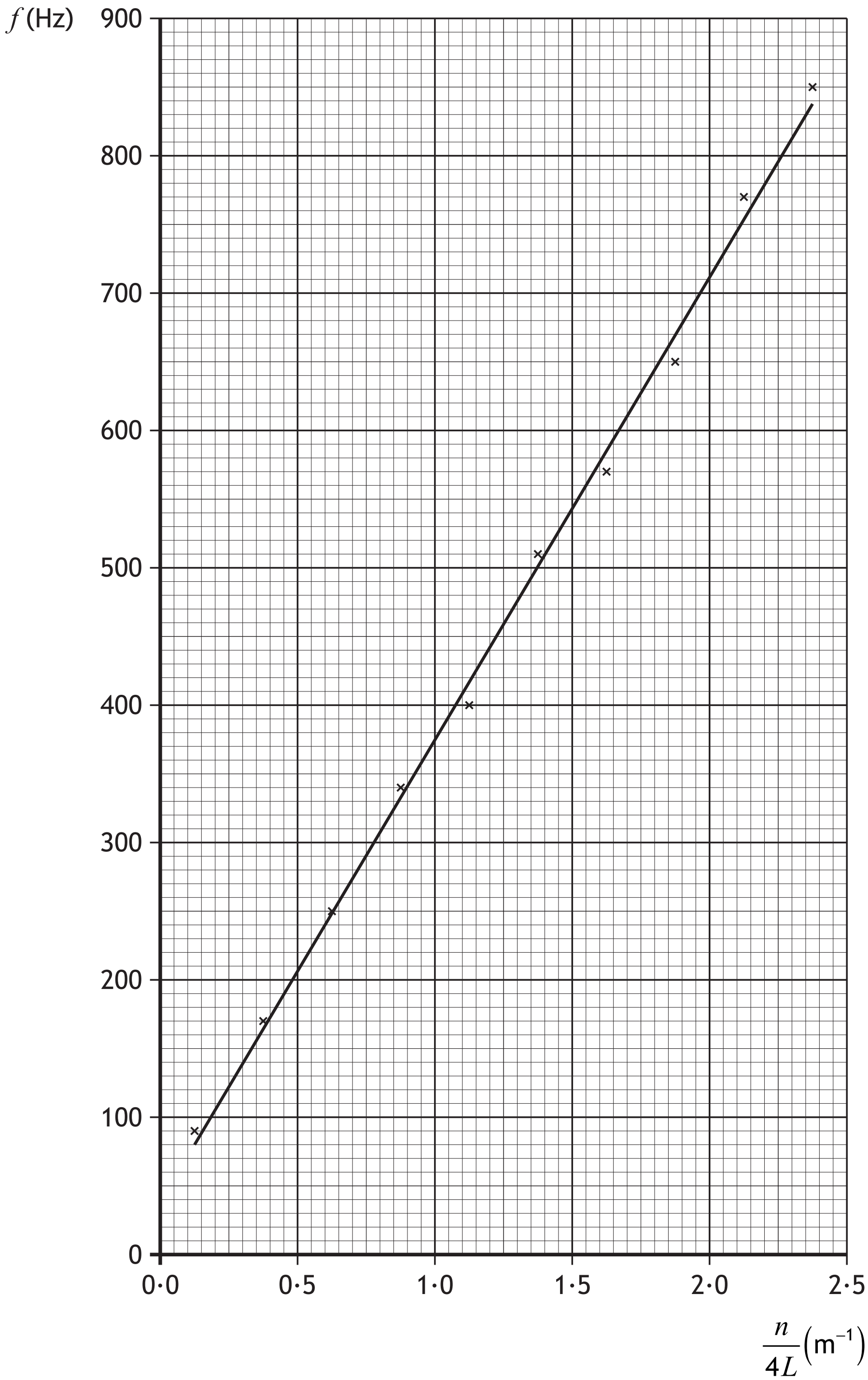

Figure 12B

MARKS DO NOT WRITE IN THIS MARGIN

12. (c) (continued)

(i) Using information from the graph, determine the speed of sound in air. **3**

Space for working and answer.

(ii) Using the graphing package, the student estimates a 2% uncertainty in the value of the speed of sound in air obtained.

(A) State how the *precision* of the value obtained by the graphical method compares with the *precision* of the value obtained in (b). **1**

(B) State how the *accuracy* of the value obtained by the graphical method compares with the *accuracy* of the value obtained in (b). **1**

(iii) The line of best fit on the graph does not pass through the origin as theory predicts. This may be due to a systematic uncertainty.

Suggest a possible source of a systematic uncertainty in the experiment. **1**

Question			Expected response	Max mark	Additional guidance
12.	(a)	(i)	(The incident wave reflects from the closed end) The incident/transmitted and reflected waves interfere/superimposed	**1**	
		(ii)	The sound will get quieter **(1)** The sound will then get louder again (when the frequency has doubled). **(1)**	**2**	2nd mark dependant on 1st mark
	(b)	(i)	$f = \frac{nv}{4L}$ $510 = \frac{11 \times v}{4 \times 2 \cdot 00}$ **(1)** $v = 370 \text{ m s}^{-1}$ **(1)**	**2**	Accept: 400, 371, 370·9
		(ii)	$\frac{\Delta W}{W} = \sqrt{\left(\frac{\Delta X}{X}\right)^2 + \left(\frac{\Delta Y}{Y}\right)^2 + \left(\frac{\Delta Z}{Z}\right)^2}$ **(1)** $\frac{\Delta L}{L} = \frac{0 \cdot 02}{2 \cdot 00}$ $\frac{\Delta f}{f} = \frac{10}{510}$ **(1 for both)** $\frac{\Delta v}{370} = \sqrt{\left(\frac{0 \cdot 02}{2 \cdot 00}\right)^2 + \left(\frac{10}{510}\right)^2}$ **(1)** $\Delta v = (\pm) 8 \text{ m s}^{-1}$ **(1)**	**4**	Speed used should be consistent with (b)(i) Use of percentage rather than fractional uncertainty is acceptable.

Question			Expected response	Max mark	Additional guidance
12.	(a)	(i)	(The incident wave reflects from the closed end) The incident/transmitted and reflected waves interfere/superimposed	**1**	
		(ii)	The sound will get quieter **(1)** The sound will then get louder again (when the frequency has doubled). **(1)**	**2**	2nd mark dependant on 1st mark
	(b)	(i)	$f = \frac{nv}{4L}$ $510 = \frac{11 \times v}{4 \times 2 \cdot 00}$ **(1)** $v = 370 \text{ m s}^{-1}$ **(1)**	**2**	Accept: 400, 371, 370·9
		(ii)	$\frac{\Delta W}{W} = \sqrt{\left(\frac{\Delta X}{X}\right)^2 + \left(\frac{\Delta Y}{Y}\right)^2 + \left(\frac{\Delta Z}{Z}\right)^2}$ **(1)** $\frac{\Delta L}{L} = \frac{0 \cdot 02}{2 \cdot 00}$ $\frac{\Delta f}{f} = \frac{10}{510}$ **(1 for both)** $\frac{\Delta v}{370} = \sqrt{\left(\frac{0 \cdot 02}{2 \cdot 00}\right)^2 + \left(\frac{10}{510}\right)^2}$ **(1)** $\Delta v = (\pm) 8 \text{ m s}^{-1}$ **(1)**	**4**	Speed used should be consistent with (b)(i) Use of percentage rather than fractional uncertainty is acceptable.

MARKS DO NOT WRITE IN THIS MARGIN

13. A student uses a double slit to produce an interference pattern with green light from an LED. This is shown in Figure 13A.

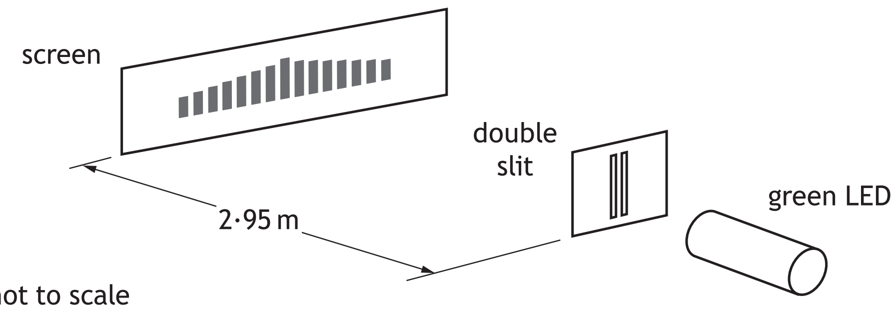

Figure 13A

The LED emits light of wavelength 550 nm.

The student makes the following measurements.

14 fringe separations	43·4 mm
Distance from slits to screen	2·95 m

(a) (i) Determine the distance between the slits. **4**

Space for working and answer

(ii) Explain why the student measured 14 fringe separations rather than measuring the separation of two adjacent fringes. **1**

MARKS DO NOT WRITE IN THIS MARGIN

13. (continued)

(b) The student replaces the green LED with an LED that emits red light.

Apart from colour, state how the fringe pattern now observed by the student differs from the pattern produced by the green LED.

You must justify your answer. **2**

[Turn over

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13. (continued)

(c) A second student uses a different arrangement to produce an interference pattern.

Monochromatic light of wavelength 550 nm is shone onto a soap film at nearly normal incidence. The light is reflected from the soap film and an interference pattern is visible on the film.

This arrangement is shown in Figure 13B.

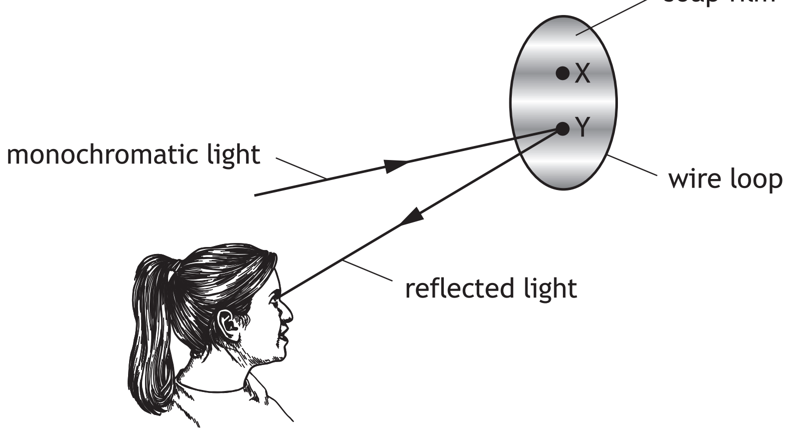

Figure 13B

An expanded side view of the soap film and light rays is shown in Figure 13C.

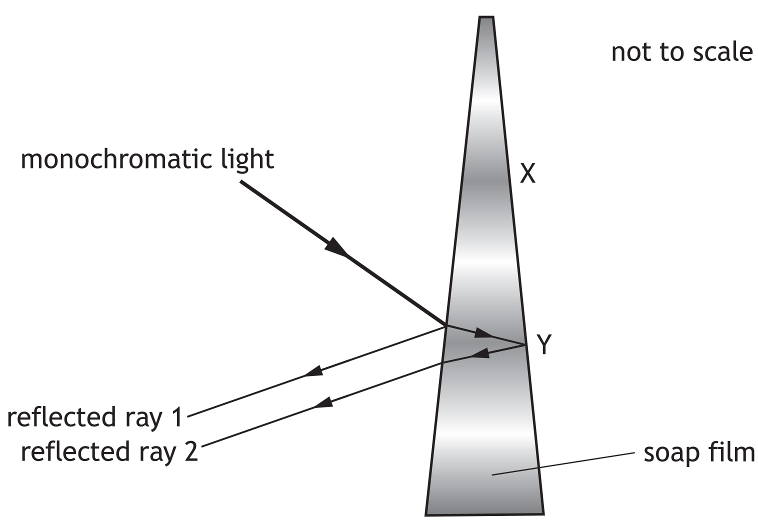

Figure 13C

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13. (c) (continued)

(i) At Y the thickness of the film is $3{\cdot}39 \times 10^{-6}$ m.

The refractive index of the film is 1·46.

Determine the optical path difference between reflected ray 1 and reflected ray 2. **3**

Space for working and answer

(ii) There is an area of destructive interference at Y.

The next area of destructive interference occurs at X, where the film is slightly thinner.

Determine the optical path difference between the reflected rays at X. **1**

Space for working and answer

Question			Expected response	Max mark	Additional guidance
13.	(a)	(i)	$\Delta x = \frac{43 \cdot 4 \times 10^{-3}}{14}$ **(1)** $\Delta x = \frac{\lambda D}{d}$ **(1)** $\frac{43 \cdot 4 \times 10^{-3}}{14} = \frac{550 \times 10^{-9} \times 2 \cdot 95}{d}$ **(1)** $d = 5 \cdot 2 \times 10^{-4}$ m **(1)**	4	The mark for substitution to determine Δx is independent Accept: 5, 5·23, 5·234
		(ii)	Measuring over multiple fringe separations reduces the uncertainty in Δx. **OR** Measuring over multiple fringe separations reduces the uncertainty in d.	1	Reducing absolute scale reading uncertainty in Δx **(0 marks)**
	(b)		The fringe separation will increase **(1)** λ has increased and d and D are unchanged **(1)**	2	MUST JUSTIFY Accept: λ has increased and $\Delta x \propto \lambda$ for second mark.
	(c)	(i)	*optical path difference* = *n×geometrical path difference* **(1)** *optical path difference* = $1 \cdot 46 \times (2 \times 3 \cdot 39 \times 10^{-6})$ **(1)** *optical path difference*= $9 \cdot 90 \times 10^{-6}$ m **(1)**	3	Accept: 9·9, 9·899, 9·8988
		(ii)	*optical path difference* = $9 \cdot 90 \times 10^{-6} - 550 \times 10^{-9}$ *optical path difference* = $9 \cdot 35 \times 10^{-6}$ m **(1)**	1	**OR** consistent with (c)(i)

MARKS DO NOT WRITE IN THIS MARGIN

14. (a) (i) A point charge of $+1{\cdot}3 \times 10^{-14}$ C is placed 48 mm from point P.

Show that the electrical potential at P due to this charge is $2{\cdot}4 \times 10^{-3}$ V. **2**

Space for working and answer.

(ii) A second point charge, of $-1{\cdot}3 \times 10^{-14}$ C, is now placed 52 mm from P.

This is shown in Figure 14A.

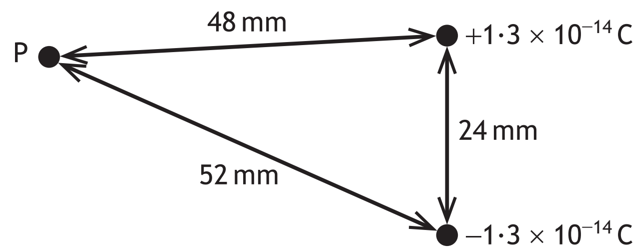

Figure 14A

Determine the electrical potential at P due to both charges. **3**

Space for working and answer.

MARKS DO NOT WRITE IN THIS MARGIN

14. (continued)

(b) Some virtual reality headsets detect changes in electrical potential caused by movement of charge within the human eye.

The human eye can be modelled as two point charges.

In this model there is a positive charge near the front of the eye (iris), and a negative charge near the back of the eye (retina).

This is shown in Figure 14B.

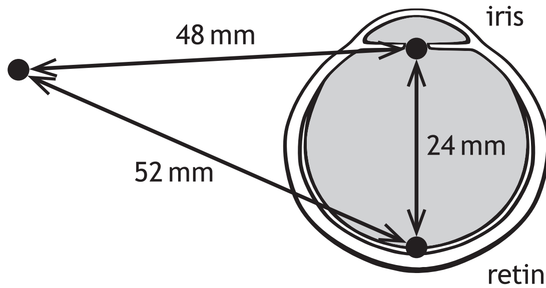

Figure 14B

When the eye looks from side to side, the positive charge moves while the negative charge remains in a fixed position.

An electrode in contact with the head can measure the electrical potential at that point due to these charges.

State what happens to the electrical potential at the electrode as the iris moves towards the electrode.

You must justify your answer. **2**

Question			Expected response	Max mark	Additional guidance
14.	(a)	(i)	$V = \frac{Q}{4\pi\varepsilon_0 r}$ **(1)** $V = \frac{1\cdot3\times10^{-14}}{4\pi\times8\cdot85\times10^{-12}\times48\times10^{-3}}$ **(1)** $V = 2\cdot4\times10^{-3}$ V	**2**	SHOW QUESTION $V = k\frac{Q}{r}$ **(1)** $V = 9\times10^{9}\times\frac{1\cdot3\times10^{-14}}{48\times10^{-3}}$ **(1)** $V = 2\cdot4\times10^{-3}$ V Final answer must be shown or max **(1 mark).**
		(ii)	$\left(V = \frac{Q}{4\pi\varepsilon_0 r}\right)$ $V_{(-)} = \frac{-1\cdot3\times10^{-14}}{4\pi\times8\cdot85\times10^{-12}\times52\times10^{-3}}$ **(1)** $(V_{(P)} = V_{(+)} + V_{(-)})$ $V_{(P)} = 2\cdot4\times10^{-3} + \frac{-1\cdot3\times10^{-14}}{4\pi\times8\cdot85\times10^{-12}\times52\times10^{-3}}$ **(1)** $V_{(P)} = 1\cdot5\times10^{-4}$ V **(1)**	**3**	Method using k as above acceptable. Accept: 2, 1·52, 1·520 (ϵ_0) Accept: 2, 1·50, 1·500 (k)
	(b)		The electrical potential (at the electrode) will increase. **(1)** As the electrical potential due to the positive charge will increase while the electrical potential due to the negative charge remains constant. **OR** As the distance from the positive charge to the electrode will decrease while the distance from the negative charge to the electrode remains constant. **(1)**	**2**	MUST JUSTIFY.

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15. A small, thin, rectangular, metal plate is connected to a d.c. power supply as shown in Figure 15A.

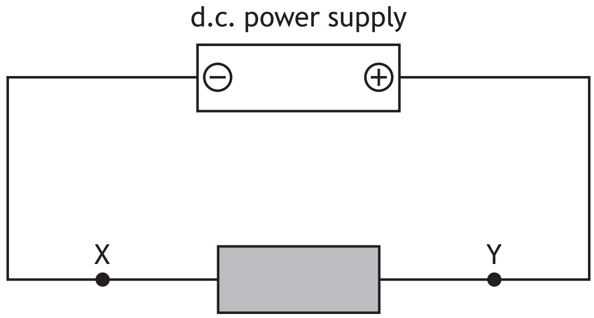

Figure 15A

Electrons move through the plate from left to right.

A uniform magnetic field is now applied at right angles to the plate.

This is shown in Figure 15B.

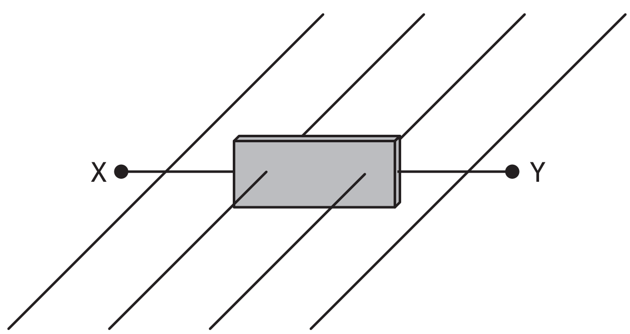

Figure 15B

As the electrons enter the metal plate they experience a force due to the magnetic field. This causes the electrons to initially follow a curved path downwards and gather at the bottom of the metal plate.

(a) Determine whether the direction of the magnetic field is into the page or out of the page. **1**

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15. (continued)

(b) After a short time, the bottom of the plate becomes negatively charged relative to the top of the plate, as shown in Figure 15C.

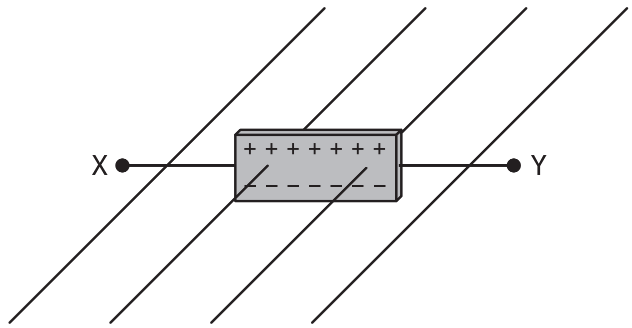

Figure 15C

This causes a uniform electric field between the top and bottom of the metal plate.

Electrons moving at a fixed speed v_d, called the *drift velocity*, will now travel horizontally across the plate. These electrons do not move vertically as the electric and magnetic forces acting on them are balanced.

(i) Show that the drift velocity is given by the relationship

$$v_d = \frac{V}{Bd}$$

where

V is the potential difference between the top and bottom of the metal plate

B is the magnetic induction

d is the height of the metal plate. **3**

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15. (b) (continued)

(ii) The metal plate has a height of $3{\cdot}25 \times 10^{-2}$ m.

The magnetic induction is $1{\cdot}25$ T.

The potential difference between the top of the plate and the bottom of the plate is $3{\cdot}47 \times 10^{-6}$ V.

Calculate the drift velocity of the electrons moving across the plate. **2**

Space for working and answer

(iii) The magnetic induction is now increased. The drift velocity of the electrons moving through the metal plate remains the same.

Explain why the drift velocity does not change. **2**

Question			Expected response	Max mark	Additional guidance
15.	(a)		Into the page.	**1**	
	(b)	(i)	$\left(F_{(E)} = QE, F_{(B)} = qvB\right)$ $EQ = qvB$ **(1) , (1)** $E = v\ B$ $V = Ed$ **(1)** $v = \frac{V}{Bd}$	**3**	SHOW QUESTION **(1 mark)** for both relationships, **(1 mark)** for equality of forces or fields Final line must appear or max **(2 marks)**
		(ii)	$v_d = \frac{V}{Bd}$ $v_d = \frac{3{\cdot}47\times10^{-6}}{1{\cdot}25\times3{\cdot}25\times10^{-2}}$ **(1)** $v_d = 8{\cdot}54\times10^{-5}\ \mathrm{ms^{-1}}$ **(1)**	**2**	Accept: 8·5, 8·542, 8·5415
		(iii)	Because more charges have been separated (vertically) across the plate. **OR** More electrons gather on the bottom of the plate. **(1)** (The increased magnetic force) increases the electric force/potential difference/electric field strength (across the plate). **(1)**	**2**	Marks are independent.

MARKS DO NOT WRITE IN THIS MARGIN

16. A technician finds an unlabelled capacitor and carries out an experiment to determine its capacitance.

The technician builds a circuit using a battery, a 2·2 kΩ resistor, a voltmeter and the unlabelled capacitor. The technician constructs the circuit so that the potential difference across the capacitor is measured as it charges.

(a) (i) Draw a diagram of a circuit that would enable the technician to carry out this experiment. **1**

(ii) The data obtained from the experiment are used to draw the graph of potential difference V against time t shown in Figure 16A.

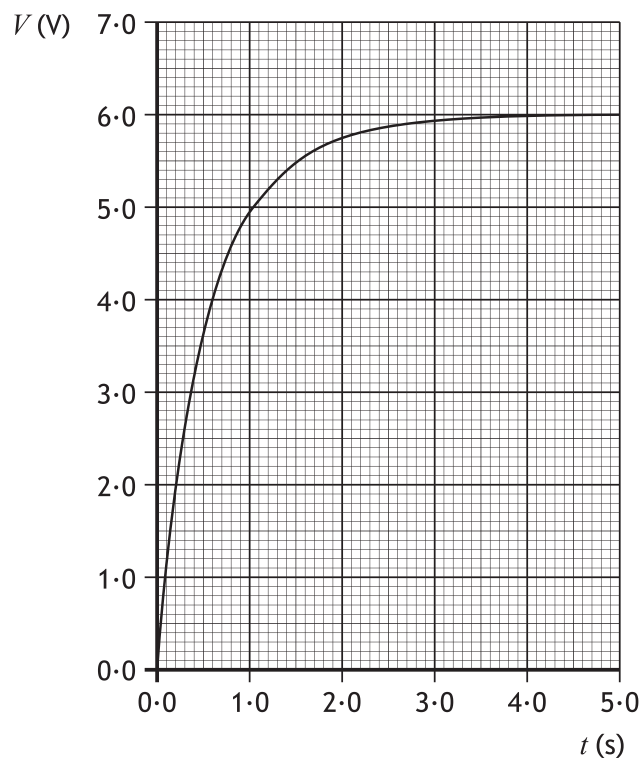


Figure 16A

Use the graph to determine the time constant of this circuit. **2**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

16. (a) (continued)

(iii) Calculate the capacitance of the unlabelled capacitor. **3**

Space for working and answer.

(b) The technician also finds an unlabelled inductor and wishes to determine its inductance.

(i) The technician connects the inductor to a data logger, a switch and a 9·0 V d.c. supply. When the circuit is switched on, the initial rate of change of current is determined to be 95·8 A s^{-1}.

Calculate the inductance of the inductor. **3**

Space for working and answer.

(ii) The technician connects the inductor and a d.c. ammeter to a 9·0 V d.c. power supply. The technician records the maximum ammeter reading.

The technician then connects the inductor and an a.c. ammeter to a 9·0 V r.m.s. a.c. power supply. The technician again records the maximum ammeter reading.

The technician notices that the values of current recorded are different.

State which ammeter displays the greater current reading.

You must justify your answer. **2**

[END OF QUESTION PAPER]

Question			Expected response	Max mark	Additional guidance
16.	(a)	(i)	A series circuit containing a battery or cell, a resistor and capacitor in series. Voltmeter connection should be in parallel with the capacitor.	**1**	
		(ii)	63% of $6{\cdot}0(V)(= 3{\cdot}8V)$ **(1)** $($From graph, $t = 0{\cdot}55\,\text{s}$ when $V = 3{\cdot}8\,\text{V})$ $t = 0{\cdot}55\,\text{s}$ **(1)**	**2**	(Considered) fully charged after 3 - 4 s **(1)** t= 0·6 → 0·8 **(1)**
		(iii)	$t = RC$ **(1)** $0{\cdot}55 = 2{\cdot}2\times10^3\times C$ **(1)** $C = 2{\cdot}5\times10^{-4}$ F **(1)**	**3**	Or consistent with (a)(ii) Accept: 3, 2·50, 2·500
	(b)	(i)	$\mathcal{E} = -L\dfrac{dI}{dt}$ **(1)** $-9{\cdot}0 = -L\times95{\cdot}8$ **(1)** $L = 9{\cdot}4\times10^{-2}$ H **(1)**	**3**	Accept: 9, 9·39, 9·395
		(ii)	The d.c. ammeter will display the greater current. **(1)** Since the a.c. current will generate reactance or impedance in the inductor **(1)**	**2**	MUST JUSTIFY

[END OF MARKING INSTRUCTIONS]

FOR OFFICIAL USE

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.

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

Marking instructions for each question

Question			Expected response	Max mark	Additional guidance
1.	(a)		$a\left(=\frac{dv}{dt}\right)=8t-2t^2$ **(1)** $a=8\times4\cdot0-2\times4\cdot0^2$ **(1)** $a=0\cdot0\ \text{m s}^{-2}$ **(1)**	**3**	Accept: 0 ms^{-2} Unit of acceleration required or max 2.
	(b)		$s\left(=\int v.dt\right)=8t+\frac{4}{3}t^3-\frac{2}{3\times4}t^4\ (+c)$ **(1)** $s=8\times4\cdot0+\frac{4}{3}\times4\cdot0^3-\frac{2}{3\times4}\times4\cdot0^4$ **(1)** $s=75$ m **(1)**	**3**	Ignore poor form with integration constant/limits. Solution with limits also acceptable. $\left(s=\left(\int_0^{4\cdot0}v.dt\right)=\int_0^{4\cdot0}(8+4t^2-\frac{2}{3}t^3).dt\right)$ $s=\left[8t-\frac{4}{3}t^3-\frac{2}{3\times4}t^4\right]_0^{4\cdot0}$ (1) $s=(8\times4\cdot0+\frac{4}{3}\times4\cdot0^3-\frac{2}{3\times4}\times4\cdot0^4)-0$ (1) $s=75$ m (1) Accept: 70, 74·7, 74·67

(1)

MARKS DO NOT WRITE IN THIS MARGIN

2. A cyclist is using an exercise bicycle.

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

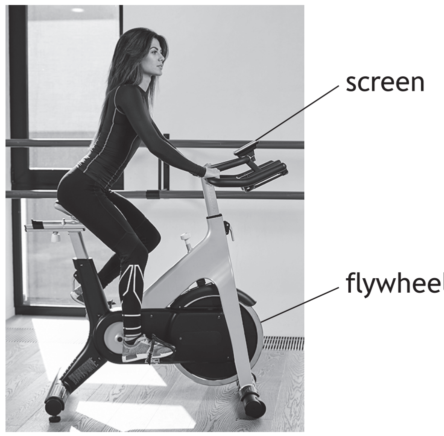


Figure 2A

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 $6{\cdot}7\ m\,s^{-1}$ 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.

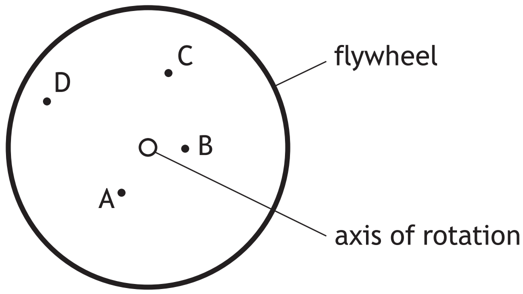


Figure 2B

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**

Question			Expected response	Max mark	Additional guidance
2.	(a)	(i)	$v = r\omega$ $6{\cdot}7 = 0{\cdot}35 \times \omega$ **(1)** $\omega = 19\ \text{rad}\,\text{s}^{-1}$ **(1)**	3	Accept: 20, 19·1, 19·14.
		(ii)	$\theta = \omega_o t + \frac{1}{2}\alpha t^2$ **(1)** $\theta = 19 \times 5{\cdot}5 + \frac{1}{2} \times -2{\cdot}4 \times 5{\cdot}5^2$ **(1)** $no.\ revolutions = \frac{19 \times 5{\cdot}5 + \frac{1}{2} \times -2{\cdot}4 \times 5{\cdot}5^2}{2\pi}$ **(1)** $no.\ revolutions = 11$ **(1)**	4	Or consistent with (a)(i) Independent 1 mark for dividing a value of θ by 2π For alternative methods: 1 mark for **all** relationships 1 mark for **all** substitutions 1 mark for dividing by 2π 1 mark for final answer Use of ω = 0 is incorrect substitution. Accept: 10, 10·9, 10·85
		(iii)	Greater (number of revolutions) **(1)** <u>Smaller angular acceleration</u> (during this 5·5 seconds means the wheel has a greater angular displacement). **(1)**	2	**JUSTIFY** For justification, do not accept reduced friction/frictional torque only. <u>Angular acceleration</u> must be specified for the second mark.
	(b)		D. **(1)** Applying the force at a <u>greater distance from the</u> <u>axis of rotation</u> (will generate a greater torque on the flywheel as $\tau = Fr$) **(1)**	2	**JUSTIFY** For justification, do not accept greater distance from the centre/middle of the flywheel

MARKS DO NOT WRITE IN THIS MARGIN

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

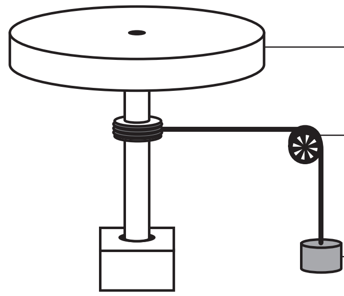


Figure 3A

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**

MARKS DO NOT WRITE IN THIS MARGIN

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

Question			Expected response	Max mark	Additional guidance
3.	(a)		$\tau = I\alpha$ **(1)** $6 \cdot 30 \times 10^{-3} = I \times 0 \cdot 618$ **(1)** $I = 1 \cdot 02 \times 10^{-2}$ kg m^2	**2**	**SHOW** Final answer must be shown or max 1.
	(b)	(i)	The total angular momentum before (an interaction) is equal to the total angular momentum after (an interaction) in the absence of external torque.	**1**	Conservation relationship on its own is insufficient. 'Angular momentum is conserved' award 0.
		(ii)	$I_1\omega_1 = I_2\omega_2$ **(1)** $1 \cdot 02 \times 10^{-2} \times 7 \cdot 75 = (1 \cdot 02 \times 10^{-2} + I_{cube}) \times 5 \cdot 74$ **(1)** $I_{cube} = 3 \cdot 57 \times 10^{-3}$ kgm^2 **(1)**	**3**	Accept alternative subscripts in the conservation relationship. Accept: 3·6, 3·572. 3·5718
		(iii)	(The angular velocity will be) less (than 5·74) **(1)** since the moment of inertia (of the system) will be greater. **(1)**	**2**	**MUST JUSTIFY** Justification must make reference to moment of inertia. Increased mass alone is insufficient for justification mark.

MARKS DO NOT WRITE IN THIS MARGIN

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**.

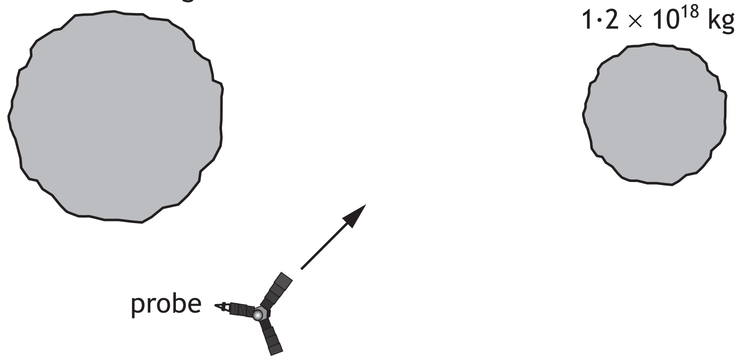


Figure 4A

(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**.

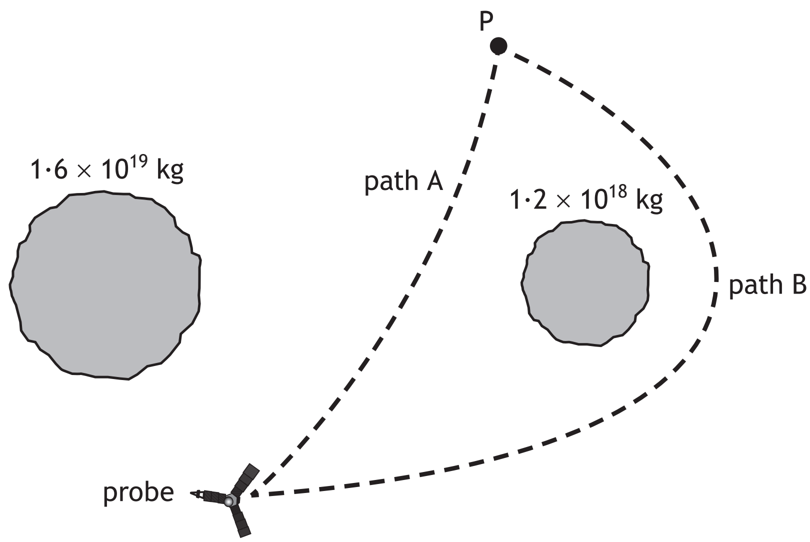


Figure 4C

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.

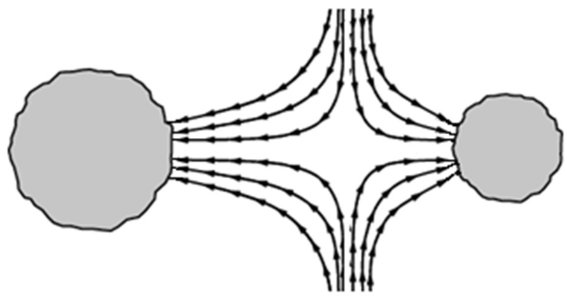
State whether the clock on board the probe runs faster or slower than clocks on Earth.

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

Question			Expected response	Max mark	Additional guidance
4.	(a)	(i)	The gravitational force acting on a unit mass.	1	'force due to gravity' acceptable alternative to 'gravitational force' 'acting on a mass of 1 kg' acceptable alternative to 'acting on a unit mass'
		(ii)	1 mark for shape of field and direction of lines. 1 mark for skew (null point closer to smaller asteroid). 	2	Independent marks Field lines should be (approximately) normal to the surface of the asteroids. Field lines should not cross. Field lines should not meet at the same point on the surface of the asteroids.
		(iii)	Equal to **(1)** Since the energy required to move mass between two points in a gravitational field is independent of the path taken. **(1)**	2	**JUSTIFY** Accept justification in terms of 'conservative field'.
	(b)		(The clock on the probe runs) faster. **(1)** As it is in a weaker gravitational field. **(1)**	2	**MUST JUSTIFY** Correct converse statement acceptable. Statement and justification must be in terms of GR, since GR dominates SR effects in this situation.
	(c)		$v=\sqrt{\frac{2GM}{r}}$ **(1)** $r=49\cdot8\times1\cdot5\times10^{11}$ **(1)** $v=\sqrt{\frac{2\times6\cdot67\times10^{-11}\times2\cdot0\times10^{30}}{49\cdot8\times1\cdot5\times10^{11}}}$ **(1)** $v=6\cdot0\times10^{3}\ \text{ms}^{-1}$ **(1)**	4	Independent mark for unit conversion. Accept: 6, 5·98, 5·976

MARKS DO NOT WRITE IN THIS MARGIN

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

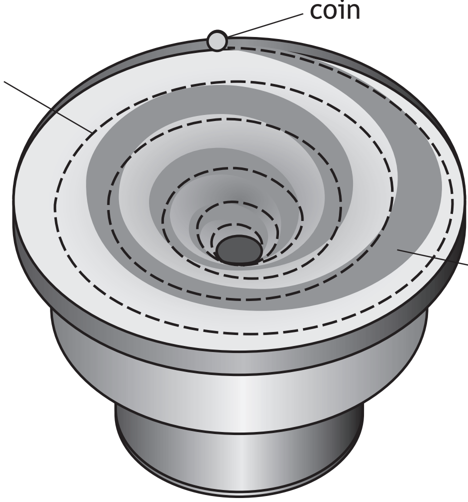


Figure 5A

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**.

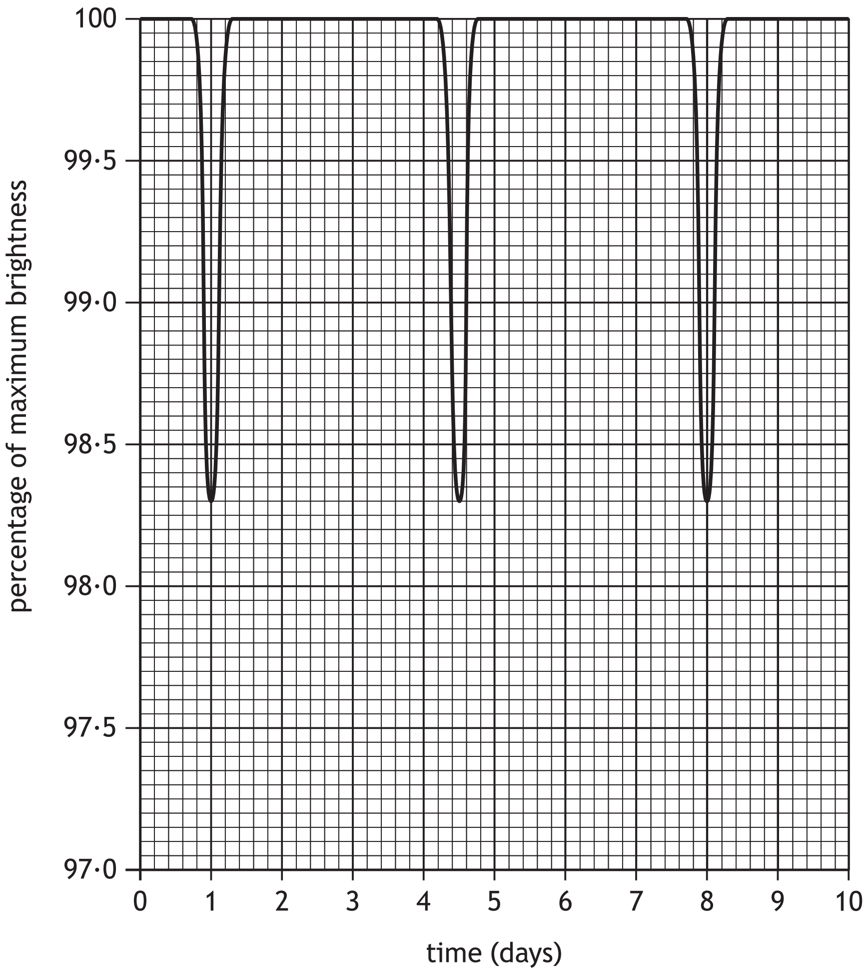


Figure 6A

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.

MARKS DO NOT WRITE IN THIS MARGIN

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

Question			Expected response	Max mark	Additional guidance
6.	(a)		The proton-proton chain.	**1**	Accept 'p-p chain'
	(b)	(i)	$L = 4\pi r^2 \sigma T^4$ **(1)** $L = 4\pi \times (8\cdot35\times10^8)^2 \times 5\cdot67\times10^{-8} \times (6070)^4$ **(1)** $L = 6\cdot74\times10^{26}$ W **(1)**	**3**	Accept: 6·7, 6·744, 6·7440
		(ii)	$d = 159\times365\cdot25\times24\times60\times60\times3\cdot00\times10^8$ **(1)** $b = \frac{L}{4\pi d^2}$ **(1)** $b = \frac{6\cdot74\times10^{26}}{4\pi\times(159\times365\cdot25\times24\times60\times60\times3\cdot00\times10^8)^2}$ **(1)** $b = 2\cdot37\times10^{-11}$ Wm^{-2} **(1)**	**4**	Or consistent with (b)(i) Independent mark for unit conversion. Accept use of 365 days. Accept: 2·4, 2·370, 2·3703 (using 365) 2·4, 2·367, 2·3670 (using 365·25)
	(c)	(i)	$T = 3\cdot5$ (days) **(1)** $\omega = \frac{2\pi}{T}$ **(1)** $\omega = \frac{2\pi}{3\cdot5\times24\times60\times60}$ **(1)** $\omega = 2\cdot1\times10^{-5}$ (rad s^{-1}) **(1)**	**4**	Mark for period from graph independent. Accept T in the range 3·4 - 3·6 days Accept: 2, 2·08, 2·078
		(ii)	$\frac{GMm}{r^2} = mr\omega^2$ **(1)** $\frac{6\cdot67\times10^{-11}\times2\cdot5\times10^{30}\times m}{r^2} = m\times r\times(2\cdot1\times10^{-5})^2$ **(1)** $r = 7\cdot2\times10^9$ m **(1)**	**3**	Or consistent with (c)(i) Not a SHOW question, therefore accept if mass cancelled correctly. Accept $\frac{2\pi}{T}$ as an alternative to ω. Accept: 7, 7·23, 7·231.

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**.

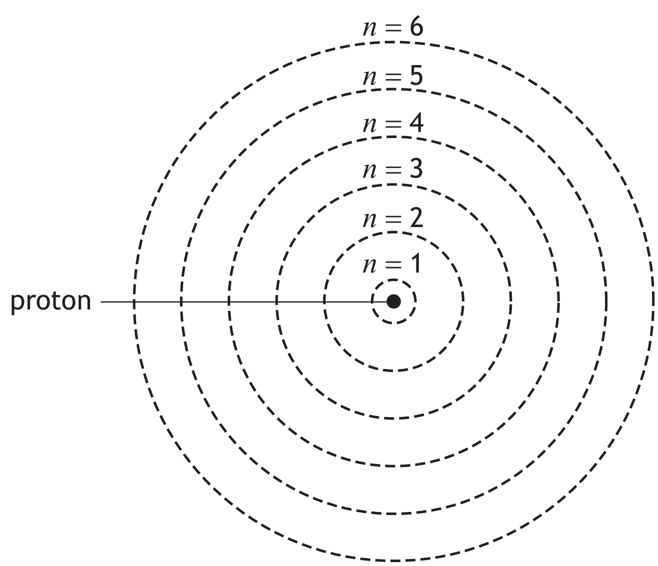


Figure 7A

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)

MARKS DO NOT WRITE IN THIS MARGIN

(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**.

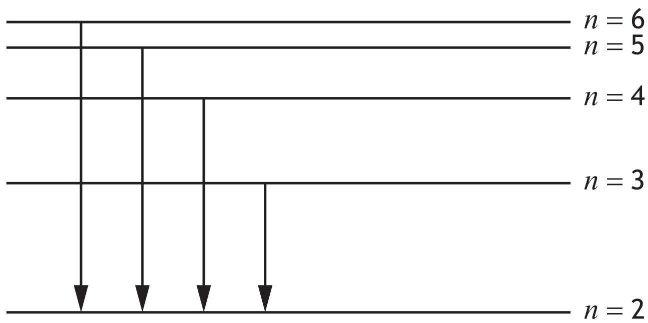


Figure 7C

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

Question			Expected response	Max mark	Additional guidance
7.	(a)		Compton scattering or Photoelectric effect	**1**	
	(b)	(i)	$mvr = \frac{nh}{2\pi}$ **(1)** $9 \cdot 11 \times 10^{-31} \times v \times 2 \cdot 12 \times 10^{-10} = \frac{2 \times 6 \cdot 63 \times 10^{-34}}{2\pi}$ **(1)** $v = 1 \cdot 09 \times 10^{6}\ \text{ms}^{-1}$	**2**	**SHOW** Final answer must be shown or max 1.
		(ii)	$\lambda = \frac{h}{p}$ **(1)** $\lambda = \frac{6 \cdot 63 \times 10^{-34}}{9 \cdot 11 \times 10^{-31} \times 1 \cdot 09 \times 10^{6}}$ **(1)** $\lambda = 6 \cdot 68 \times 10^{-10}\ \text{m}$ **(1)** Wavelength (comparable to atomic radius so) suitable for demonstrating <u>interference</u> or Wavelength (comparable to atomic radius so) suitable for demonstrating <u>diffraction</u> **(1)**	**4**	Accept: 6·7, 6·677, 6·6768 Alternative acceptable approach for calculation $\lambda = \frac{2\pi r}{n}$ **(1)** $\lambda = \frac{2\pi \times 2 \cdot 12 \times 10^{-10}}{2}$ **(1)** $\lambda = 6 \cdot 66 \times 10^{-10}\ \text{m}$ **(1)** Accept: 6·7, 6·660, 6·6602
	(c)		$\frac{1}{\lambda} = RZ^2\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$ $\frac{1}{410 \times 10^{-9}} = R \times 1^2\left(\frac{1}{2^2} - \frac{1}{6^2}\right)$ **(1)** $R = 1 \cdot 1 \times 10^{7}\ \text{m}^{-1}$ **(1)**	**2**	Accept:1, 1·10, 1·098

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

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**.

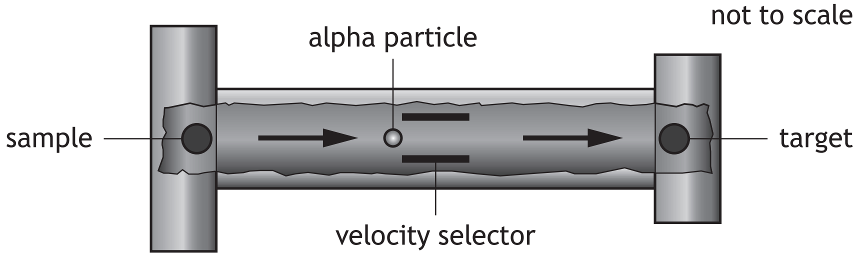


Figure 8A

(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**.

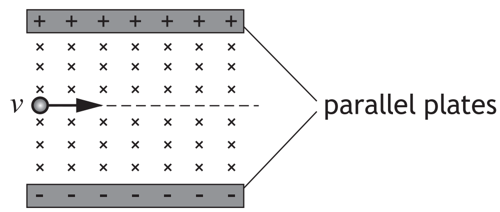


Figure 8B

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

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

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 **2**

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

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**.

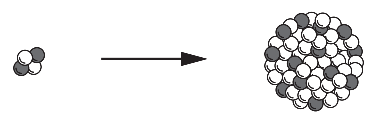


Figure 8C

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

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

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

MARKS DO NOT WRITE IN THIS MARGIN

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**

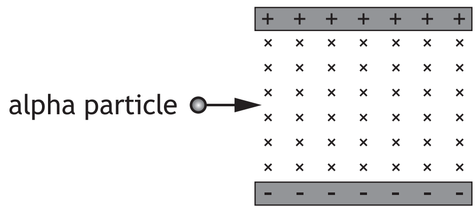
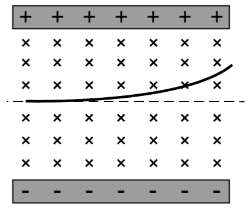


Figure 8D

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

[Turn over

Question			Expected response	Max mark	Additional guidance
8.	(a)		A quantum particle can exist in a position that, according to classical physics, it has insufficient energy to occupy	1	Accept responses in terms of a quantum particle/waveform able to pass through a potential barrier.
	(b)		$\Delta x \Delta p_x \geq \frac{h}{4\pi}$ or $\Delta x \Delta p_{x_{\min}} = \frac{h}{4\pi}$ (1) $54\times10^{-15}\times\Delta p_x \geq \frac{6\cdot63\times10^{-34}}{4\pi}$ (1) $\Delta p_{x_{\min}} = (\pm)9\cdot8\times10^{-22}$ kgms^{-1} (1)	3	Do not accept $\Delta x \Delta p_{x_{\min}} \geq \frac{h}{4\pi}$ Accept: 10, 9·77, 9·770 Do not accept $\Delta p_{x_{\min}} \geq 9\cdot8\times10^{-22}$ kgms^{-1} or $\Delta p_x \geq 9\cdot8\times10^{-22}$ kgms^{-1} or $\Delta p_x = 9\cdot8\times10^{-22}$ kgms^{-1} for the third mark.
	(c)	(i) (A)	$E_k = \frac{1}{2}mv^2$ (1) $8\cdot8\times10^6\times1\cdot60\times10^{-19}$ $= 0\cdot5\times6\cdot645\times10^{-27}\times v^2$ (1,1) $v = 2\cdot1\times10^7$ m s^{-1} (1)	4	Independent mark for energy conversion from MeV to J. Accept: 2, 2·06, 2·059
		(B)	$(F = QE$ and $F = qvB)$ $QE = qvB$ (1),(1) $v = \frac{E}{B}$	2	**SHOW** 1 for both relationships 1 for equating Accept: qE Final relationship must be shown or max 1.
		(C)	$E = \frac{V}{d}$ (1) $v = \frac{E}{B}$ $2\cdot1\times10^7 = \frac{\left(\frac{27\times10^3}{15\times10^{-3}}\right)}{B}$ (1) $B = 8\cdot6\times10^{-2}$ T (1)	3	Or consistent with (c)(i)(A) Accept 9, 8·57, 8·571
	(c)	(ii)	$r = \frac{qQ}{2\pi\varepsilon_0 mv^2}$ $r = \frac{(3\cdot20\times10^{-19})\times(4\cdot64\times10^{-18})}{2\pi\times8\cdot85\times10^{-12}\times6\cdot645\times10^{-27}\times(2\cdot1\times10^7)^2}$ (1) $r = 9\cdot1\times10^{-15}$ m (1)	2	Or consistent with (c)(i)(A) Accept $(2\times1\cdot60\times10^{-19})$ and $(29\times1\cdot60\times10^{-19})$ as substitutions for q and Q Accept 9, 9·11, 9·112

Question			Expected response	Max mark	Additional guidance
8.	(d)		Path drawn as an upward curve in B-field **(1)** 	**1**	Ignore any path drawn to the right of the parallel plates.

MARKS DO NOT WRITE IN THIS MARGIN

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**.

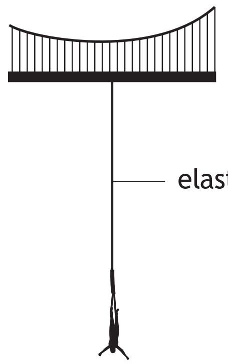


Figure 9A

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 $1{\cdot}5 \times 10^2\ \mathrm{N\,m^{-1}}$. The bungee jumper has a mass of 77 kg.

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

Space for working and answer

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

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

MARKS DO NOT WRITE IN THIS MARGIN

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**

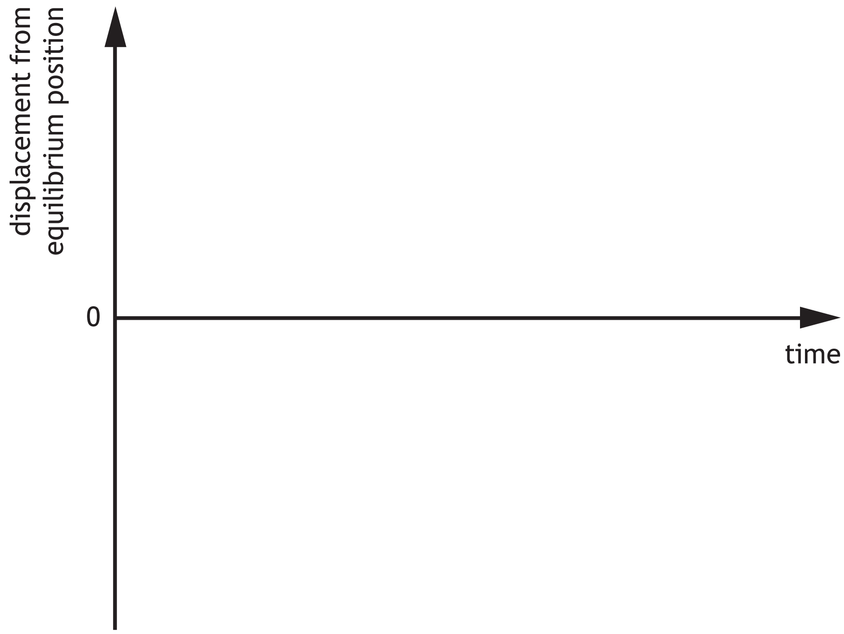


Figure 9B

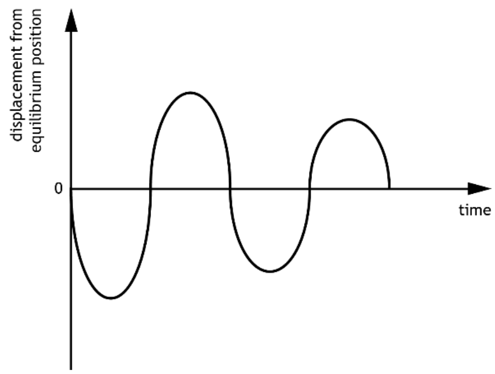
(An additional graph, if required, can be found on *page 52*.)

(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**

Question			Expected response	Max mark	Additional guidance
9.	(a)		Unbalanced force/acceleration is proportional to, and in the opposite direction to, the displacement (from the rest position)	**1**	Accept $F=-ky$ or equivalent Do not accept 'force is proportional to displacement' without reference to direction.
	(b)		$(y = A\sin\omega t)$ $(v=)\frac{dy}{dt} = \omega A\cos\omega t$ **(1) for both differentiations** $(a=)\frac{d^2y}{dt^2} = -\omega^2 A\sin\omega t$ **(1)** $F = ma$ **(1)** $F = -m\omega^2 A\sin\omega t$ $F = -m\omega^2 y$	**3**	**SHOW** Final relationship must be shown or max 2.
	(c)	(i)	$(F = -m\omega^2 y)$ $F = -ky$ **(1)** $(-)k(y) = (-)m\omega^2(y)$ **(1)** $1{\cdot}5\times10^2 = 77\times\omega^2$ **(1)** $\omega = 1{\cdot}4$ rads^{-1}	**3**	**SHOW** Final answer must be shown or max 2.
		(ii)	$v = \pm\omega\sqrt{(A^2 - y^2)}$ **(1)** $18 = 1{\cdot}4A$ **(1)** $A = 13$ m **(1)**	**3**	Accept $v_{max} = \omega A$ as first line. Accept: 10, 12·9, 12·86
		(iii)	$E_p = \frac{1}{2}m\omega^2 y^2$ **(1)** $E_p = 0{\cdot}5\times77\times1{\cdot}4^2\times13^2$ **(1)** $E_p = 1{\cdot}3\times10^4$ J **(1)**	**3**	Or consistent with (c)(ii) Accept: 1, 1·28, 1·275

Question			Expected response	Max mark	Additional guidance
9.	(d)		sine function **(1)** reducing amplitude **(1)**  	**2**	Displacement must be zero at t=0. Displacement for first half cycle may be positive. Minimum of two cycles must be shown otherwise 0 marks.
	(e)		ω is same **(1)** $ky = m\omega^2 y$ k is the same and m is same (y has no effect). **(1)**	**2**	**JUSTIFY** Accept 'ω depends on mass and spring constant only, and these haven't changed'.

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**.

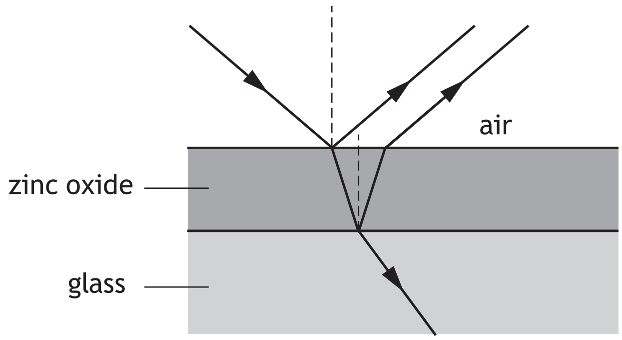


Figure 10A

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**.

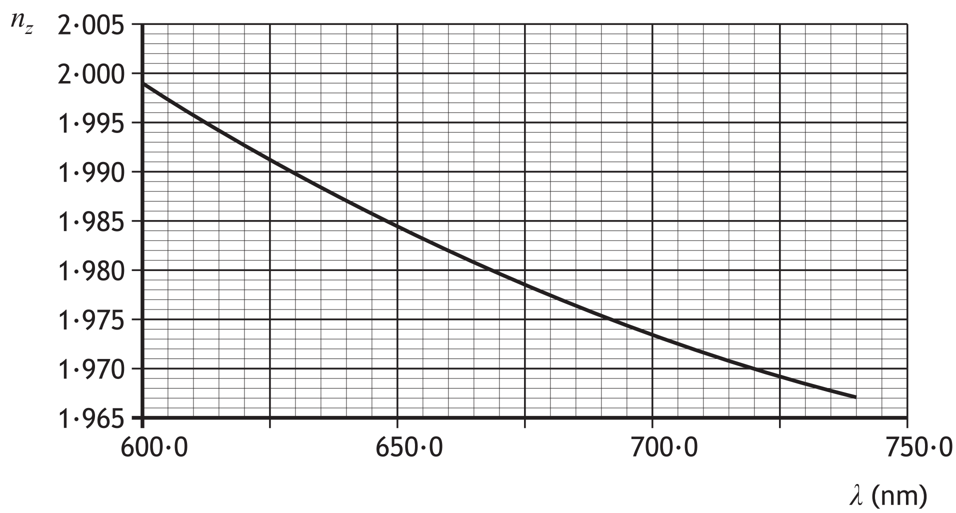


Figure 10B

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 **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

Question			Expected response	Max mark	Additional guidance
10.	(a)		(Particular thickness will produce) destructive interference of reflected rays (for the specific wavelength of light).	**1**	Accept '(Particular thickness will) maximise the energy transmitted into the glass (for the specific wavelength of light)'.
	(b)	(i)	(Phase change of) π (radians).	**1**	Accept (Phase change of) 180°.
		(ii)	No phase change.	**1**	Accept 0 (radians)/ 0$^{(°)}$
	(c)	(i)	$d = \dfrac{\lambda}{2n_z}$ $d = \dfrac{660\cdot0\times10^{-9}}{2\times1\cdot982}$ **(1)** $d = 1\cdot665\times10^{-7}$ m **(1)**	**2**	Allow a range for n_z of 1·9815 to 1·9825 Accept: 1·66, 1·6650, 1·66498
		(ii)	The coating is anti-reflecting for red light/red light is transmitted. **(1)** (Some of the) blue and green light/the remainder of the light is reflected, (hence the blue-green appearance). **(1)**	**2**	
	(d)	(i)	$v = f\lambda$ **(1)** $v = 4\cdot55\times10^{14}\times4\cdot37\times10^{-7}$ **(1)** $v = 1\cdot99\times10^{8}$ ms^{-1} **(1)**	**3**	Accept: 2·0, 1·988, 1·9884
		(ii)	$E = kA^2$ **(1)** $A_2^{\ 2} = \dfrac{90\times\left(1\cdot60\times10^{3}\right)^2}{100}$ **(1)** $A_2 = 1520$ V m^{-1} **(1)**	**3**	Accept: 1500, 1518, 1517·9

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

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

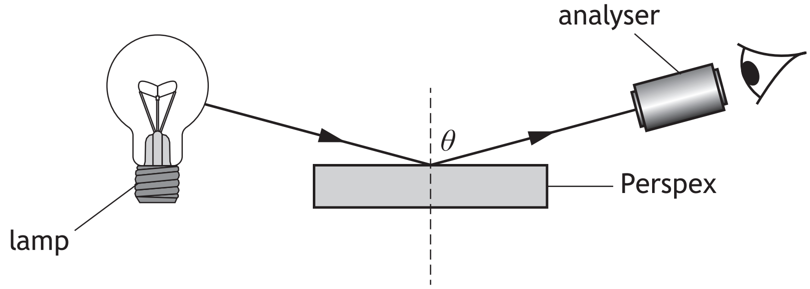


Figure 11A

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**

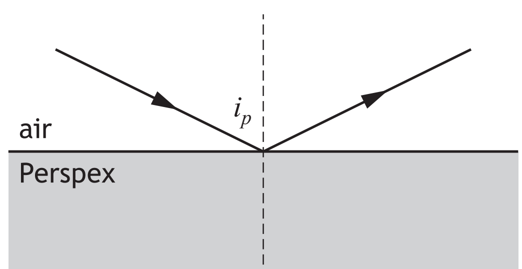


Figure 11B

(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**.

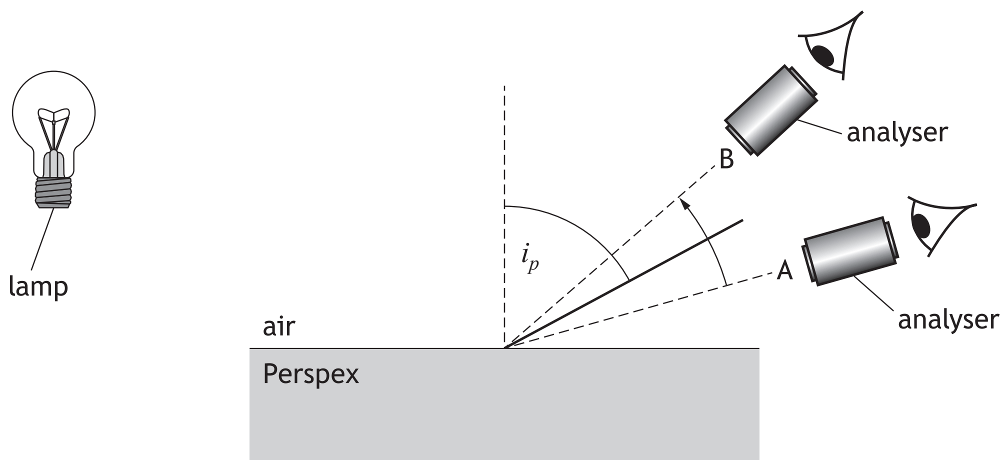
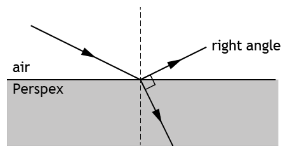


Figure 11C

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

Question			Expected response	Max mark	Additional guidance
11.	(a)		(The electric vector of) light oscillates in a single plane.	**1**	Accept 'vibrates in a single plane' Do not accept: Travels in a single plane/direction Oscillates in one direction
	(b)	(i)	The refracted ray should be at 90° to the reflected ray. 	**1**	No arrow required on the refracted ray but if one is included it must be in the correct direction. Accept a diagram where there is an indication that the angle between the refracted ray and the reflected ray is 90°.
		(ii)	$n = \tan i_p$ **(1)** $1 \cdot 49 = \tan i_p$ **(1)** $i_p = 56 \cdot 1°$ **(1)**	**3**	Accept: 56, 56·13, 56·133
	(c)		The reflected light becomes dimmer (as the analyser approaches Brewster's angle, at which point it is not seen) **(1)** and then becomes brighter (again as it moves away from Brewster's angle) **(1)**	**2**	The response must not indicate a sudden change, otherwise 0 marks.

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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**

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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**.

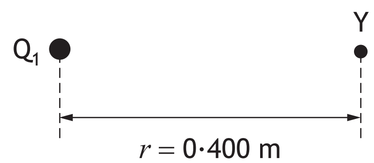

Figure 13A

(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**.

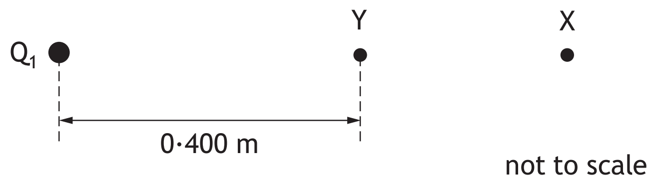

Figure 13B

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

Question			Expected response	Max mark	Additional guidance
13	(a)		$E=\frac{Q}{4\pi\varepsilon_0 r^2}$ **(1)** $(+)144=\frac{Q}{4\pi\times8\cdot85\times10^{-12}\times0\cdot400^2}$ **(1)** $Q=(+)2\cdot56\times10^{-9}\,\text{C}$ **(1)**	3	Accept use of 'k' value (9×10^9 or $8\cdot99\times10^9$) Accept: 2·6, 2·562, 2·5623($1/4\pi\varepsilon_0$) 2·6, 2·560, 2·5600 (9×10^9) 2·6, 2·563, 2·5628($8\cdot99\times10^9$)
	(b)		$V=\frac{Q}{4\pi\varepsilon_0 r}$ **(1)** $V=\frac{2\cdot56\times10^{-9}}{4\pi\times8\cdot85\times10^{-12}\times0\cdot400}$ **(1)** $V=57\cdot5\text{ V}$ **(1)**	3	Or consistent with (a) Accept $V=Er$ $V=144\times0\cdot400$ $V=57\cdot6\text{ V}$ Accept: 58, 57·55, 57·540($1/4\pi\varepsilon_0$) 58, 57·6, 57·560, 57·5600 (9×10^9) 58, 57·54, 57·536($8\cdot99\times10^9$)
	(c)		$V=(57\cdot5-19\cdot2)$ **(1)** $W=QV$ **(1)** $W=2\cdot00\times10^{-12}\times(57\cdot5-19\cdot2)$ **(1)** $W=7\cdot66\times10^{-11}\text{J}$ **(1)**	4	Or consistent with (b) Alternative method: $W=QV$ $W_Y=2\cdot00\times10^{-12}\times57\cdot5$ $W_X=2\cdot00\times10^{-12}\times19\cdot2$ $W=(2\cdot00\times10^{-12}\times57\cdot5)-(2\cdot00\times10^{-12}\times19\cdot2)$ $W=7\cdot66\times10^{-11}\text{J}$ 1 mark for relationship 1 mark for **both** substitutions 1 mark for subtraction 1 mark for final answer Accept: 7·7, 7·660, 7·6600

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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**.

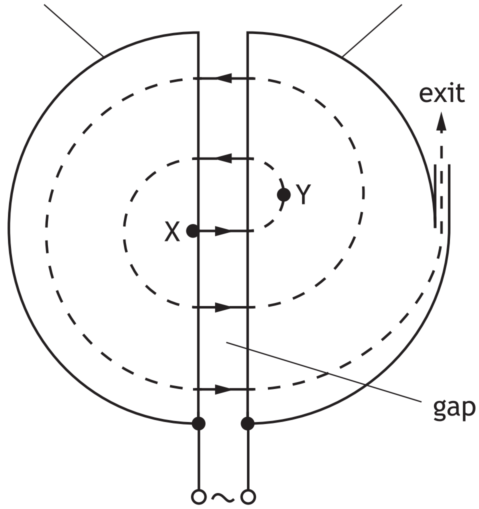

Figure 14A

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**

Question			Expected response	Max mark	Additional guidance
14.	(a)		Into the page.	**1**	Do not accept 'down'.
	(b)	(i)	$(F = qvB)$ $\left(F = \frac{mv^2}{r}\right)$ $\frac{mv^2}{r} = qvB$ **(1),(1)** $v = \frac{qBr}{m}$	**2**	**SHOW** 1 for both relationships 1 for equating Alternative method $(F = qvB)$ $(F = mr\omega^2)$ $(v = r\omega)$ $mr\left(\frac{v}{r}\right)^2 = qvB$ $v = \frac{qBr}{m}$ 1 mark for **all** relationships 1 mark for substitution for ω and equating Final relationship must be shown or max 1.
		(ii)	$v = \frac{qBr}{m}$ $v = \frac{1 \cdot 60 \times 10^{-19} \times 0 \cdot 714 \times 0 \cdot 105}{1 \cdot 673 \times 10^{-27}}$ **(1)** $v = 7 \cdot 17 \times 10^6 \text{ ms}^{-1}$ **(1)**	**2**	Accept: 7·2, 7·170, 7·1700
	(c)		The direction of (electrical) force acting on the proton must change (every time the proton crosses the gap).	**1**	Accept The proton travels in opposite directions (every time the proton crosses the gap).

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

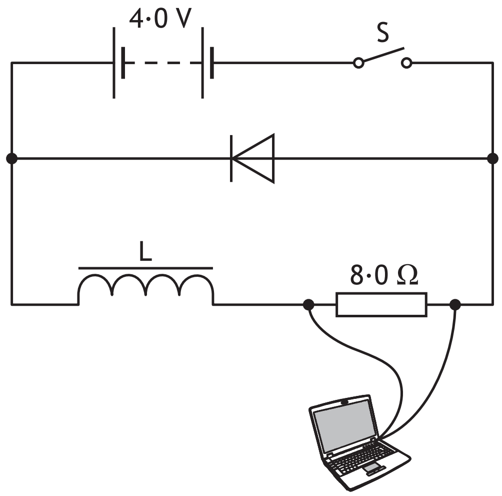


Figure 15A

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.

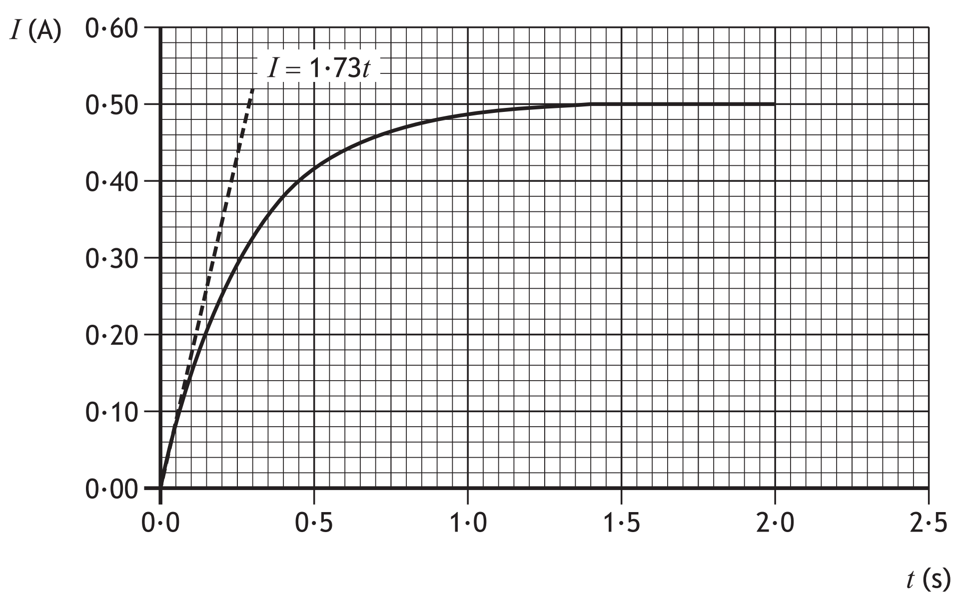


Figure 15B

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**

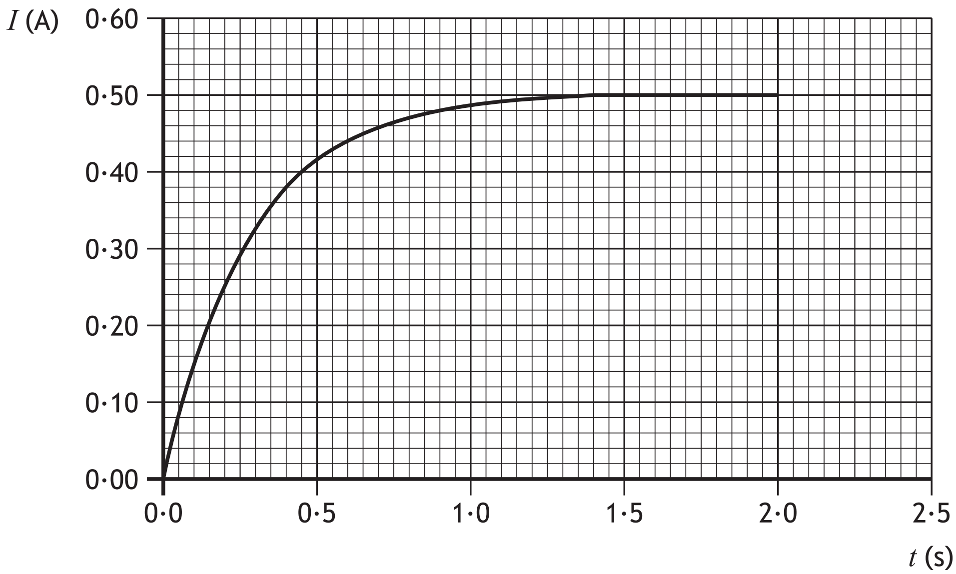
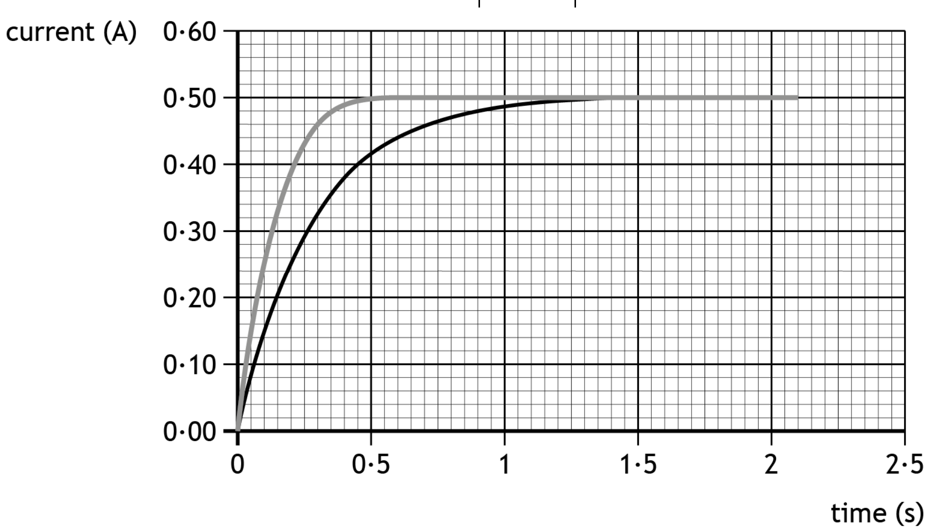


Figure 15C

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

Question			Expected response	Max mark	Additional guidance
15.	(a)	(i)	<u>Changing current</u> produces a <u>changing magnetic field</u>, (which induces a back EMF across the inductor)	1	
		(ii)	$\frac{dI}{dt}=1{\cdot}73$ (1) $\varepsilon=-L\frac{dI}{dt}$ (1) $-4{\cdot}0=-L\times1{\cdot}73$ (1) $L=2{\cdot}3$ H (1)	4	Accept use of gradient calculated for tangent (Acceptable range 1·70-1·75) Accept: 2, 2·31, 2·312
		(iii)	$(V=IR)$ $3{\cdot}2=I\times8{\cdot}0$ (1) $E=\frac{1}{2}LI^2$ (1) $E=\frac{1}{2}\times2{\cdot}3\times\left(\frac{3{\cdot}2}{8{\cdot}0}\right)^2$ (1) $E=0{\cdot}18$ J (1)	4	Or consistent with (a)(ii) Accept: 0·2, 0·184, 0·1840
	(b)		 1 mark for curve showing shorter time to I_{max} 1 mark for I_{max} = 0·50 A	2	Do not penalise if the line extends beyond 2·0 s.

DO NOT WRITE IN THIS MARGIN

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**.

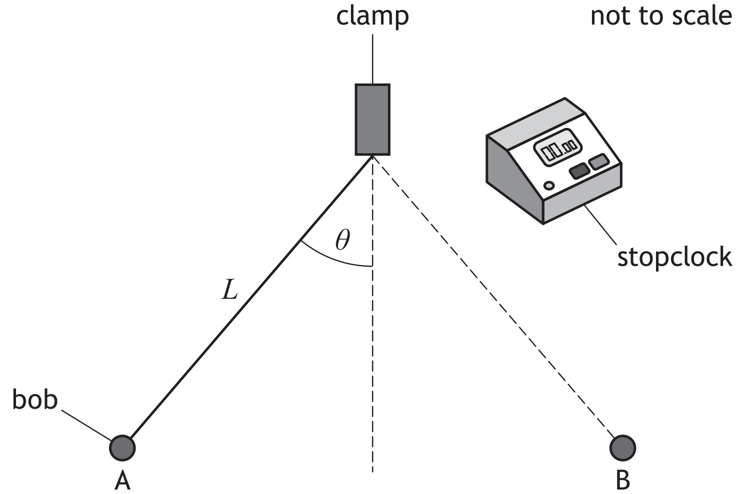


Figure 16A

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)

MARKS DO NOT WRITE IN THIS MARGIN

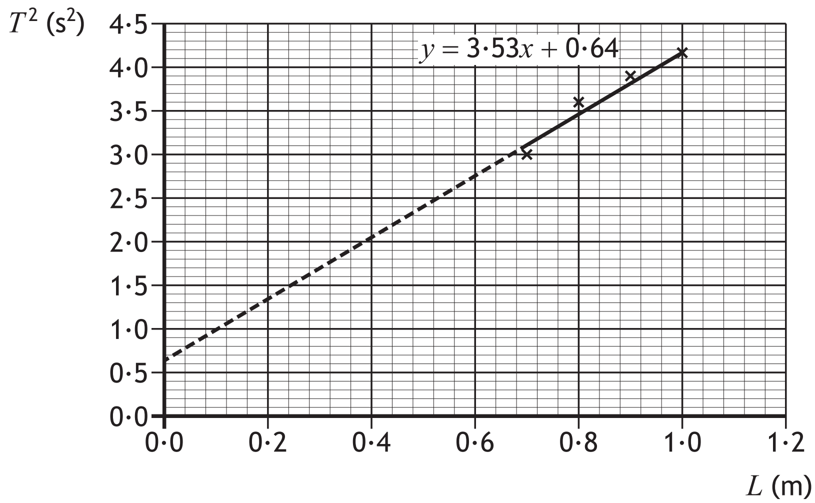


Figure 16B

(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

MARKS DO NOT WRITE IN THIS MARGIN

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]

Question			Expected response	Max mark	Additional guidance
16.	(a)	(i)	$\left(T^2 = \frac{4\pi^2}{g}L\right)$ $m = \frac{4\pi^2}{g}$ **(1)** $3\cdot53 = \frac{4\pi^2}{g}$ **(1)** $g = 11\cdot2\ \text{Nkg}^{-1}$ **(1)**	3	Accept use of gradient calculated for the line of best fit. (Acceptable range 3·40-3·60) Accept: 11, 11·18, 11·184
		(ii)	$\left(\frac{\Delta g}{g} = \frac{\Delta m}{m}\right)$ $\frac{\Delta g}{11\cdot2} = \frac{0\cdot69}{3\cdot53}$ **(1)** $\Delta g = 2\ \text{Nkg}^{-1}$ **(1)**	2	Or consistent with (a)(i) Accept the use of percentage uncertainties Suspend significant figures rule. Accept 3 N kg^{-1}
		(iii)	Uncertainty in gradient takes into account the uncertainties in length and period	1	Accept the suggestion that the uncertainty in the gradient incorporates/amalgamates/combines the uncertainties in length and period.
	(b)		Any two suggestions from: Measure length to centre of mass of bob **(1)** Time over multiple swings (and find mean value of T) **(1)** Increase range of lengths **(1)** Increase number of lengths **(1)** Reduce the angle of swing **(1)** Automatic timing **(1)**	2	Do not accept the suggestion of improving precision of instrumentation. Do not accept 'repeat measurements' alone
	(c)		T measurement (consistently too large) **OR** L measurement (consistently too small)	1	

[END OF MARKING INSTRUCTIONS]

FOR OFFICIAL USE

AH

National Qualifications 2022

Mark

X857/77/01 Physics

FRIDAY, 13 MAY

9:00 AM – 12:00 NOON

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	$9.8\ \text{m s}^{-2}$	Mass of electron	m_e	9.11×10^{-31} kg
Radius of Earth	R_E	6.4×10^{6} m	Charge on electron	e	-1.60×10^{-19} C
Mass of Earth	M_E	6.0×10^{24} kg	Mass of neutron	m_n	1.675×10^{-27} kg
Mass of Moon	M_M	7.3×10^{22} kg	Mass of proton	m_p	1.673×10^{-27} kg
Radius of Moon	R_M	1.7×10^{6} m	Mass of alpha particle	m_α	6.645×10^{-27} kg
Mean Radius of Moon Orbit		3.84×10^{8} m	Charge on alpha particle		3.20×10^{-19} C
Solar radius		6.955×10^{8} m	Charge on copper nucleus		4.64×10^{-18} C
Mass of Sun		2.0×10^{30} kg	Planck's constant	h	6.63×10^{-34} J s
1 AU		1.5×10^{11} m	Permittivity of free space	ε_0	$8.85 \times 10^{-12}\ \text{F m}^{-1}$
Stefan-Boltzmann constant	σ	$5.67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$	Permeability of free space	μ_0	$4\pi \times 10^{-7}\ \text{H m}^{-1}$
Universal constant of gravitation	G	$6.67 \times 10^{-11}\ \text{m}^3\ \text{kg}^{-1}\ \text{s}^{-2}$	Speed of light in vacuum	c	$3.00 \times 10^{8}\ \text{m s}^{-1}$
			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
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	2.70×10^{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	4.18×10^{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.

MARKS | DO NOT WRITE IN THIS MARGIN

Total marks — 155

Attempt ALL questions

1. During a short test run, a dragster accelerates from rest along a straight track.

The test run starts at time $t = 0$ s.

During the test run, the velocity v of the dragster at time t is given by the relationship

$$v = 6.6t^2 + 2.2t$$

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

(a) Using calculus methods:

(i) determine the acceleration of the dragster at $t = 4.1$ s **3**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

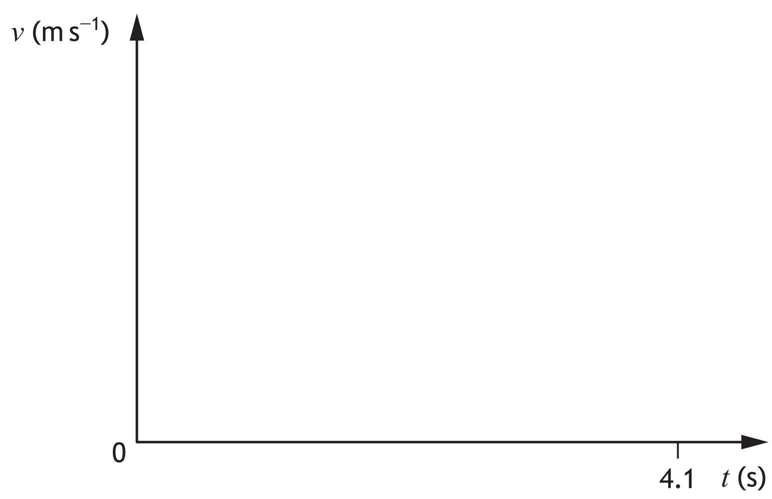
1. (a) (continued)

(ii) determine the distance travelled by the dragster between $t = 0$ s and $t = 4.1$ s. **3**

Space for working and answer

(b) On the axes below, sketch a graph to show the variation of velocity of the dragster with time, between $t = 0$ s and $t = 4.1$ s.

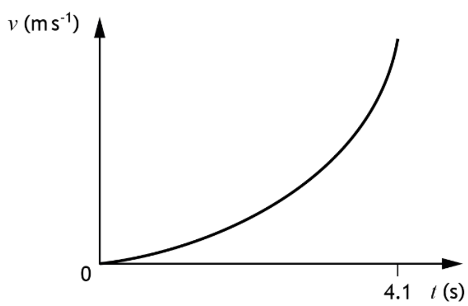
Numerical values are not required on the velocity axis. **1**



(An additional graph, if required, can be found on *page 54*.)

[Turn over

Marking Instructions for each question

Question			Expected response	Max mark	Additional guidance
1.	(a)	(i)	$\left(v = 6.6t^2 + 2.2t\right)$ $a\left(= \frac{dv}{dt}\right) = 13.2t + 2.2$ **(1)** $a = (13.2 \times 4.1) + 2.2$ **(1)** $a = 56 \text{ ms}^{-2}$ **(1)**	**3**	Accept: 60, 56.3, 56.32
		(ii)	$\left(s = \int (6.6t^2 + 2.2t).dt\right)$ $s = \frac{6.6}{3}t^3 + \frac{2.2}{2}t^2 (+c)$ **(1)** $(s = 0 \text{ when } t = 0, \text{ so } c = 0)$ $s = \frac{6.6}{3} \times 4.1^3 + \frac{2.2}{2} \times 4.1^2$ **(1)** $s = 170 \text{ m}$ **(1)**	**3**	Accept: 200, 170.1 Solution with limits also acceptable $\left(s = \int_0^{4.1} (6.6t^2 + 2.2t).dt\right)$ $s = \left[\frac{6.6}{3}t^3 + \frac{2.2}{2}t^2\right]_0^{4.1}$ **(1)** $s = \left(\frac{6.6}{3} \times 4.1^3 + \frac{2.2}{2} \times 4.1^2\right) \; (-0)$ **(1)** $s = 170 \text{ m}$ **(1)**
	(b)			**1**	Single smooth curve with increasing gradient. Must start at the origin and extend to 4.1 s. Ignore any lines beyond t = 4.1 s

MARKS DO NOT WRITE IN THIS MARGIN

2. A merry-go-round at a funfair rotates about an axis through its centre.

(a) The merry-go-round accelerates uniformly from rest. It takes 18 s to reach an angular velocity of 0.52 rad s^{-1}.

(i) Calculate the angular acceleration of the merry-go-round in this time. **3**

Space for working and answer

(ii) Calculate the angular displacement of the merry-go-round in this time. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

2. (continued)

(b) Two students, X and Y, ride on the merry-go-round. The students are sitting on adjacent horses as shown in Figure 2A.

not to scale

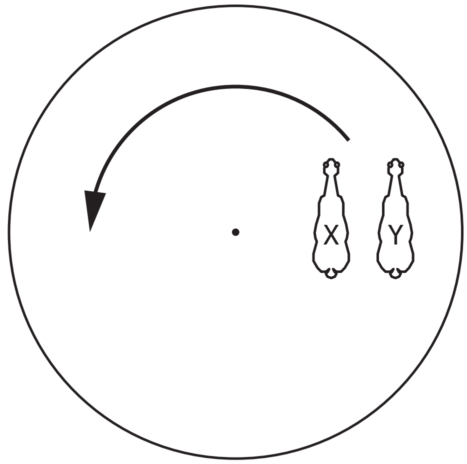


Figure 2A

(i) Explain why student Y has a greater tangential velocity than student X. **2**

(ii) State whether the centripetal acceleration of student Y is greater than, equal to, or less than the centripetal acceleration of student X.

You must justify your answer. **2**

Question			Expected response	Max mark	Additional guidance
2.	(a)	(i)	$\omega = \omega_0 + \alpha t$ **(1)** $0.52 = 0 + \alpha \times 18$ **(1)** $\alpha = 0.029$ rads^{-2} **(1)**	**3**	Accept 0.03, 0.0289, 0.02889
		(ii)	$\theta = \omega_0 t + \frac{1}{2}\alpha t^2$ **(1)** $\theta = 0 \times 18 + 0.5 \times 0.029 \times 18^2$ **(1)** $\theta = 4.7$ rad **(1)**	**3**	Or consistent with (a)(i) Accept: 5, 4.70, 4.698 $\omega^2 = \omega_0^2 + 2\alpha\theta$ **(1)** $0.52^2 = 0^2 + 2 \times 0.029 \times \theta$ **(1)** $\theta = 4.7$ rad **(1)** Accept: 5, 4.66, 4.662 $\theta = \left(\frac{\omega_0 + \omega}{2}\right)t$ **(1)** $\theta = \left(\frac{0 + 0.52}{2}\right) \times 18$ **(1)** $\theta = 4.7$ rad **(1)** Accept: 5, 4.68, 4.680
	(b)	(i)	$v = r\omega$ **(1)** <u>greater r same ω</u> **(1)**	**2**	$v = \frac{d}{t}$ **(1)** <u>greater d same t</u> **(1)**
		(ii)	(Centripetal acceleration of Y is) greater **(1)** Student Y is a greater distance from the axis of rotation $a_r = r\omega^2$, ω is the same for X and Y. **(1)**	**2**	MUST JUSTIFY Accept as justification: $a_r = \frac{v^2}{r}$ both v and r increase but v is squared (so more significant) (1) Could be answered by calculation $a_t = r\alpha$ or $a = r\alpha$ is incorrect justification (0)

MARKS DO NOT WRITE IN THIS MARGIN

3. A golf trolley consists of a frame with two identical wheels, as shown in Figure 3A.

Figure 3A

Each wheel can be modelled as a hoop and five rods, as shown in Figure 3B.

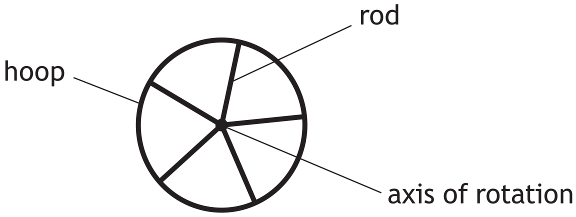


Figure 3B

The mass of the hoop is 0.38 kg. The radius of the hoop is 0.14 m.

The mass of each rod is 0.07 kg.

(a) Show that the moment of inertia of the wheel is 9.7×10^{-3} kg m^2. **3**

Space for working and answer

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

(b) A golfer cleans the wheels on the trolley by using a jet of air.

A wheel is raised off the ground. The jet of air exerts a tangential force of 1.2 N on the rim of the wheel as shown in Figure 3C. This causes the wheel to rotate.

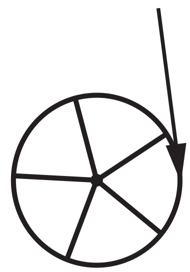


Figure 3C

(i) Calculate the torque acting on the wheel. **3**

Space for working and answer

(ii) A frictional torque also acts on the wheel.

When the 1.2 N force is applied, the wheel has an angular acceleration of 16 rad s^{-2}.

Determine the magnitude of the frictional torque. **4**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

3. (continued)

(c) The golfer now cleans the other wheel on the trolley. This wheel has a small stone stuck to the rim. The angular velocity of the wheel increases and the small stone 'flies off' the rim, as shown in Figure 3D.

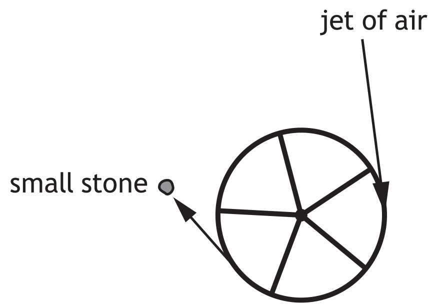


Figure 3D

Explain, in terms of forces, why the stone 'flies off' the rim. **2**

Question			Expected response	Max mark	Additional guidance
3.	(a)		$I_{(rod)} = \frac{1}{3}ml^2$ and $I_{(hoop)} = mr^2$ **(1), (1)** $I = \left(5 \times \frac{1}{3} \times 0.07 \times 0.14^2\right) + \left(0.38 \times 0.14^2\right)$ **(1)** $I = 9.7 \times 10^{-3}$ kgm^2	3	NON-STANDARD SHOW 1 for rod relationship 1 for hoop relationship $I_{(wheel)} = \left(5 \times \frac{1}{3}ml^2\right) + mr^2$ (1), (1) Final answer must be shown, otherwise max 2. May also be calculated separately but addition must be shown before the final answer.
	(b)	(i)	$\tau = Fr$ **(1)** $\tau = 1.2 \times 0.14$ **(1)** $\tau = 0.17$ Nm **(1)**	3	Accept: 0.2, 0.168, 0.1680
		(ii)	$\tau = I\alpha$ **(1)** $\tau = 9.7 \times 10^{-3} \times 16$ **(1)** $(\tau_F = \tau_A - \tau_U)$ $\tau_F = 0.17 - \left(9.7 \times 10^{-3} \times 16\right)$ **(1)** $\tau_F = 0.015$ Nm **(1)**	4	Or consistent with (b)(i) Accept: 0.01, 0.0148, 0.01480
	(c)		(The angular velocity increases so the required) centripetal force increases **(1)** until the friction is insufficient (to hold the stone in place) **(1)**	2	Accept: central force

MARKS DO NOT WRITE IN THIS MARGIN

4. A satellite of mass 2.30×10^3 kg is in a circular low Earth orbit.

The satellite orbits at an altitude of 312 km above the surface of the Earth, as shown in Figure 4A.

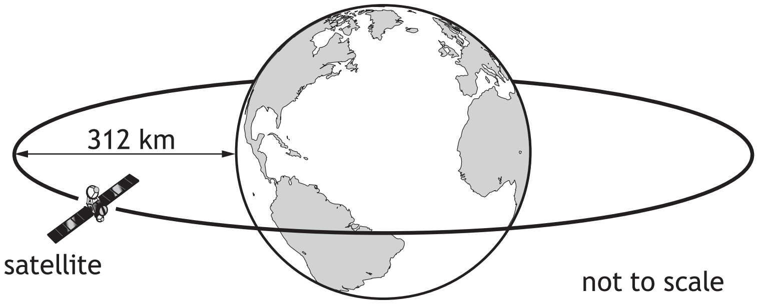


Figure 4A

(a) Show that the gravitational potential energy of the satellite in this orbit is -1.4×10^{11} J. **2**

Space for working and answer

(b) The satellite has an orbital period of 90.7 minutes.

Determine the speed of the satellite in this orbit. **3**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

4. (continued)

(c) Determine the total energy of the satellite in this orbit. **3**

Space for working and answer

(d) Suggest why a satellite in a low-altitude orbit will lose energy at a greater rate than a similar satellite in a high-altitude orbit. **1**

[Turn over

MARKS | DO NOT WRITE IN THIS MARGIN

4. (continued)

(e) The gravitational fields of the Earth and the Moon create five Lagrangian points.

A Lagrangian point is a position near two large bodies in orbit around each other, where a smaller object, such as a satellite, will remain in a fixed position relative to both orbiting bodies.

The distance r from the centre of the Moon to one of the Lagrangian points can be calculated using the relationship

$$r^3 = R^3\left(\frac{M_2}{3M_1}\right)$$

where R is the mean radius of the Moon's orbit

M_1 is the mass of the Earth

M_2 is the mass of the Moon.

Calculate the distance r from the centre of the Moon to this Lagrangian point. **2**

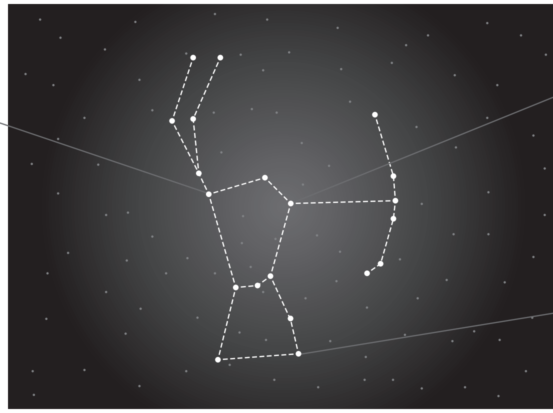
Space for working and answer

Question			Expected response	Max mark	Additional guidance
4.	(a)		$E_P = -\frac{GMm}{r}$ **(1)** $E_P = -\frac{6.67\times10^{-11}\times6.0\times10^{24}\times2.30\times10^3}{(6.4\times10^6+3.12\times10^5)}$ **(1)** $E_P = -1.4\times10^{11}$ J	2	SHOW Final answer must be shown otherwise MAX 1 $V = -\frac{GM}{r}$ and $E_p = Vm$ both relationships required for 1st mark all substitutions required for 2nd mark.
	(b)		$d = \bar{v}t$ **(1)** $2\pi\times(6.4\times10^6+3.12\times10^5) = \bar{v}\times90.7\times60$ **(1)** $\bar{v} = 7750$ ms^{-1} **(1)**	3	Accept: 7700, 7749, 7749.5 $\omega = \frac{2\pi}{T}$ and $v = r\omega$ (1) $v = (6.4\times10^6+3.12\times10^5)\times\frac{2\pi}{(90.7\times60)}$ (1) $v = 7750$ ms^{-1} (1) OR $\frac{mv^2}{r} = \frac{GMm}{r^2}$ (1) $\frac{2.30\times10^3\times v^2}{3.12\times10^5+6.4\times10^6} = \frac{6.67\times10^{-11}\times6.0\times10^{24}\times2.3\times10^3}{(3.12\times10^5+6.4\times10^6)^2}$ (1) $v = 7720$ ms^{-1} (1) Accept: 7700, 7722, 7721.7
	(c)		$(E_{total} = E_P + E_K)$ $E_{total} = E_P + \frac{1}{2}mv^2$ **(1)** $E_{total} = -1.4\times10^{11} + (0.5\times2.30\times10^3\times7750^2)$ **(1)** $E_{total} = -7.1\times10^{10}$ J **(1)**	3	Or consistent with (b) Accept: 7, 7.09, 7.093 $E_{total} = -\frac{GMm}{2r}$ **(1)** $E_{total} = -\frac{6.67\times10^{-11}\times6.0\times10^{24}\times2.30\times10^3}{2\times(6.4\times10^6+3.12\times10^5)}$ **(1)** $E_{total} = -6.9\times10^{10}$ J **(1)** Accept: 7, 6.86, 6.857
	(d)		(low-altitude orbit satellites experience) greater drag/friction from the atmosphere (than high-altitude orbit satellites). or similar	1	Do not accept: drag or friction alone or arguments about gravitational field strength alone.

Question			Expected response	Max mark	Additional guidance
4.	(e)		$\left(r^3 = R^3\left(\frac{M_2}{3M_1}\right)\right)$ $r^3 = \left(3.84\times10^8\right)^3 \times \left(\frac{7.3\times10^{22}}{3\times6.0\times10^{24}}\right)$ **(1)** $r = 6.1\times10^7$ m **(1)**	2	Accept 6, 6.12, 6.124

MARKS | DO NOT WRITE IN THIS MARGIN

5. Betelgeuse, Rigel, and Bellatrix are stars in the constellation Orion.



(a) Betelgeuse may ultimately become a black hole.

Betelgeuse has a mass of 2.19×10^{31} kg.

Calculate the Schwarzschild radius of Betelgeuse. **3**

Space for working and answer

(b) Rigel is no longer a main sequence star.

State the change that occurred in the fusion reactions within the core of Rigel at the point when it left the main sequence. **1**

MARKS DO NOT WRITE IN THIS MARGIN

5. (continued)

(c) Bellatrix is approximately 250 ly from Earth. It has a radius of 4.0×10^9 m and an apparent brightness of 5.0×10^{-8} W m^{-2}.

Determine the surface temperature of Bellatrix. **5**

Space for working and answer

[Turn over

MARKS DO NOT WRITE IN THIS MARGIN

5. (continued)

(d) A group of students are discussing Rigel and Betelgeuse.

Student 1: 'Why does Rigel appear to have a blue-white colour, while Betelgeuse appears orange in colour?'

Student 2: 'Betelgeuse also looks brighter than Rigel, so it must be closer.'

Student 3: 'Betelgeuse and Rigel must be roughly the same distance from Earth, because they're in the same constellation.'

Student 4: 'I don't think Betelgeuse and Rigel are even in the same galaxy.'

Use your knowledge of physics to comment on the discussion. **3**

Question			Expected response	Max mark	Additional guidance
5.	(a)		$r_{schwarzschild} = \frac{2GM}{c^2}$ **(1)** $r_{schwarzschild} = \frac{2\times 6.67\times 10^{-11}\times 2.19\times 10^{31}}{(3.00\times 10^{8})^2}$ **(1)** $r_{schwarzschild} = 3.25\times 10^{4}$ m **(1)**	**3**	Accept: 3.2, 3.246, 3.2461
	(b)		Hydrogen fusion stops/ceases.	**1**	
	(c)		$b = \frac{L}{4\pi d^2}$ **(1)** $L = 4\pi r^2 \sigma T^4$ **(1)** $5.0\times 10^{-8}\times 4\pi(250\times 365.25\times 24\times 60\times 60\times 3.00\times 10^{8})^2$ $= 4\pi(4.0\times 10^{9})^2\times 5.67\times 10^{-8}\times T^4$ (1),**(1)** $T = 2.4\times 10^{4}$ K **(1)**	**5**	Accept 2, 2.36, 2.357 If 365 used Accept: 2, 2.36, 2.356 250 ly conversion mark independent

MARKS DO NOT WRITE IN THIS MARGIN

6. The Heisenberg uncertainty principle can be expressed as

$$\Delta x \Delta p_x \geq \frac{h}{4\pi}$$

(a) State an implication of this relationship for a quantum particle. **1**

(b) An alpha particle is emitted from a uranium-235 nucleus. According to classical physics, the alpha particle cannot overcome the strong nuclear force holding it in place in the nucleus.

Explain, in terms of the Heisenberg uncertainty principle, why alpha emission is possible from the uranium-235 nucleus. **2**

MARKS DO NOT WRITE IN THIS MARGIN

6. (continued)

(c) The mean lifetime of an alpha particle within the uranium-235 nucleus is 0.70 μs.

Determine the minimum uncertainty in the energy of this alpha particle. **3**

Space for working and answer

[Turn over

Question			Expected response	Max mark	Additional guidance
6.	(a)		It is not possible to know the (precise) momentum and position of a quantum particle simultaneously.	1	It is not possible to know the (precise) lifetime and associated energy change of a quantum particle simultaneously.
	(b)		The momentum of the alpha particle is known precisely therefore its position is not known precisely **(1)** there is a (small) probability that the particle could exist outside the nucleus (even although classically it does not have sufficient energy to escape). **(1)**	2	Second mark is dependent on the first mark being awarded. The lifetime of the alpha particle is known precisely therefore its energy is not known precisely **(1)** there is a (small) probability that the particle could escape from the nucleus (even although classically it does not have sufficient energy to escape). **(1)**
	(c)		$\Delta E \Delta t \geq \frac{h}{4\pi}$ **(1)** $\Delta E_{(\min)} \times 0.70 \times 10^{-6} = \frac{6.63 \times 10^{-34}}{4\pi}$ **(1)** $\Delta E_{(\min)} = 7.5 \times 10^{-29}$ J **(1)**	3	Accept: 8, 7.54, 7.537 Accept: $\Delta E_{\min} \Delta t = \frac{h}{4\pi}$ Do not accept as starting point: $\Delta E_{\min} \Delta t \geq \frac{h}{4\pi}$ $\Delta E \Delta t = \frac{h}{4\pi}$ Do not accept as final answer: $\Delta E_{\min} \geq 7.5 \times 10^{-29}$ J $\Delta E \geq 7.5 \times 10^{-29}$ J

MARKS DO NOT WRITE IN THIS MARGIN

7. A student finds the diagram shown in Figure 7A in a textbook. The diagram represents some of the possible electron orbits in the Bohr model of an atom.

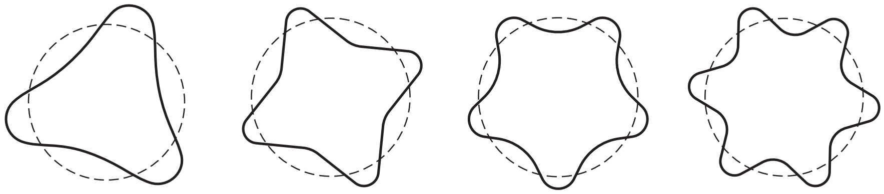


Figure 7A

Using your knowledge of physics, comment on the suitability of the diagram as a representation of electron orbits in an atom. **3**

MARKS DO NOT WRITE IN THIS MARGIN

8. To produce an image of an atom, some microscopes use particles such as electrons or neutrons.

The de Broglie wavelengths of the particles should be approximately the same magnitude as, or smaller than, the diameter of the atom being imaged.

(a) In one electron microscope, the electrons used have a velocity of 1.75×10^7 m s^{-1}.

(i) Calculate the de Broglie wavelength of the electrons used. **3**

Space for working and answer

(ii) The diameter of an atom can be measured in ångströms (Å).

1 Å is equal to 0.1 nm.

The diameter of a gold atom is 2.6 Å.

(A) Explain whether electrons with velocity 1.75×10^7 m s^{-1} are suitable for imaging the gold atom. **1**

MARKS DO NOT WRITE IN THIS MARGIN

8. (a) (ii) (continued)

(B) A neutron microscope uses neutrons with a velocity three orders of magnitude less than that of the electrons in the electron microscope.

Explain fully why the neutron microscope is suitable for imaging gold atoms. **2**

(b) Optical microscopes use visible light. Individual atoms are too small to be viewed using an optical microscope.

Estimate the diameter of the smallest object that could be imaged using an optical microscope. **1**

[Turn over

Question			Expected response	Max mark	Additional guidance
8.	(a)	(i)	$\lambda = \frac{h}{p}$ **(1)** $\lambda = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 1.75 \times 10^{7}}$ **(1)** $\lambda = 4.16 \times 10^{-11}$ m **(1)**	3	Accept: 4.2, 4.159, 4.1587 Accept: $\lambda = \frac{h}{mv}$ (1)
		(ii) (A)	Yes, as 4.16×10^{-11} (m) < 2.6×10^{-10} (m) **OR** Yes, as the de Broglie wavelength is of the same magnitude as the diameter of the atom	1	Or consistent with (a)(i) Accept: Yes, as the de Broglie wavelength is smaller than the diameter of the atom
		(B)	mass three orders of magnitude greater (and velocity three orders of magnitude less) **(1)** de Broglie wavelength is similar to diameter of gold atom. **(1)**	2	Can show by calculation. 2nd mark is dependent on the 1st mark being awarded.
	(b)		A single value from 398 – 410 nm	1	

MARKS DO NOT WRITE IN THIS MARGIN

9. Charged particles originating from space approach the magnetic field of the Earth.

Most of the particles are high-energy protons.

A high-energy proton with a velocity of 2.75×10^7 m s^{-1} enters the magnetic field of the Earth at a point where the magnetic induction is 23 μT. The proton enters the field at an angle of 60.0° and follows a helical path as shown in Figure 9A.

not to scale

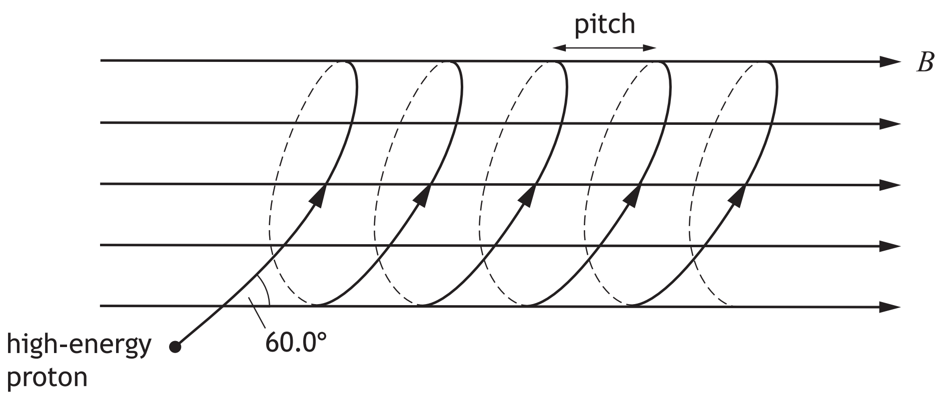


Figure 9A

(a) (i) Determine the component of the velocity of the proton parallel to the magnetic field. **1**

Space for working and answer

(ii) Determine the component of the velocity of the proton perpendicular to the magnetic field. **1**

Space for working and answer

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

(b) (i) The component of the velocity of the proton perpendicular to the magnetic field causes it to experience a magnetic force.

Show that the magnetic force experienced by the proton in the magnetic field is 8.8×10^{-17} N. **2**

Space for working and answer

(ii) (A) This magnetic force causes the proton to undergo circular motion.

Calculate the radius of this circular motion. **3**

Space for working and answer

(B) Determine the period of this circular motion. **3**

Space for working and answer

9. (b) (continued) MARKS DO NOT WRITE IN THIS MARGIN

(iii) The distance that the proton moves parallel to the magnetic field lines during one period of the circular motion is known as the pitch.

Calculate the pitch of the helical path. **3**

Space for working and answer

(c) The magnetic induction increases closer to the poles, as shown in Figure 9B.

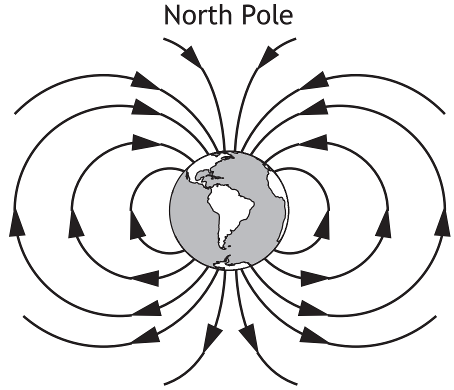


Figure 9B

The helical path of the proton follows a field line as it approaches the North Pole. The protons can be considered to be travelling at a constant speed.

Other than direction, state two changes to the helical path followed by the proton as it approaches the pole. **2**

Question			Expected response	Max mark	Additional guidance
9.	(a)	(i)	$v_{(parallel)} = 1.38 \times 10^7$ ms^{-1}	1	Accept: 1.4, 1.375, 1.3750
		(ii)	$v_{(perpendicular)} = 2.38 \times 10^7$ ms^{-1}	1	Accept: 2.4, 2.382, 2.3816
	(b)	(i)	$F = qvB$ (1) $F = 1.60 \times 10^{-19} \times 2.38 \times 10^7 \times 23 \times 10^{-6}$ (1) $F = 8.8 \times 10^{-17}$ N	2	SHOW Accept: $F = qvB\sin\theta$ $F = 1.60 \times 10^{-19} \times 2.75 \times 10^7 \times 23 \times 10^{-6} \times \sin 60.0$ Must have final answer, otherwise max 1.
		(ii) (A)	$F = \frac{mv^2}{r}$ (1) $8.8 \times 10^{-17} = \frac{1.673 \times 10^{-27} \times (2.38 \times 10^7)^2}{r}$ (1) $r = 1.1 \times 10^4$ m (1)	3	Or consistent with (a)(ii) Accept: 1, 1.08, 1.077 $r = \frac{mv}{qB}$ ok as starting point Accept: 1, 1.08, 1.082
		(ii) (B)	$v = r\omega$ and $\omega = \frac{2\pi}{T}$ (1) $\left(T = \frac{2\pi r}{v}\right)$ $T = \frac{2\pi \times 1.1 \times 10^4}{2.38 \times 10^7}$ (1) $T = 2.9 \times 10^{-3}$ s (1)	3	Or consistent with (a)(ii) and (b)(ii)(A) Accept:3, 2.90, 2.904 Accept: $d = \bar{v}t$ and $d = 2\pi r$ as starting point $F = mr\omega^2$ and $\omega = \frac{2\pi}{T}$ (1) $8.8 \times 10^{-17} = \frac{1.673 \times 10^{-27} \times 1.1 \times 10^4 \times 4 \times \pi^2}{T^2}$ (1) $T = 2.9 \times 10^{-3}$ s (1) Accept: 3, 2.87, 2.873
		(iii)	$d = vt$ (1) $d = 1.38 \times 10^7 \times 2.9 \times 10^{-3}$ (1) $d = 4.0 \times 10^4$ m (1)	3	Or consistent with (a)(i) and (b)(ii)(B) Accept: 4, 4.00, 4.002
	(c)		radius decreases (1) pitch decreases (1)	2	

MARKS DO NOT WRITE IN THIS MARGIN

10. A student is studying simple harmonic motion (SHM) using a mass oscillating vertically on the end of a spring.

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

(b) The vertical displacement of an oscillating mass on a spring can be described by the expression

$$y = A\cos\left(\sqrt{\frac{k}{m}}\,t\right)$$

where the symbols have their usual meaning.

Show that this expression is a solution to the relationship

$$m\frac{d^2y}{dt^2} + ky = 0$$ **2**

MARKS | DO NOT WRITE IN THIS MARGIN

10. (continued)

(c) A mass of 0.75 kg is suspended from a spring of negligible mass, as shown in Figure 10A.

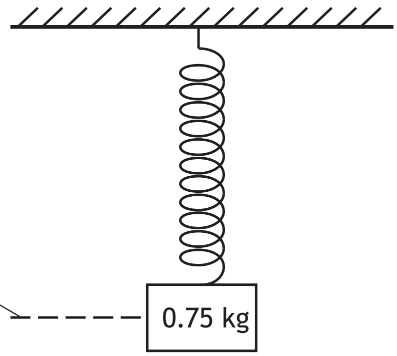


Figure 10A

The mass is now pulled down through a vertical distance of 0.038 m. It is then released, allowing it to oscillate about the equilibrium position.

The spring has a spring constant k of 24 N m^{-1}.

(i) By considering the expression

$$y = A\cos\left(\sqrt{\frac{k}{m}}\,t\right)$$

show that the angular frequency of the mass is 5.7 rad s^{-1}. **2**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

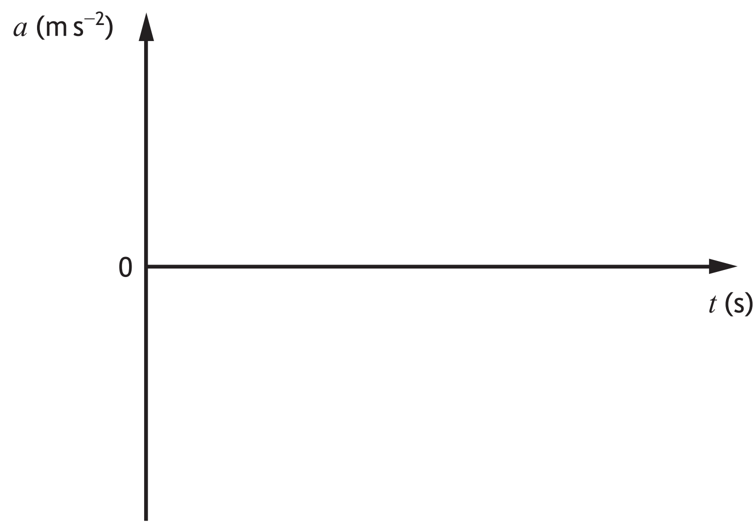
10. (c) (continued)

(ii) Determine the maximum acceleration of the mass. **3**

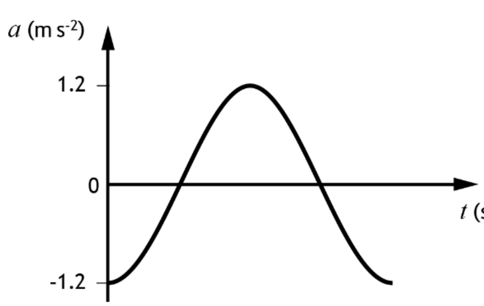
Space for working and answer

(iii) On the axes below, sketch a graph showing how the acceleration of the mass varies with time, for the first full oscillation.

Numerical values are required on the acceleration axis only. **2**



(An additional graph, if required, can be found on *page 54*.)

Question			Expected response		Max mark	Additional guidance
10.	(a)		Displacement is proportional to and in the opposite direction to the acceleration/unbalanced force.		1	$F = -ky$ or equivalent.
	(b)		$y = A\cos\left(\sqrt{\frac{k}{m}}t\right)$ $\frac{dy}{dt} = -A\sqrt{\frac{k}{m}}\sin\left(\sqrt{\frac{k}{m}}t\right)$ $\frac{d^2y}{dt^2} = -A\frac{k}{m}\cos\left(\sqrt{\frac{k}{m}}t\right)$ $m\frac{d^2y}{dt^2} = -kA\cos\left(\sqrt{\frac{k}{m}}t\right)$ **OR** $m\frac{d^2y}{dt^2} = -ky$ $m\frac{d^2y}{dt^2} + ky = 0$	 (1) (1)	2	NON-STANDARD SHOW 1 mark for <u>both differentiations</u> When first differentiation shown, it must be correct, otherwise 0 marks. Final relationship must be shown, otherwise max 1.
	(c)	(i)	$\omega = \sqrt{\frac{k}{m}}$ $\omega = \sqrt{\frac{24}{0.75}}$ $\omega = 5.7 \text{ rads}^{-1}$	(1) (1)	2	NON-STANDARD SHOW Final answer must be shown, otherwise max 1
		(ii)	$a = (-)\omega^2 y$ $a_{(\max)} = (-)5.7^2 \times 0.038$ $a_{(\max)} = (-)1.2 \text{ ms}^{-2}$	(1) (1) (1)	3	Accept:1, 1.23, 1.235 Accept: $a = (-)\omega^2 A$
		(iii)			2	Or consistent with (c)(ii) If harmonic function shown: 1 for values of a_{max} 1 for shape (cos or -cos curve) Non-harmonic function (0) Can show damping if done correctly.

MARKS DO NOT WRITE IN THIS MARGIN

11. A travelling wave is represented by the equation

$$y = 12.6\sin 2\pi(1.32t - 1.04x)$$

(a) The energy of the wave is 8.17 mJ.

The wave is reflected and its amplitude halves.

(i) Calculate the energy of this reflected wave. **3**

Space for working and answer

(ii) State the equation that represents this reflected wave. **2**

MARKS DO NOT WRITE IN THIS MARGIN

11. (continued)

(b) A graph of another travelling wave, at one instant in time, is shown in Figure 11A.

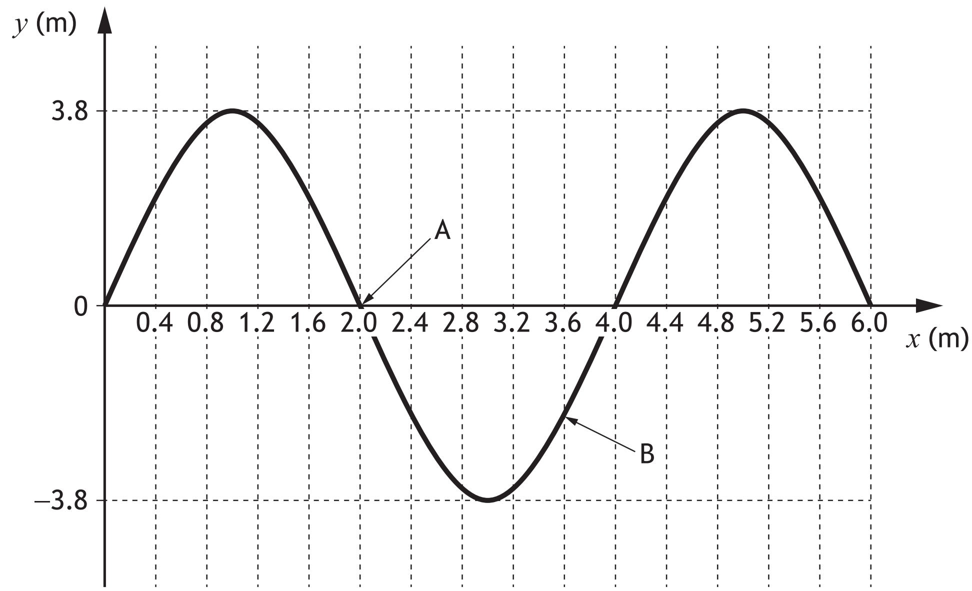


Figure 11A

Determine the phase difference between points A and B. **3**

Space for working and answer

Question			Expected response	Max mark	Additional guidance
11.	(a)	(i)	$E = kA^2$ **(1)** $\left(8.17 = k \times 12.6^2\right)$ $E_2 = \frac{8.17}{12.6^2} \times 6.3^2$ **(1)** $E_2 = 2.04$ mJ **(1)**	3	Accept: 2.0, 2.043, 2.0425 Accept: $\frac{E_1}{A_1^2} = \frac{E_2}{A_2^2}$ (1) $\frac{8.17}{12.6^2} = \frac{E_2}{6.3^2}$ (1) $E_2 = 2.04$ mJ (1)
	(a)	(ii)	$y = 6.3 \sin 2\pi(1.32t + 1.04x)$	2	1 for all numerical values 1 for change of sign
	(b)		$\phi = \frac{2\pi x}{\lambda}$ **(1)** $\phi = \frac{2\pi \times (3.6 - 2.0)}{4.0}$ **(1)** $\phi = \frac{4\pi}{5}$ rad **(1)**	3	Accept: 3, 2.5, 2.51, 2.513

MARKS DO NOT WRITE IN THIS MARGIN

12. A student carries out a Young's double slit experiment using a helium-neon laser.

The student observes an interference pattern on the screen as shown in Figure 12A.

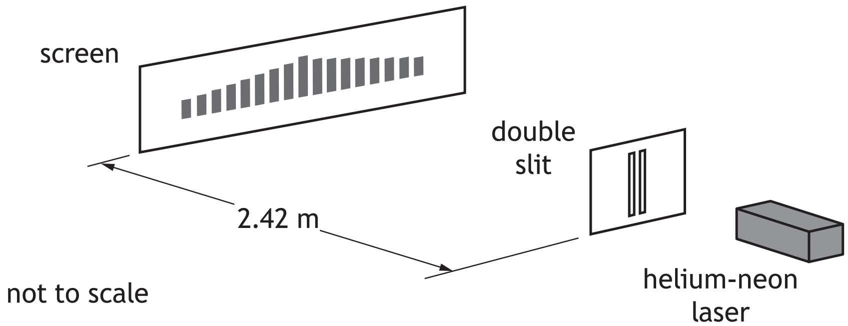


Figure 12A

(a) The student records their measurements.

Slit to screen distance (m)	**Slit separation (mm)**
2.42 ± 0.02	0.38 ± 0.01

(i) Using the student's measurements, calculate the fringe separation. **3**

Space for working and answer

(ii) Calculate the absolute uncertainty in this fringe separation. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

12. (continued)

(b) The student now measures across 16 fringe separations.

16 fringe separations = (62.4 ± 0.5) mm

Using this data, determine the fringe separation.

You must include an uncertainty in your answer. **1**

Space for working and answer

(c) State whether more confidence should be placed in the value for fringe separation obtained in (a) or in (b).

You must justify your answer. **2**

(d) The student now repeats the experiment using a laser that produces light of wavelength 532 nm.

State the effect this has on the fringe separation.

You must justify your answer. **2**

Question			Expected response	Max mark	Additional guidance
12.	(a)	(i)	$\Delta x = \frac{\lambda D}{d}$ **(1)** $\Delta x = \frac{633 \times 10^{-9} \times 2.42}{0.38 \times 10^{-3}}$ **(1)** $\Delta x = 4.0 \times 10^{-3}$ m **(1)**	3	Accept: 4, 4.03, 4.031
		(ii)	$\frac{\Delta(\Delta x)}{\Delta x} = \sqrt{\left(\frac{\Delta D}{D}\right)^2 + \left(\frac{\Delta d}{d}\right)^2}$ **(1)** $\frac{\Delta(\Delta x)}{4.0 \times 10^{-3}} = \sqrt{\left(\frac{0.02}{2.42}\right)^2 + \left(\frac{0.01}{0.38}\right)^2}$ **(1)** $\Delta(\Delta x) = 1.1 \times 10^{-4}$ m **(1)**	3	Or consistent with (a)(i) Suspend significant figures rule Accept: rule of three applied Accept calculations using percentages.
	(b)		$\Delta x = (3.90 \pm 0.03)$ mm	1	Suspend significant figures rule Accept uncertainty as a %
	(c)		(b) or 3.90 mm **(1)** As it has a smaller (absolute/fractional/percentage) uncertainty **(1)**	2	**MUST JUSTIFY** Or consistent with (a) and/or (b) Accept: It is more precise. (1) Smaller random/systematic/scale reading uncertainty is incorrect.
	(d)		(The fringe separation) decreases **(1)** λ decreases, d and D remain constant **(1)**	2	**MUST JUSTIFY** Accept: $\Delta x \propto \lambda$ for second mark

13. A student carries out an experiment to investigate the intensity of plane-polarised light transmitted through an analyser. MARKS DO NOT WRITE IN THIS MARGIN

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

(b) The analyser can be rotated. The angle θ between the plane of polarisation and the transmission axis of the analyser is varied.

The light intensity is measured using a light meter.

This is shown in Figure 13A.

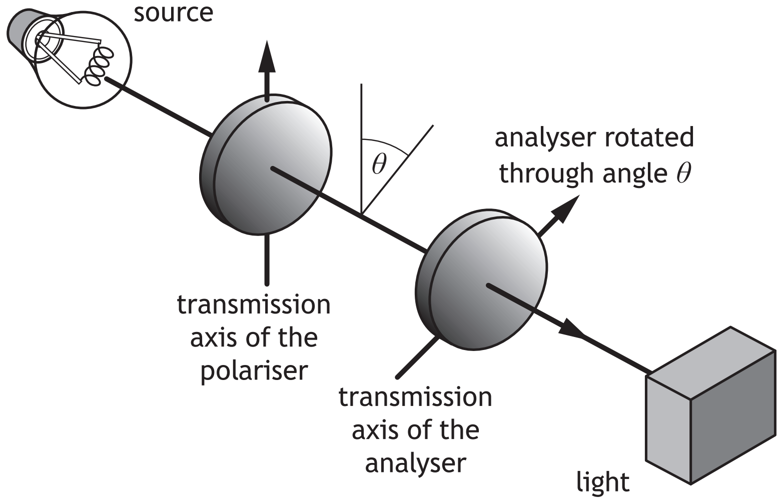


Figure 13A

The variation of measured light intensity I with θ is given by the relationship

$$I = I_0 \cos^2 \theta$$

where I_0 is the maximum light intensity.

Data from the student's experiment is shown in the table.

I (W m^{-2})	θ (°)	$\cos^2\theta$
4.0	30.0	0.75
3.2	40.0	
2.8	45.0	
1.6	60.0	
0.5	80.0	

DO NOT WRITE IN THIS MARGIN

MARKS DO NOT WRITE IN THIS MARGIN

13. (b) (continued)

(i) Complete the table on *page 38* to show all derived values of $\cos^2\theta$. **1**

(ii) Using the square-ruled paper on *page 39*, draw a graph from which a value of I_0 can be determined.

(Additional square-ruled paper, if required, can be found on *pages 52* and *53*.) **3**

(iii) Use information from your graph to determine a value for I_0. **2**

(iv) Use information from your graph to determine the angle θ that gives a value for I of 3.5 W m^{-2}. **2**

(v) Use your graph to estimate the background light intensity. **1**

MARKS DO NOT WRITE IN THIS MARGIN

13. (continued)

(c) (i) Suggest one change to the **experimental procedure** that would improve the accuracy of measurements of light intensity. **1**

(ii) Suggest one change to the **experimental procedure** that would improve the precision of measurements of light intensity. **1**

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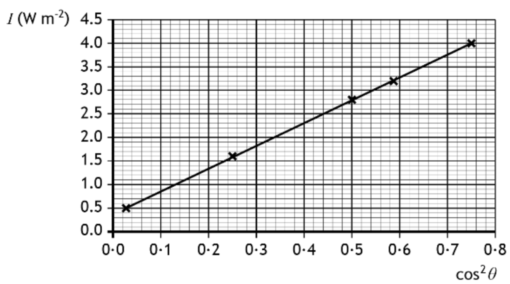
<table>
<tr><th colspan="3">Question</th><th>Expected response</th><th>Max mark</th><th>Additional guidance</th></tr>
<tr><td>13.</td><td>(a)</td><td></td><td>(The electric field vector) oscillates (or vibrates) in one plane only.</td><td>1</td><td>Do not accept:
direction instead of plane
or
travels instead of oscillates</td></tr>
<tr><td></td><td>(b)</td><td>(i)</td><td><table><tr><th>I (W m^{-2})</th><th>$\cos^2\theta$</th></tr><tr><td>4.0</td><td>0.75</td></tr><tr><td>3.2</td><td>0.59</td></tr><tr><td>2.8</td><td>0.50</td></tr><tr><td>1.6</td><td>0.25</td></tr><tr><td>0.5</td><td>0.03</td></tr></table></td><td>1</td><td>Accept a range of 1 to 4 significant figures</td></tr>
<tr><td></td><td></td><td>(ii)</td><td>
</td><td>3</td><td>1 mark for labels including unit and suitable scales
1 mark for accurate plotting (±½ box tolerance and consistent with (b)(i))
1 mark for line of best fit

Non-linear scale(s) across the range of the data
– award 0 marks
Do not penalise for swapping the axes</td></tr>
<tr><td></td><td></td><td>(iii)</td><td>(1) for substitution into gradient relationship (may be implied)
(1) for answer</td><td>2</td><td>Must be consistent with candidate's line
Determine gradient
Must use two points on the line.</td></tr>
<tr><td></td><td></td><td>(iv)</td><td>(1) for value of $\cos^2\theta$ from graph
(1) for θ</td><td>2</td><td>Must be consistent with candidate's line

If using the equation of a straight line, must include y-axis intercept, otherwise 0 marks.</td></tr>
<tr><td></td><td></td><td>(v)</td><td>intercept of candidate's line with I axis</td><td>1</td><td>Must be consistent with candidate's line.</td></tr>
</table>

Question			Expected response	Max mark	Additional guidance
13.	(c)	(i)	Reduce the background light level **OR** Place a black cloth on the bench **OR** Repeat measurements (and take the mean)	**1**	Measurements of angle only not acceptable. 0 marks
		(ii)	Repeat measurements (and take the mean) **OR** Use a (light) meter that measures to more decimal places/finer graduations on scale	**1**	Measurements of angle only not acceptable. 0 marks

MARKS DO NOT WRITE IN THIS MARGIN

14. In a cathode ray oscilloscope, electrons are accelerated from rest between the cathode and anode. The electrons then travel with a constant horizontal velocity between the parallel deflection plates.

This arrangement is shown in Figure 14A.

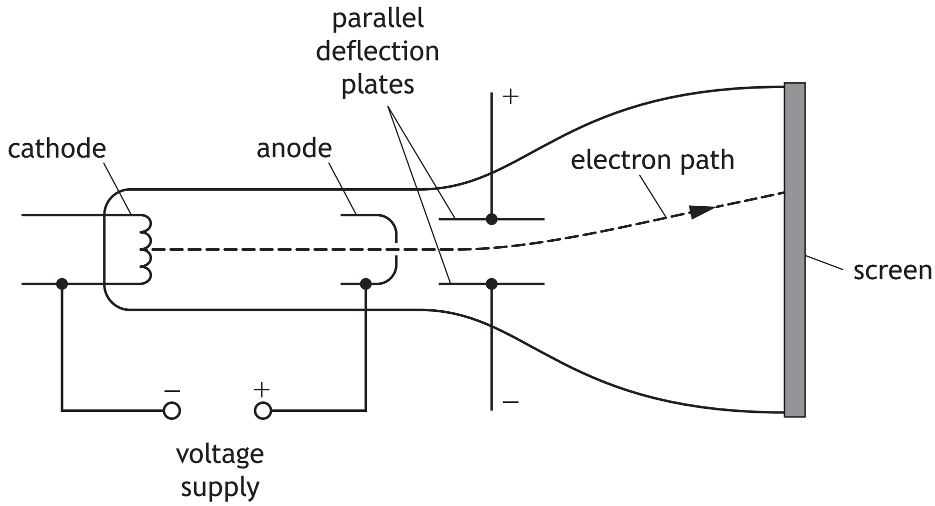


Figure 14A

(a) The electrons pass through the anode with a horizontal velocity of 2.9×10^{7} m s^{-1}.

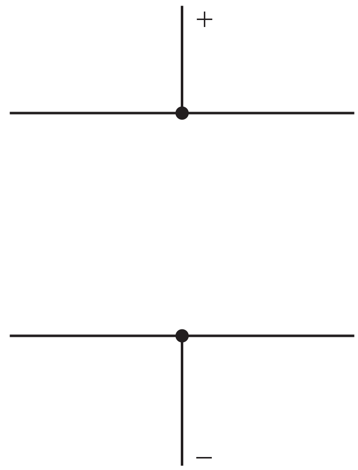
Determine the potential difference between the cathode and anode. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

14. (continued)

(b) On the diagram below, sketch the electric field pattern between the parallel deflection plates. **1**



(An additional diagram, if required, can be found on *page 55*.)

(c) Explain why the electrons follow a curved path between the parallel deflection plates. **2**

[Turn over

MARKS DO NOT WRITE IN THIS MARGIN

14. (continued)

(d) The potential difference across the parallel deflection plates is 0.90 kV. Electrons passing between the plates are deflected by 4.0 mm in the vertical direction.

This is shown in Figure 14B.

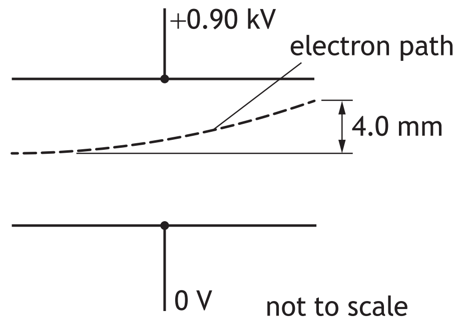


Figure 14B

(i) The vertical component of the velocity of the electrons is 1.2×10^{7} m s^{-1} as they exit the region between the plates.

Show that the vertical acceleration of the electrons between the parallel deflection plates is 1.8×10^{16} m s^{-2}. **2**

Space for working and answer

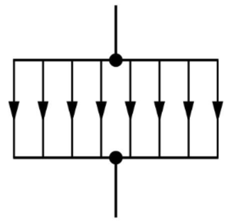
MARKS | DO NOT WRITE IN THIS MARGIN

14. (d) (continued)

(ii) By considering the electric field between the plates, determine the vertical separation of the plates. **4**

Space for working and answer

[Turn over

Question			Expected response	Max mark	Additional guidance
14.	(a)		$\frac{1}{2}mv^2 = QV$ **(1)** $0.5\times9.11\times10^{-31}\times(2.9\times10^{7})^2 = 1.60\times10^{-19}\times V$ **(1)** $V = 2.4\times10^{3}$ V **(1)**	3	Accept:2, 2.39, 2.394 Accept negative value for ***Q***.
	(b)			1	Ignore end effects. Field lines must be straight/spaced uniformly. Field lines must start and end on the plates.
	(c)		The electrons travel with (constant) horizontal speed/velocity. **(1)** Electrons travel with (constant) vertical acceleration. **(1)**	2	No force in the horizontal direction **(1)** Unbalanced force in the vertical direction **(1)** Accept: Perpendicular to field in place of horizontal Parallel to field in place of vertical. Do not accept: Attracted to the top/positive plate without reference to unbalanced force for second mark
	(d)	(i)	$v^2 = u^2 + 2as$ **(1)** $(1.2\times10^{7})^2 = 0^2 + 2\times a\times4.0\times10^{-3}$ **(1)** $a = 1.8\times10^{16}$ ms^{-2}	2	SHOW Final answer must be shown, otherwise MAX 1.
		(ii)	$(F = ma)$ $F = 9.11\times10^{-31}\times1.8\times10^{16}$ **(1)** $F = QE$ and $E = \frac{V}{d}$ **(1)** $\left(F = \frac{QV}{d}\right)$ $9.11\times10^{-31}\times1.8\times10^{16} = 1.60\times10^{-19}\times\frac{0.90\times10^{3}}{d}$ **(1)** $d = 8.8\times10^{-3}$ m **(1)**	4	Accept: 9, 8.78, 8.782

MARKS DO NOT WRITE IN THIS MARGIN

15. An undersea high voltage DC electrical power link consists of two cables buried under the seabed.

The magnetic permeability of the seabed can be taken to be the same as the permeability of free space.

There is a current of 1.80 kA in each cable.

The cables are buried 30.0 m apart, as shown in Figure 15A.

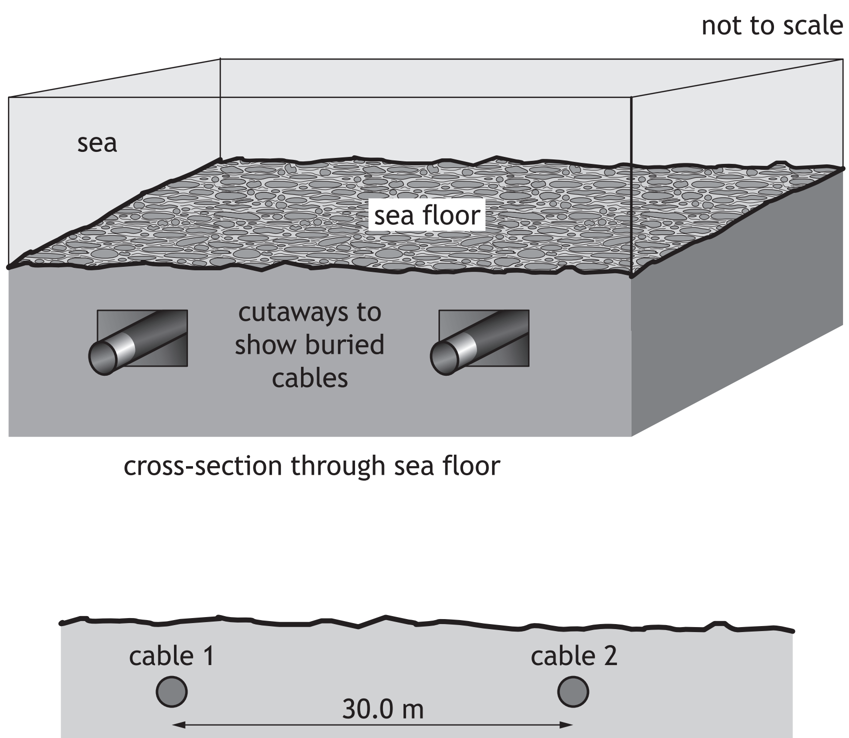


Figure 15A

(a) (i) Calculate the magnetic induction at cable 2 due to the current in cable 1. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

15. (a) (continued)

(ii) Determine the magnitude of the **force per unit length** acting on cable 2 due to the current in cable 1. **3**

Space for working and answer

(b) A third cable carries a fibre-optic link. The optical fibre is made of silicon dioxide.

The speed v_m of an electromagnetic wave in an optical fibre is given by the relationship

$$v_m = \frac{1}{\sqrt{\varepsilon_r \varepsilon_0 \mu_r \mu_0}}$$

where ε_r is the relative permittivity of the optical fibre material

μ_r is the relative permeability of the optical fibre material

and the other symbols have their usual meaning.

The speed of light in the optical fibre is 1.52×10^8 m s^{-1}.

The relative permeability of silicon dioxide is 1.00.

Determine the relative permittivity of silicon dioxide. **2**

Space for working and answer

Question			Expected response	Max mark	Additional guidance
15.	(a)	(i)	$B = \frac{\mu_0 I}{2\pi r}$ **(1)** $B = \frac{4\pi \times 10^{-7} \times 1.8 \times 10^3}{2\pi \times 30.0}$ **(1)** $B = 1.2 \times 10^{-5}$ T **(1)**	**3**	Accept: 1, 1.20, 1.200
		(ii)	$F = IlB$ **(1)** $\frac{F}{l} = 1.8 \times 10^3 \times 1.2 \times 10^{-5}$ **(1)** $\frac{F}{l} = 2.2 \times 10^{-2}$ Nm^{-1} **(1)**	**3**	or consistent with (a)(i) Accept: 2, 2.16, 2.160 Where l is substituted as 1 accept final answer in N
	(b)		$\left(v_m = \frac{1}{\sqrt{\varepsilon_r \varepsilon_0 \mu_r \mu_0}}\right)$ $1.52 \times 10^8 = \frac{1}{\sqrt{\varepsilon_r \times 8.85 \times 10^{-12} \times 1.00 \times 4\pi \times 10^{-7}}}$ **(1)** $\varepsilon_r = 3.89$ **(1)**	**2**	Accept:3.9, 3.892, 3.8919 If unit given in final answer (1) max.

MARKS DO NOT WRITE IN THIS MARGIN

16. An LC circuit in a radio receiver has an inductor and capacitor connected in parallel. The LC circuit is used to select different radio frequencies by varying the capacitance C of the capacitor.

The inductor has a fixed inductance L of 120 μH.

Part of the LC circuit is shown in Figure 16A.

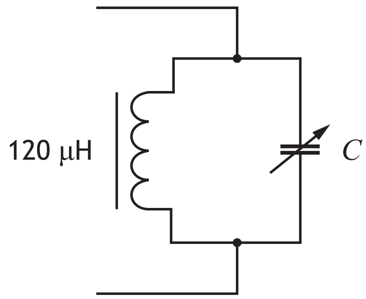


Figure 16A

(a) State what is meant by *inductive reactance*. **1**

(b) (i) The resonant frequency f_0 of the LC circuit is the frequency at which the inductive reactance equals the capacitive reactance.

Show that this frequency can be expressed as

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

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

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

16. (b) (continued)

(ii) The variation of the current with frequency in the LC circuit is shown in Figure 16B.

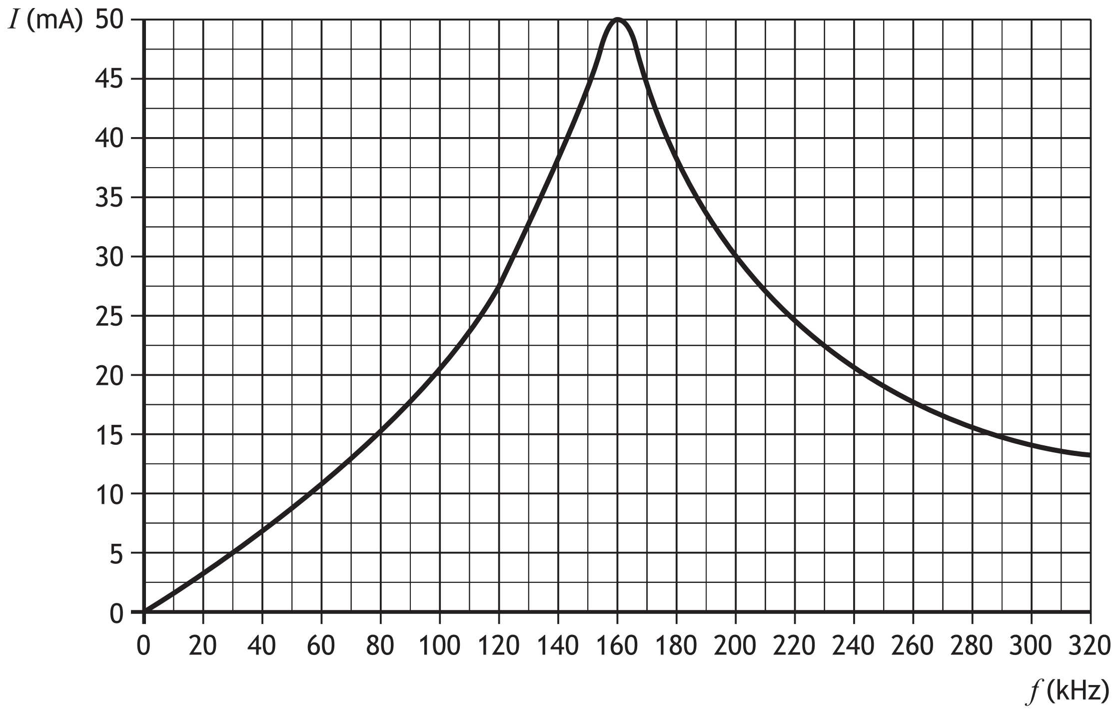


Figure 16B

At the resonant frequency, the current in the LC circuit is at a maximum.

Determine the capacitance of the capacitor at the resonant frequency. **3**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

16. (continued)

(c) The radio receiver also contains an RC circuit. The RC circuit is shown in Figure 16C.

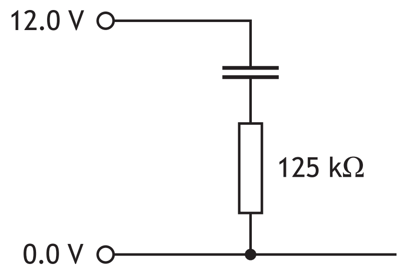


Figure 16C

The capacitor in the RC circuit is fully charged.

When the radio receiver is switched off, this capacitor discharges through a resistor of resistance 125 kΩ.

The time constant for the circuit is 250 s.

(i) Calculate the capacitance of this capacitor. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

16. (c) (continued)

(ii) A graph of the potential difference V across the capacitor against time t is shown in Figure 16D.

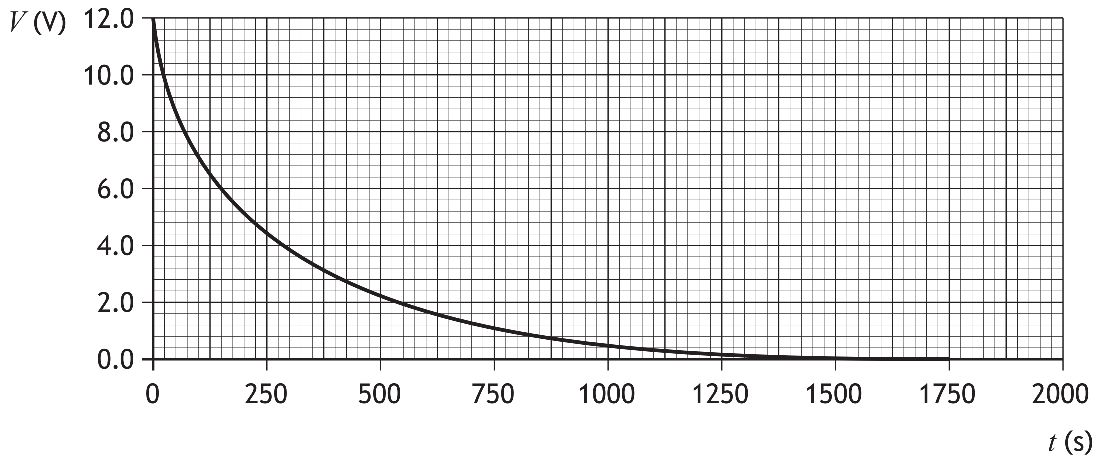


Figure 16D

Using information from the graph, show that the voltage across the capacitor reduces to 37% of its original value after one time constant. **2**

Space for working and answer

[END OF QUESTION PAPER]

Question			Expected response	Max mark	Additional guidance
16.	(a)		Inductive reactance is the opposition (of an inductor) to changing current **(1)**	**1**	
	(b)	(i)	$\left(X_L = 2\pi fL,\ X_C = \dfrac{1}{2\pi fC}\right)$ $2\pi f_0 L = \dfrac{1}{2\pi f_0 C}$ **(1), (1)** $f_0 = \dfrac{1}{2\pi\sqrt{LC}}$	**2**	NON-STANDARD SHOW 1 mark for both relationships 1 mark for equating using f_0 If equated using f then maximum 1 mark Final relationship must be shown otherwise maximum 1 mark
		(ii)	$f_0 = \dfrac{1}{2\pi\sqrt{LC}}$ $160\times10^3 = \dfrac{1}{2\pi\sqrt{120\times10^{-6}\times C}}$ **(1), (1)** $C = 8.2\times10^{-9}$ F **(1)**	**3**	Accept: 8, 8.25, 8.246 1 mark for $f_0 = 160\times10^3$ (Hz)
	(c)	(i)	$\tau = RC$ **(1)** $250 = 125\times10^3\times C$ **(1)** $C = 2.0\times10^{-3}$ F **(1)**	**3**	Accept: 2, 2.00, 2.000
		(ii)	At 250 s, voltage = 4.4 V **(1)** $\dfrac{4.4}{12.0}$ **(1)** $(=0.37) = 37\%$	**2**	NON-STANDARD SHOW $37\%\times12 = 4.4$ (V) **(1)** 4.4 (V) gives a time of 250 s **(1)** Accept 4.44 (V) Do not accept: 4 (V)

[END OF MARKING INSTRUCTIONS]

FOR OFFICIAL USE

National Qualifications 2023

Mark

X857/77/01 Physics

WEDNESDAY, 17 MAY

9:00 AM – 12:00 NOON

* X 8 5 7 7 7 0 1 *

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.

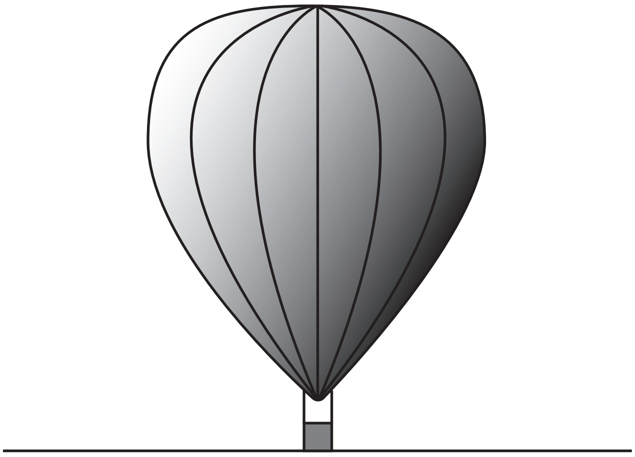
Before leaving the examination room you must give this booklet to the Invigilator; if you do not, you may lose all the marks for this paper.

MARKS | DO NOT WRITE IN THIS MARGIN

Total marks — 155

Attempt ALL questions

1. A hot air balloon accelerates vertically upwards from the ground.



During the first 8.0 seconds of flight, the vertical velocity v of the balloon is given by the relationship

$$v = 0.0044t^3 + 0.012t^2$$

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

Using calculus methods:

(a) determine the vertical acceleration of the balloon at $t = 8.0$ s **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

1. (continued)

(b) determine the vertical displacement of the balloon at $t = 8.0$ s. **3**

Space for working and answer

[Turn over

Marking Instructions for each question

Question			Expected response	Max mark	Additional guidance
1.	(a)		$a\left(=\frac{dv}{dt}\right)=3\times0.0044t^2+2\times0.012t$ 1 $a=3\times0.0044\times8.0^2+2\times0.012\times8.0$ 1 $a=1.0\ \text{ms}^{-2}$ 1	3	Accept: 1, 1.04, 1.037
	(b)		$s\left(=\int v dt\right)=\frac{0.0044t^4}{4}+\frac{0.012t^3}{3}(+c)$ 1 (at $t=0$ $s=0$ $\therefore c=0$) $s=\frac{0.0044\times8.0^4}{4}+\frac{0.012\times8.0^3}{3}$ 1 $s=6.6$ m 1	3	Accept: 7, 6.55, 6.554 $\left(s=\int_0^{8.0} v.dt\right)$ $s=\left[\frac{0.0044t^4}{4}+\frac{0.012t^3}{3}\right]_0^{8.0}$ 1 $s=\left(\frac{0.0044\times8.0^4}{4}+\frac{0.012\times8.0^3}{3}\right)-0$ 1 $s=6.6$ m 1

MARKS DO NOT WRITE IN THIS MARGIN

2. A student is investigating rotational motion using the circular plate in a microwave oven. This is shown in **Figure 2A**.

Figure 2A

(a) The microwave oven is switched on and the plate rotates with an angular velocity of 6.2 revolutions per minute.

Show that the angular velocity of the plate is $0.65\ \text{rad s}^{-1}$. **2**

Space for working and answer

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2. (continued)

(b) The microwave oven is switched off. The student places a pea on the plate, 83 mm from the axis of rotation as shown in **Figure 2B**.

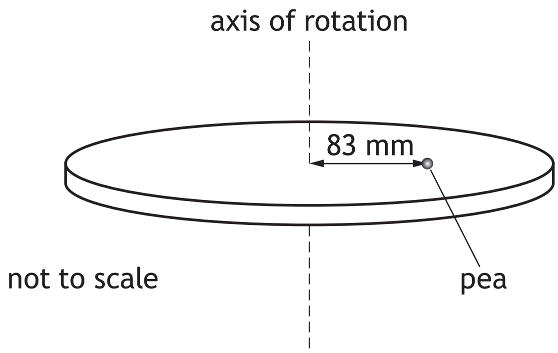

Figure 2B

The microwave oven is now switched on and the plate again rotates with an angular velocity of 0.65 rad s^{-1}.

(i) The pea has a mass of 0.36 g and follows a circular path.

Calculate the centripetal force acting on the pea. **3**

Space for working and answer

(ii) State the direction of the centripetal force. **1**

[Turn over

MARKS DO NOT WRITE IN THIS MARGIN

2. (continued)

(c) The microwave oven is again switched off. The student places a second, identical pea on the plate, 120 mm from the axis of rotation as shown in **Figure 2C**.

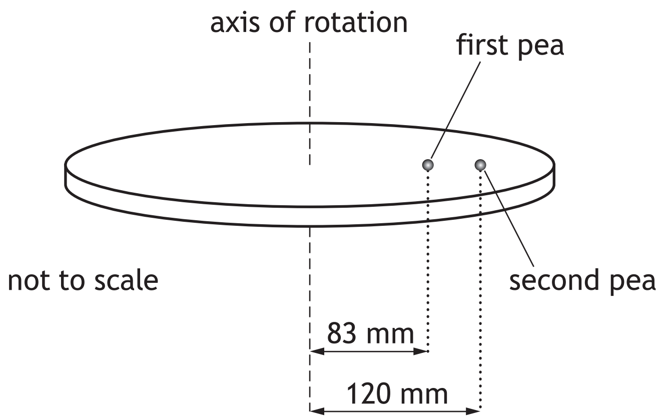

Figure 2C

The microwave oven is switched on.

Explain why the second pea is less likely to follow a circular path as the plate reaches an angular velocity of $0.65\ \text{rad s}^{-1}$. **2**

Question			Expected response	Max mark	Additional guidance
2.	(a)		$\omega = \frac{d\theta}{dt}$ or $\omega = \frac{\theta}{t}$ 1 $\omega = \frac{6.2 \times 2\pi}{60}$ 1 $\omega = 0.65$ rad s^{-1}	2	Non-standard SHOW Question Accept: $\omega = 2\pi f$ or $\omega = \frac{2\pi}{T}$
	(b)	(i)	$F = mr\omega^2$ 1 $F = 0.36 \times 10^{-3} \times 83 \times 10^{-3} \times 0.65^2$ 1 $F = 1.3 \times 10^{-5}$ N 1	3	Accept: 1, 1.26, 1.262 $F = \frac{mv^2}{r}$ and $v = r\omega$ 1 all substitutions 1
		(ii)	Towards the centre of the plate/circular path.	1	
	(c)		(for a given ω) the (required/ needed) centripetal/central force is greater for the second pea since radius/distance from axis of rotation is greater 1 friction is insufficient to provide the required centripetal force 1	2	Independent marks Any indication of second pea having centripetal force greater than friction (max 1)

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3. A rotational dynamics investigation is carried out using a turntable of radius 150 mm as shown in **Figure 3A**.

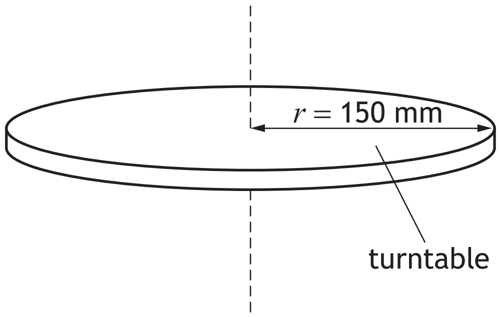


Figure 3A

(a) The turntable consists of a uniform, solid disc of mass 0.82 kg.

Show that the moment of inertia of this disc is 9.2×10^{-3} kg m^2. **2**

Space for working and answer

[Turn over

MARKS | DO NOT WRITE IN THIS MARGIN

3. (continued)

(b) The turntable rotates at an angular velocity of 12 rad s^{-1}.

A thin ring is dropped gently onto the disc. The mass of the ring is 75 g.

The radius of the ring is 130 mm.

This system is shown in **Figure 3B**.

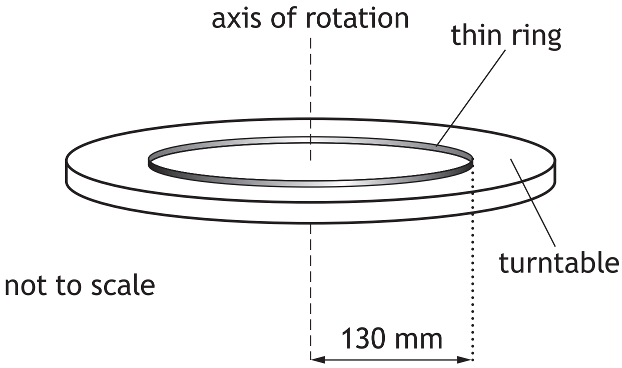


Figure 3B

(i) By considering the principle of conservation of angular momentum, determine the angular velocity of the system. **4**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

3. (b) (continued)

(ii) Determine the loss in rotational kinetic energy due to the interaction between the ring and the turntable. **4**

Space for working and answer

(iii) During the interaction some rotational kinetic energy is converted into heat.

Explain how this heat is generated. **1**

[Turn over

Question			Expected response	Max mark	Additional guidance
3.	(a)		$I = \frac{1}{2}mr^2$ 1 $I = 0.5 \times 0.82 \times (150 \times 10^{-3})^2$ 1 $I = 9.2 \times 10^{-3}\ \text{kg m}^2$	2	SHOW question
	(b)	(i)	$I_{ring} = mr^2$ 1 $I_{table}\omega_{table} = (I_{table} + I_{ring})\omega_2$ 1 $9.2 \times 10^{-3} \times 12 =$ $(9.2 \times 10^{-3} + 75 \times 10^{-3} \times (130 \times 10^{-3})^2)\omega_2$ 1 $\omega_2 = 11\ \text{rad s}^{-1}$ 1	4	Accept: 10, 10.5, 10.55 Indication of conservation of angular momentum - independent 1 mark
		(ii)	$E_k = \frac{1}{2}I\omega^2$ 1 $\left(\Delta E_k = \frac{1}{2}I_{table}\omega_{table}^2 - \frac{1}{2}(I_{table} + I_{ring})\omega_2^2\right)$ $\Delta E_k = (0.5 \times 9.2 \times 10^{-3} \times 12^2) -$ $\left(0.5\left(9.2 \times 10^{-3} + \left(75 \times 10^{-3} \times (130 \times 10^{-3})^2\right)\right) \times 11^2\right)$ 1,1 $\Delta E_k = 0.029\ \text{J}$ 1	4	Or consistent with (b)(i) Accept: 0.03, 0.0291, 0.02912 1 for substitution into $E_{k\ \text{before}}$ 1 for substitution into $E_{k\ \text{after}}$
		(iii)	(Work done against) friction between the ring and turntable.	1	Friction alone, 0 marks.

MARKS DO NOT WRITE IN THIS MARGIN

4. In planning for a crewed mission to Mars, scientists have designed an Earth Return Vehicle (ERV). When the crew is on the surface of Mars, the ERV will be in a circular orbit around Mars at an altitude of 2.5×10^5 m above the surface.

(a) Show that the gravitational potential at this altitude is -1.18×10^7 J kg^{-1}. **2**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

4. (continued)

(b) The ERV will then move into a higher circular orbit. The gravitational potential at the higher orbit is -1.10×10^{7} J kg^{-1}.

The ERV will have a mass of 4.3×10^{3} kg.

Determine the change in gravitational potential energy of the ERV when it has moved from the lower orbit to the higher orbit. **4**

Space for working and answer

[Turn over

MARKS DO NOT WRITE IN THIS MARGIN

4. (continued)

(c) Another spacecraft, the Mars Ascent Vehicle (MAV), will transport crew and cargo from the surface of Mars to the ERV.

(i) Calculate the escape velocity from the surface of Mars. **3**

Space for working and answer

(ii) The MAV will dock with the ERV in the higher circular orbit, at an altitude of 5.0×10^5 m above the surface of Mars.

Explain why the MAV does not have to attain the escape velocity calculated in (c) (i) to reach this altitude. **1**

MARKS DO NOT WRITE IN THIS MARGIN

4. (c) (continued)

(iii) Calculate the tangential speed of the ERV in this orbit. **3**

Space for working and answer

(iv) Suggest a reason why the docking manoeuvre will be easier to carry out at an altitude of 5.0×10^5 m rather than at an altitude of 2.5×10^5 m. **1**

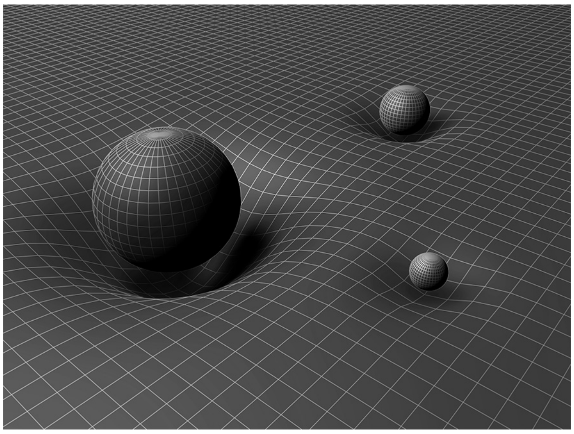
[Turn over

Question			Expected response	Max mark	Additional guidance
4	(a)		$V = -\frac{GM}{r}$ 1 $V = -\frac{6.67\times10^{-11}\times6.42\times10^{23}}{(3.39\times10^{6}+2.5\times10^{5})}$ 1 $V = -1.18\times10^{7}\ \text{J kg}^{-1}$	2	SHOW question
	(b)		$\Delta V = -1.10\times10^{7} - (-1.18\times10^{7})$ 1 $(\Delta)E_p = (\Delta)Vm$ 1 $(\Delta)E_p = (-1.10\times10^{7} - (-1.18\times10^{7}))\times4.3\times10^{3}$ 1 $(\Delta)E_p = 3.4\times10^{9}$ J 1	4	Accept: 3, 3.44, 3.440 Alternative method: $E_p = Vm$ 1 $E_{p\ \text{low}} = -1.18\times10^{7}\times4.3\times10^{3}$ $E_{p\ \text{high}} = -1.10\times10^{7}\times4.3\times10^{3}$ } 1 $(\Delta)E_p = (-1.10\times10^{7} - (-1.18\times10^{7}))\times4.3\times10^{3}$ 1 $(\Delta)E_p = 3.4\times10^{9}$ J 1
	(c)	(i)	$v_{esc} = \sqrt{\frac{2GM}{r}}$ 1 $v_{esc} = \sqrt{\frac{2\times6.67\times10^{-11}\times6.42\times10^{23}}{3.39\times10^{6}}}$ 1 $v_{esc} = 5.03\times10^{3}\ \text{ms}^{-1}$ 1	3	Accept: 5.0, 5.026, 5.0263
		(ii)	the orbit of the ERV is not at infinity **OR** the escape velocity enables an object to reach infinity	1	Allow arguments relating to the MAV being powered (continually) as it rises. the ERV is in the gravitational field of Mars **OR** the escape velocity enables an object to escape the gravitational field of Mars

Question			Expected response	Max mark	Additional guidance
4.	(c)	(iii)	$\frac{GMm}{r^2} = \frac{mv^2}{r}$ 1 $\frac{6.67\times10^{-11}\times6.42\times10^{23}\times4.3\times10^{3}}{(3.39\times10^{6}+5.0\times10^{5})^2}$ $= \frac{4.3\times10^{3}\times v^2}{(3.39\times10^{6}+5.0\times10^{5})}$ 1 $v = 3.3\times10^{3}$ m s^{-1} 1	3	Accept: 3, 3.32, 3.318 Accept: $v = \sqrt{\frac{GM}{r}}$
		(iv)	Lower (tangential) velocity (makes docking easier).	1	Do not accept: arguments relating to friction with atmosphere or gravitational field strength.

MARKS DO NOT WRITE IN THIS MARGIN

5. When discussing general relativity, the American physicist John Wheeler stated ‘spacetime tells matter how to move; matter tells spacetime how to curve’.



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

MARKS DO NOT WRITE IN THIS MARGIN

5. (continued)

[Turn over

Question Table

Question			Expected response	Max mark	Additional guidance
5.			**Award 3 marks** where the candidate has demonstrated a good understanding of the physics involved. They show a good comprehension of the physics of the situation and provide a logically correct answer to the question posed. This type of response might include a statement of the principles involved, a relationship or an equation, and the application of these to respond to the problem. The answer does not need to be 'excellent' or 'complete' for the candidate to gain full marks. **Award 2 marks** where the candidate has demonstrated a reasonable understanding of the physics involved. They make some statement(s) that are relevant to the situation, showing that they have understood the problem. **Award 1 mark** where the candidate has demonstrated a limited understanding of the physics involved. They make some statement(s) that are relevant to the situation, showing that they have understood at least a little of the physics within the problem. **Award 0 marks** where the candidate has not demonstrated an understanding of the physics involved. There is no evidence that they have recognised the area of physics involved, or they have not given any statement of a relevant physics principle. Award this mark also if the candidate merely restates the physics given in the question.	3	Candidates may use a variety of physics arguments to answer this question. Award marks based on candidates demonstrating overall good, reasonable, limited, or no understanding.

MARKS DO NOT WRITE IN THIS MARGIN

6. The Sun is a main sequence star.

(a) In the core of the Sun, energy is released when hydrogen is converted to helium in a series of nuclear fusion reactions.

State the name given to this series of fusion reactions. **1**

(b) The Sun has a surface temperature of 5800 K.

(i) Calculate the luminosity of the Sun. **3**

Space for working and answer

(ii) State one assumption made in this calculation of luminosity. **1**

MARKS DO NOT WRITE IN THIS MARGIN

6. (continued)

(c) When hydrogen fusion in its core stops, the Sun will leave the main sequence and become a red giant.

Explain, in terms of thermal pressure and gravitational forces, what happens to the radius of the Sun as it becomes a red giant. **2**

[Turn over

MARKS DO NOT WRITE IN THIS MARGIN

6. **(continued)**

(d) The Plough is a pattern of seven bright stars in the constellation Ursa Major as shown in **Figure 6A**. Delta Ursae Majoris is the dimmest of these stars as viewed from Earth.

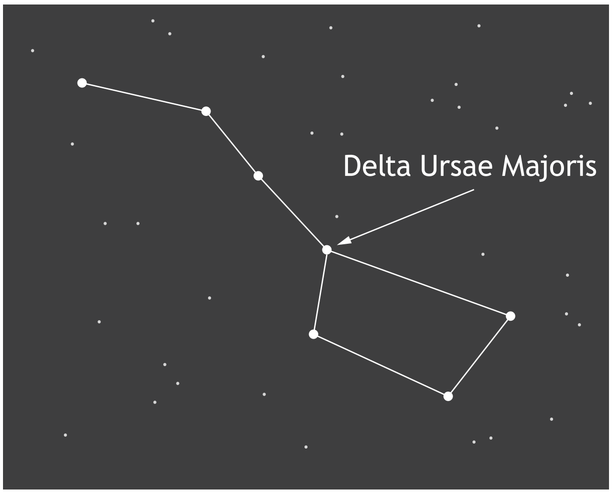


Figure 6A

The distance to Delta Ursae Majoris from Earth is 24.7 parsecs. 1 parsec is equal to 3.26 ly.

Delta Ursae Majoris has a luminosity of 5.46×10^{27} W.

Determine the apparent brightness of Delta Ursae Majoris when observed from Earth. **4**

Space for working and answer

* X 8 5 7 7 7 0 1 2 0 *

6. (continued)

MARKS DO NOT WRITE IN THIS MARGIN

(e) Epsilon Ursae Majoris is another of the stars in the Plough as shown in **Figure 6B**.

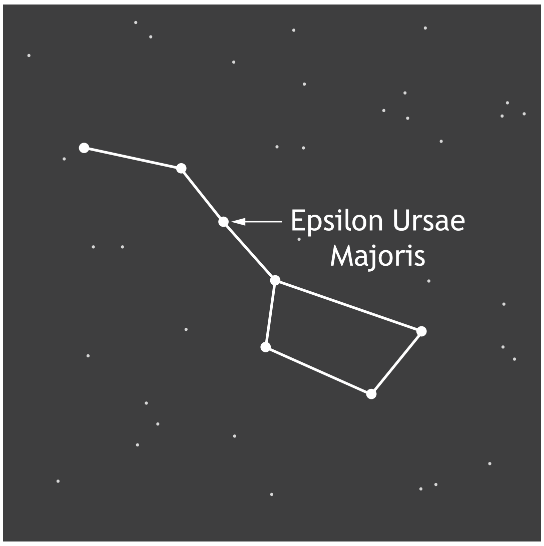


Figure 6B

The luminosity of Epsilon Ursae Majoris is approximately two orders of magnitude greater than the luminosity of the Sun. Epsilon Ursae Majoris has a surface temperature of approximately 9000 K.

On the HR diagram shown in **Figure 6C**, circle the star at the position of Epsilon Ursae Majoris. **1**

(*An additional diagram, if required, can be found on page 54.*)

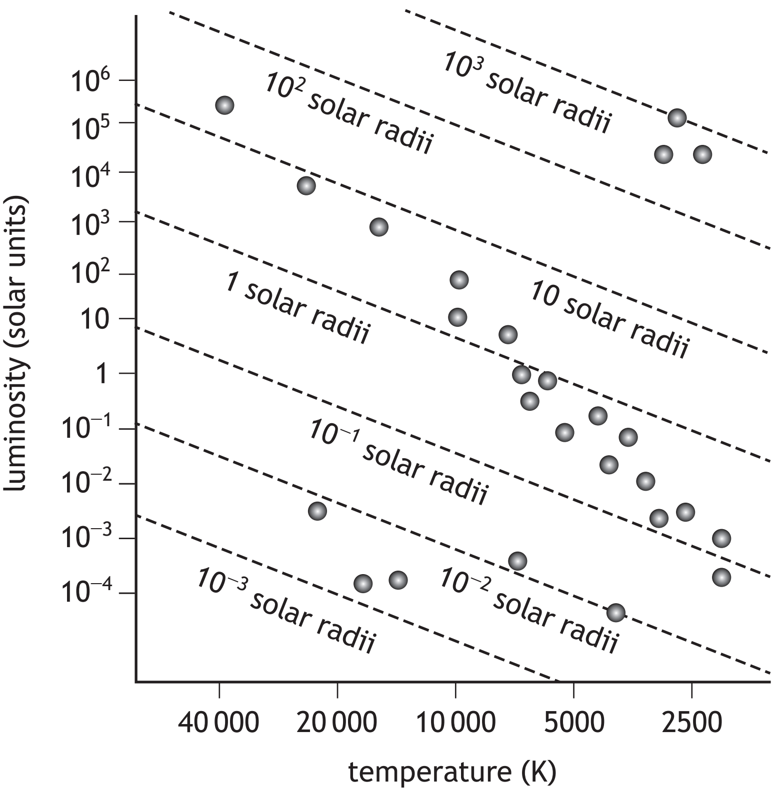
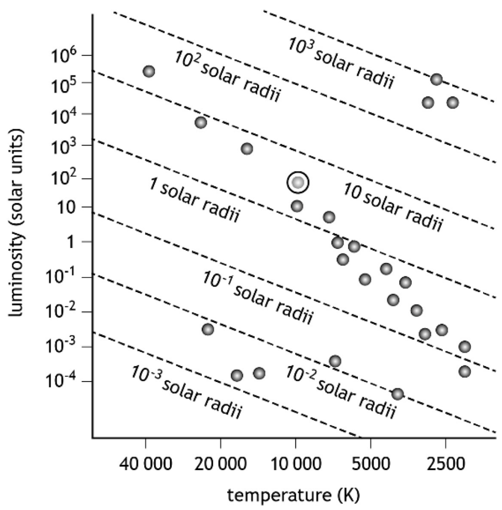


Figure 6C

Question			Expected response	Max mark	Additional guidance
6.	(a)		Proton-proton chain/p-p chain	**1**	
	(b)	(i)	$L = 4\pi r^2 \sigma T^4$ 1 $L = 4\pi \times (6.955 \times 10^8)^2 \times 5.67 \times 10^{-8} \times 5800^4$ 1 $L = 3.9 \times 10^{26}$ W 1	**3**	Accept: 4, 3.90, 3.900 If π = 3.14, accept 3.898
		(ii)	Blackbody	**1**	Accept: Uniform radius/spherical Uniform surface temperature
	(c)		Radius increases because (the forces due to) thermal pressure greater than gravitational force **1** Radius stops increasing when (the forces due to) thermal pressure balances gravitational forces. **1**	**2**	Ignore description of initial reduction in (core) radius and any fusion processes (in the core)
	(d)		$b = \frac{L}{4\pi d^2}$ 1 $b = \frac{5.46 \times 10^{27}}{4\pi \times (3.26 \times 24.7 \times 3.00 \times 10^8 \times 365.25 \times 24 \times 60 \times 60)^2}$ 1,1 $b = 7.48 \times 10^{-10}$ W m^{-2} 1	**4**	Accept: 7.5, 7.477, 7.4766 unit conversion from 24.7 parsecs is an independent mark Incorrect sub in unit conversion max 1 mark If 365 used, accept 7.5, 7.49, 7.487, 7.4868 Accept use of π = 3.14
	(e)			**1**	

MARKS DO NOT WRITE IN THIS MARGIN

7. The emission spectrum from a mercury vapour lamp includes a spectral line corresponding to photons of frequency 1.18×10^{15} Hz.

In practice, the spectral line is produced by photons with a range of frequencies Δf. This results in a spectral line of width $\Delta\lambda$, as shown in **Figure 7A**.

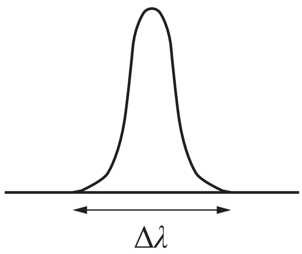


Figure 7A

The width of this spectral line can be explained using the Heisenberg uncertainty principle.

(a) (i) State what is meant by the *Heisenberg uncertainty principle*. **1**

(ii) The range of photon frequencies is due to the uncertainty in photon energy ΔE.

The uncertainty in the photon energy can be determined from the lifetime of the electron Δt in the excited state.

The lifetime of an electron in this excited state is 1.2×10^{-13} s.

Determine the minimum uncertainty in the photon energy. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

7. (a) (continued)

(iii) Determine the minimum uncertainty in the frequency of the emitted photon. **3**

Space for working and answer

(b) The width of the spectral line can be calculated using the relationship

$$\Delta\lambda = \frac{c\Delta f}{f^2}$$

where $\Delta\lambda$ is the width of the spectral line in metres

Δf is the minimum uncertainty in the frequency of the emitted photon

and the other symbols have their usual meaning.

Calculate the width of the spectral line. **2**

Space for working and answer

Question			Expected response	Max mark	Additional guidance
7.	(a)	(i)	It is not possible to know the (precise/exact) position and the momentum of a quantum particle simultaneously. 1	1	Accept 'energy and lifetime' The precise/exact position of a (quantum) particle and its momentum cannot be known simultaneously Do not accept: accurate in place of precise
		(ii)	$\Delta E \Delta t \geq \frac{h}{4\pi}$ 1 $\Delta E_{(\min)} \times 1.2\times10^{-13} = \frac{6.63\times10^{-34}}{4\pi}$ 1 $\Delta E_{(\min)} = 4.4\times10^{-22}\,\text{J}$ 1	3	Accept: 4, 4.40, 4.397 Accept: $\Delta E_{\min}\Delta t = \frac{h}{4\pi}$ Do not accept as starting point: $\Delta E_{\min}\Delta t \geq \frac{h}{4\pi}$ or $\Delta E \Delta t = \frac{h}{4\pi}$ Do not accept as final answer: $\Delta E_{\min} \geq 4.4\times10^{-22}\,\text{J}$ or $\Delta E \geq 4.4\times10^{-22}\,\text{J}$ Ignore ± in final answer
		(iii)	$(\Delta)E = h(\Delta)f$ 1 $4.4\times10^{-22} = 6.63\times10^{-34}\times(\Delta)f$ 1 $(\Delta)f = 6.6\times10^{11}\,\text{Hz}$ 1	3	Or consistent with (b)(ii) Accept: 7, 6.64, 6.637 Ignore ± in final answer
	(b)		$\Delta\lambda = \frac{c\Delta f}{f^2}$ $\Delta\lambda = \frac{3.00\times10^{8}\times6.6\times10^{11}}{(1.18\times10^{15})^2}$ 1 $\Delta\lambda = 1.4\times10^{-10}\,\text{m}$ 1	2	Or consistent with (a)(iii) Accept: 1, 1.42,1.422

MARKS DO NOT WRITE IN THIS MARGIN

8. The Bohr model of the hydrogen atom states that the electron orbits the nucleus in discrete levels.

These levels correspond to quantised units of angular momentum.

(a) The radius of the orbit of the electron around the nucleus of the hydrogen atom is given by the relationship

$$r = \frac{n^2 h^2 \varepsilon_o}{\pi m_e e^2}$$

where the symbols have their usual meaning.

(i) Calculate the radius of the orbit of the electron when it is in the ground state ($n = 1$). **2**

Space for working and answer

(ii) Determine the de Broglie wavelength of the electron in this orbit. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

8. (continued)

(b) (i) By considering the centripetal force acting on the orbiting electron, show that the tangential speed v of the electron orbiting the nucleus at radius r is given by

$$v = \sqrt{\frac{Q_1 Q_2}{4\pi\varepsilon_0 rm}}$$

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

Space for working and answer

(ii) The electron now moves from the ground state to the orbit corresponding to $n = 2$.

State whether the tangential speed of the electron in this orbit is greater than, equal to or less than the tangential speed of the electron when it was in the ground state.

Justify your answer. **2**

[Turn over

Question			Expected response	Max mark	Additional guidance
8.	(a)	(i)	$r=\frac{n^2h^2\varepsilon_o}{\pi m_e e^2}$ $r=\frac{1^2\times(6.63\times10^{-34})^2\times8.85\times10^{-12}}{\pi\times9.11\times10^{-31}\times((-)1.60\times10^{-19})^2}$ 1 $r=5.31\times10^{-11}$ m 1	2	Accept: 5.3, 5.310, 5.3096 Accept use of π = 3.14
		(ii)	$\left.\begin{matrix}\lambda=\frac{h}{p}\\ p=mv\\ mvr=\frac{nh}{2\pi}\end{matrix}\right\}$ 1 $\left(2\pi r=\frac{nh}{mv}=n\lambda\right)$ $(n\lambda=2\pi r)$ $1\times\lambda=2\times\pi\times5.31\times10^{-11}$ 1 $\lambda=3.34\times10^{-10}$ m 1	3	Or consistent with (a)(i) Accept: 3.3, 3.336, 3.3364 Accept: (When n = 1, $\lambda=2\pi r$) $\lambda=2\pi r$ 1 $\lambda=2\pi\times5.31\times10^{-11}$ 1 $\lambda=3.34\times10^{-10}$ m 1 Accept use of π = 3.14
	(b)	(i)	$(F_e=F_c)$ $\frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}=\frac{mv^2}{r}$ 1,1 $v=\sqrt{\frac{Q_1Q_2}{4\pi\varepsilon_0 rm}}$	2	SHOW question 1 mark for both relationships 1 mark for equating Final line must be shown or max 1 mark

Question			Expected response	Max mark	Additional guidance
8.	(b)	(ii)	Speed is less. **1** since radius increases (by 4 times) and all other variables remain constant $v = \sqrt{\dfrac{Q_1 Q_2}{4\pi\varepsilon_0 rm}}$ **1** **OR** $v^2 \propto \dfrac{1}{r}$ **1** **OR** $v \propto \dfrac{1}{\sqrt{r}}$ **1**	**2**	JUSTIFY question Alternatively Speed is less. **1** In 2nd orbit (n = 2). This corresponds to 2 de Broglie wavelengths $\lambda\left(=\dfrac{h}{p}\right)=\dfrac{h}{mv}$ Wavelength is doubled, (velocity must be halved.) **1**

DO NOT WRITE IN THIS MARGIN

9. A bubble chamber is used to detect sub-atomic particles.

The chamber is filled with a liquid. There is a uniform magnetic field within the chamber, as shown in **Figure 9A**.

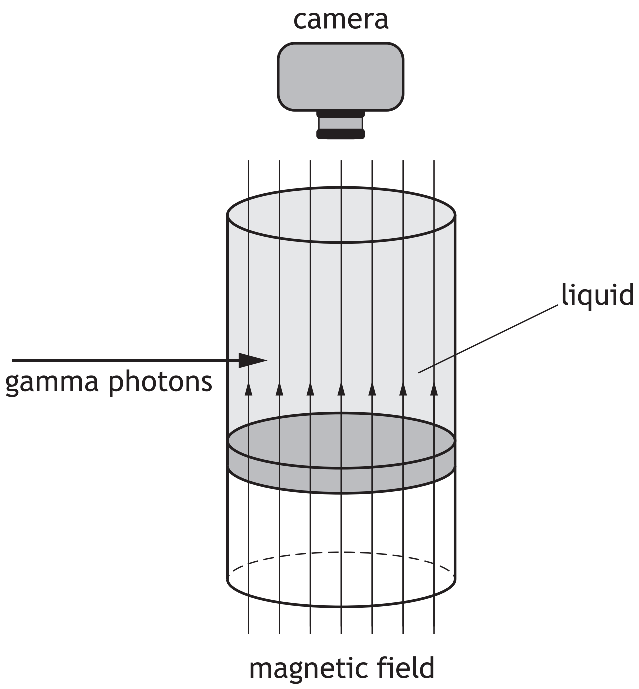


Figure 9A

A gamma photon enters the chamber and collides with an electron in an atom of the liquid. This electron is ejected from the atom. An electron-positron pair is also produced.

Figure 9B shows the incident gamma photon and the path of the particles following the collision.

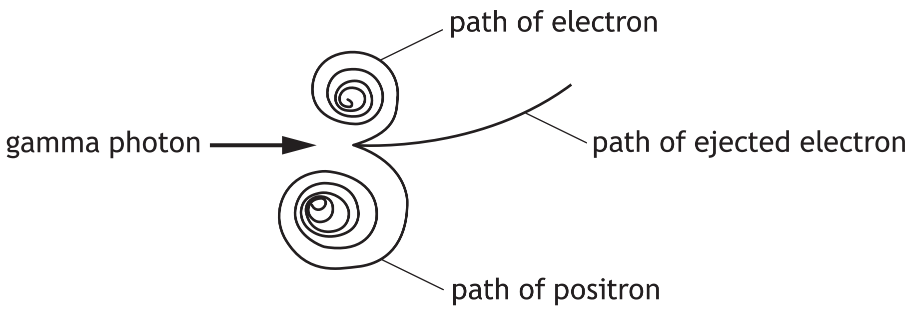


Figure 9B

The magnetic induction B in the bubble chamber is 2.20×10^{-2} T.

The initial radius of the path of the positron is 1.50×10^{-3} m.

* X 8 5 7 7 7 0 1 2 6 *

MARKS DO NOT WRITE IN THIS MARGIN

9. (continued)

(a) (i) The initial radius of the path of the positron is determined using the relationship

$$r = \frac{mv}{qB}$$

Calculate the initial speed of the positron. **2**

Space for working and answer

(ii) Explain why the radius of the path of the positron decreases. **1**

(iii) Explain the two differences between the path followed by the **ejected** electron and the path followed by the positron. **2**

MARKS DO NOT WRITE IN THIS MARGIN

9. (continued)

(b) Some of the energy of the gamma photon is required to produce the electron-positron pair. The remaining energy is converted to kinetic energy of the three particles.

The table shows these energies.

Energy required for production of electron-positron pair	1.02 MeV
Initial kinetic energy of produced positron	95.6 eV
Initial kinetic energy of produced electron	34.4 eV
Initial kinetic energy of ejected electron	1.70 MeV

Determine the frequency of the incident gamma photon. **4**

Space for working and answer

Question			Expected response	Max mark	Additional guidance
9.	(a)	(i)	$r=\frac{mv}{qB}$ $1.50\times10^{-3}=\frac{9.11\times10^{-31}\times v}{1.60\times10^{-19}\times2.20\times10^{-2}}$ 1 $v=5.80\times10^{6}\ \text{ms}^{-1}$ 1	**2**	Accept: 5.8, 5.796, 5.7958
		(ii)	Loses energy through radiation/to the liquid	**1**	Accept: velocity/speed decreases and m, q, B are unchanged **OR** accelerating charges radiate energy
		(iii)	(Ejected) electron follows a path with a much larger radius because it is moving faster. **1** Opposite curvature/direction/sense due to opposite charge. **1**	**2**	
	(b)		$E=\left(1.02\times10^{6}+95.6+34.4+1.70\times10^{6}\right)$ $\times1.60\times10^{-19}$ 1 $E=hf$ 1 $\left(1.02\times10^{6}+95.6+34.4+1.70\times10^{6}\right)$ $\times1.60\times10^{-19}=6.63\times10^{-34}\times f$ 1 $f=6.56\times10^{20}\ \text{Hz}$ 1	**4**	Accept: 6.6, 6.564, 6.5644 Initial kinetic energy of produced pair can be ignored: $E=\left(1.02\times10^{6}+1.70\times10^{6}\right)\times1.60\times10^{-19}$ 1 $E=hf$ 1 $\left(1.02\times10^{6}+1.70\times10^{6}\right)$ $\times1.60\times10^{-19}=6.63\times10^{-34}\times f$ 1 $f=6.56\times10^{20}\ \text{Hz}$ 1 Accept: 6.6, 6.564, 6.5641 Conversion can be demonstrated using $W=QV$

MARKS DO NOT WRITE IN THIS MARGIN

10. A loudspeaker consists of a coil of wire, attached to a cone, which is free to move in the field produced by a permanent magnet.

A simplified diagram of the loudspeaker is shown in **Figure 10A**.

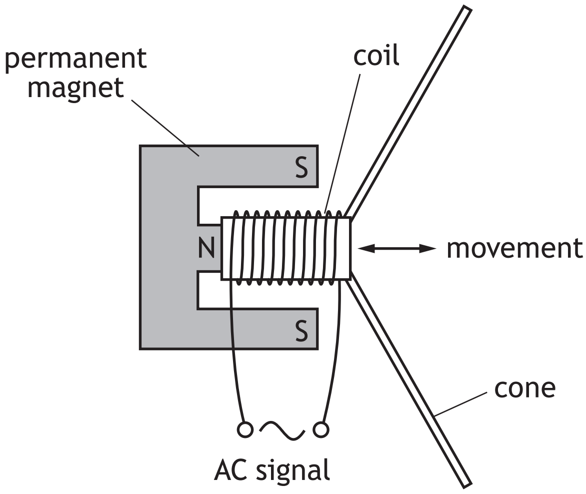


Figure 10A

The coil and cone oscillate when an AC signal is supplied to the coil.

The oscillation of the coil and cone can be modelled as simple harmonic motion.

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

(b) An AC signal supplied to the coil has a frequency of 55.1 Hz.

(i) Show that the angular frequency of the coil and cone is 346 rad s^{-1}. **2**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

10. (b) (continued)

(ii) The amplitude of the oscillation of the coil and cone is 8.24 mm.

Calculate the maximum acceleration of the coil and cone. **3**

Space for working and answer

(c) A magnetic force acts on the coil when there is current in the coil.

The following information is taken from the loudspeaker data sheet.

mass of coil and cone m	0.177 kg
magnetic induction B	1.10 T
length of conductor in coil l	21.8 m

By considering the magnetic force acting on the coil, determine the minimum current required to produce the maximum acceleration of the coil and cone. **4**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

10. (continued)

(d) The loudspeaker produces a sound wave.

The sound wave is described by the relationship

$$y = 8.24 \times 10^{-3} \sin 2\pi \left(55.1t - \frac{x}{6.00} \right)$$

Calculate the speed of the sound wave. **3**

Space for working and answer

(e) The amplitude of the sound wave is now reduced, and the energy of the wave decreases to 25% of its original value.

Determine the new amplitude of the sound wave. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

10. (continued)

(f) Critical damping is used in the operation of the loudspeaker.

The AC signal is turned off when the cone is at its maximum amplitude.

The coil and cone undergo critical damping and return to the equilibrium position.

On **Figure 10B**, sketch a graph showing how the displacement of the coil and cone varies with time during critical damping.

Numerical values are not required on either axis. **1**

(*An additional graph, if required, can be found on page 54.*)

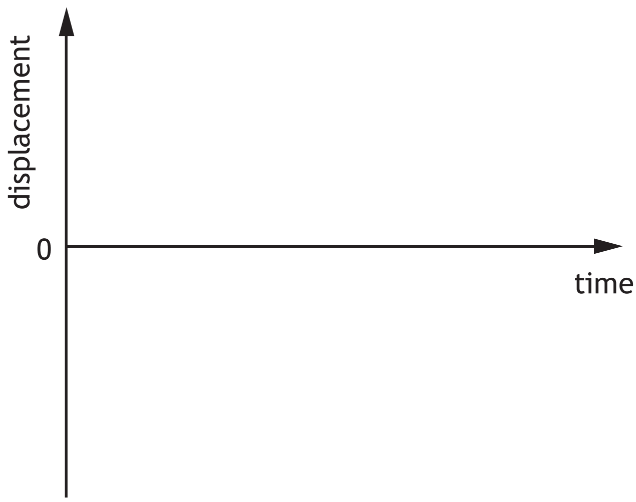
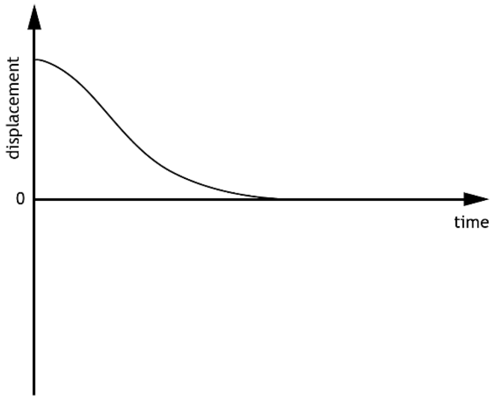


Figure 10B

[Turn over

Question			Expected response		Max mark	Additional guidance
10.	(a)		(motion caused by) unbalanced force/acceleration (directly) proportional to and in the opposite direction to the displacement (of a particle).		1	Accept: $F=-ky$ or equivalent Accept answer in terms of displacement is (directly) proportional to the restoring force. Do not accept force is (directly) proportional to displacement without reference to direction.
	(b)	(i)	$\omega = 2\pi f$ $\omega = 2\pi \times 55.1$ $\omega = 346$ rads^{-1}	1 1	2	SHOW question Accept use of π = 3.14
		(ii)	$a=(-)\omega^2 y$ $a_{(\max)}=(-)346^2\times 8.24\times 10^{-3}$ $a_{(\max)}=(-)986$ ms^{-2}	1 1 1	3	Accept: 990, 986.5, 986.46 Accept as starting point: $a=(-)\omega^2 A$ Accept determination of a using calculus methods
	(c)		$(F=)\,IlB=ma$ $I\times 21.8\times 1.10=0.177\times 986$ $I=7.28$ A	1,1 1 1	4	Or consistent with (b) Accept:7.3, 7.278, 7.2778 1 mark both relationships 1 mark equating
	(d)		$v=f\lambda$ $v=55.1\times 6.00$ $v=331$ ms^{-1}	1 1 1	3	Accept: 330, 330.6, 330.60
	(e)		$E=kA^2$ $k=\dfrac{E}{\left(8.24\times 10^{-3}\right)^2}=\dfrac{0.25E}{A_2^2}$ $A_2=4.12\times 10^{-3}$ m	1 1 1	3	Accept: 4.1, 4.120, 4.1200 $\dfrac{E_1}{A_1^2}=\dfrac{E_2}{A_2^2}$ 1 $\dfrac{E}{\left(8.24\times 10^{-3}\right)^2}=\dfrac{0.25E}{A_2^2}$ 1 $A_2=4.12\times 10^{-3}$ m 1

Question			Expected response	Max mark	Additional guidance
10.	(f)			**1**	Line must be a curve decreasing from maximum and reaching zero. Do not accept an exponential decay curve. Do not accept ¼ of cos curve. Line should not cross the x-axis.

DO NOT WRITE IN THIS MARGIN

11. A special type of lamp produces a cold, visible light beam.

The lamp consists of a light source and a glass reflector. The light source produces both visible and infrared radiation. The reflector reflects visible light.

The infrared radiation is emitted from the back of the reflector.

A cross section of the lamp is shown in **Figure 11A**.

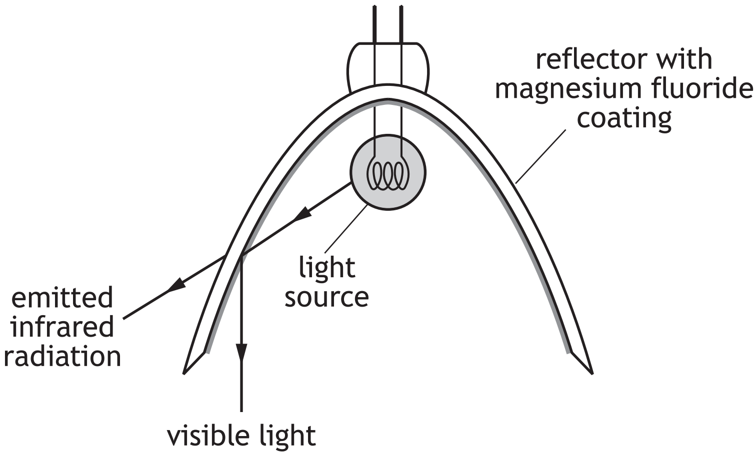


Figure 11A

The inside of the reflector is coated with a thin film of magnesium fluoride, which is non-reflecting for infrared radiation.

The refractive index of magnesium fluoride is 1.38 for infrared radiation.

The refractive index of glass is 1.50 for infrared radiation.

A diagram of a section of the reflector is shown in **Figure 11B**.

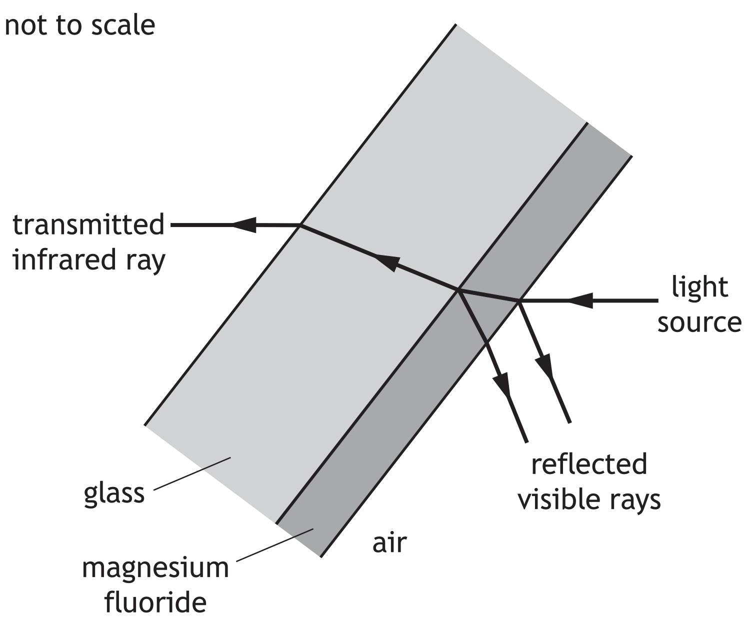


Figure 11B

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11. (continued)

(a) State the phase change, in radians, experienced by the visible light reflected from:

(i) the air-magnesium fluoride boundary **1**

(ii) the magnesium fluoride-glass boundary. **1**

(b) The peak wavelength of infrared radiation emitted from the light source is 967 nm.

Calculate the minimum thickness of magnesium fluoride required to ensure maximum transmission of infrared radiation of this wavelength into the glass. **3**

Space for working and answer

[Turn over

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11. (continued)

(c) Protective glass is placed in front of the lamp. This glass also has a thin film coating of magnesium fluoride, as shown in **Figure 11C**.

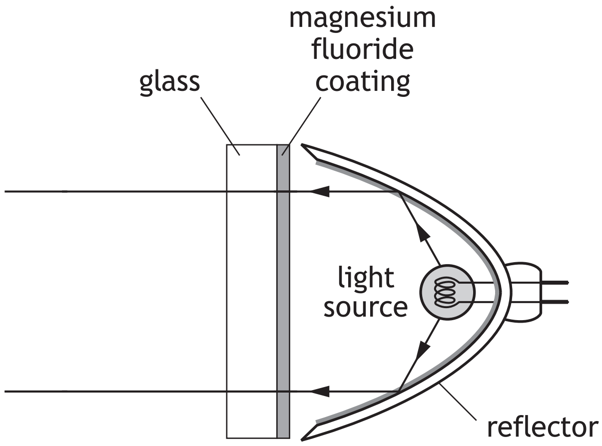


Figure 11C

The thin film allows maximum transmission of light of wavelength 550 nm through the protective glass.

The percentage of light transmitted through the protective glass for wavelengths across the range 400 nm – 850 nm is shown in **Figure 11D**.

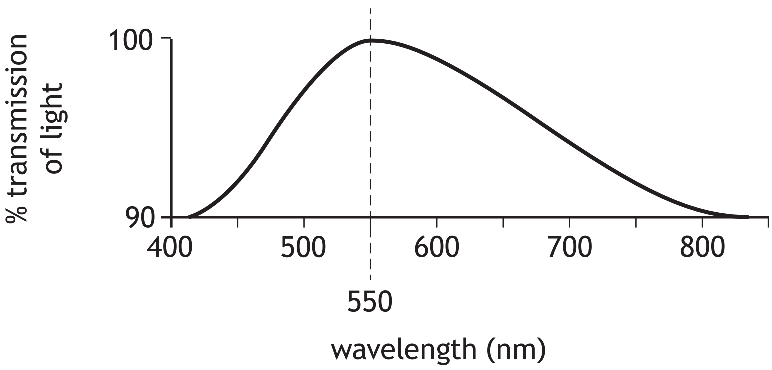


Figure 11D

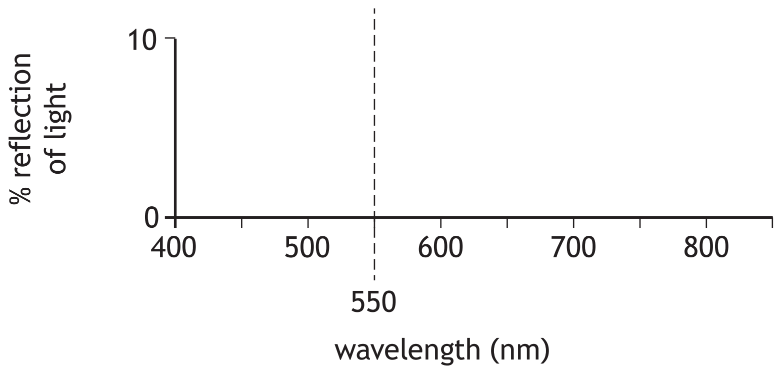
MARKS DO NOT WRITE IN THIS MARGIN

11. (c) (continued)

(i) On **Figure 11E**, draw a line showing the percentage of light **reflected** from the protective glass across this range of wavelengths. **1**

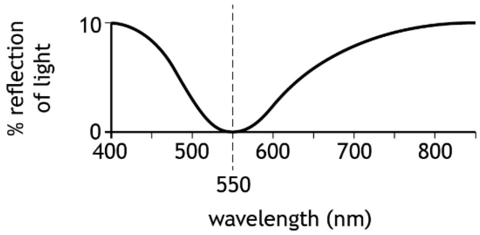
(An additional diagram, if required, can be found on page 55.)

Figure 11E



(ii) Explain why the protective glass has a purple tint when reflected light from the surface of the glass is viewed. **1**

[Turn over

Question			Expected response	Max mark	Additional guidance
11.	(a)	(i)	π (rad)	**1**	Unit not required but, if given, must be correct.
		(ii)	π (rad)	**1**	Unit not required but, if given, must be correct.
	(b)		$d = \frac{\lambda}{4n}$ 1 $d = \frac{967 \times 10^{-9}}{4 \times 1.38}$ 1 $d = 1.75 \times 10^{-7}$ m 1	**3**	Accept: 1.8, 1.752, 1.7518
	(c)	(i)		**1**	Decrease from maximum (10%) at both ends of spectrum. Minimum (0%) at 550 nm.
		(ii)	(Reflected) red and violet light mix/combine (to give a purple tint).	**1**	Accept blue/indigo for violet. Suggestion of purple being single colour/wavelength (0 marks)

MARKS DO NOT WRITE IN THIS MARGIN

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

(b) Unpolarised monochromatic light is incident on a glass block of refractive index n, at an angle i_p. This is shown in **Figure 12A**.

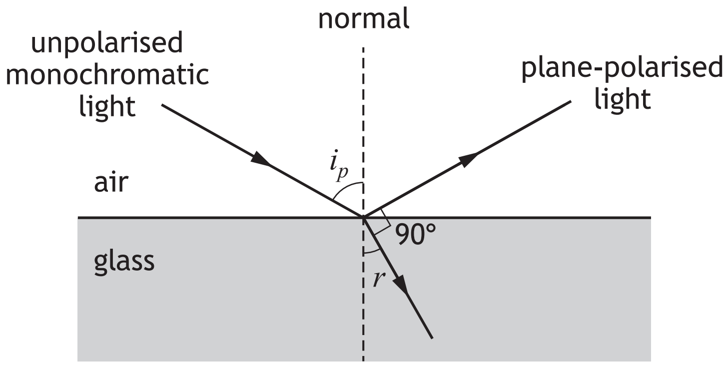


Figure 12A

Some of the light is refracted into the glass and the remaining light is reflected. The reflected light is plane-polarised.

Derive the relationship

$$n = \tan i_p$$

where i_p is Brewster's angle. **3**

Space for working and answer

12. (continued)

MARKS DO NOT WRITE IN THIS MARGIN

(c) Sunlight can be plane-polarised when it is reflected from water.

A tram driver wears polarising sunglasses to reduce the glare from reflected sunlight. After a rain shower, sunlight is reflected from the surface of a puddle of water towards the tram. This is shown in **Figure 12B**.

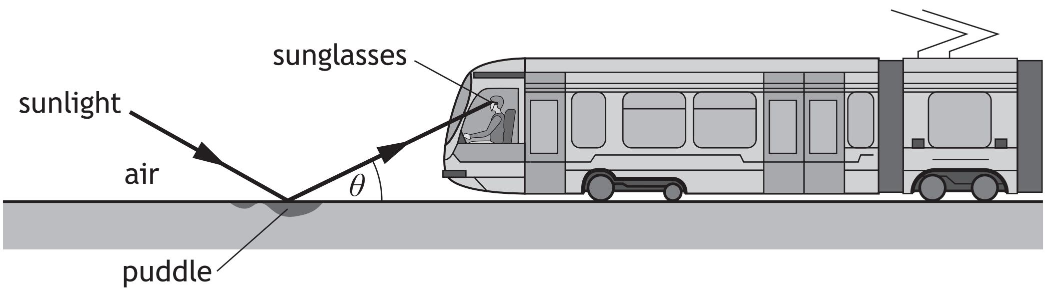


Figure 12B **not to scale**

(i) Determine the angle θ at which the sunlight reflected from the water surface is plane-polarised. **3**

Space for working and answer

(ii) By considering the transmission axis of the driver's sunglasses, explain why the sunglasses reduce glare from the puddle of water. **1**

(d) The tram driver observes a rainbow in the sky while still wearing polarising sunglasses. The driver notices that both ends of the rainbow are bright, but the brightness gradually decreases towards the highest point of the rainbow.

Explain why the brightness of the rainbow varies as described. **2**

Question			Expected response	Max mark	Additional guidance
12.	(a)		(The electric field vector) oscillates (or vibrates) in one plane only.	**1**	Do not accept: travels instead of oscillates **OR** direction instead of plane **OR** axis instead of plane
	(b)		$n = \frac{\sin\theta_1}{\sin\theta_2}$ 1 $n = \frac{\sin i_p}{\sin(90 - i_p)}$ 1 $n = \frac{\sin i_p}{\cos i_p}$ 1 $n = \tan i_p$	**3**	Derive question If final line is missing then max 2. Alternative starting point: $n = \frac{\sin i}{\sin r}$ Must include a statement of Snell's law else zero marks
	(c)	(i)	$(n = \tan i_p)$ $1.33 = \tan i_p$ 1 $\theta = 90 - (\tan^{-1}(1.33))$ 1 $\theta = 36.9°$ 1	**3**	Accept: 37, 36.94, 36.939
		(ii)	Transmission axis of the driver's sunglasses is perpendicular/not parallel to the plane of the polarised reflected light. (This absorbs/blocks the reflected plane polarised light.)	**1**	
	(d)		Light from a rainbow is (plane) polarised 1 The plane of the (plane) polarised light gradually changes (from vertical to horizontal.) 1	**2**	Answer must be in terms of a gradual change. Digital change max 1.

MARKS DO NOT WRITE IN THIS MARGIN

13. A polar molecule is positively charged at one side and negatively charged at the other side.

One polar molecule can be modelled as two point charges connected together and separated by a fixed distance of 1.33×10^{-10} m. This is shown in **Figure 13A**.

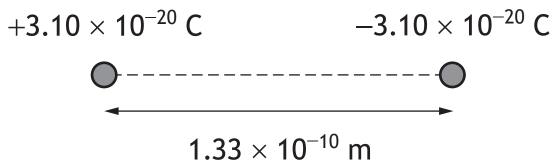


Figure 13A

(a) Point P is 2.10×10^{-10} m to the right of the negative charge as shown in **Figure 13B**.

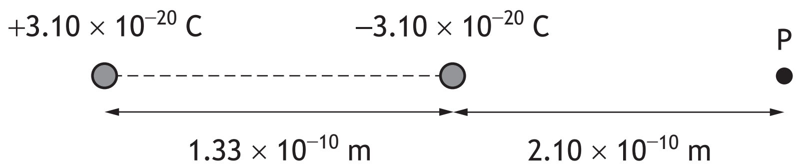


Figure 13B

Determine the electric potential at point P due to both charges. **4**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

13. (continued)

(b) The charges in this model of the polar molecule produce an electric field.

On **Figure 13C**, sketch the electric field pattern of this model. **2**

(*An additional diagram, if required, can be found on page 55.*).

Figure 13C

[Turn over

MARKS DO NOT WRITE IN THIS MARGIN

13. (continued)

(c) Liquid crystal displays use polar molecules placed in external electric fields.

A polar molecule is in a uniform electric field of strength 2550 $N\,C^{-1}$. This arrangement is shown in **Figure 13D.**

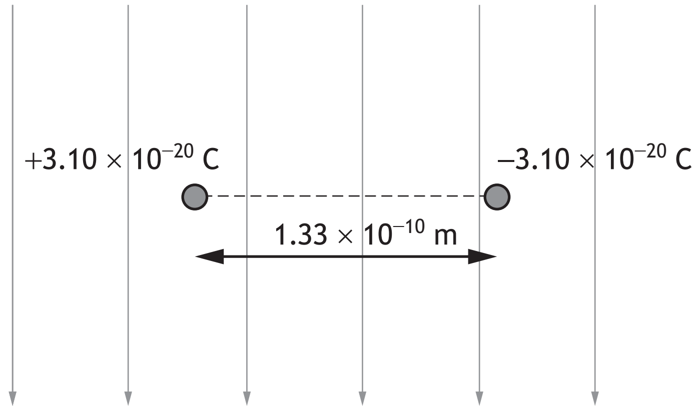


Figure 13D

Each charge experiences a force due to the electric field.

(i) Calculate the magnitude of the force acting on one of the charges. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

13. (c) (continued)

(ii) The force acting on each charge causes the molecule to rotate about an axis of rotation midway between the charges. The axis of rotation is out of the page.

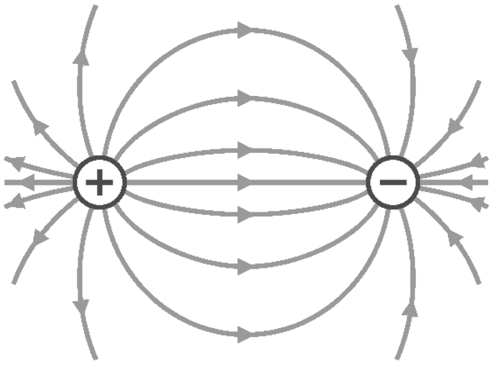
(A) Determine the initial magnitude of the resultant torque acting on the polar molecule. **4**

Space for working and answer

(B) The polar molecule rotates from its starting position shown in **Figure 13D**.

State whether the unbalanced torque increases, remains the same or decreases as the polar molecule rotates through 90°.

Justify your answer. **2**

Question			Expected response	Max mark	Additional guidance
13.	(a)		$V = \frac{Q}{4\pi\varepsilon_0 r}$ 1 $V_1 = \frac{3.10\times10^{-20}}{4\pi\times8.85\times10^{-12}\times(1.33\times10^{-10}+2.10\times10^{-10})}$ 1 $V_2 = \frac{-3.10\times10^{-20}}{4\pi\times8.85\times10^{-12}\times2.10\times10^{-10}}$ 1 $(V = V_1 + V_2)$ $V = -0.515$ V 1	4	Accept: 0.51, 0.5147, 0.51469 For 9×10^9: Accept: 0.52, 0.5152, 0.51516
	(b)			2	1 mark for arrow direction 1 mark for pattern that has no field lines crossing If no attempt at an attractive field pattern zero marks
	(c)	(i)	$F = QE$ 1 $F = 3.10\times10^{-20}\times2550$ 1 $F = 7.91\times10^{-17}$ N 1	3	Accept: 7.9, 7.905, 7.9050
		(ii) (A)	$\tau = Fr$ 1 $\tau = \left(7.91\times10^{-17}\times\frac{1.33\times10^{-10}}{2}\right)$ 1 $\tau_{resultant} = 2\times\left(7.91\times10^{-17}\times\frac{1.33\times10^{-10}}{2}\right)$ 1 $\tau_{resultant} = 1.05\times10^{-26}$ N m 1	4	Or consistent with (c)(i) Accept: 1.1, 1.052, 1.0520
		(B)	Decrease 1 The component of the force (perpendicular to the radius) decreases (for the same electric field strength) **OR** The component of the radius (perpendicular to the field) decreases (for the same electric field strength) 1	2	JUSTIFY

MARKS DO NOT WRITE IN THIS MARGIN

14. A student designs an experiment to determine the permeability of free space (μ_0) by measuring the magnetic induction around a current carrying wire.

The experimental setup is shown in **Figure 14A**.

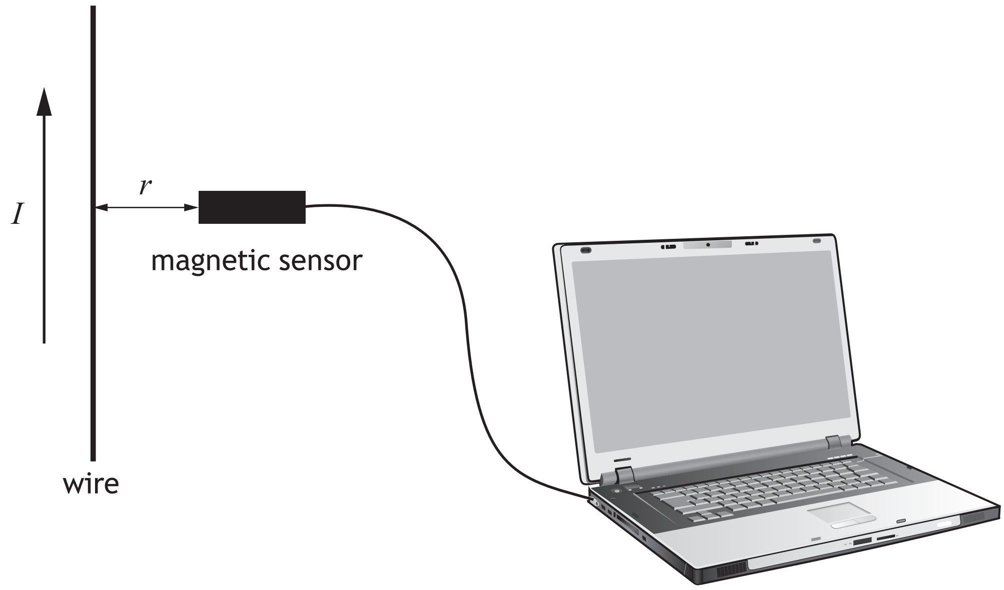


Figure 14A

The front of the magnetic sensor is positioned 0.010 m from the wire.

(a) The student tests the setup using a current of 1.2 A in the wire. The student measures the magnetic induction due to the current in the wire to be 27 μT.

Show that the value obtained for μ_0 is 1.4×10^{-6} H m^{-1}. **2**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

14. (continued)

(b) The current in the wire is now varied and the magnetic induction is measured using the magnetic sensor.

The data from the experiment are plotted on a graph using a spreadsheet package.

The graph is shown in **Figure 14B**.

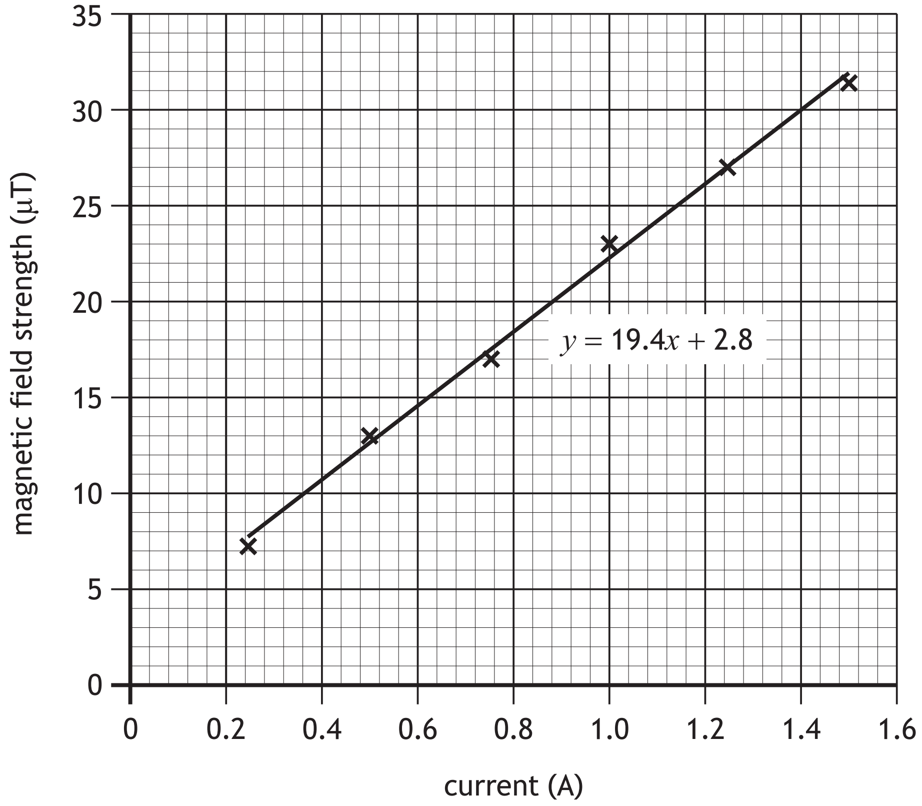


Figure 14B

(i) Using information from the graph, determine a value for μ_0. **3**

Space for working and answer

[Turn over

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

(ii) Explain why the student should have more confidence in the value obtained for μ_0 in (b) (i). **1**

(iii) Data from the graphing software are shown below.

Gradient	y-intercept
19.4	2.8
Uncertainty in gradient	Uncertainty in y-intercept
0.6	0.7

The uncertainty in the measurement of the distance from the front of the sensor to the wire is 0.0005 m.

Calculate the absolute uncertainty in the value of μ_0 obtained by the student in (b) (i). **3**

Space for working and answer

(iv) The line of best fit does not pass through the origin as theory predicts.

Suggest a source for this systematic uncertainty. **1**

Question			Expected response	Max mark	Additional guidance
14.	(a)		$B = \frac{\mu_0 I}{2\pi r}$ 1 $27\times10^{-6} = \frac{\mu_0 \times 1.2}{2\pi \times 0.010}$ 1 $\mu_0 = 1.4\times10^{-6}\ \text{Hm}^{-1}$	**2**	SHOW QUESTION
	(b)	(i)	$\text{Gradient} = 19.4\times10^{-6}$ 1 $\left(B = \frac{\mu_0 I}{2\pi r}\right)$ $19.4\times10^{-6} = \frac{\mu_0}{2\pi \times 0.010}$ 1 $\mu_0 = 1.2\times10^{-6}\ \text{Hm}^{-1}$ 1	**3**	Accept: 1, 1.22, 1.219 Or consistent with calculated gradient <u>using two points on the line</u>
		(ii)	The data are taken over a range	**1**	Accept calculation for part (a) only uses one data point Allow mention of graph plotting as this implies a range of values
		(iii)	$\frac{\Delta W}{W} = \sqrt{\left(\frac{\Delta X}{X}\right)^2 + \left(\frac{\Delta Y}{Y}\right)^2 + \left(\frac{\Delta Z}{Z}\right)^2}$ 1 $\frac{\Delta \mu_0}{1.2\times10^{-6}} = \sqrt{\left(\frac{0.6\times10^{-6}}{19.4\times10^{-6}}\right)^2 + \left(\frac{0.0005}{0.010}\right)^2}$ 1 $\Delta\mu_0 = 7\times10^{-8}\ \text{Hm}^{-1}$ 1	**3**	Or consistent with (b)(i) Accept: 7.1, 7.06 Accept use of method involving the calculation of percentage uncertainties Suspend sig figs rule
		(iv)	<u>Measurement</u> of magnetic induction (too large) **OR** <u>Measurement</u> of current (too small)	**1**	Accept reference to the Earth's magnetic field/external magnetic field Any indication of direction must be correct

MARKS DO NOT WRITE IN THIS MARGIN

15. A technician designs a circuit that will make a neon lamp flash. This circuit is shown in **Figure 15A**.

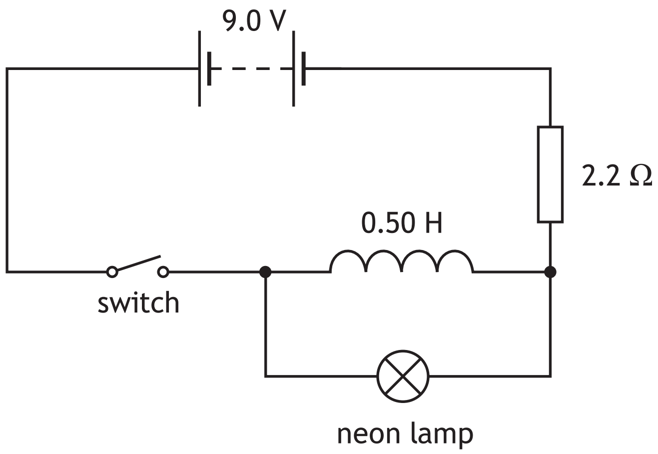


Figure 15A

The inductor has an inductance of 0.50 H and negligible resistance.

(a) The switch is closed and a back EMF is induced.

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

(b) In the inductor circuit, the time constant τ is the time taken for the current to reach 63% of the maximum value.

The time constant is given by the relationship

$$\tau = \frac{L}{R}$$

(i) Calculate the time constant for the circuit. **2**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

15. (b) (continued)

(ii) The back EMF across the inductor varies with time from the instant the switch is closed. This is shown on the graph in **Figure 15B**.

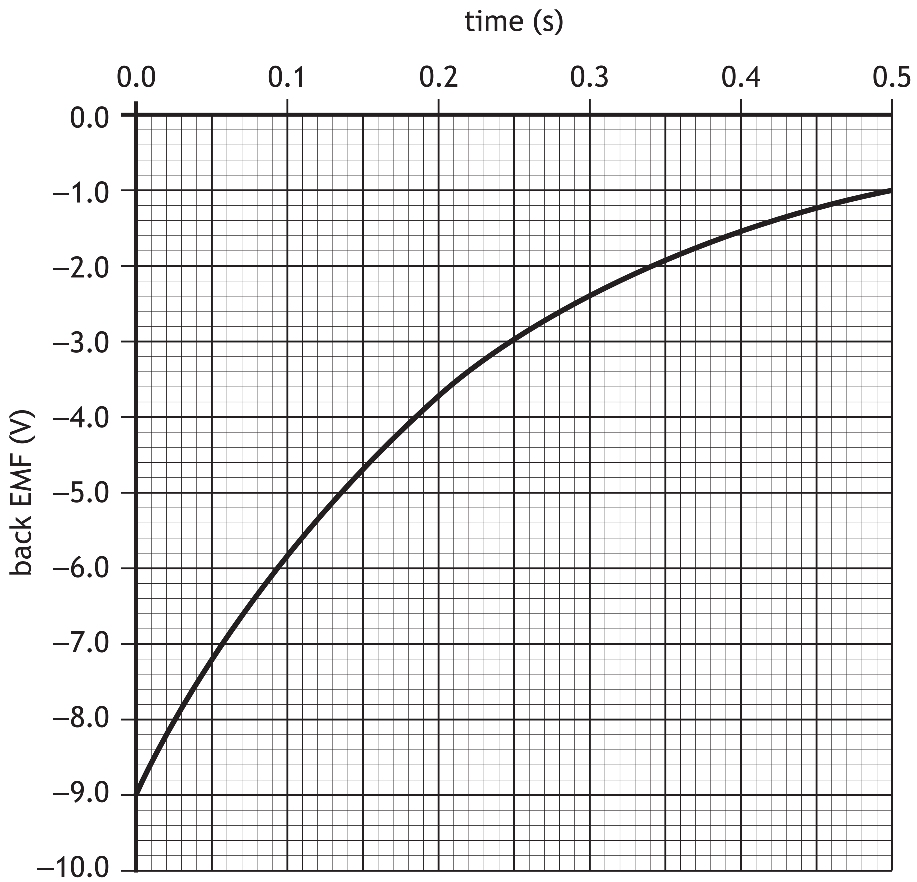


Figure 15B

Determine the rate of change of current in the circuit after one time constant. **4**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

15. (continued)

(c) The neon lamp requires a potential difference of 80 V to conduct.

The switch is opened and the neon lamp flashes.

By considering the magnetic field around the inductor, explain why the back EMF produced is large enough to allow the neon lamp to flash. **1**

(d) The switch is replaced by an automatic switch.

This switch is closed. After **five time constants** the switch opens automatically. The neon lamp flashes immediately when the switch opens and then the switch closes again. This cycle repeats and the neon lamp flashes at regular intervals.

(i) Determine the frequency at which the neon lamp flashes. **2**

Space for working and answer

(ii) The technician increases the inductance of the inductor and keeps all other components the same.

State whether the frequency of the flashes will increase, stay the same or decrease.

You must justify your answer. **2**

[Turn over

Question			Expected response	Max mark	Additional guidance
15.	(a)		Changing current produces a changing magnetic field (which induces a back EMF in the inductor).	**1**	
	(b)	(i)	$\tau = \frac{L}{R}$ $\tau = \frac{0.50}{2.2}$ 1 $\tau = 0.23$ s 1	**2**	Accept: 0.2, 0.227, 0.2273
		(ii)	$\varepsilon = -L\frac{dI}{dt}$ 1 $-3.2 = -0.50 \times \frac{dI}{dt}$ 1,1 $\frac{dI}{dt} = 6.4$ A s^{-1} 1	**4**	Accept: 6, 6.40, 6.400 Or consistent with (b) (i) 1 mark for value from graph 1 mark for substitutions For $\tau = 0.23$ accept a range of values for ε of -3.2 to -3.3 from the graph. If 63% is used accept ε = -3.33
	(c)		magnetic field collapses **OR** rapid change in current/large $\frac{dI}{dt}$ (induces a large back EMF of greater than 80 V)	**1**	
	(d)	(i)	$\left(T = \frac{1}{f}\right)$ $5 \times 0.23 = \frac{1}{f}$ 1 $f = 0.87$ Hz 1	**2**	Accept: 0.9, 0.870, 0.8696 Or consistent with (b) (i)
		(ii)	Frequency decreases 1 (Increase inductance) increases the time constant 1	**2**	MUST JUSTIFY Justification in terms of reactance zero marks.

MARKS DO NOT WRITE IN THIS MARGIN

16. It is suggested that, around the year 1900, Lord Kelvin stated there was nothing new left to be discovered in physics and all that remained was more and more precise measurement.

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

MARKS DO NOT WRITE IN THIS MARGIN

16. (continued)

[END OF QUESTION PAPER]

Question			Expected response	Max mark	Additional guidance
16.			**Award 3 marks** where the candidate has demonstrated a good understanding of the physics involved. They show a good comprehension of the physics of the situation and provide a logically correct answer to the question posed. This type of response might include a statement of the principles involved, a relationship or an equation, and the application of these to respond to the problem. The answer does not need to be 'excellent' or 'complete' for the candidate to gain full marks. **Award 2 marks** where the candidate has demonstrated a reasonable understanding of the physics involved. They make some statement(s) that are relevant to the situation, showing that they have understood the problem. **Award 1 mark** where the candidate has demonstrated a limited understanding of the physics involved. They make some statement(s) that are relevant to the situation, showing that they have understood at least a little of the physics within the problem. **Award 0 marks** where the candidate has not demonstrated an understanding of the physics involved. There is no evidence that they have recognised the area of physics involved, or they have not given any statement of a relevant physics principle. Award this mark also if the candidate merely restates the physics given in the question.	3	Candidates may use a variety of physics arguments to answer this question. Award marks based on candidates demonstrating overall good, reasonable, limited, or no understanding.

[END OF MARKING INSTRUCTIONS]

FOR OFFICIAL USE

AH National Qualifications 2024

Mark

X857/77/01 Physics

THURSDAY, 25 APRIL

9:00 AM – 12:00 NOON

* X 8 5 7 7 7 0 1 *

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.

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

DATA SHEET

COMMON PHYSICAL QUANTITIES

Quantity	Symbol	Value	Quantity	Symbol	Value
Gravitational acceleration on Earth	g	9.8 m s^{-2}	Mass of electron	m_e	9.11×10^{-31} kg
Radius of Earth	R_E	6.4×10^6 m	Charge on electron	e	-1.60×10^{-19} C
Mass of Earth	M_E	6.0×10^{24} kg	Mass of neutron	m_n	1.675×10^{-27} kg
Mass of Moon	M_M	7.3×10^{22} kg	Mass of proton	m_p	1.673×10^{-27} kg
Radius of Moon	R_M	1.7×10^6 m	Mass of positron	m_{e^+}	9.11×10^{-31} kg
Mean Radius of Moon Orbit		3.84×10^8 m	Charge on positron	e^+	1.60×10^{-19} C
Solar radius		6.955×10^8 m	Charge on copper nucleus		4.64×10^{-18} C
Mass of Sun		2.0×10^{30} kg	Planck's constant	h	6.63×10^{-34} J s
Mass of Mars	M_{Mars}	6.42×10^{23} kg	Permittivity of free space	ε_0	$8.85 \times 10^{-12} \text{ F m}^{-1}$
Radius of Mars	R_{Mars}	3.39×10^6 m	Permeability of free space	μ_0	$4\pi \times 10^{-7} \text{ H m}^{-1}$
1 AU		1.5×10^{11} m	Speed of light in vacuum	c	$3.00 \times 10^8 \text{ m s}^{-1}$
Stefan-Boltzmann constant	σ	$5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$	Speed of sound in air	v	$3.4 \times 10^2 \text{ m s}^{-1}$
Universal constant of gravitation	G	$6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$			

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	2.70×10^3	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	4.18×10^3	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.

X857770102

Total marks — 155

Attempt ALL questions

MARKS | DO NOT WRITE IN THIS MARGIN

1. An electric car is travelling at a constant velocity.

The car then accelerates along a straight road.

The car starts accelerating at $t = 0$ s.

While accelerating, the velocity v of the car at time t is given by the relationship

$$v = 2.4 + 13t - 0.69t^2$$

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

Using calculus methods:

(a) determine the acceleration of the car at $t = 2.0$ s **3**

Space for working and answer

(b) determine the distance travelled by the car between $t = 0$ s and $t = 2.0$ s. **3**

Space for working and answer

Marking Instructions for each question

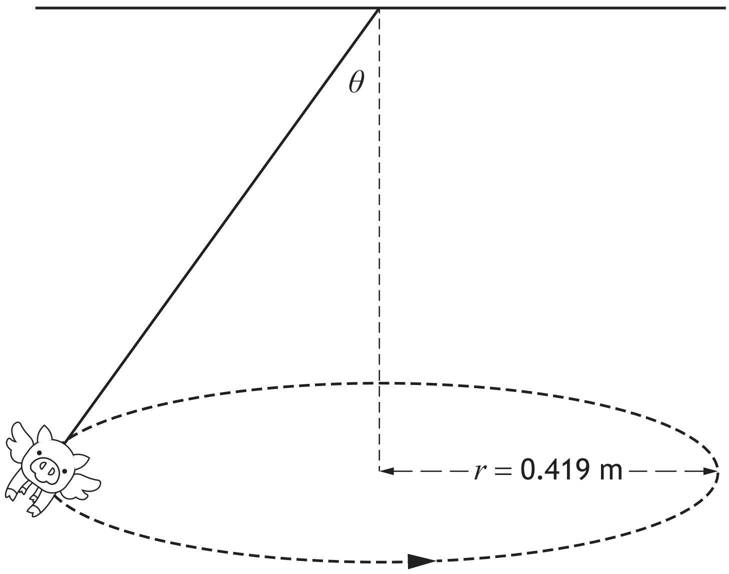
Question			Expected response	Max mark	Additional guidance
1.	(a)		$v = 2.4 + 13t - 0.69t^2$ $a = \frac{dv}{dt} = 13 - 1.38t$ **(1)** at t = 2.0 $a = 13 - (1.38 \times 2.0)$ **(1)** $a = 10\ \text{ms}^{-2}$ **(1)**	3	Accept: 10.2, 10.24
	(b)		$s = \left(\int v dt = \right)\ 2.4t + \frac{13}{2}t^2 - \frac{0.69}{3}t^3 (+c)$ **(1)** **(at t = 0, s = 0 $\therefore$ c = 0)** $s = (2.4 \times 2.0) + \left(\frac{13}{2} \times 2.0^2\right) - \left(\frac{0.69}{3} \times 2.0^3\right)$ **(1)** $s = 29$ **m** **(1)**	3	Accept: 30, 29.0, 28.96 Alternative limits method $\left(s = \int_0^2 (2.4 + 13t - 0.69t^2)\ dt\right)$ $s = \left[2.4t + \frac{13t^2}{2} - \frac{0.69t^3}{3}\right]_0^2$ **(1)** $s = \left(2.4 \times 2.0 + \frac{13 \times 2.0^2}{2} - \frac{0.69 \times 2.0^3}{3}\right)(-0)$ **(1)** $s = 29$ m **(1)**

MARKS DO NOT WRITE IN THIS MARGIN

2. The motion of a battery-powered flying toy pig can be modelled as a conical pendulum.

The pig has a mass of 0.230 kg and is attached to a ceiling with a thin string.

The pig is set in motion and moves in a horizontal circle of radius 0.419 m as shown in **Figure 2A**.



not to scale

Figure 2A

The pig has an angular velocity of 3.01 rad s^{-1}.

(a) Show that the tangential speed of the pig is 1.26 m s^{-1}. **2**

Space for working and answer

[Turn over

MARKS DO NOT WRITE IN THIS MARGIN

2. (continued)

(b) (i) On **Figure 2B**, show the forces acting on the pig as it travels at a constant speed in a horizontal circle.

You must name these forces and show their directions. **2**

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

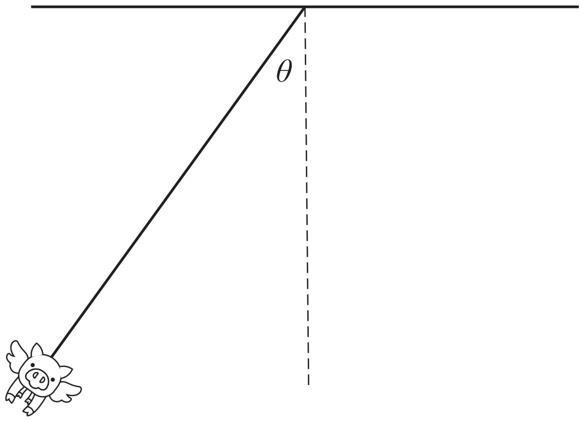


Figure 2B

(ii) By considering the effect of the forces acting on the pig, show that $\tan\theta$ is given by the relationship

$$\tan\theta = \frac{v^2}{gr}$$

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

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

2. (b) (continued)

(iii) Calculate the angle θ when the tangential speed is $1.26\ m\,s^{-1}$. **2**

Space for working and answer

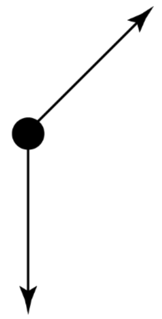
(c) The pig is battery powered to keep it moving in a horizontal circle. As the batteries run out, the tangential speed decreases.

State the effect this has on the angle θ.

You must justify your answer. **2**

[Turn over

<table>
<tr><th colspan="3">Question</th><th>Expected response</th><th>Max mark</th><th>Additional guidance</th></tr>
<tr><td>2.</td><td>(a)</td><td></td><td>$v = r\omega$ (1)
$v = 0.419 \times 3.01$ (1)
$v = 1.26\ \text{ms}^{-1}$</td><td>2</td><td>SHOW question

If final line is missing max 1.</td></tr>
<tr><td></td><td>(b)</td><td>(i)</td><td>
</td><td>2</td><td>Accept: mg or W for weight
Accept: T for tension
1 mark for each correctly labelled force with correct direction.

If centripetal force is shown correctly - ignore

If centripetal force is shown incorrectly – max 1 mark

Any mention of centrifugal force - award 0 marks</td></tr>
<tr><td></td><td></td><td>(ii)</td><td>$\left(T\sin\theta = \frac{mv^2}{r}\right.$ and $\left.T\cos\theta = mg\right)$
$\frac{T\sin\theta}{T\cos\theta} = \frac{\left(\frac{mv^2}{r}\right)}{mg}$ (1,1)
$\tan\theta = \frac{v^2}{gr}$</td><td>2</td><td>Not a standard show question

1 mark for both components of tension
1 mark for dividing

Accept:
$\left(\tan\theta = \frac{F_c}{W}\right)$
$\tan\theta = \frac{\left(\frac{mv^2}{r}\right)}{mg}$ (1, 1)
$\tan\theta = \frac{v^2}{gr}$

1 mark for both forces F_c and W
1 mark for dividing</td></tr>
<tr><td></td><td></td><td>(iii)</td><td>$\tan\theta = \frac{v^2}{gr}$
$\tan\theta = \frac{1.26^2}{9.8 \times 0.419}$ (1)
$\theta = 21°$ (1)</td><td>2</td><td>Accept: 20, 21.1, 21.14

Accept answers in radians</td></tr>
</table>

Question			Expected response	Max mark	Additional guidance
2.	(c)		θ decreases **(1)** (As $\tan\theta = \frac{v^2}{gr}$) v and r both decrease but <u>v is squared</u>. **(1)**	2	MUST JUSTIFY Accept: θ decreases W stays the same and F_c decreases

MARKS DO NOT WRITE IN THIS MARGIN

3. A wind turbine is used to generate electrical energy from the kinetic energy of the wind.

The wind turbine comprises a tower and a rotor assembly.

The rotor assembly consists of three identical blades attached to a central rotating hub as shown in **Figure 3A**.

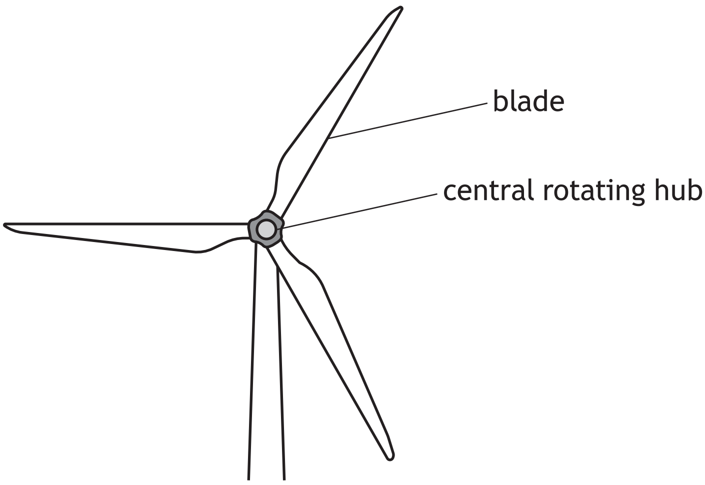


Figure 3A

Each blade has a mass of 2.0×10^4 kg and a length of 54 m. Each blade can be modelled as a solid rod rotating about its end.

The mass of the rotating hub is negligible compared to the mass of the blades.

(a) Show that the moment of inertia of the rotor assembly is 5.8×10^7 kg m^2. **2**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

3. (continued)

(b) When the wind speed reaches 25 m s^{-1}, the angular velocity of the rotor assembly is 3.7 rad s^{-1}.

At this velocity, brakes are applied to bring the rotor assembly to a stop.

The brakes apply a frictional torque on the rotor assembly.

The rotor assembly comes to rest in 550 s.

(i) Calculate the angular acceleration of the rotor assembly during this time. **3**

Space for working and answer

(ii) Calculate the magnitude of the unbalanced torque acting on the rotor assembly during this time. **3**

Space for working and answer

[Turn over

MARKS | DO NOT WRITE IN THIS MARGIN

3. (continued)

(c) In winter, ice forms on the rotor assembly, adding mass to the blades.

As the temperature rises, ice can be thrown from the blades.

(i) On the diagram shown in **Figure 3B**, show the direction of the **initial** velocity of a piece of ice thrown from the tip of a blade at the bottom of its circular path. **1**

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

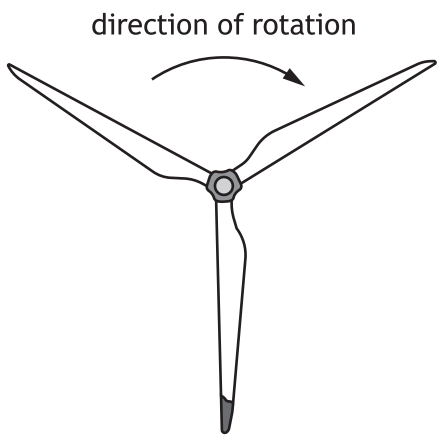


Figure 3B

(ii) As a result of the ice being thrown, mass is removed from the blades.

Explain why, despite this loss of mass, there is no observable change in the angular velocity of the rotor assembly. **1**

MARKS | DO NOT WRITE IN THIS MARGIN

3. (continued)

(d) The maximum power P generated by this wind turbine is given by the following relationship

$$P = 0.3\rho A v^3$$

where: ρ is the density of air = 1.29 kg m^{-3}

A is the area of the circle swept by the rotor assembly in m^2

v is the windspeed in m s^{-1}.

Calculate the maximum power generated when the windspeed is 11.5 m s^{-1}. **2**

Space for working and answer

[Turn over

Question			Expected response	Max mark	Additional guidance
3.	(a)		$I=\left(\frac{1}{3}ml^2\right)\times 3$ or $I=\left(\frac{1}{3}ml^2\right)$ **(1)** $I=\left(\frac{1}{3}\times 2.0\times 10^4\times 54^2\right)\times 3$ **(1)** $I=5.8\times 10^7$ kg m^2	**2**	SHOW question 1 for relationship 1 for all substitutions, including ×3 ×3 can appear at any stage of the calculation $I_{(blade)}=\left(\frac{1}{3}ml^2\right)$ $I_{(blade)}=\left(\frac{1}{3}\times 2.0\times 10^4\times 54^2\right)$ $I_{(total)}=\left(\frac{1}{3}\times 2.0\times 10^4\times 54^2\right)\times 3$ $I_{(total)}=5.8\times 10^7$ kg m^2
	(b)	(i)	$\omega=\omega_0+\alpha t$ **(1)** $0=3.7+(\alpha\times 550)$ **(1)** $\alpha=-6.7\times 10^{-3}$ rad s^{-2} **(1)**	**3**	Accept: −7, −6.73, −6.727
		(ii)	$\tau=I\alpha$ **(1)** $\tau=5.8\times 10^7\times(-)6.7\times 10^{-3}$ **(1)** $\tau=(-)3.9\times 10^5$ N m **(1)**	**3**	Accept: 4, 3.89, 3.886 Or consistent with (b)(i)
	(c)	(i)	←	**1**	
		(ii)	The mass of the ice is negligible.	**1**	Alternatives: Change in moment of inertia (of the system) is negligible.
	(d)		$P=0.3\rho Av^3$ $P=0.3\times 1.29\times\pi\times 54^2\times 11.5^3$ **(1)** $P=5.4\times 10^6$ W **(1)**	**2**	Accept: 5, 5.39, 5.392

MARKS DO NOT WRITE IN THIS MARGIN

4. The Double Asteroid Redirection Test (DART) was a recent NASA mission. It was designed to crash a spacecraft into an asteroid to deflect the asteroid from its path.

This was a test to see if a spacecraft could deflect an asteroid that is on a collision course with Earth.

The target of the DART spacecraft was the asteroid Dimorphos, which is in a circular orbit around a larger asteroid Didymos as shown in **Figure 4A**.

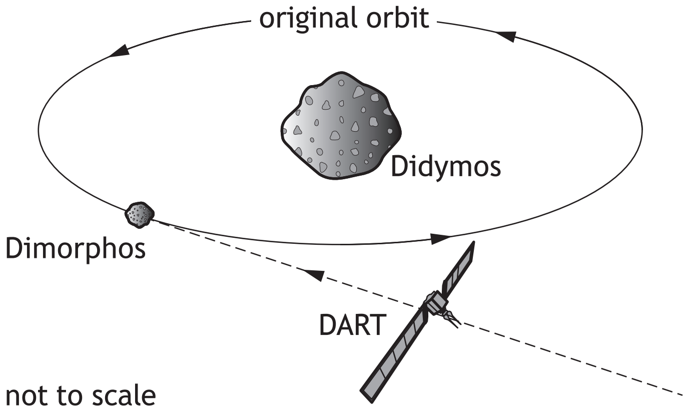


Figure 4A

The radius of orbit of Dimorphos is 1.2×10^3 m.

The period of orbit of Dimorphos is 11.9 hours.

(a) Calculate the mass of Didymos. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

4. (continued)

(b) The mission was planned so that the impact did not knock Dimorphos out of orbit around Didymos and put it on a collision course with Earth.

(i) Calculate the escape velocity from Didymos at the orbit of Dimorphos. **3**

Space for working and answer

(ii) The DART spacecraft collided with Dimorphos, which resulted in the period of orbit of Dimorphos around Didymos decreasing by 30 minutes.

Explain fully the change to the gravitational potential energy of Dimorphos as a result of this collision. **2**

(c) Asteroids on a potential collision course with Earth must be impacted at a large distance away from Earth.

Suggest why this impact must occur at a large distance in order to prevent a collision with Earth. **1**

[Turn over

Question			Expected response	Max mark	Additional guidance
4.	(a)		$\frac{GMm}{r^2} = mr\left(\frac{2\pi}{T}\right)^2$ (1) $\frac{6.67\times10^{-11}\times M}{\left(1.2\times10^3\right)^2} = 1.2\times10^3\left(\frac{2\pi}{11.9\times60\times60}\right)^2$ (1) $M = 5.6\times10^{11}$ kg (1)	3	Accept: 6, 5.57, 5.573 $\frac{GMm}{r^2} = mr\omega^2$ and $\omega = \frac{2\pi}{T}$ (1)
	(b)	(i)	$v = \sqrt{\frac{2GM}{r}}$ **(1)** $v = \sqrt{\frac{2\times6.67\times10^{-11}\times5.6\times10^{11}}{1.2\times10^3}}$ **(1)** $v = 0.25$ ms^{-1} **(1)**	3	Accept: 0.2, 0.250, 0.2495 Or consistent with (a)
		(ii)	Gravitational potential energy is less (as $E_p = -\frac{GMm}{r}$) **(1)** r has decreased/Dimorphos is now in a lower orbit **(1)**	2	Accept gravitational potential energy is more negative Any statement about change of mass zero marks.
	(c)		Collision only results in a small deflection. (Large distance required for a change of trajectory greater than the diameter of the Earth).	1	Accept arguments in terms of more time for the deflection to affect the path of the asteroid.

MARKS DO NOT WRITE IN THIS MARGIN

5. (a) A clock in curved spacetime and a clock in flat spacetime will measure different time intervals between the same two events.

The difference Δt between the time intervals measured by the two clocks is given by the relationship

$$\Delta t = t_G\left(\frac{1}{\sqrt{1-\left(\frac{r_{schwarzchild}}{r}\right)}}-1\right)$$

where t_G is the time interval between two events as measured by the clock in curved spacetime and the other symbols have their usual meaning.

(i) Calculate the Schwarzschild radius of the Earth. **3**

Space for working and answer

(ii) A clock on the surface of the Earth measures a time interval t_G between two events of 24 hours.

Calculate the time difference Δt, in seconds, between the intervals measured by a clock in flat spacetime and the clock on the surface of the Earth, where r is equal to the radius of the Earth. **2**

Space for working and answer

* X 8 5 7 7 7 0 1 1 4 *

MARKS DO NOT WRITE IN THIS MARGIN

5. (continued)

(b) Clocks onboard global positioning system (GPS) satellites experience the following effects due to special relativity and general relativity.

	Time difference per day (with reference to a clock on the surface of Earth)
Special relativity	7 μs slower
General relativity	46 μs faster

Determine the daily adjustment that must be made to a clock onboard a GPS satellite so that it remains synchronised with a clock on the surface of the Earth. **1**

Space for working and answer

[Turn over

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

(c) The Stanford Torus is a NASA design for a space habitat capable of housing ten thousand permanent residents. The Torus is a doughnut-shaped ring, which is 1.8 km in diameter. The Torus rotates about a central axis of rotation through its hub as shown in **Figure 5A**.

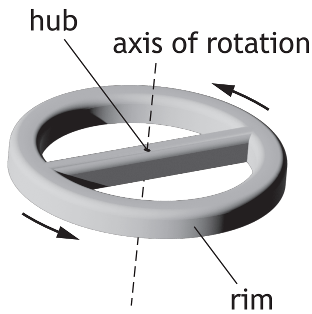


Figure 5A

The rotation of the Torus results in 'artificial gravity' on the inside surface of the rim.

The angular velocity of the Torus is chosen so that a resident on the inside surface of the rim will experience an equivalent gravitational effect to that experienced on the surface of the Earth. A resident at the centre of the hub will experience no 'artificial gravity'.

(i) Calculate the angular velocity of the Torus required to produce this effect. **3**

Space for working and answer

(ii) General relativity predicts that a clock at the rim and a clock at the centre of the hub would not stay synchronised.

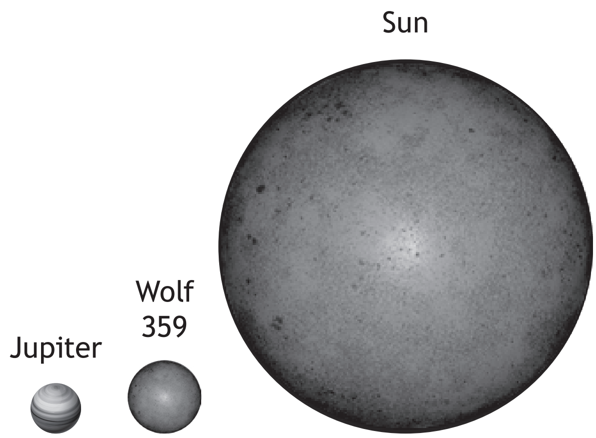
State which clock would run slower.

You must justify your answer. **2**

Question			Expected response	Max mark	Additional guidance
5.	(a)	(i)	$r_{schwarzchild} = \frac{2GM}{c^2}$ **(1)** $r_{schwarzchild} = \frac{2 \times 6.67 \times 10^{-11} \times 6.0 \times 10^{24}}{\left(3.00 \times 10^{8}\right)^2}$ **(1)** $r_{schwarzchild} = 8.9 \times 10^{-3}$ m **(1)**	3	Accept: 9, 8.89, 8.893
		(ii)	$\Delta t = t_G \left(\frac{1}{\sqrt{1-\left(\frac{r_{schwarzchild}}{r}\right)}} - 1 \right)$ $\Delta t = (24 \times 60 \times 60) \times \left(\frac{1}{\sqrt{1-\left(\frac{8.9 \times 10^{-3}}{6.4 \times 10^{6}}\right)}} - 1 \right)$ **(1)** $\Delta t = 6.0 \times 10^{-5}$ (s) **(1)**	2	Accept: 6, 6.01, 6.007 Or consistent with (a)(i)
	(b)		Clocks on the satellites have to be slowed by 39 μs (per day) **(1)**	1	Accept reduced by 39 μs (per day) Do not accept -39 μs on its own.
	(c)	(i)	$a_r = r\omega^2$ **(1)** $9.8 = \frac{1.8 \times 10^3}{2} \times \omega^2$ **(1)** $\omega = 0.10$ rad s^{-1} **(1)**	3	0.1, 0.104, 0.1043 Accept: $mr\omega^2 = mg$ as a starting point
		(ii)	(Clock) at the rim (would run slower). **(1)** It experiences a greater acceleration **OR** It experiences the same effect as being in a stronger gravitational field **OR** Equivalent to being in a stronger gravitational field **(1)**	2	MUST JUSTIFY Accept stronger artificial gravity for second mark.

MARKS DO NOT WRITE IN THIS MARGIN

6. Wolf 359 is a main sequence star located in the constellation Leo.



Some information about Wolf 359 is given in the table.

Mass	0.11 solar masses
Surface temperature	2800 K
Luminosity	4.38×10^{23} W
Distance from Earth	7.9 ly

(a) (i) Calculate the power per unit area emitted from the surface of Wolf 359. **3**

Space for working and answer

(ii) Calculate the radius of Wolf 359. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

6. (continued)

(b) A main sequence star fuses hydrogen in its core.

Figure 6A shows one possible p-p chain in the hydrogen fusion process.

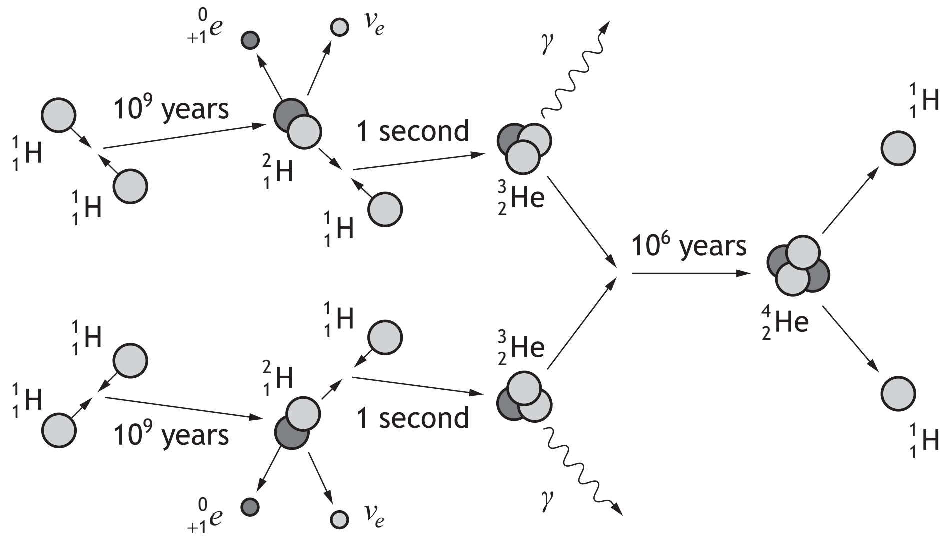


Figure 6A

(i) State the name of the particles represented by the symbols:

v_e

$^{0}_{+1}e$ **1**

(ii) Suggest why deuterium $^{2}_{1}H$ does not build up in the star due to this p-p chain. **1**

(c) Wolf 359 belongs to a class of stars that will stay on the main sequence for thousands of billions of years.

Suggest why, despite knowing the mass of these stars, scientists have not yet observed the fate of these stars. **1**

Question			Expected response	Max mark	Additional guidance
6.	(a)	(i)	$\frac{P}{A} = \sigma T^4$ **(1)** $\frac{P}{A} = 5.67 \times 10^{-8} \times 2800^4$ **(1)** $\frac{P}{A} = 3.5 \times 10^6\ \text{W m}^{-2}$ **(1)**	**3**	Accept: 3, 3.49, 3.485
		(ii)	$L = 4\pi r^2 \sigma T^4$ **(1)** $4.38 \times 10^{23} = 4\pi \times r^2 \times 5.67 \times 10^{-8} \times 2800^4$ **(1)** $r = 1.0 \times 10^8$ m **(1)**	**3**	Accept: 1, 1.00, 1.000 Or consistent with (a)(i) $\frac{P}{A} = 3.5 \times 10^6 \left(= 5.67 \times 10^{-8} \times 2800^4\right)$
	(b)	(i)	(electron) neutrino Positron	**1**	 Accept: anti-electron
		(ii)	Deuterium only exists for 1 second (before fusing again)	**1**	Accept deuterium only exists for a (very) short time
	(c)		Lifetime is greater than the age of the (observable) Universe	**1**	

MARKS DO NOT WRITE IN THIS MARGIN

7. Wave-particle duality is a key concept in quantum theory.

Louis de Broglie proposed that a particle of matter, which is moving, has an associated wavelength.

(a) State one piece of experimental evidence for a 'particle' showing wave-like behaviour. **1**

(b) A proton is moving with a velocity of 1.50×10^{7} m s^{-1}.

(i) Calculate the de Broglie wavelength of the proton. **3**

Space for working and answer

(ii) Explain why wave-like behaviour is not observed for this proton. **1**

[Turn over

DO NOT WRITE IN THIS MARGIN

7. (continued)

(c) Albert Einstein proposed that electromagnetic radiation was comprised of quanta called photons rather than being a continuous wave.

Arthur Compton provided experimental evidence for the existence of photons.

In a similar experiment, X-ray photons are scattered by collisions with stationary electrons as shown in **Figure 7A**.

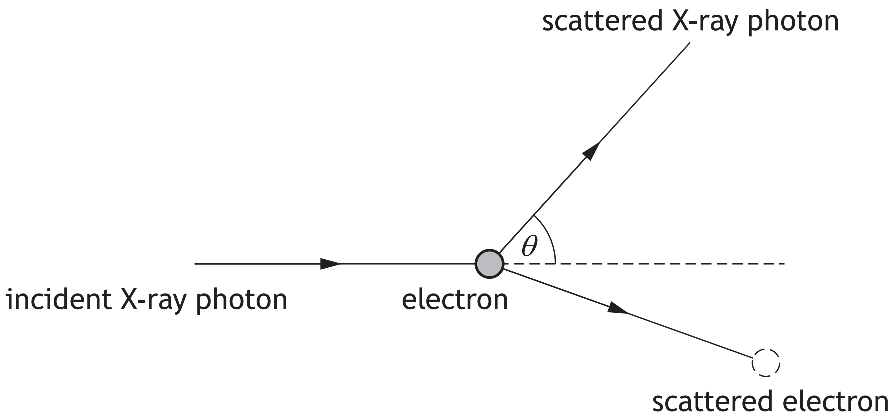


Figure 7A

The electron gains momentum from the collision and is scattered. Therefore, the scattered X-ray photon has less momentum than the incident X-ray photon.

The scattered photon has a longer wavelength than the incident X-ray photon. The difference in wavelength $\Delta\lambda$ is referred to as the Compton shift.

The Compton shift of an X-ray photon scattered through an angle θ is given by the relationship

$$\Delta\lambda = \frac{h}{m_e c}(1 - \cos\theta)$$

where the symbols have their usual meaning.

7. (c) (continued)

MARKS DO NOT WRITE IN THIS MARGIN

(i) An X-ray photon detector is positioned at an angle θ to the path of the incident photon.

A graph showing the variation of intensity with wavelength for the incident and scattered X-ray photons is shown in **Figure 7B**.

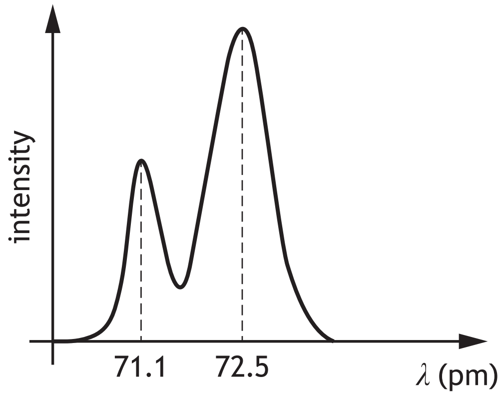


Figure 7B

Determine the scattering angle θ of the X-ray photons. **3**

Space for working and answer

(ii) The X-ray detector is now moved to detect X-ray photons at a smaller scattering angle.

State whether the magnitude of the observed Compton shift will increase, stay the same or decrease.

Justify your answer. **2**

Question			Expected response	Max mark	Additional guidance
7.	(a)		Electron diffraction/interference	1	Must include experimental evidence rather than just naming an experiment
	(b)	(i)	$\lambda = \frac{h}{p}$ **(1)** $\lambda = \frac{6.63\times10^{-34}}{1.673\times10^{-27}\times1.50\times10^{7}}$ **(1)** $\lambda = 2.64\times10^{-14}$ m **(1)**	3	Accept: 2.6, 2.642, 2.6420
		(ii)	(de Broglie) wavelength too small (for wave-like effects) **OR** (de Broglie) wavelength very small (so object behaves like a particle)	1	Do not accept: the de Broglie wavelength is smaller than the size of the proton.
	(c)	(i)	$\left(\Delta\lambda = \frac{h}{mc}(1-\cos\theta)\right)$ $\Delta\lambda = (72.5-71.1)\times10^{-12}$ (1) $(72.5-71.1)\times10^{-12} = \frac{6.63\times10^{-34}}{9.11\times10^{-31}\times3.00\times10^{8}}(1-\cos\theta)$ (1) $\theta = 65.0°$ (1)	3	Accept: 65, 64.98, 64.982 (72.5 - 71.1) is an independent mark
		(ii)	Decrease **(1)** $\cos\theta$ has increased **(1)**	2	JUSTIFY (θ has decreased, so) $1-\cos\theta$ has decreased Accept justification by calculation

DO NOT WRITE IN THIS MARGIN

8. A plasma consists of highly energetic charged particles. The plasma has a high temperature and can be contained by a device called a magnetic bottle.

The magnetic bottle uses a non-uniform magnetic field as shown in **Figure 8A**.

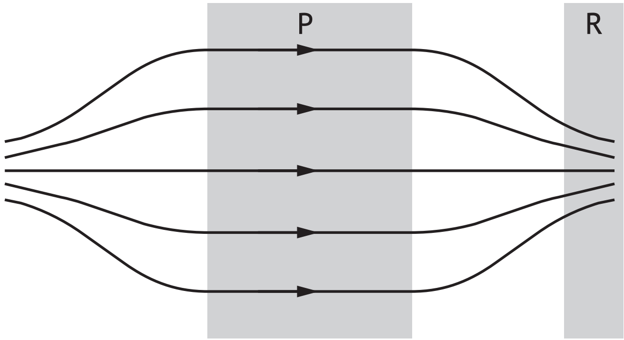


Figure 8A

(a) The magnetic field in region P can be considered to be uniform.

The magnetic induction in region P is 95.0 mT.

A proton is moving through region P with a velocity of 2.40×10^6 m s^{-1}, at an angle of 55.0° to the direction of the magnetic field, as shown in **Figure 8B**.

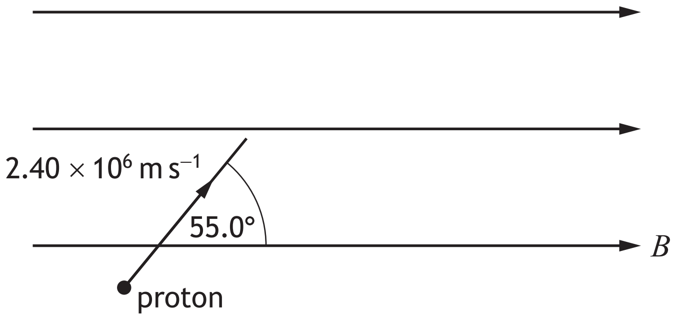


Figure 8B

* X 8 5 7 7 7 0 1 2 2 *

MARKS DO NOT WRITE IN THIS MARGIN

8. (a) (continued)

The proton follows a helical path in the magnetic field.

(i) Explain why the proton follows a helical path. **2**

(ii) By considering the forces acting on the proton, determine the radius of the helical path in region P. **5**

Space for working and answer

[Turn over

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8. (continued)

(b) The proton reflects inside the magnetic bottle at a point in region R. The path of the proton after it reflects is shown in **Figure 8C**.

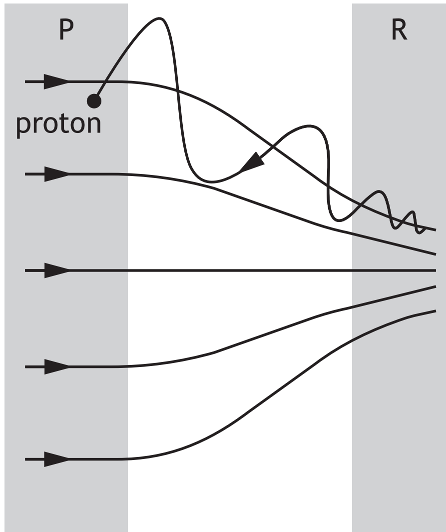

Figure 8C

Apart from direction, state one change to the helical path followed by the proton as it travels between regions R and P.

Justify your answer. **2**

Question			Expected response	Max mark	Additional guidance
8.	(a)	(i)	(Component of) the <u>velocity</u> parallel to the (magnetic) field is constant/ results in no (unbalanced) force/is unaffected by the (magnetic) field. **(1)** (Component of) the <u>velocity</u> perpendicular to the (magnetic) field results in circular motion/ central force. **(1)**	2	Independent marks 'Horizontal component', 'vertical component' not acceptable
		(ii)	$F = qvB$ or $F = qvB\sin\theta$ **(1)** $F = 1.60\times10^{-19}\times2.40\times10^{6}\times95.0\times10^{-3}\times\sin55.0$ **(1)** $F = \frac{mv^2}{r}$ or $F = \frac{m(v\sin\theta)^2}{r}$ **(1)** $F = \frac{1.673\times10^{-27}\times(2.40\times10^{6}\times\sin55.0)^2}{r}$ **(1)** $\left(1.60\times10^{-19}\times2.40\times10^{6}\times95.0\times10^{-3}\times\sin55.0 = \frac{1.673\times10^{-27}\times(2.40\times10^{6}\times\sin55.0)^2}{r}\right)$ $r = 0.216$ m **(1)**	5	Accept: 0.22, 0.2164, 0.21639 $r = \frac{mv}{qB}$ **(2)** $r = \frac{1.673\times10^{-27}\times2.40\times10^{6}\times\sin55.0}{1.60\times10^{-19}\times95.0\times10^{-3}}$ **(2)** $r = 0.216$ m **(1)**
	(b)		The radius will increase or the pitch will increase **(1)** The magnetic induction has reduced **(1)**	2	JUSTIFY

MARKS DO NOT WRITE IN THIS MARGIN

9. The suspension system of a car is designed to reduce the effects of bumps in a road for the car and its occupants. The suspension system uses coil springs.

An engineer investigates one of the springs used in a car.

The spring has a spring constant of 8.6×10^4 N m^{-1}.

(a) The engineer connects the spring to a lightweight platform.

A block of mass 510 kg is placed on the platform, causing the spring to compress through a distance Δy. This spring and block system is shown in **Figure 9A**.

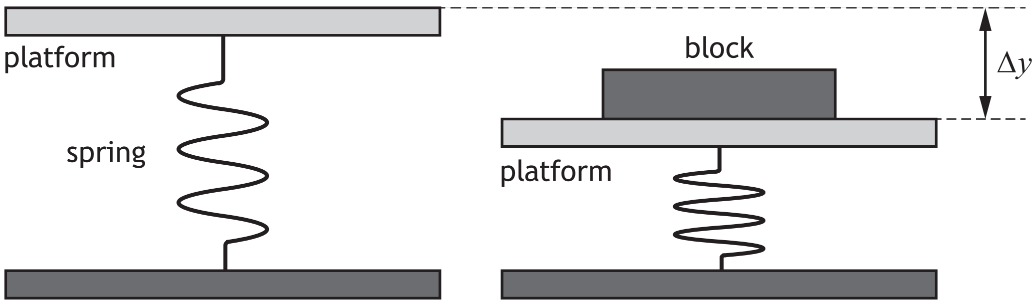

Figure 9A

Determine the compression distance Δy of the spring due to the block. **3**

Space for working and answer

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

(b) The engineer now investigates the oscillation of the spring and block system.

This oscillation can be modelled as simple harmonic motion.

(i) Show that the angular frequency of the oscillation is

$$\omega = \sqrt{\frac{k}{m}}$$

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

Space for working and answer

(ii) Calculate the angular frequency of the oscillation. **2**

Space for working and answer

(iii) Cars designed for motorsport competition typically use stiffer springs, which require a greater force to produce the same compression.

The engineer uses the same system to test a stiffer spring.

State whether the angular frequency of the oscillation of the stiffer spring will be greater than, the same as or less than that of the original spring.

You must justify your answer. **2**

9. (continued)

MARKS DO NOT WRITE IN THIS MARGIN

(c) For safety and comfort the suspension system should be damped.

The engineer models the damping system by adding a damper as shown in **Figure 9B**.

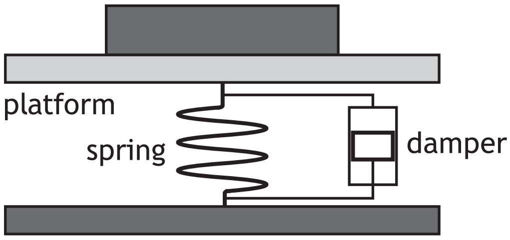

Figure 9B

The damper consists of a piston inside a cylinder filled with oil. The oil provides a resistive force that opposes the motion of the piston.

(i) The damping system is tested by pushing down on the platform and block system, and then releasing it. This causes the suspension system to oscillate.

The results of the test are shown in **Figure 9C**.

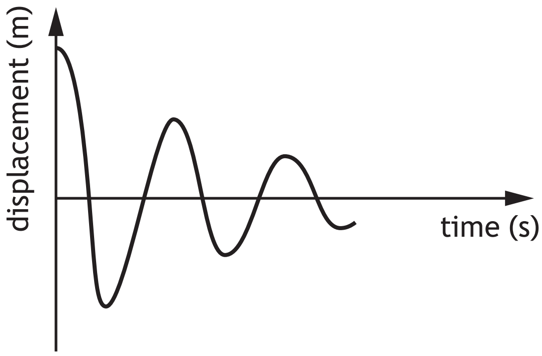

Figure 9C

State the type of damping shown in **Figure 9C**. 1

(ii) To pass the test, the damping system should not complete more than one full oscillation.

Suggest a change that could be made to this damping system so that the system passes the test. 1

Question			Expected response	Max mark	Additional guidance
9.	(a)		$F = -ky$ **(1)** $(mg = k\Delta y)$ $510 \times 9.8 = (-)8.60 \times 10^4 \times \Delta y$ **(1)** $\Delta y = (-)0.058$ m **(1)**	3	Accept: 0.06, 0.0581, 0.05812
	(b)	(i)	$(F = ma\ ,\ F = -ky)$ $ma = -ky$ **(1, 1)** $a = -\omega^2 y$ **(1)** $((-)m\omega^2 y = (-)ky\ )$ $\omega = \sqrt{\frac{k}{m}}$	3	Not a standard SHOW question 1 mark for both force relationships 1 mark for equating $a = -\omega^2 y$ on its own 1 mark Final answer not shown max 2 marks
		(ii)	$\omega = \sqrt{\frac{k}{m}}$ $\omega = \sqrt{\frac{8.60 \times 10^4}{510}}$ (1) $\omega = 13$ rad s^{-1} (1)	2	Accept: 10, 13.0, 12.99
		(iii)	Greater **(1)** The spring constant is greater and the mass remains constant or $\omega \propto \sqrt{k}$ **(1)**	2	MUST JUSTIFY Accept justification by calculation
	(c)	(i)	Underdamping	1	
		(ii)	Any change that reflects an increase in resistive force: density of oil, area of piston.	1	Do not accept increase the resistive force alone.

MARKS DO NOT WRITE IN THIS MARGIN

10. Scorpions are able to detect their prey by sensing vibrations travelling through sand.

When a beetle walks across sand it creates vibrations that can be modelled as two travelling waves produced at the same time. One of the waves is a transverse wave and the other is a longitudinal wave.

(a) The transverse wave produced by the beetle can be modelled by the relationship

$$y = 1.95 \times 10^{-5} \sin 2\pi\left(9.5t - 0.18x\right)$$

where y is measured in metres.

(i) Determine the speed of the transverse wave. **4**

Space for working and answer

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

(ii) When the transverse wave reaches the scorpion, the energy of the wave has reduced to one eighth of its original value.

Calculate the amplitude of the wave when it reaches the scorpion. **3**

Space for working and answer

(iii) Explain why there is a maximum distance at which the scorpion can detect the beetle. **1**

(b) The beetle is 0.34 m from the scorpion.

The scorpion detects the longitudinal wave before it detects the transverse wave.

The longitudinal wave travels through the sand at a speed of 150 $m\,s^{-1}$.

Determine the time interval between the scorpion detecting the longitudinal wave and the transverse wave. **3**

Space for working and answer

Question			Expected response	Max mark	Additional guidance
10.	(a)	(i)	$v = f\lambda$ **(1)** $\lambda = \frac{1}{0.18}$ (m) **(1)** $v = 9.5 \times \frac{1}{0.18}$ **(1)** $v = 53\ \text{ms}^{-1}$ **(1)**	4	Accept: 50, 52.8, 52.78
		(ii)	$E = kA^2$ **(1)** $\left(1 = k \times \left(1.95 \times 10^{-5}\right)^2\right)$ $\frac{1}{8} = \frac{1}{\left(1.95 \times 10^{-5}\right)^2} \times A^2$ **(1)** $A = 6.89 \times 10^{-6}\ \text{m}$ **(1)**	3	Accept: 6.9, 6.894, 6.8943 Accept: $\frac{E_1}{A_1^2} = \frac{E_2}{A_2^2}$ **(1)** $\frac{1}{\left(1.95 \times 10^{-5}\right)^2} = \frac{0.125}{A_2^2}$ **(1)** $A_2 = 6.89 \times 10^{-6}\ \text{m}$ **(1)**
		(iii)	The energy/amplitude of the wave becomes too small to be detected.	1	Accept: The energy/amplitude of the wave would reduce to zero.
	(b)		$(d = vt)$ $\Delta t = \frac{0.34}{53} - \frac{0.34}{150}$ **(1),(1)** $\Delta t = 4.1 \times 10^{-3}\ \text{s}$ **(1)**	3	Or consistent with (a)(i) Accept: 4, 4.15, 4.148 (1) for all substitutions (1) for subtraction (1) for final answer

MARKS DO NOT WRITE IN THIS MARGIN

11. A technician in a laboratory carries out a Young's double slit experiment to verify the operational wavelengths of three lasers.

The technician uses the experimental set up shown in **Figure 11A.**

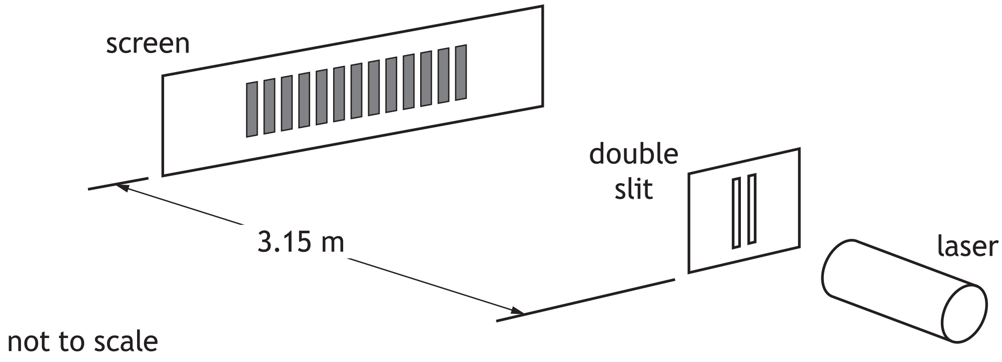

Figure 11A

The types of laser tested and their stated operational wavelengths are shown in the table.

Laser type	Operational wavelength (nm)
Helium-neon	633
Copper vapour	511
Argon	455

(a) State which of the lasers tested should produce an interference pattern with the largest fringe separation.

Justify your answer. **2**

MARKS DO NOT WRITE IN THIS MARGIN

11. (continued)

(b) The copper vapour laser produced the interference pattern shown in **Figure 11B.**

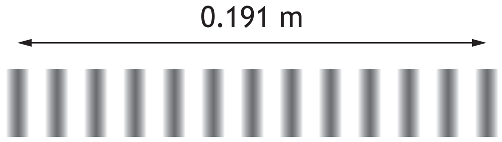

Figure 11B

The technician used a double slit with a slit separation of 1.00×10^{-4} m.

The technician measured a distance of 0.191 m across twelve fringe spacings.

(i) Determine the wavelength obtained by the technician. **4**

Space for working and answer

(ii) Suggest a reason why the wavelength obtained by the technician is **less than** the stated operational wavelength. **1**

[Turn over

MARKS DO NOT WRITE IN THIS MARGIN

11. (continued)

(c) The technician now uses the helium-neon laser to investigate the separation of the circular tracks on a CD, as shown in **Figure 11C**.

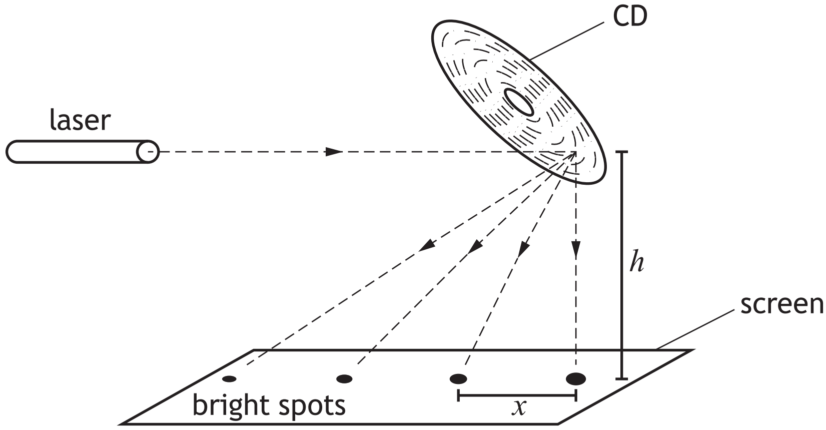

Figure 11C

(i) Explain fully how a series of bright spots is produced on the screen. **2**

(ii) The technician measures the separation x of the bright spots and the height h of the CD above the screen. These results are used to determine the separation of the tracks on the CD.

The technician now moves the screen further away from the CD.

(A) Suggest one advantage for determining the separation of the tracks by moving the screen further away. **1**

(B) Suggest one disadvantage for determining the separation of the tracks by moving the screen further away. **1**

Question			Expected response	Max mark	Additional guidance
11.	(a)		Helium-neon laser **(1)** Longest wavelength and $\Delta x = \frac{\lambda D}{d}$, D and d are constant **OR** Longest wavelength and $\Delta x \propto \lambda$ **(1)**	**2**	JUSTIFY
	(b)	(i)	$\Delta x = \frac{0.191}{12}$ **(1)** $\Delta x = \frac{\lambda D}{d}$ **(1)** $\frac{0.191}{12} = \frac{\lambda \times 3.15}{1.00 \times 10^{-4}}$ **(1)** $\lambda = 5.05 \times 10^{-7}$ m **(1)**	**4**	Accept: 5.1, 5.053, 5.0529 First mark independent
		(ii)	Measurement of separation of the fringes is too small. **OR** Measurement of slits to screen distance too large. **OR** Measurement of slit separation too small.	**1**	
	(c)	(i)	(The multiple tracks on the CD result in multiple) <u>coherent</u> sources of light (multiple reflections) **(1)** (Bright spots are where) the light meets <u>in phase</u> (to give constructive interference). **(1)**	**2**	Accept: division of wavefront in place of coherent Independent marks
		(ii) (A)	Reduce the (percentage/fractional) uncertainty in the measurements (of x and/or h) **OR** Reduces the (percentage/fractional) uncertainty in the separation of the tracks.	**1**	Do not accept reduces the scale reading uncertainty. Do not accept reduces the absolute uncertainty in the measurement.
		(ii) (B)	Dimmer spots, wider spots, fewer spots on the screen	**1**	

MARKS DO NOT WRITE IN THIS MARGIN

12. A student is planning a project on polarisation.

(a) Describe an experiment that the student could carry out to determine whether the light from a laptop screen is plane polarised. **2**

(b) As part of their project, the student finds the diagram shown in **Figure 12A**.

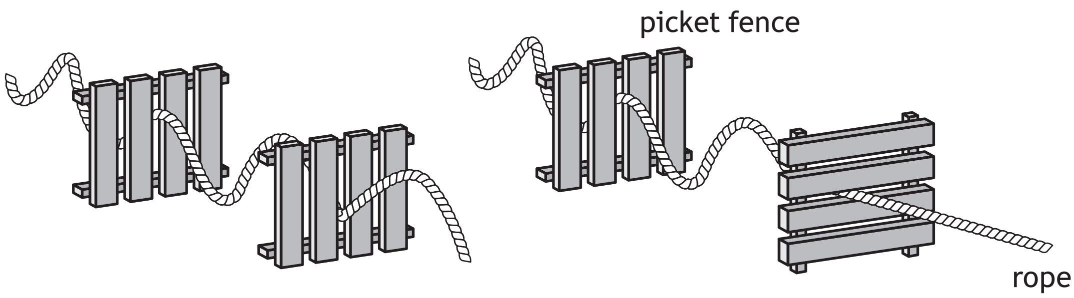

Figure 12A

The diagram represents an analogy for the transmission of light through a polarising filter.

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

MARKS DO NOT WRITE IN THIS MARGIN

12. (b) (continued)

[Turn over

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Question			Expected response	Max mark	Additional guidance
12.	(a)		Polaroid sheet/analyser (in front of screen) **(1)** (Observation of) light intensity change when the polaroid sheet / analyser is rotated **(1)**	**2**	If mention of two polaroid sheets (both polariser and analyser) – zero marks.
	(b)		**Award 3 marks** where the candidate has demonstrated a good understanding of the physics involved. They show a good comprehension of the physics of the situation and provide a logically correct answer to the question posed. This type of response might include a statement of the principles involved, a relationship or an equation, and the application of these to respond to the problem. The answer does not need to be 'excellent' or 'complete' for the candidate to gain full marks. **Award 2 marks** where the candidate has demonstrated a reasonable understanding of the physics involved. They make some statement(s) that are relevant to the situation, showing that they have understood the problem. **Award 1 mark** where the candidate has demonstrated a limited understanding of the physics involved. They make some statement(s) that are relevant to the situation, showing that they have understood at least a little of the physics within the problem. **Award 0 marks** where the candidate has not demonstrated an understanding of the physics involved. There is no evidence that they have recognised the area of physics involved, or they have not given any statement of a relevant physics principle. Award this mark also if the candidate merely restates the physics given in the question.	**3**	Candidates may use a variety of physics arguments to answer this question. Award marks based on candidates demonstrating overall good, reasonable, limited, or no understanding.

MARKS DO NOT WRITE IN THIS MARGIN

13. (a) An electric field exists around a point charge Q_1.

The charge of Q_1 is –4.5 nC.

(i) State what is meant by *electric field strength*. **1**

(ii) Calculate the electric field strength at a distance of 0.088 m from Q_1. **3**

Space for working and answer

(b) Point S is at a distance of 0.088 m from charge Q_1.

A second identical charge Q_2 is now placed at a distance of 0.088 m from point S as shown in **Figure 13A**.

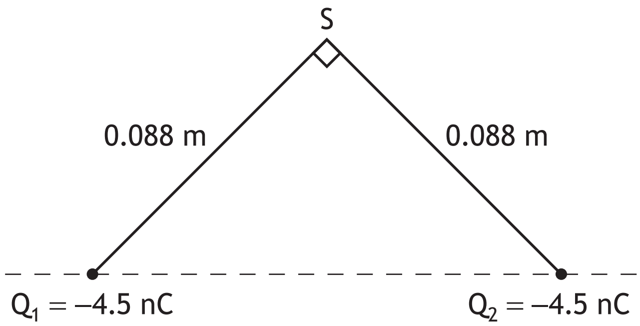


Figure 13A

(i) Determine the magnitude of the resultant electric field strength at point S due to both charges. **2**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

13. (b) (continued)

(ii) State the direction of the resultant electric field strength at point S due to both charges. **1**

(c) The electric potential at the position of Q_2, due to Q_1, is –325 V.

(i) Determine the maximum work done, in electron volts, in bringing charge Q_2 to this point. **4**

Space for working and answer

(ii) Suggest a reason why the work done to move Q_2 to this point would be less than this maximum value. **1**

[Turn over

Question			Expected response	Max mark	Additional guidance
13.	(a)	(i)	(The electrical) force acting on a unit positive charge.	1	
		(ii)	$E = \frac{Q}{4\pi\varepsilon_0 r^2}$ **(1)** $E = \frac{-4.5\times10^{-9}}{4\pi\times8.85\times10^{-12}\times0.088^2}$ **(1)** $E = -5.2\times10^3$ NC^{-1} **(1)**	3	Accept: -5, -5.23, -5.225 Using 9 × 10^9 gives -5.230
	(b)	(i)	$\left(E_T = \sqrt{E_1^2 + E_2^2}\right)$ $E_T = \sqrt{\left(-5.2\times10^3\right)^2 + \left(-5.2\times10^3\right)^2}$ **(1)** $E_T = 7.4\times10^3$ NC^{-1} **(1)**	2	Accept: 7, 7.35, 7.354 Or consistent with (a)(ii) Accept alternative methods using trigonometry.
		(ii)	(Vertically) down the page	1	Do not accept down/downwards on its own
	(c)	(i)	$W = QV$ **(1)** $W = (-)4.5\times10^{-9}\times(-)325$ **(1)** $(eV) = \frac{W}{1.60\times10^{-19}}$ $(eV) = \frac{4.5\times10^{-9}\times325}{1.60\times10^{-19}}$ **(1)** $(eV) = 9.1\times10^{12}$ (electron volts) **(1)**	4	Accept: 9, 9.14, 9.141
		(ii)	The starting position for Q_2 was not at the zero of electric potential.	1	Accept: Q_2 did not come from infinity.

MARKS DO NOT WRITE IN THIS MARGIN

14. A solenoid is a helical coil of wire. When there is a current in the wire a magnetic field is produced in and around the solenoid.

(a) **Figure 14A** shows a solenoid.

On **Figure 14A**, sketch the magnetic field pattern produced by the current. **2**

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

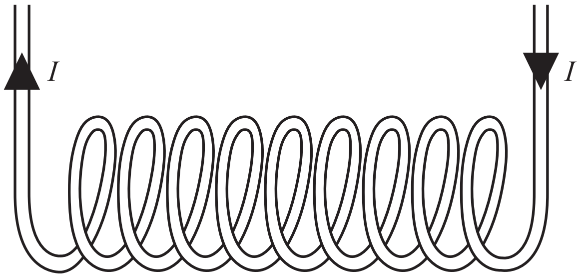


Figure 14A

14. (continued)

MARKS DO NOT WRITE IN THIS MARGIN

(b) For a short, wide solenoid, the magnetic induction produced depends on the current I in the solenoid, the radius R of the solenoid, the number of turns N of the coil, and the distance x along the central axis of the solenoid from the centre of the solenoid.

This solenoid is shown in **Figure 14B**.

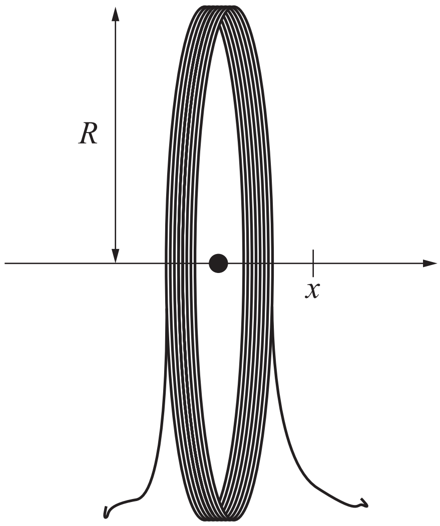


Figure 14B

The magnetic induction of this type of solenoid is given by the relationship

$$B = \frac{\mu_0 INR^2}{2\left(R^2 + x^2\right)^{\frac{3}{2}}}$$

There is a current of 3.5 A in the wire.

The radius of the solenoid is 120 mm.

The solenoid has 64 turns.

The maximum magnetic induction occurs at the centre of the solenoid, where $x = 0$ m.

Determine the maximum magnetic induction produced by this solenoid. **2**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

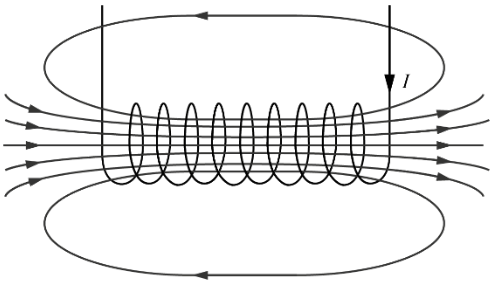
14. (continued)

(c) A ferromagnetic material can be inserted into a solenoid, along its central axis, to increase the magnetic induction.

(i) State what is meant by the term *ferromagnetic*. **1**

(ii) Suggest a ferromagnetic material that will increase the magnetic induction. **1**

(iii) Predict the effect that the insertion of this ferromagnetic material will have on the magnetic field lines around the solenoid. **1**

Question			Expected response	Max mark	Additional guidance
14.	(a)			**2**	1 mark for shape 1 mark for direction
	(b)		$\left(B = \dfrac{\mu_0 INR^2}{2\left(R^2 + x^2\right)^{\frac{3}{2}}}\right)$ $B = \dfrac{4\pi \times 10^{-7} \times 3.5 \times 64 \times (120 \times 10^{-3})^2}{2\left((120 \times 10^{-3})^2 + 0^2\right)^{\frac{3}{2}}}$ **(1)** $B = 1.2 \times 10^{-3}$ T **(1)**	**2**	Accept: 1, 1.17, 1.173 Substitution of x = 0 not required for first mark
	(c)	(i)	(In a ferromagnetic material) the magnetic dipoles/domains (in the material) can be made to align, (resulting in the material becoming magnetised).	**1**	
		(ii)	Iron (or nickel or cobalt)	**1**	Any other ferromagnetic material is acceptable, such as steel or neodymium
		(iii)	The field lines will be more densely/ tightly packed together **OR** there will be more of them.	**1**	

MARKS DO NOT WRITE IN THIS MARGIN

15. Two tourists are taking an evening walk while on holiday in the north of Scotland. The aurora borealis or 'Northern Lights' are clearly visible in the night sky.

The tourists have the following conversation.

Tourist 1: It's amazing to think that all that light is because of tiny charges accelerating into the atmosphere.

Tourist 2: So where do these tiny charges come from?

Tourist 1: Space somewhere? I'm not really sure, but I think it's because they're coming straight down into the magnetic field of the Earth at the North Pole.

Tourist 2: Does that explain why we don't see them down south?

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

MARKS DO NOT WRITE IN THIS MARGIN

15. (continued)

[Turn over

Question			Expected response	Max mark	Additional guidance
15.			**Award 3 marks** where the candidate has demonstrated a good understanding of the physics involved. They show a good comprehension of the physics of the situation and provide a logically correct answer to the question posed. This type of response might include a statement of the principles involved, a relationship or an equation, and the application of these to respond to the problem. The answer does not need to be 'excellent' or 'complete' for the candidate to gain full marks. **Award 2 marks** where the candidate has demonstrated a reasonable understanding of the physics involved. They make some statement(s) that are relevant to the situation, showing that they have understood the problem. **Award 1 mark** where the candidate has demonstrated a limited understanding of the physics involved. They make some statement(s) that are relevant to the situation, showing that they have understood at least a little of the physics within the problem. **Award 0 marks** where the candidate has not demonstrated an understanding of the physics involved. There is no evidence that they have recognised the area of physics involved, or they have not given any statement of a relevant physics principle. Award this mark also if the candidate merely restates the physics given in the question.	**3**	Candidates may use a variety of physics arguments to answer this question. Award marks based on candidates demonstrating overall good, reasonable, limited, or no understanding.

MARKS DO NOT WRITE IN THIS MARGIN

16. A capacitor and resistor are connected in series to a variable DC supply. This combination of components, called an RC circuit, is connected to a signal processing unit in an electronic timer.

The RC circuit is shown in **Figure 16A**.

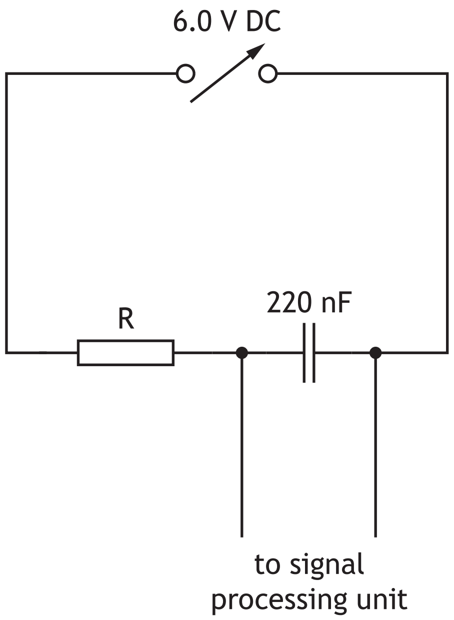


Figure 16A

(a) (i) State the number of time constants required for a capacitor in an RC circuit to be considered fully charged. **1**

(ii) In this RC circuit the capacitor is considered to be fully charged 1.0 ms after charging commences.

Determine the resistance of resistor R. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

16. (continued)

(b) The capacitor is now fully discharged and the voltage of the variable DC supply is halved. The capacitor is then charged again.

State whether the time taken to fully charge the capacitor is now less than, equal to or greater than 1.0 ms.

You must justify your answer. **2**

(c) The RC circuit is now connected to a 6.0 V rms, 77 Hz AC supply.

(i) State what is meant by the term *capacitive reactance*. **1**

(ii) Calculate the reactance of the capacitor. **3**

Space for working and answer

[Turn over

Question			Expected response	Max mark	Additional guidance
16.	(a)	(i)	Five (time constants)	1	
		(ii)	$\tau = RC$ **(1)** $\frac{1.0\times10^{-3}}{5} = R\times220\times10^{-9}$ **(1)** $R = 9.1\times10^{2}\ \Omega$ **(1)**	3	Accept: 9, 9.09, 9.091 Or consistent with (a)(i)
	(b)		Equal to. **(1)** $(\tau = RC)$ and R and C are unchanged **(1)**	2	MUST JUSTIFY Accept: The time constant for the circuit is independent of the potential difference of the power supply.
	(c)	(i)	The opposition of a capacitor to changing current.	1	Accept: the opposition of a capacitor to AC Do not accept change in direction or change in magnitude on its own
		(ii)	$X_C = \frac{1}{2\pi fC}$ **(1)** $X_C = \frac{1}{2\pi\times77\times220\times10^{-9}}$ **(1)** $X_C = 9.4\times10^{3}\ \Omega$ **(1)**	3	Accept: 9, 9.40, 9.395

MARKS DO NOT WRITE IN THIS MARGIN

17. A compound pendulum consists of a thin rectangular bar with holes at regular intervals. These holes can be used as pivot points for oscillations of the compound pendulum.

This is shown in **Figure 17A**.

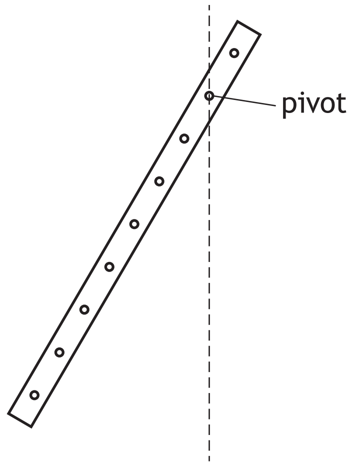


Figure 17A

(a) A student is using the compound pendulum in an experiment to determine the acceleration due to gravity. At one pivot point the student measures the time for ten oscillations of the pendulum. The student repeats this measurement another four times.

The times measured are:

16.09 s, 16.26 s, 16.15 s, 16.48 s, 16.22 s.

(i) Determine the mean period of the pendulum for this pivot point. **1**

Space for working and answer

(ii) Determine the absolute uncertainty in the period of the pendulum for this pivot point. **2**

Space for working and answer

DO NOT WRITE IN THIS MARGIN

17. (continued)

(b) The student now repeats the experiment for a number of different pivot points on the pendulum. The student varies the distance l between the pivot point and the centre of mass of the pendulum. This causes the period of the pendulum T to change.

The relationship between l and T for a compound pendulum is

$$T^2 l = \frac{4\pi^2}{g} l^2 + k$$

where k is a constant.

Acceleration due to gravity can be determined from of a graph of $T^2 l$ against l^2.

The graph obtained from the student's results is shown in **Figure 17B**.

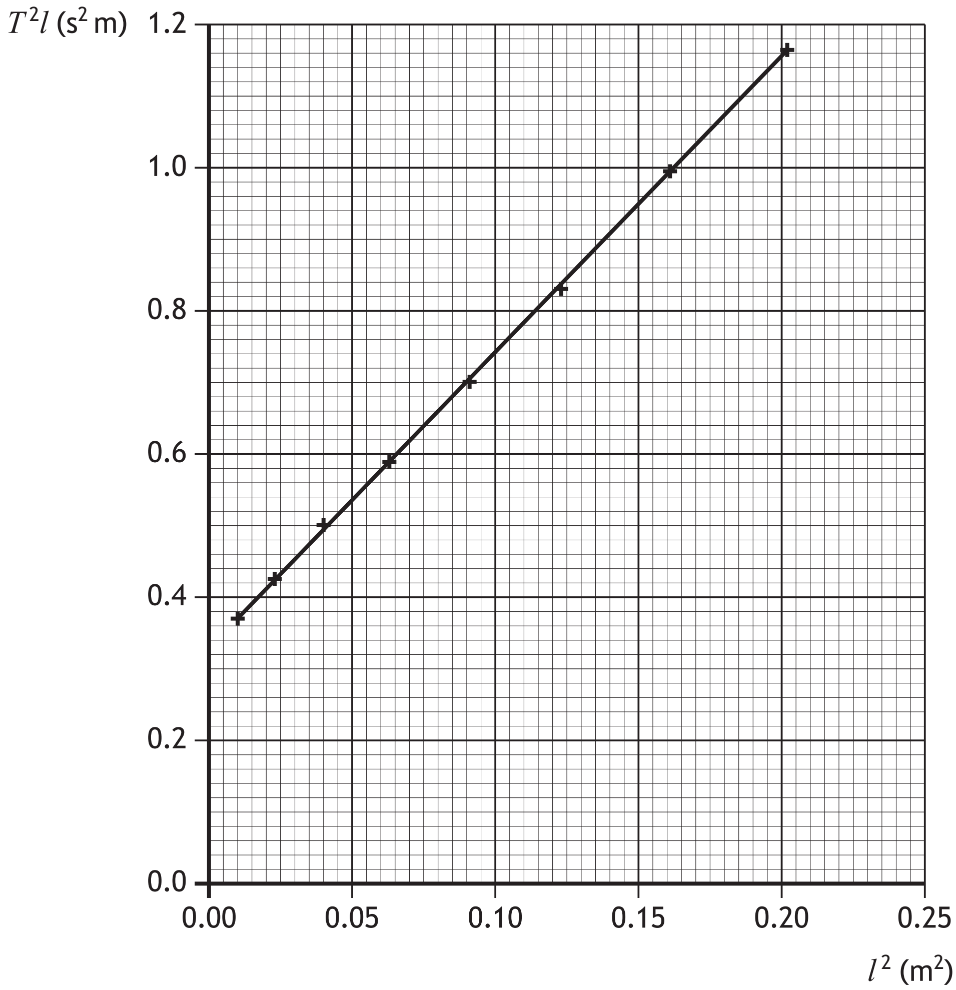


Figure 17B

MARKS DO NOT WRITE IN THIS MARGIN

17. (b) (continued)

Using information from the graph, determine the value for acceleration due to gravity obtained from this experiment. **3**

Space for working and answer

(c) After analysing all of the data, the student states that the experiment has been, ‘very precise, but not accurate’.

Explain whether the student’s statement is correct. **2**

[END OF QUESTION PAPER]

Question			Expected response	Max mark	Additional guidance
17.	(a)	(i)	$\left(\bar{t} = \frac{(16.09+16.26+16.15+16.48+16.22)}{5}\right)$ $\bar{t} = 16.24(\text{s})$ $\left(\bar{T} = \frac{\bar{t}}{10}\right)$ $\bar{T} = 1.624\ \text{s}$ **(1)**	**1**	Accept: 1.62
		(ii)	$\Delta t = \frac{(16.48-16.09)}{5}$ **(1)** $\left(\begin{array}{l}\Delta t = 0.078\ (\text{s}) \\ \frac{\Delta T}{T} = \frac{\Delta t}{t} \\ \frac{\Delta T}{1.624} = \frac{0.078}{16.24}\end{array}\right)$ $\Delta T = 0.008\ \text{s}$ **(1)**	**2**	Suspend sig figs rules Or consistent with (a) (i) Accept: 0.01, 0.0078 $\Delta t = \frac{(1.648-1.609)}{5}$ wrong physics zero marks.
	(b)		Acceptable substitutions into gradient relationship. **(1)** $\left(m = \frac{4\pi^2}{g}\right)$ $4.14 = \frac{4\pi^2}{g}$ **(1)** $g = 9.54\ \text{ms}^{-2}$ **(1)**	**3**	Or consistent with points chosen from the line Evidence of data extracted from the graph must be shown Use of single point only - award 0 marks.
	(c)		The uncertainties (in the experiment) are very small and hence the experiment is precise. **(1)** The value obtained in the experiment doesn't agree with the accepted value (for acceleration due to gravity) and hence is not accurate. **(1)**	**2**	Or consistent with (b) Independent marks. Accept: points all close to the line of best fit for precision

[END OF MARKING INSTRUCTIONS]

FOR OFFICIAL USE

AH National Qualifications 2025

Mark

X857/77/01 Physics

THURSDAY, 15 MAY

9:00 AM – 12:00 NOON

* X 8 5 7 7 7 0 1 *

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	$9.8\ m\ s^{-2}$	Mass of electron	m_e	9.11×10^{-31} kg
Radius of Earth	R_E	6.4×10^6 m	Charge on electron	e	-1.60×10^{-19} C
Mass of Earth	M_E	6.0×10^{24} kg	Mass of neutron	m_n	1.675×10^{-27} kg
Mass of Moon	M_M	7.3×10^{22} kg	Mass of proton	m_p	1.673×10^{-27} kg
Radius of Moon	R_M	1.7×10^6 m	Mass of positron	m_{e^+}	9.11×10^{-31} kg
Mean Radius of Moon Orbit		3.84×10^8 m	Charge on positron	e^+	1.60×10^{-19} C
Solar radius		6.955×10^8 m	Charge on copper nucleus		4.64×10^{-18} C
Mass of Sun		2.0×10^{30} kg	Planck's constant	h	6.63×10^{-34} J s
Mass of Mars	M_{Mars}	6.42×10^{23} kg	Permittivity of free space	ε_0	$8.85 \times 10^{-12}\ F\ m^{-1}$
Radius of Mars	R_{Mars}	3.39×10^6 m	Permeability of free space	μ_0	$4\pi \times 10^{-7}\ H\ m^{-1}$
1 AU		1.5×10^{11} m	Speed of light in vacuum	c	$3.00 \times 10^8\ m\ s^{-1}$
Stefan-Boltzmann constant	σ	$5.67 \times 10^{-8}\ W\ m^{-2}\ K^{-4}$	Speed of sound in air	v	$3.4 \times 10^2\ m\ s^{-1}$
Universal constant of gravitation	G	$6.67 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$			

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
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 ($J\ kg^{-1}\ K^{-1}$)	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	4.18×10^3	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.

X857770102

DO NOT WRITE IN THIS MARGIN

Total marks — 155 marks

Attempt ALL questions

1. A Space Transportation System craft uses a parachute to assist with braking after touchdown.

The velocity of the craft, from touchdown at $t = 0$ s to coming to rest, is shown in **Figure 1A**.

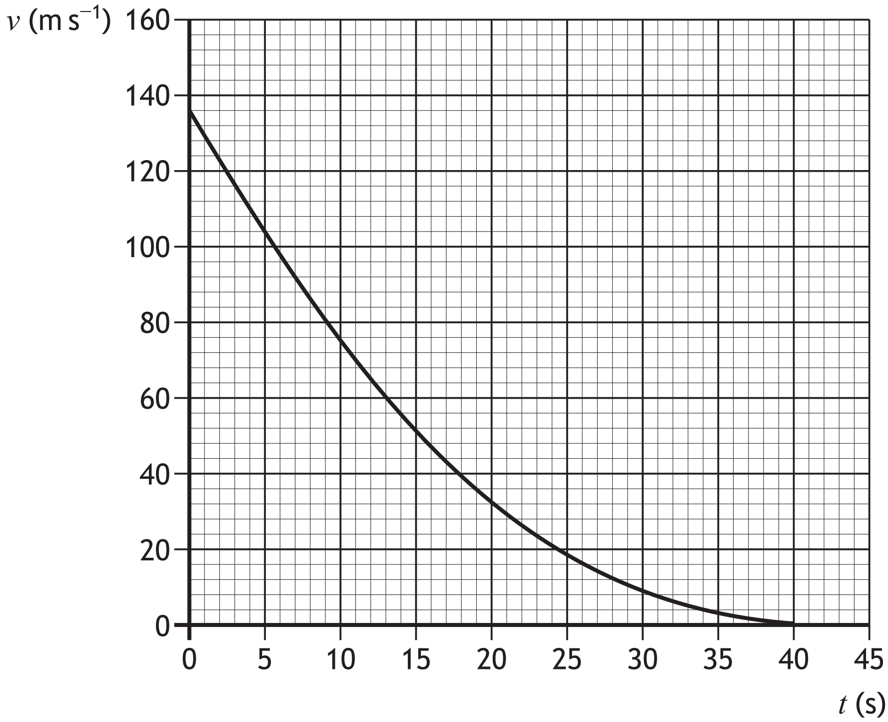


Figure 1A

The velocity v at time t is given by

$$v = 0.09t^2 - 7.0t + 136$$

MARKS DO NOT WRITE IN THIS MARGIN

1. (continued)

Using calculus methods:

(a) determine the acceleration of the craft 15 s after touchdown **3**

Space for working and answer

(b) determine the displacement of the craft between touchdown and coming to rest. **4**

Space for working and answer

Marking Instructions for each question

Question			Expected response	Max mark	Additional guidance
1.	(a)		$a\left(=\frac{dv}{dt}\right)=(2\times 0.09\times t)-7.0$ (1) $a=(2\times 0.09\times 15)-7.0$ (1) $a=-4.3\text{ ms}^{-2}$ (1)	**3**	Accept: -4, -4.30, -4.300 Do not accept: $a=\frac{dv}{dx}$ or $a=\frac{dy}{dx}$
	(b)		$s\left(=\int vdt\right)=\frac{0.09t^3}{3}-\frac{7.0t^2}{2}+136t(+c)$ (1) (at $t=0, s=0 \therefore c=0$) $t=40$ s (1) $s=\frac{0.09\times 40^3}{3}-\frac{7.0\times 40^2}{2}+(136\times 40)$ (1) $s=1800$ m (1)	**4**	Accept: 2000, 1760 Alternative limits method is acceptable. 1 mark for upper limit 40, 1 mark for integration. $\left(s=\int_0^{40}\left(0.09t^2-7.0t^2+136\right)dt\right)$ $s=\left[\frac{0.09t^3}{3}-\frac{7.0t^2}{2}+136t\right]_0^{40}$ (1),(1) $s=\left(\frac{0.09\times 40^3}{3}-\frac{7.0\times 40^2}{2}+136\times 40\right)-\left(\frac{0.09\times 0^3}{3}-\frac{7.0\times 0^2}{2}+136\times 0\right)$ (1) $s=1800$ m (1)

MARKS DO NOT WRITE IN THIS MARGIN

2. A fairground ride consists of a rotating drum with a moveable floor.

This is shown in **Figure 2A**.

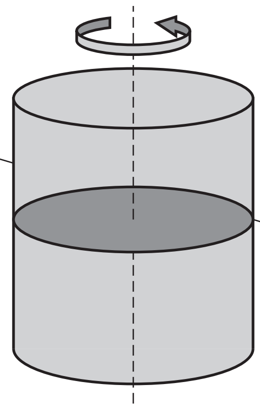


Figure 2A

(a) During a test of the fairground ride, the drum is initially at rest. It then accelerates at 0.12 rad s^{-2} for 34 s.

(i) Calculate the angular velocity of the drum at 34 s. **3**

Space for working and answer

(ii) The moment of the inertia of the ride during the test is 2.4×10^4 kg m^2.

Calculate the unbalanced torque required to produce an acceleration of 0.12 rad s^{-2}. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

2. (continued)

(b) The ride is now operated with people standing against the inside wall of the drum.

State how the unbalanced torque required to produce an acceleration of 0.12 rad s^{-2} compares with the value calculated in part (a) (ii).

Justify your answer. **2**

(c) When the ride reaches its maximum angular velocity, the moveable floor is lowered. The people remain 'stuck' to the wall, as shown in **Figure 2B**.

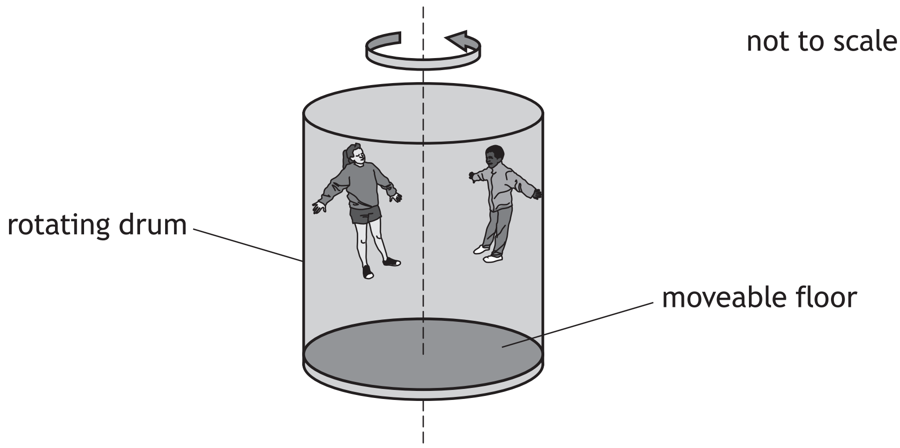


Figure 2B

The rotating drum then slows down and the people slide down the wall.

Explain, in terms of forces, why the people slide down the wall. **1**

[Turn over

Question			Expected response	Max mark	Additional guidance
2.	(a)	(i)	$\omega = \omega_o + \alpha t$ (1) $\omega = (0) + 0.12 \times 34$ (1) $\omega = 4.1 \text{ rads}^{-1}$ (1)	**3**	Accept: 4, 4.08, 4.080
		(ii)	$\tau = I\alpha$ (1) $\tau = 2.4 \times 10^4 \times 0.12$ (1) $\tau = 2900 \text{ Nm}$ (1)	**3**	Accept: 3000, 2880
	(b)		Torque increases (1) as moment of inertia has increased (due to increase in mass). (1)	**2**	Justify. 'Mass increases' alone, max 1 mark.
	(c)		<u>Friction</u> (between people and wall) no longer balances the <u>weight</u> (of people).	**1**	'Friction' alone zero marks. Accept: weight now greater than friction.

MARKS DO NOT WRITE IN THIS MARGIN

3. A pulsar is a rotating neutron star that emits radio waves from its magnetic poles. An artist's impression of this is shown in **Figure 3A**.

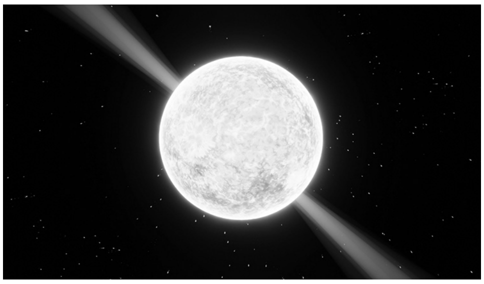


Figure 3A

PSR B1919+21 is a spherical pulsar of approximately uniform density, with the following properties:

period of rotation = 1.34 s

mass = 2.8×10^{30} kg

radius = 9.74×10^{3} m

(a) Show that the angular velocity of PSR B1919+21 is 4.69 rad s^{-1}. **2**

Space for working and answer

(b) Calculate the moment of inertia of PSR B1919+21. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

3. (continued)

(c) The pulsar was formed when the core of its rotating parent star collapsed under its own gravity.

When this occurred, the loss of mass from the core of the parent star was negligible.

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

(ii) The core of the parent star had a moment of inertia of 2.7×10^{42} kg m^2.

Determine the angular velocity of the core of the parent star immediately before it collapsed. **3**

Space for working and answer

[Turn over

MARKS DO NOT WRITE IN THIS MARGIN

3. (continued)

(d) Using your knowledge of physics, comment on the similarities and differences in the evolution of stars into neutron stars, black holes, and white dwarfs. **3**

Question			Expected response	Max mark	Additional guidance
3.	(a)		$\omega = \frac{2\pi}{T}$ (1) $\omega = \frac{2\pi}{1.34}$ (1) $\omega = 4.69\ \text{rad s}^{-1}$	2	SHOW question Final line must be shown or max 1 mark. Alternative starts: $\omega = \frac{d\theta}{dt}, \omega = \frac{\theta}{t}$ $v = r\omega$ and $d = vt$ (1 BOTH equations) **OR** $\omega = 2\pi f$ and $T = \frac{1}{f}$ (1 BOTH equations)
	(b)		$I = \frac{2}{5}mr^2$ (1) $I = \frac{2}{5} \times (2.8 \times 10^{30}) \times (9.74 \times 10^3)^2$ (1) $I = 1.1 \times 10^{38}\ \text{kg m}^2$ (1)	3	Accept: 1, 1.06, 1.063
	(c)	(i)	The <u>total</u> angular momentum before (an interaction) is equal to the <u>total</u> angular momentum after (an interaction) in the absence of (net) external torques.	1	
		(ii)	$I_1\omega_1 = I_2\omega_2$ (1) $2.7 \times 10^{42} \times \omega_1 = 1.1 \times 10^{38} \times 4.69$ (1) $\omega_1 = 1.9 \times 10^{-4}\ \text{rad s}^{-1}$ (1)	3	Or consistent with (b) Accept: 2, 1.91, 1.911

MARKS DO NOT WRITE IN THIS MARGIN

4. Spacecraft can be manoeuvred into trajectories passing close to planets in our Solar System, as shown in **Figure 4A**.

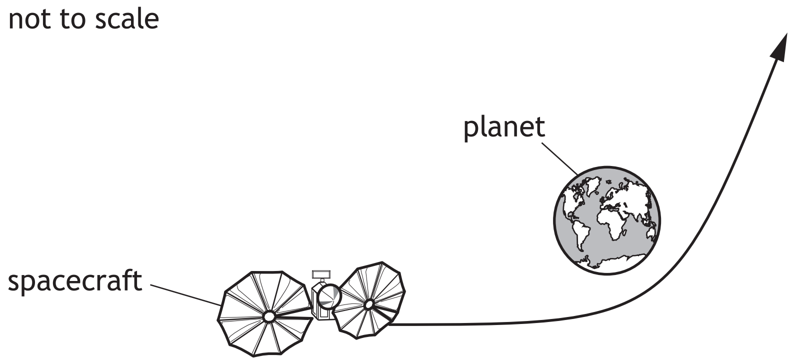


Figure 4A

In following such a trajectory, the speed of the spacecraft can be increased due to a gravity assist effect.

The NASA mission Lucy launched in 2021. The purpose of the mission is to explore asteroids in the outer Solar System.

In 2022, the Lucy spacecraft experienced a gravity assist effect from the Earth. The spacecraft passed 3.6×10^5 m above Earth's surface at its closest approach.

(a) (i) Determine the escape velocity at the point of closest approach of the Lucy spacecraft. **3**

Space for working and answer

(ii) Explain why the speed of the spacecraft at its closest approach should exceed the escape velocity. **1**

MARKS DO NOT WRITE IN THIS MARGIN

4. (continued)

(b) The maximum gain in speed Δv_{max} for this gravity assist manoeuvre can be calculated using the relationship

$$\Delta v_{max} = \frac{2ugr}{gr + u^2}$$

where: u is the approach speed

r is the distance from the centre of the planet to the point of closest approach

g is the gravitational field strength at the surface of the planet.

The approach speed of the spacecraft towards Earth was 1.7×10^4 m s^{-1}.

Determine the maximum speed of the spacecraft after the gravity assist manoeuvre. **3**

Space for working and answer

(c) State how the rate at which time passes on the spacecraft, relative to an observer on the Earth, changes as the spacecraft moves away from Earth.

Justify your answer. **2**

[Turn over

Question			Expected response	Max mark	Additional guidance
4.	(a)	(i)	$v_{esc} = \sqrt{\frac{2GM}{r}}$ (1) $v_{esc} = \sqrt{\frac{2 \times 6.67 \times 10^{-11} \times 6.0 \times 10^{24}}{6.4 \times 10^6 + 3.6 \times 10^5}}$ (1) $v_{esc} = 1.1 \times 10^4 \text{ ms}^{-1}$ (1)	3	Accept: 1, 1.09, 1.088
		(ii)	Allows spacecraft to leave Earth's gravitational field.	1	To ensure the spacecraft is not trapped in the Earth's gravitational field. Do not accept 'gravitational pull'. Any reference to orbit alone - zero marks
	(b)		$\Delta v = \frac{2ugr}{gr + u^2}$ $\Delta v = \frac{2 \times 1.7 \times 10^4 \times 9.8 \times (6.4 \times 10^6 + 3.6 \times 10^5)}{9.8 \times (6.4 \times 10^6 + 3.6 \times 10^5) + (1.7 \times 10^4)^2}$ (1) $v = \left(\frac{2 \times 1.7 \times 10^4 \times 9.8 \times (6.4 \times 10^6 + 3.6 \times 10^5)}{9.8 \times (6.4 \times 10^6 + 3.6 \times 10^5) + (1.7 \times 10^4)^2} \right) + 1.7 \times 10^4$ (1) $v = 2.3 \times 10^4 \text{ ms}^{-1}$ (1)	3	Accept: 2, 2.33, 2.334
	(c)		The rate (at which time passes on the spacecraft clock) increases (as the spacecraft moves away from Earth) (1) The gravitational field strength decreases (1)	2	Explanation in terms of Special Relativity alone, max 1 mark. Do not accept: 'time passes faster' without reference to the rate at which time passes.

MARKS DO NOT WRITE IN THIS MARGIN

5. The spectrum of a star can be approximated as a black-body spectrum.

The star Sirius A, and the stars Betelgeuse and Rigel in the constellation Orion, can be seen in the winter night sky from Scotland.

Sirius A is the brightest observed star in the night sky.

This is represented in **Figure 5A**.

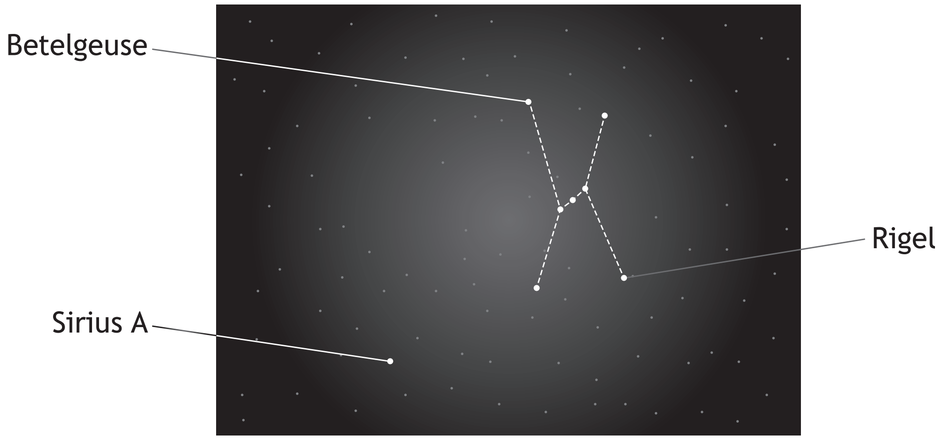


Figure 5A

(a) Sirius A has a companion star, Sirius B, which is a white dwarf.

Sirius B has a radius of 5.6×10^{6} m and a luminosity of 9.4×10^{24} W.

Calculate the surface temperature of Sirius B. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

5. (continued)

(b) Orion's two brightest stars are the blue supergiant Rigel and the red supergiant Betelgeuse.

Rigel is 8.0×10^{18} m from Earth and has an apparent brightness of 5.8×10^{-8} W m^{-2}.

(i) Show that the luminosity of Rigel is 4.7×10^{31} W. **2**

Space for working and answer

(ii) The luminosity of Betelgeuse is the same order of magnitude as the luminosity of Rigel.

Rigel has a surface temperature of 1.2×10^{4} K.

Betelgeuse has a surface temperature of 3.5×10^{3} K.

State whether the radius of Betelgeuse is greater than, less than or equal to that of Rigel.

Justify your answer. **2**

[Turn over

MARKS | DO NOT WRITE IN THIS MARGIN

5. (continued)

(c) The black-body spectra of Betelgeuse, Rigel, Sirius B, and the Sun (a main sequence star) are shown in **Figure 5B** below.

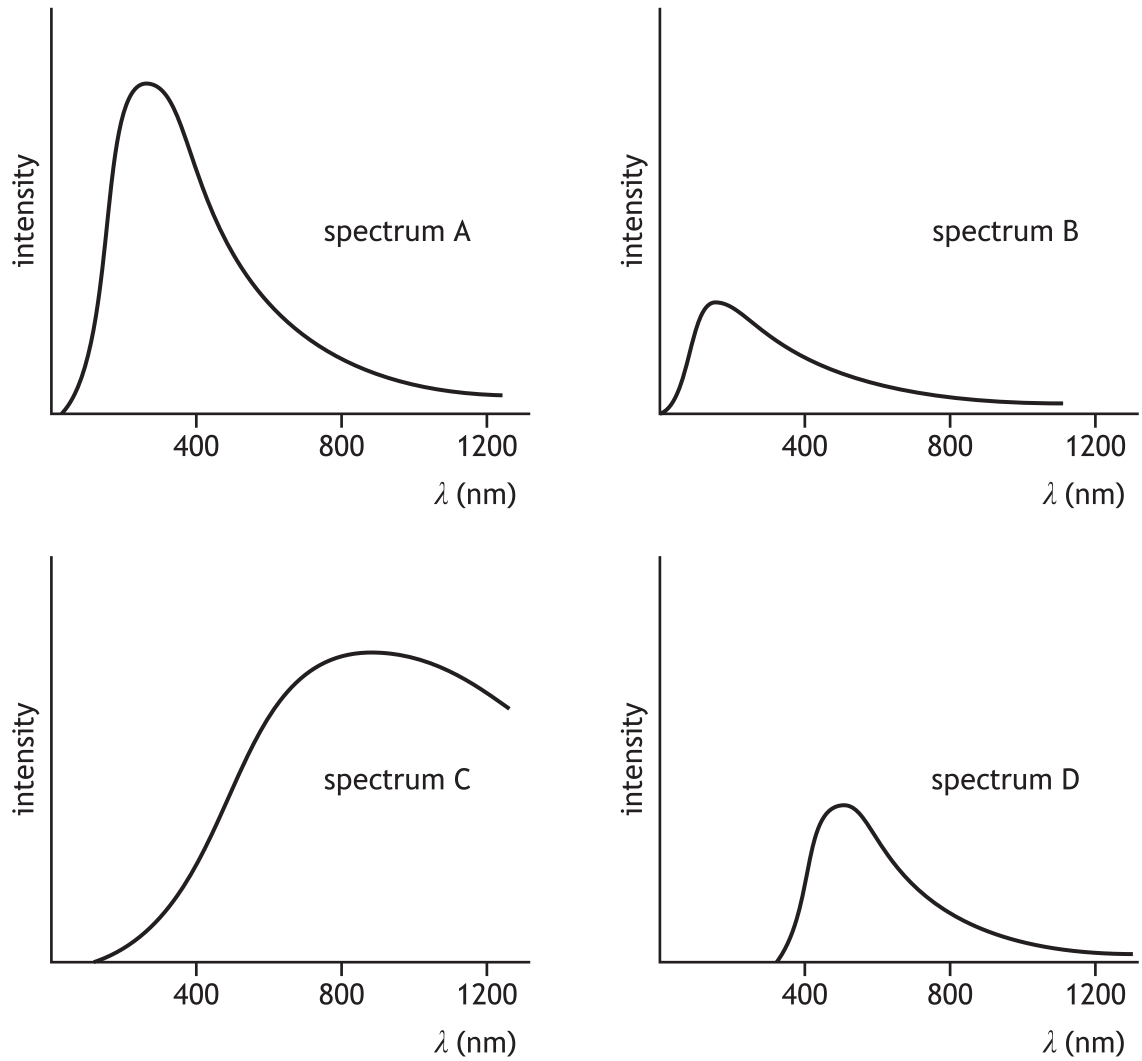


Figure 5B

By considering the peak wavelength of each spectrum, complete the table to identify the correct spectrum for each star. **3**

Star	Spectrum
Betelgeuse	
Rigel	
Sirius B	
Sun	

X857770116

Question			Expected response	Max mark	Additional guidance
5.	(a)		$L = 4\pi r^2 \sigma T^4$ (1) $9.4\times10^{24} = 4\pi\times\left(5.6\times10^{6}\right)^2\times5.67\times10^{-8}\times T^4$ (1) $T = 2.5\times10^4$ K (1)	3	Accept: 3, 2.55, 2.547
	(b)	(i)	$b = \dfrac{L}{4\pi d^2}$ (1) $5.8\times10^{-8} = \dfrac{L}{4\pi\times\left(8.0\times10^{18}\right)^2}$ (1) $L = 4.7\times10^{31}$ W	2	SHOW question Final line must be shown, if not max 1 mark.
		(ii)	Greater than (1) Betelgeuse has (a similar luminosity and) a lower surface temperature (so radius must be greater) and $L = 4\pi r^2\sigma T^4$ (1)	2	Justify $L \propto r^2 T^4$ acceptable. Justification in terms of area or $\dfrac{P}{A} = \sigma T^4$ alone is insufficient.
	(c)		See table below	3	All correct award 3 marks. Two or three correct award 2 marks. One correct award 1 mark.

Star	Spectrum
Betelgeuse	C
Rigel	A
Sirius B	B
Sun	D

MARKS DO NOT WRITE IN THIS MARGIN

6. Classical physics theory predicts incorrectly that, at certain wavelengths, the energy emitted by black-body radiators tends to infinity.

(a) (i) State the name given to this prediction. **1**

(ii) The spectrum obtained from an experiment into the properties of black-body radiators is shown in **Figure 6A**.

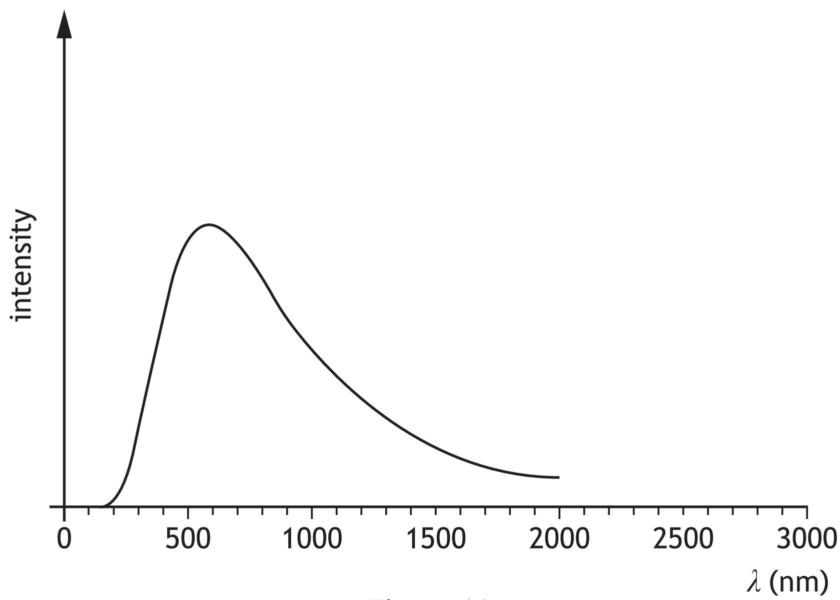


Figure 6A

On **Figure 6A**, add a line to represent the spectrum predicted by classical theory. **1**

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

[Turn over

6. (continued)

MARKS DO NOT WRITE IN THIS MARGIN

(b) The relationship between peak wavelength λ_{peak} and temperature T for a black-body radiator is shown in **Figure 6B**.

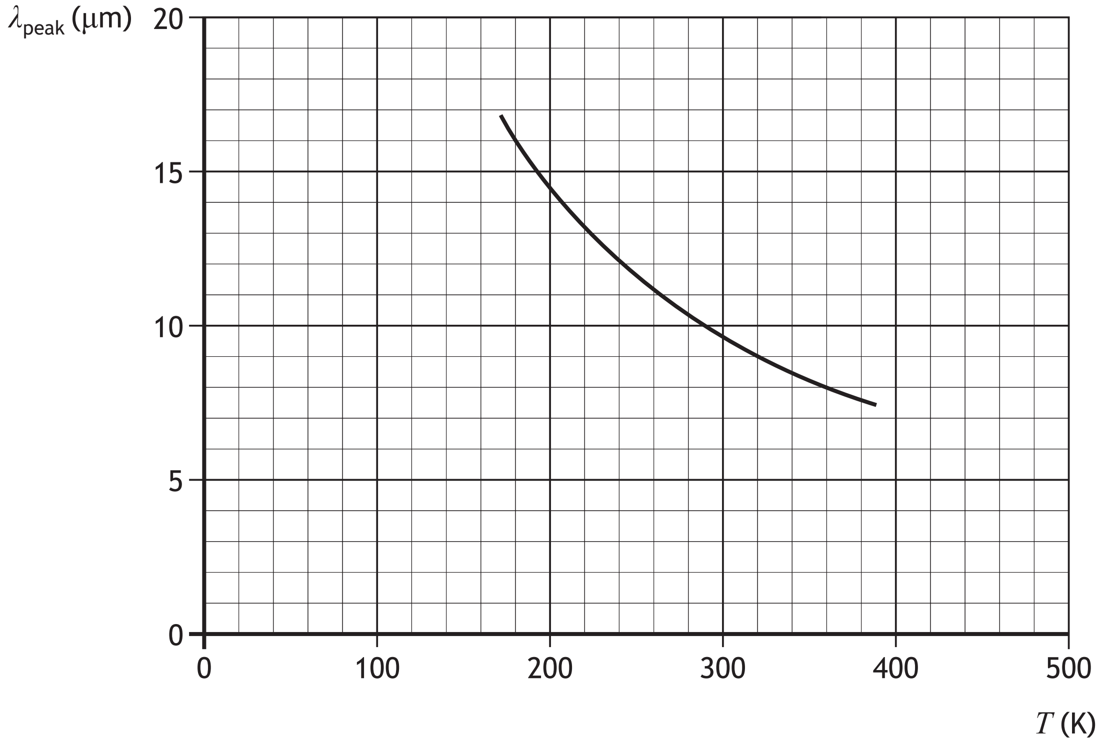


Figure 6B

(i) The peak wavelength emitted by a black-body radiator is 8.5 μm.

Determine the temperature of the black-body radiator. **1**

(ii) Calculate the power per unit area emitted from a black-body radiator at this temperature. **3**

Space for working and answer

MARKS | DO NOT WRITE IN THIS MARGIN

6. (b) (continued)

(iii) In a laboratory experiment, the measured power per unit area emitted from an object at this temperature is less than the value calculated in (b) (ii).

Suggest a reason why this is the case. **1**

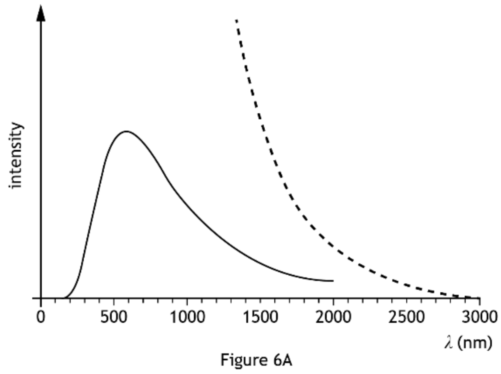
(c) Infrared thermometers detect photons emitted by an object to determine the temperature of the object.

(i) Calculate the momentum of a photon of wavelength 5.6 μm. **3**

Space for working and answer

(ii) Explain the implication of the phrase *the momentum of a photon*. **1**

[Turn over

Question			Expected response	Max mark	Additional guidance
6.	(a)	(i)	(The) Ultraviolet Catastrophe	**1**	Accept UV for Ultraviolet. Accept 'Rayleigh-Jeans Law'.
		(ii)	Figure 6A	**1**	Line asymptotic to y-axis. Line must be above or on the line shown on the original figure.
	(b)	(i)	340 K	**1**	Accept 67 °C. 335-345 K acceptable.
		(ii)	$\frac{P}{A} = \sigma T^4$ (1) $\frac{P}{A} = 5.67 \times 10^{-8} \times 340^4$ (1) $\frac{P}{A} = 760 \text{ Wm}^{-2}$ (1)	**3**	Or consistent with (b)(i). Accept: 800, 758, 757.7
		(iii)	The object is not a (perfect) black-body radiator.	**1**	
	(c)	(i)	$\lambda = \frac{h}{p}$ (1) $5.6 \times 10^{-6} = \frac{6.63 \times 10^{-34}}{p}$ (1) $p = 1.2 \times 10^{-28} \text{ kgms}^{-1}$ (1)	**3**	Accept: 1, 1.18, 1.184
		(ii)	The photon can be considered as a particle.	**1**	Do not accept 'the photon has (rest) mass'.

MARKS DO NOT WRITE IN THIS MARGIN

7. Cosmic rays consist of charged and uncharged particles.

As the charged particles approach Earth, they interact with the magnetic field of Earth.

(a) State the origin of cosmic rays. **1**

(b) Some of the charged particles will follow a helical path due to their interaction with the magnetic field.

Explain why these charged particles follow a helical path. **2**

MARKS DO NOT WRITE IN THIS MARGIN

7. (continued)

(c) Some of these cosmic rays will collide with the nuclei of atoms in the upper atmosphere of the Earth.

These collisions create new particles, such as muons, which have short lifetimes.

(i) A muon created in one such collision has an energy of 5.56 GeV.

Determine the energy of this muon in joules. **1**

Space for working and answer

(ii) The Heisenberg uncertainty principle states that the uncertainty in the energy of a short-lived quantum particle is related to its lifetime.

The uncertainty in the energy of a muon is 4.55×10^{-31} J.

Determine the lifetime of this muon. **3**

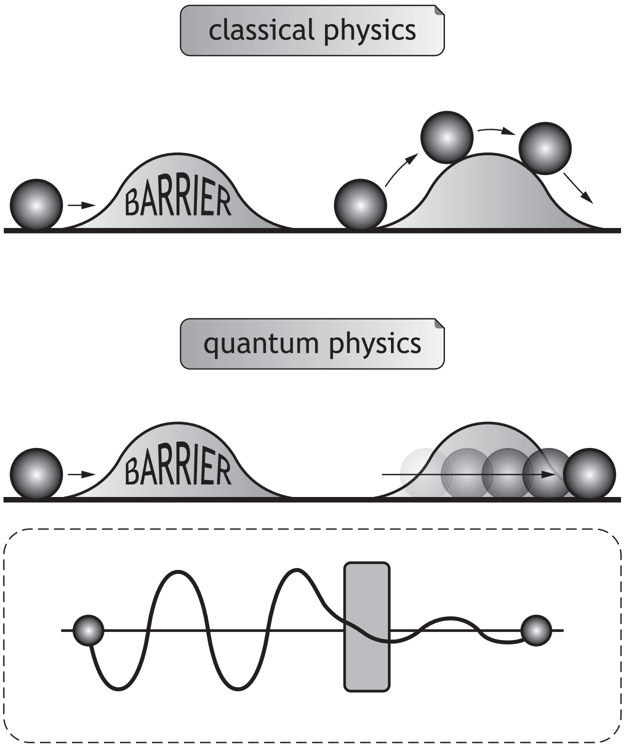
Space for working and answer

[Turn over

Question			Expected response	Max mark	Additional guidance
7.	(a)		The Sun/stars/black holes.	1	Do not accept 'solar wind'.
	(b)		(Component of) the velocity parallel to the (magnetic) field is constant/ results in no (unbalanced) force/ is unaffected by the (magnetic) field. (1) (Component of) the velocity perpendicular to the (magnetic) field results in circular motion/ central force. (1)	2	Independent marks 'Horizontal component', 'vertical component' alone not acceptable.
	(c)	(i)	$\left(\begin{array}{l} W = QV \\ W = 1.60 \times 10^{-19} \times 5.56 \times 10^{9} \end{array}\right)$ $W = 8.90 \times 10^{-10}$ (J)	1	Unit not required. Accept: 8.9, 8.896, 8.8960 Do not accept substitution of -1.6×10^{-19}
		(ii)	$\Delta E \Delta t \geq \frac{h}{4\pi}$ (1) $4.55 \times 10^{-31} \times \Delta t \geq \frac{6.63 \times 10^{-34}}{4\pi}$ (1) $\Delta t = 1.16 \times 10^{-4}$ s (1)	3	Do not accept as starting point: $\Delta E \Delta t = \frac{h}{4\pi}$ Do not accept as final answer: $\Delta t \geq 1.16 \times 10^{-4}$ s Accept: 1.2, 1.160, 1.1596

MARKS DO NOT WRITE IN THIS MARGIN

8. The diagram shown is part of a website article that discusses the differences and similarities between classical and quantum physics.



Using your knowledge of physics, comment on the concepts represented in the diagram. **3**

MARKS DO NOT WRITE IN THIS MARGIN

9. An adult takes a child to a play park.

The child sits on one side of a seesaw, at a distance of 1.8 m from the pivot point, creating a torque.

The adult applies a vertical force to the opposite side of the seesaw to balance that torque, keeping the seesaw level. This force is applied at a distance of 2.3 m from the pivot point.

This is shown in **Figure 9A**.

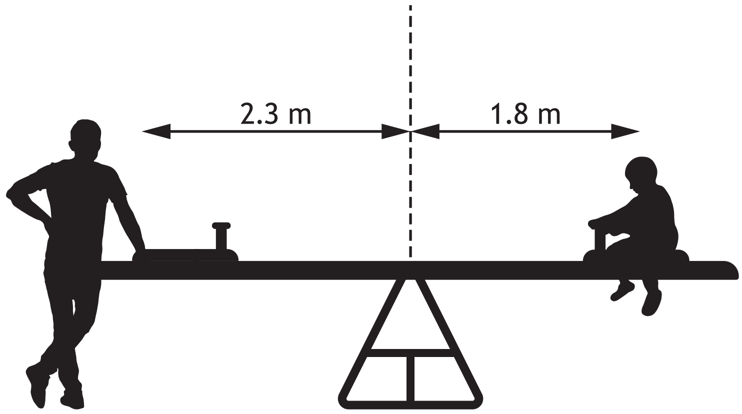


Figure 9A not to scale

(a) The mass of the child is 19 kg.

Determine the magnitude of the force applied by the adult to keep the seesaw level. **4**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

9. (continued)

(b) The adult now applies a force that varies continuously with time t. This causes the seesaw and child to move up and down. The vertical displacement of the child can be approximated to simple harmonic motion (SHM).

(i) The vertical displacement, in metres, of the child from their starting position is given by the relationship

$$y = 0.33 \sin 2.2t$$

Using calculus methods, show that this relationship is consistent with SHM. **3**

Space for working and answer

(ii) Calculate the period of the motion of the child. **3**

Space for working and answer

[Turn over

MARKS DO NOT WRITE IN THIS MARGIN

9. (b) (continued)

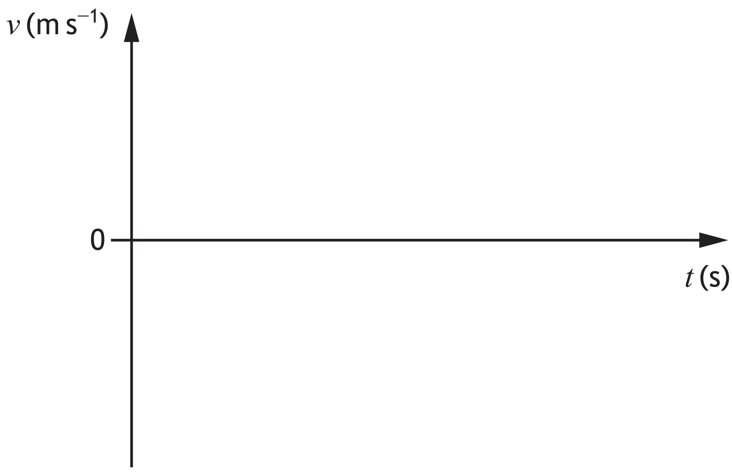
(iii) Calculate the maximum vertical velocity of the child during this motion. **3**

Space for working and answer

(iv) On the axes below, sketch a graph showing how the vertical velocity v of the child varies over **one full period** of their motion, beginning as they pass through the equilibrium position.

Numerical values are required on both axes. **3**

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



MARKS DO NOT WRITE IN THIS MARGIN

9. (continued)

(c) A second child also wants to play on the seesaw.

The two children take turns pushing on the ground to move the seesaw.

This is shown in **Figure 9B**.

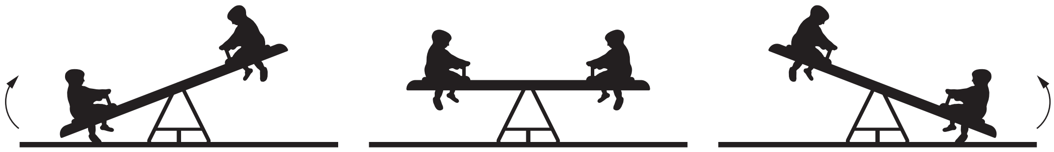
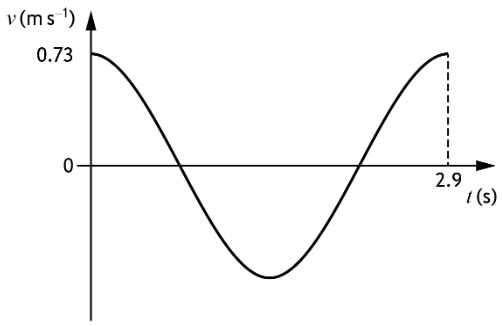


Figure 9B

Explain why the vertical movement of the first child no longer approximates to SHM. **1**

[Turn over

Question			Expected response	Max mark	Additional guidance
9.	(a)		$\tau = Fr$ (1) $\tau = 19 \times 9.8 \times 1.8$ (1) $19 \times 9.8 \times 1.8 = F \times 2.3$ (1) $F = 150$ N (1)	4	Accept: 100, 146, 145.7 $F_1 r_1 = F_2 r_2$ acceptable starting point.
	(b)	(i)	$v =$ or $\frac{dy}{dt} = 2.2 \times 0.33 \cos 2.2t$ and $a =$ or $\frac{d^2y}{dt^2} = -2.2^2 \times 0.33 \sin 2.2t$ (1) $a =$ or $\frac{d^2y}{dt^2} = -2.2^2 y$ (1) (since the equation is in the form) $a = -\omega^2 y$ (the vertical displacement is consistent with SHM). (1)	3	Non-standard SHOW. First mark is for BOTH differentiations performed correctly. Second mark is for the substitution of y back into second differential (including correct treatment of negatives). Numerical constant may be evaluated without penalty. Statement regarding significance of equation required for third mark. Any differentiation with respect to x, award 0 marks.
		(ii)	$\omega = \frac{2\pi}{T}$ (1) $2.2 = \frac{2\pi}{T}$ (1) $T = 2.9$ s (1)	3	Accept: 3, 2.86, 2.856
		(iii)	$v = \pm\omega\sqrt{(A^2 - y^2)}$ (1) $v = (\pm)2.2 \times \sqrt{(0.33^2 - 0^2)}$ (1) $v = (\pm)0.73$ m s^{-1} (1)	3	Accept: 0.7, 0.726, 0.7260 Accept $v = \pm\omega A$ as a starting point.
		(iv)		3	Minimum one full period of sin or cos curve, else 0 marks. 1 mark for cos curve (positive or negative). 1 mark for 2.9 s on time axis. 1 mark for 0.73 m s^{-1} on velocity axis or consistent with (b) parts (ii) and (iii). Sine curve max 2 marks.

Question			Expected response	Max mark	Additional guidance
9.	(c)		The force/acceleration is no longer directly proportional to the displacement (from equilibrium).	**1**	$F \neq -ky$ $a \neq -ky$

MARKS DO NOT WRITE IN THIS MARGIN

10. Parking sensors are used in cars to assist the driver during parking. The sensors emit and detect waves of specific frequencies. Emitted waves are reflected back to the sensor by nearby objects. The car's onboard computer then determines the distance between the car and the objects.

One model of sensor emits a wave which is described by the relationship

$$y = 7.17 \times 10^{-5} \sin 2\pi \left(3.94 \times 10^{4} t - \frac{x}{8.63 \times 10^{-3}} \right)$$

where the symbols have their usual meanings.

(a) State whether the wave being emitted by the sensor is a sound wave or an electromagnetic wave.

You must justify your answer by calculation. **3**

Space for working and answer

(b) The wave now reflects from an object and 40% of the initial energy of the wave returns to the sensor.

Determine a relationship that fully describes the reflected wave as it arrives at the sensor. **4**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

10. (continued)

(c) A sensor on the car detects the reflected wave. A simplified diagram of the detecting circuit is shown in **Figure 10A**.

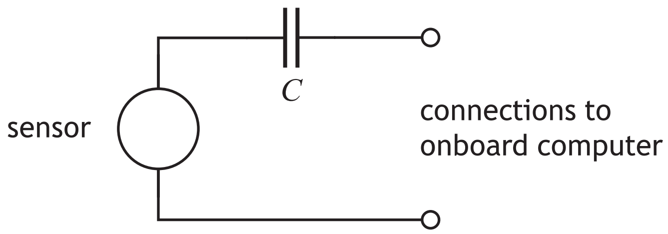


Figure 10A

When the sensor detects the wave, an alternating current is generated in the circuit. This alternating current has the same frequency as the detected wave. Sufficient current will only pass to the onboard computer if the frequency is high enough.

Explain why the frequency needs to be high enough for sufficient current to pass to the onboard computer. **1**

[Turn over

Question			Expected response	Max mark	Additional guidance
10.	(a)		The wave is a sound wave. (1) $v = f\lambda$ (1) $v = 3.94 \times 10^4 \times 8.63 \times 10^{-3}$ $v = 340 \ (\text{ms}^{-1})$ (1)	**3**	Must Justify by calculation. Suspend sig fig rule.
	(b)		$E = kA^2$ or $\frac{E_1}{A_1^2} = \frac{E_2}{A_2^2}$ (1) $\frac{100}{(7.17 \times 10^{-5})^2} = \frac{40}{A_2^2}$ (1) $(A_2 = 4.53 \times 10^{-5} \ (\text{m}))$ $y = 4.53 \times 10^{-5} \sin 2\pi \left(3.94 \times 10^4 t + \frac{x}{8.63 \times 10^{-3}}\right)$ (1), (1)	**4**	Accept: 4.5, 4.535, 4.5347 Final mark for + sign in relationship is independent.
	(c)		At high enough frequencies the reactance/impedance of the capacitor is low. **OR** At lower frequencies the reactance/impedance of the capacitor is too high.	**1**	Do not accept any explanation relating to resistance.

MARKS DO NOT WRITE IN THIS MARGIN

11. A student is investigating interference as part of their Advanced Higher Physics project. The student sets up an experiment using a microwave transmitter and a double slit constructed from three metal plates. The apparatus is set up as shown in **Figure 11A**.

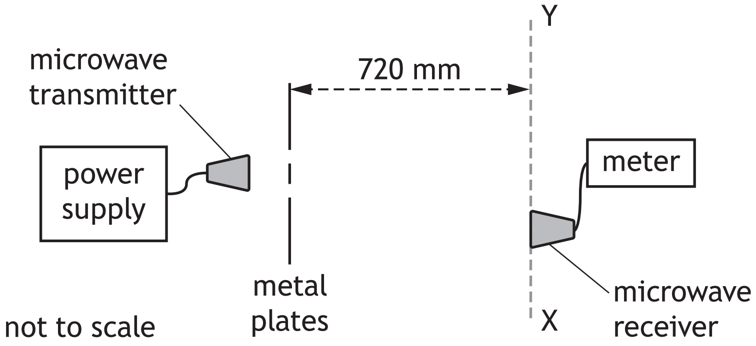


Figure 11A

The double slit has a slit separation of 42 mm.

The student slowly moves the microwave receiver from X to Y and detects regions of constructive interference.

(a) (i) State the **two** required conditions for the waves to produce regions of constructive interference. **1**

(ii) Explain how the student was able to identify the regions of constructive interference from this experimental set up. **1**

[Turn over

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

(iii) Two adjacent regions of constructive interference are detected. The regions are separated by a distance of 470 mm.

Calculate the wavelength of the microwaves. **3**

Space for working and answer

(b) The student now investigates another aspect of interference to determine if it is suitable to include in their project. The student finds some notes about thin film interference and non-reflective coatings.

The notes include the diagram shown in **Figure 11B**.

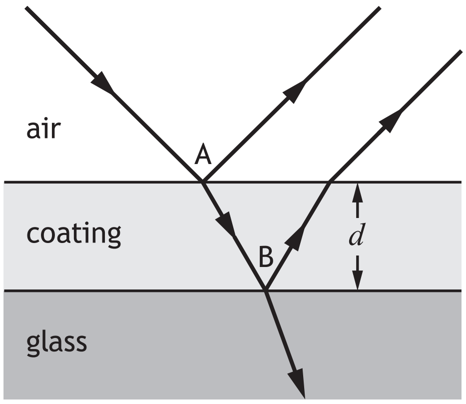


Figure 11B

The refractive index of the coating is less than the refractive index of the glass.

(i) (A) State the phase change, in radians, experienced by a light wave when it reflects at the air-coating boundary at A. **1**

(B) State the phase change, in radians, experienced by a light wave when it reflects at the coating-glass boundary at B. **1**

MARKS DO NOT WRITE IN THIS MARGIN

11. (b) (continued)

(ii) Derive the relationship

$$d = \frac{\lambda}{4n}$$

where d is the minimum thickness for a coating of refractive index n to be non-reflecting for light of wavelength λ. **2**

Space for working and answer

(c) The student considers setting up an experiment to investigate the relationship derived in (b) (ii).

The student plans to form a non-reflecting layer of ice on top of a glass slide. A helium-neon laser will be used as the light source for this experiment.

(i) Calculate the minimum thickness of the layer of ice required for this experiment. **2**

Space for working and answer

(ii) After calculating the minimum thickness of ice required, the student decides against carrying out this experiment.

Based on this calculation, suggest a reason why the student makes this decision. **1**

Question			Expected response	Max mark	Additional guidance
11.	(a)	(i)	(When) two coherent waves meet in-phase.	**1**	Both conditions must be stated. Accept: 'path difference $= m\lambda$' in place of 'in-phase' 'constant phase relationship' in place of 'coherent'.
		(ii)	A maximum reading is displayed on the meter.	**1**	
		(iii)	$\Delta x = \frac{\lambda D}{d}$ (1) $470\times10^{-3} = \frac{\lambda\times720\times10^{-3}}{42\times10^{-3}}$ (1) $\lambda = 0.027$ m (1)	**3**	Accept: 0.03, 0.0274, 0.02742
	(b)	(i) A	π (rad)	**1**	Unit not required but, if given, must be correct.
		(i) B	π (rad)	**1**	Unit not required but, if given, must be correct.
		(ii)	$\left(\begin{array}{l} opd = n\times gpd \\ gpd = 2d \\ opd = 2nd \\ opd = \left(m+\frac{1}{2}\right)\lambda \end{array}\right)$ $2nd = \left(m+\frac{1}{2}\right)\lambda$ (1) $m = 0$ (1) $d = \frac{\lambda}{4n}$	**2**	Use of (minus formula) and m = 1 is acceptable. $2nd = \frac{\lambda}{2}$ (1), (1) $d = \frac{\lambda}{4n}$
	(c)	(i)	$\left(d = \frac{\lambda}{4n}\right)$ $d = \frac{633\times10^{-9}}{4\times1.31}$ (1) $d = 1.21\times10^{-7}$ m (1)	**2**	Accept: 1.2, 1.208, 1.2080
		(ii)	It is impossible to make a layer of ice so thin (in a school).	**1**	Or consistent with (c)(i)

MARKS DO NOT WRITE IN THIS MARGIN

12. A technician carries out an experiment to measure Brewster's angle for a type of plastic.

A laser beam passes through a polariser and then reflects from a plastic prism on a platform. The platform can be rotated to change the angle θ. The reflected beam is detected by a light meter.

This experimental setup is shown in **Figure 12A**.

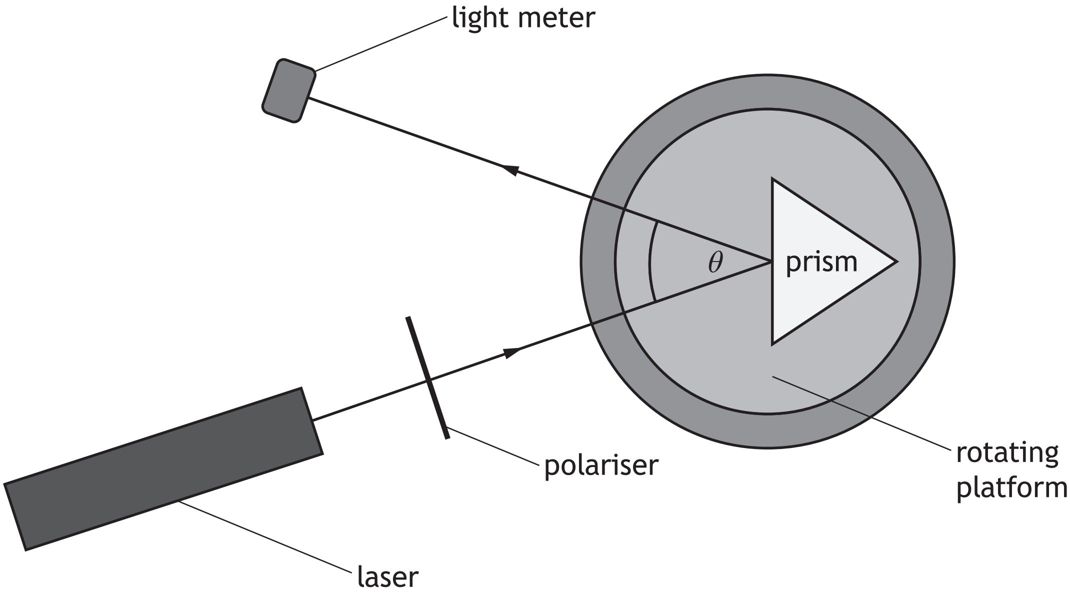


Figure 12A

The polariser ensures that the light reaching the prism is plane-polarised.

As the platform rotates, the light meter is moved to measure the irradiance I of the reflected beam.

At Brewster's angle there is no reflection of the beam from the prism.

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

MARKS DO NOT WRITE IN THIS MARGIN

12. (continued)

(b) **Figure 12B** shows a graph produced from this experiment.

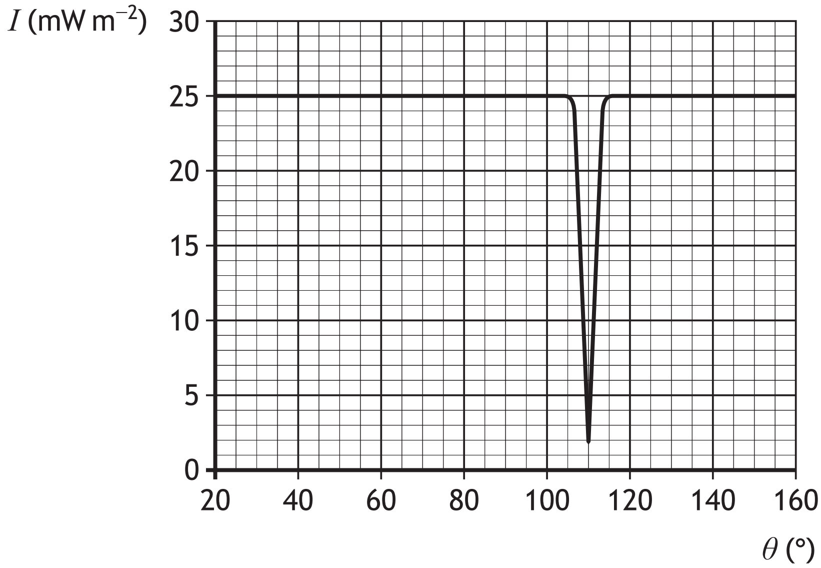


Figure 12B

(i) Determine the refractive index of the plastic. **4**

Space for working and answer

(ii) Suggest a reason why the irradiance detected by the light meter does not reach zero. **1**

[Turn over

Question			Expected response	Max mark	Additional guidance
12.	(a)		(The electric field vector) oscillates (or vibrates) in one plane only.	**1**	Do not accept: 'travels' instead of 'oscillates' 'direction' instead of plane 'axis' instead of plane.
	(b)	(i)	$n = \tan i_p$ (1) $i_p = \frac{110}{2}$ (1) $n = \tan\left(\frac{110}{2}\right)$ (1) $n = 1.4$ (1)	**4**	Independent mark for halving 110° for Brewster angle. Accept: 1, 1.43, 1.428
		(ii)	Background light from other sources. **OR** Imperfections on the surface of the prism.	**1**	Do not accept 'not fully polarised'. Accept: systematic uncertainty in the light meter.

MARKS DO NOT WRITE IN THIS MARGIN

13. A small, positively charged sphere is fixed to an insulated stand, as shown in **Figure 13A**.

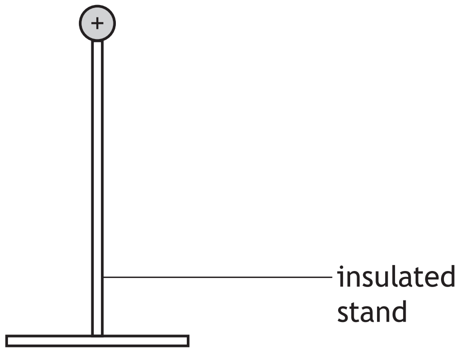


Figure 13A

(a) On **Figure 13A**, sketch the electric field pattern around the charged sphere. **1**

(An additional diagram, if required, can be found on *page 54*.)

(b) The charge on the sphere is +12 nC.

Show that the electric field strength at a distance of 0.15 m from the centre of the charged sphere is 4800 $N\,C^{-1}$. **2**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

13. (continued)

(c) Another charged sphere of mass 16 g is suspended by a thin, insulating cord.

This suspended sphere is moved towards the fixed sphere. When the distance between the two spheres is 0.15 m the deflection of the cord is 5.0° from the vertical.

This is shown in **Figure 13B**.

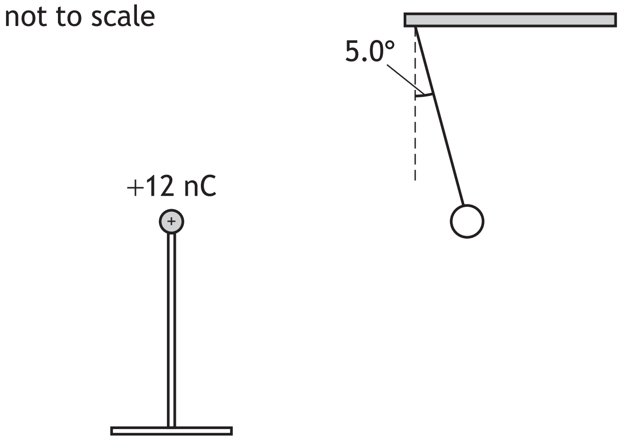


Figure 13B

(i) Determine the magnitude of the electrostatic force acting on the suspended sphere. **3**

Space for working and answer

MARKS DO NOT WRITE IN THIS MARGIN

13. (c) (continued)

(ii) Calculate the charge on the suspended sphere. **3**

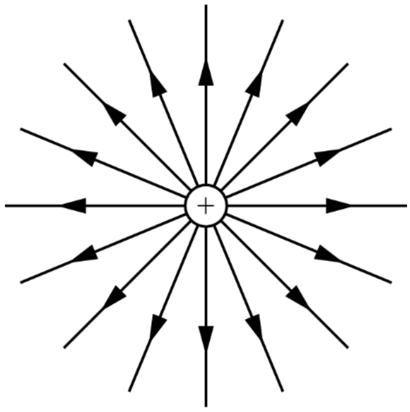
Space for working and answer

(d) The suspended sphere is moved to a distance of 0.30 m from the fixed sphere. The charge on the suspended sphere is now doubled.

State whether the angle of the cord from the vertical will be greater than, less than or equal to 5.0°.

Justify your answer. **2**

[Turn over

Question			Expected response	Max mark	Additional guidance
13.	(a)			**1**	Field lines should be evenly spaced around the charge. Field lines should be passably straight. Field lines should be touching the charge. Minimum number of field lines is five.
	(b)		$E=\frac{Q}{4\pi\varepsilon_0 r^2}$ (1) $E=\frac{12\times10^{-9}}{4\pi\times8.85\times10^{-12}\times0.15^2}$ (1) $E=4800\ \text{NC}^{-1}$	**2**	SHOW question $E=k\frac{Q}{r^2}$ (1) $E=9\times10^9\times\frac{12\times10^{-9}}{0.15^2}$ (1) $E=4800\ \text{NC}^{-1}$ Final line must be shown or max 1 mark.
	(c)	(i)	$F=mg\tan\theta$ (1) $F=16\times10^{-3}\times9.8\times\tan5.0$ (1) $F=1.4\times10^{-2}\ \text{N}$ (1)	**3**	Accept 1, 1.37, 1.372
		(ii)	$F=EQ$ (1) $1.4\times10^{-2}=4800\times Q$ (1) $Q=2.9\times10^{-6}\ \text{C}$ (1)	**3**	Or consistent with (c)(i) Accept: 3, 2.92, 2.917 $F=\frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$ $1.4\times10^{-2}=\frac{12\times10^{-9}\times Q_2}{4\pi\times8.85\times10^{-12}\times0.15^2}$ $Q_2=2.9\times10^{-6}\ \text{C}$
	(d)		The angle will be less. (1) r^2 term greater influence than Q (1)	**2**	Justify Can justify by calculation of force.

DO NOT WRITE IN THIS MARGIN

14. A mass spectrometer is an instrument that is used to investigate some properties of charged particles.

A simplified illustration showing the path of an ion as it passes through the mass spectrometer is shown in **Figure 14A**.

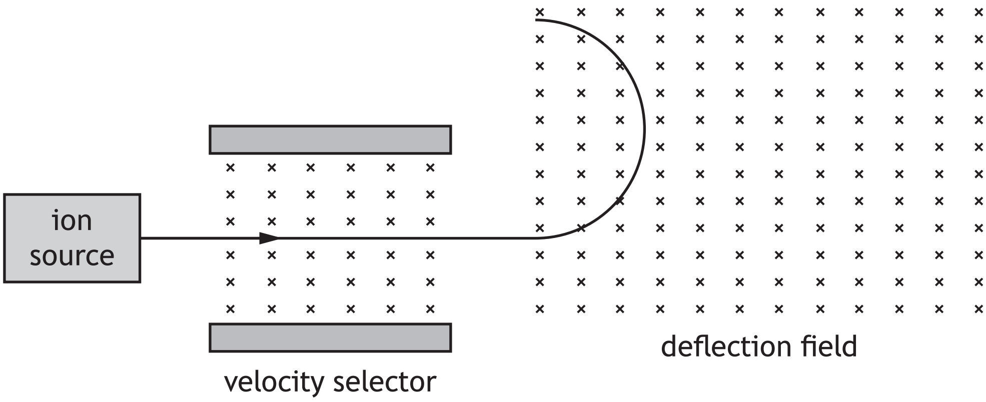


Figure 14A

The velocity selector contains a region in which there is both 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 ions.

The electric field is produced by a potential difference of 4.80 kV between two parallel plates. The plates are separated by a distance of 10.0 mm.

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

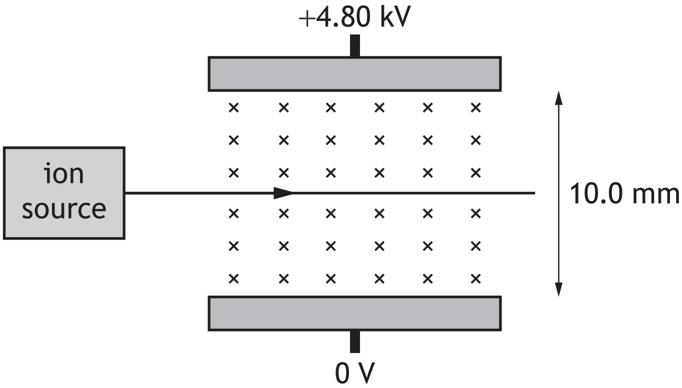


Figure 14B

The magnetic induction in the velocity selector is 225 mT.

MARKS DO NOT WRITE IN THIS MARGIN

14. (continued)

(a) (i) By considering the electric and magnetic forces acting on an ion, show that the velocity v of an ion passing undeflected through the velocity selector is given by the relationship

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

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

Space for working and answer

(ii) Determine the velocity of an ion that passes through the velocity selector undeflected. **3**

Space for working and answer

(iii) Explain why different types of ion passing through the velocity selector undeflected have the same velocity. **1**

DO NOT WRITE IN THIS MARGIN

14. (continued)

(b) The mass spectrometer is now used to investigate the paths followed by two types of hydrogen ion.

Data for the hydrogen ions are shown below.

Ion	Symbol	Mass ($\times 10^{-27}$ kg)	Charge ($\times 10^{-19}$ C)
Deuterium	$^{2}H^{+}$	3.34	1.60
Tritium	$^{3}H^{+}$	5.01	1.60

These ions enter the deflection field with the velocity determined in (a) (ii) and follow semi-circular paths in the field.

One type of ion leaves the field at point Y and the other type of ion leaves at point Z.

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

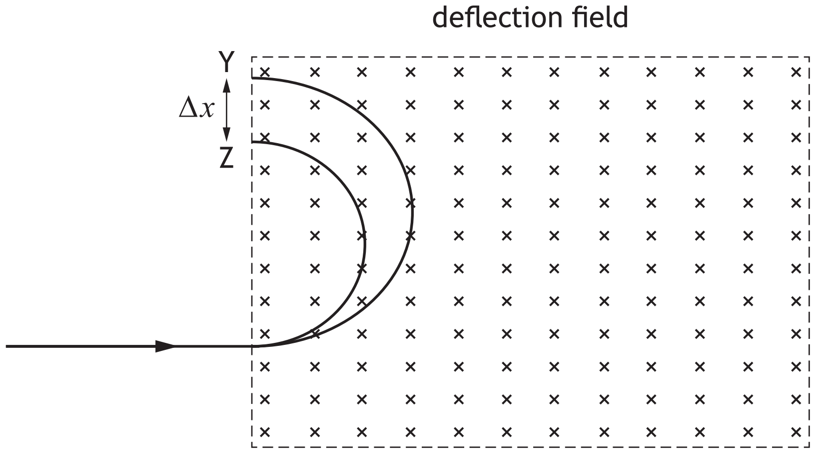


Figure 14C

The magnetic induction in the deflection field is 0.65 T.

MARKS DO NOT WRITE IN THIS MARGIN

14. (b) (continued)

The radius of the curved path of the ions is given by the relationship

$$r = \frac{mv}{qB}$$

where the symbols have their usual meanings.

Determine the separation Δx of the ions when they leave the deflection field. **4**

Space for working and answer

(c) The potential difference between the parallel plates in the velocity selector is now increased. The magnetic inductions of both the velocity selector and the deflection field are unchanged.

State the change to the paths of the ions in the deflection field.

Justify your answer. **2**

[Turn over

Question			Expected response	Max mark	Additional guidance
14.	(a)	(i)	$(F_B = qvB)$ $(F_E = QE)$ $qvB = QE$ (1, 1) $v = \frac{E}{B}$	2	SHOW question 1 mark for both relationships. 1 mark for equating. Final line must be shown or max 1 mark.
		(ii)	$E = \frac{V}{d}$ (1) $\left(v = \frac{E}{B}\right)$ $v = \frac{\left(\frac{4.80\times10^{3}}{10.0\times10^{-3}}\right)}{225\times10^{-3}}$ (1) $v = 2.13\times10^{6}$ ms^{-1} (1)	3	Accept 2.1, 2.133, 2.1333
		(iii)	Velocity is dependent on E and B only.	1	Velocity is independent of mass and charge.
	(b)		$r = \frac{mv}{qB}$ $r_{2_H} = \frac{3.34\times10^{-27}\times2.13\times10^{6}}{1.60\times10^{-19}\times0.65}$ (1) $r_{3_H} = \frac{5.01\times10^{-27}\times2.13\times10^{6}}{1.60\times10^{-19}\times0.65}$ (1) $\Delta x = 2\times\left(\left(\frac{5.01\times10^{-27}\times2.13\times10^{6}}{1.60\times10^{-19}\times0.65}\right)-\left(\frac{3.34\times10^{-27}\times2.13\times10^{6}}{1.60\times10^{-19}\times0.65}\right)\right)$ (1) $\Delta x = 0.068$ m (1)	4	Accept 0.07, 0.0684, 0.06841 Or consistent with (a)(ii)
	(c)		Radii (of curvature) increase (1) Velocity of ions increases (1)	2	Justify

DO NOT WRITE IN THIS MARGIN

15. A circuit is set up to investigate some properties of inductors. The circuit diagram is shown in **Figure 15A**.

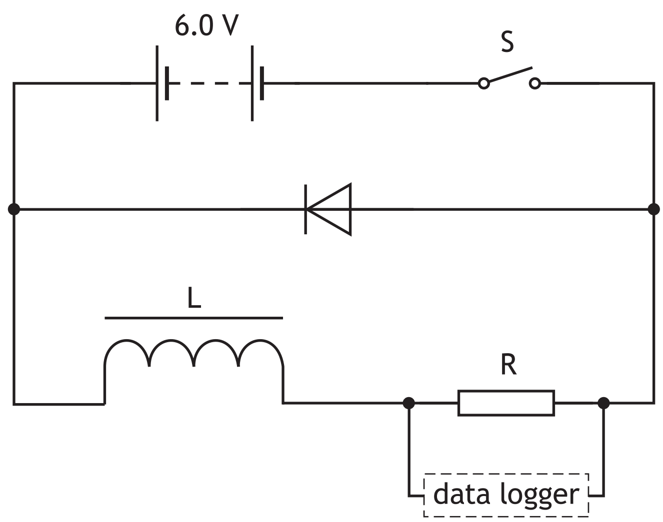


Figure 15A

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

(a) Switch S is closed and the data logger records data.

The data is used to produce a graph of current I against time t.

The graph is shown in **Figure 15B**.

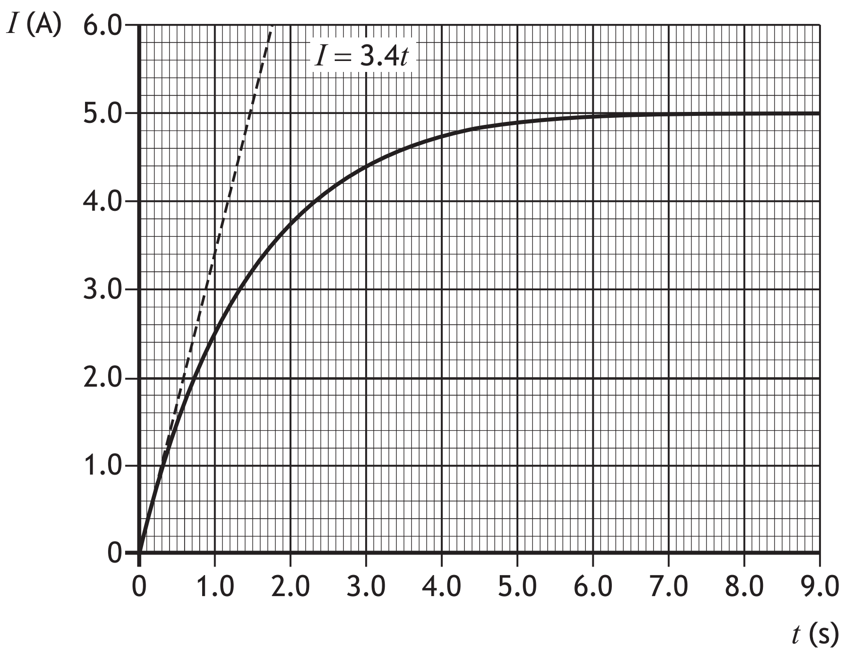


Figure 15B

The dashed line is the tangent to the curve at the origin and indicates the initial rate of change of current.

MARKS DO NOT WRITE IN THIS MARGIN

15. (a) (continued)

(i) Explain fully why the current does not immediately reach its maximum value. **2**

(ii) Calculate the self-inductance of inductor L. **3**

Space for working and answer

(iii) Calculate the maximum energy stored in the inductor. **3**

Space for working and answer

[Turn over

MARKS DO NOT WRITE IN THIS MARGIN

15. (continued)

(b) The iron core is now removed from inductor L. The resistance of the circuit remains the same.

State whether the time taken to reach the maximum current will be greater than, less than or equal to the time taken for inductor L.

Justify your answer. **2**

MARKS DO NOT WRITE IN THIS MARGIN

15. (continued)

(c) The quality factor Q is a property of an AC circuit.

In a series AC circuit containing an inductor and a resistor the quality factor is given by the relationship

$$Q = \frac{\omega L}{R}$$

where the symbols have their usual meanings.

An inductor of inductance 2.4 mH is connected in the circuit shown in **Figure 15C**.

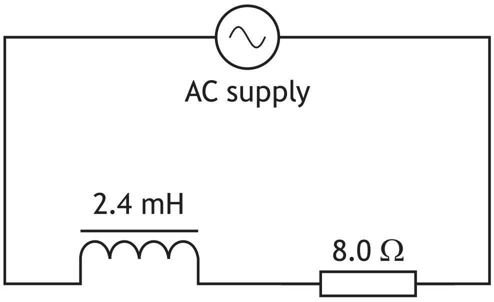


Figure 15C

The quality factor of the circuit is 44.2.

Determine the frequency of the AC supply. **3**

Space for working and answer

[Turn over

Question			Expected response	Max mark	Additional guidance
15.	(a)	(i)	Changing current produces a changing magnetic field. (1) This induces a back EMF in the inductor which opposes the change in current. (1)	**2**	Independent marks.
		(ii)	$\mathcal{E} = -L\frac{dI}{dt}$ (1) $-6.0 = -L \times 3.4$ (1) $L = 1.8$ H (1)	**3**	Accept 2, 1.76, 1.765 Accept: $\mathcal{E} = -L\frac{dI}{dt}$ (1) $6.0 = L \times 3.4$ (1) $L = 1.8$ H (1)
		(iii)	$E = \frac{1}{2}LI^2$ (1) $E = \frac{1}{2} \times 1.8 \times 5.0^2$ (1) $E = 23$ J (1)	**3**	Accept 20, 22.5, 22.50 Or consistent with (a)(ii)
	(b)		Time will be less (1) The (self-) inductance has decreased. (1)	**2**	Justify question Rate of change of current increases.
	(c)		$\left(Q = \frac{\omega L}{R}\right)$ $44.2 = \frac{\omega \times 2.4 \times 10^{-3}}{8.0}$ (1) $\omega = 2\pi f$ (1) $\left(\frac{44.2 \times 8.0}{2.4 \times 10^{-3}} = 2\pi f\right)$ $f = 2.3 \times 10^4$ Hz (1)	**3**	Accept 2, 2.34, 2.345 $\omega = 2\pi f$ independent mark.

DO NOT WRITE IN THIS MARGIN

16. As part of their project, a student conducts an experiment to determine a value for Young's modulus of steel using a steel beam. Young's modulus of a material is a measure of how easily it can be stretched and deformed.

The initial experimental set up is shown in **Figure 16A**.

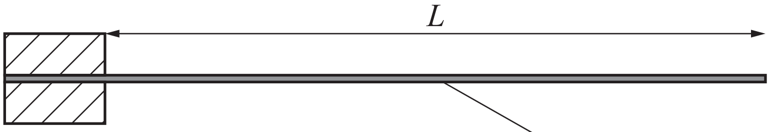


Figure 16A

The student applies a force F to the beam, by attaching a mass to the end of the beam. This causes the beam to be deflected by a displacement s, as shown in **Figure 16B**.

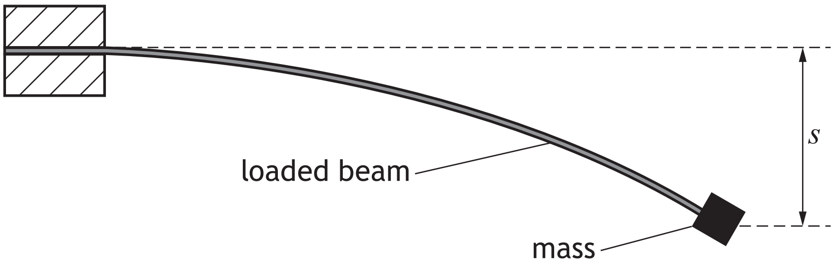


Figure 16B

The force is now varied by attaching additional masses to the end of the beam. The resulting displacements are measured.

The student then uses an app to plot a graph of force against displacement. The graph is shown in **Figure 16C**.

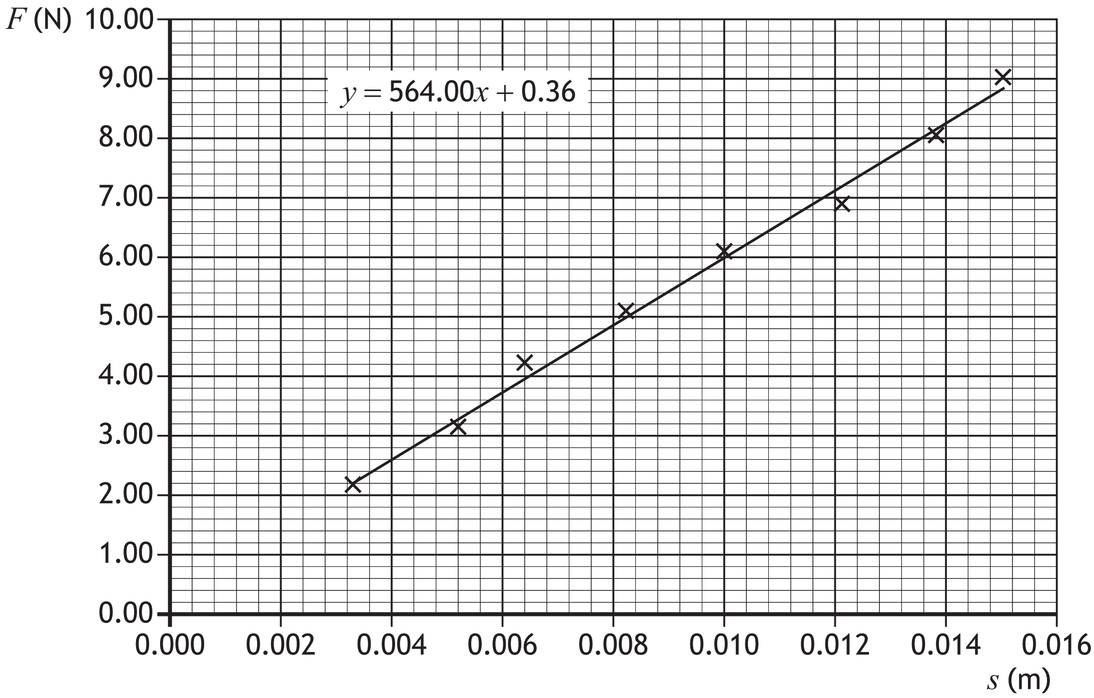


Figure 16C

* X 8 5 7 7 7 0 1 4 8 *

MARKS | DO NOT WRITE IN THIS MARGIN

16. (continued)

(a) Young's modulus E, in pascals, is given by the relationship

$$E = \frac{F}{s} \times \frac{L^3}{3I}$$

The second moment of inertia I of the steel beam is 7.2×10^{-10} m^4.

The length L of the unloaded beam is 0.90 m.

Using information from the graph, determine a value for Young's modulus of the steel used in this experiment. **3**

Space for working and answer

[Turn over

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

(b) Data from the app are shown in the table.

Gradient	y-intercept
564.00	0.36
Uncertainty in gradient	**Uncertainty in y-intercept**
8.47	0.19

The student notes the following uncertainties in each quantity:

$\Delta s = \pm 0.0005$ m

$\Delta F = \pm 0.01$ N

$\Delta L = \pm 0.005$ m

$\Delta I = \pm 0.01 \times 10^{-10}$ kg m^2

(i) Determine the absolute uncertainty in the value of Young's modulus obtained in (a). **4**

(ii) The line of best fit does not pass through the origin as theory predicts.

Suggest a source for this systematic uncertainty. **1**

[END OF QUESTION PAPER]

Question			Expected response	Max mark	Additional guidance
16.	(a)		$E = gradient \times \frac{L^3}{3I}$ (1) $E = 564.00 \times \frac{0.90^3}{3 \times 7.2 \times 10^{-10}}$ (1) $E = 1.9 \times 10^{11}$ Pa (1)	**3**	Accept 2, 1.90, 1.904
	(b)	(i)	$\frac{\Delta W}{W} = \sqrt{\left(\frac{\Delta X}{X}\right)^2 + \left(\frac{\Delta Y}{Y}\right)^2 + \left(\frac{\Delta Z}{Z}\right)^2}$ $\left(\frac{\Delta E}{E} = \sqrt{\left(\frac{\Delta grad}{grad}\right)^2 + \left[3 \times \left(\frac{\Delta L}{L}\right)\right]^2 + \left(\frac{\Delta I}{I}\right)^2}\right)$ $\frac{\Delta E}{1.9 \times 10^{11}} = \sqrt{\left(\frac{8.47}{564.00}\right)^2 + \left[3 \times \left(\frac{0.005}{0.90}\right)\right]^2 + \left(\frac{0.01 \times 10^{-10}}{7.20 \times 10^{-10}}\right)^2}$ $\Delta E = 0.04 \times 10^{11}$ Pa	**4**	Accept % method 1 relationship 1 tripling $\%\Delta L$ 1 all subs 1 final answer Suspend significant figures rule Allow 'rule of 3' for ΔI Accept: 0.043, 0.0427, 0.04271
		(ii)	The force measurement could be consistently too high. **OR** The displacement measurement could be consistently too low.	**1**	

[END OF MARKING INSTRUCTIONS]