GuideMyGrades

YOUR GOALS. OUR EXPERTISE.

AQA A LEVEL PHYSICS (7408): QUESTIONS BY TOPIC

Further mechanics and thermal physics (3.6)

A Level Physics (7408) · Section 3.6

90 questions · 382 marks · Mark schemes included

AQA A Level Physics (7408), June 2017 – June 2025

guidemygrades.com
@Guidemygrades
@Guidemygrades
@Guidemygrades
info@guidemygrades.com
Piccadilly Business Centre, Unit C, Aldow Enterprise Park
Blackett Street, Manchester, M12 6AE

HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.
Click any row below to jump straight to that sub-topic or question.
On every question page, click ANSWER in the top-right corner to jump to its mark scheme.
Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

	QUESTION		SOURCE	MARKS	PAGE
3.6.1.1	**CIRCULAR MOTION**			7 Qs · 31 marks	**5**
1.	**Q30**	*also 3.4*	7408/1 June 2017	1	**6**
2.	**Q10**	*also 3.7*	7408/2 June 2022	1	**7**
3.	**Q30**		7408/1 June 2023	1	**8**
4.	**Q28**		7408/1 June 2024	1	**9**
5.	**Q5**	*also 3.4*	7408/1 June 2018	8	**10**
6.	**Q7**	*also 3.4*	7408/1 June 2025	8	**11**
7.	**Q4**	*also 3.4*	7408/1 November 2021	11	**14**
3.6.1.2	**SIMPLE HARMONIC MOTION AND SYSTEMS**			25 Qs · 76 marks	**17**
8.	**Q31**	*also 3.4*	7408/1 June 2017	1	**18**
9.	**Q32**		7408/1 June 2017	1	**19**
10.	**Q29**	*also 3.3 & 3.4*	7408/1 June 2018	1	**20**
11.	**Q30**	*also 3.4*	7408/1 June 2018	1	**21**
12.	**Q31**	*also 3.4 & 3.7*	7408/1 June 2018	1	**22**
13.	**Q29**	*also 3.4*	7408/1 June 2019	1	**23**
14.	**Q30**		7408/1 June 2019	1	**24**
15.	**Q31**		7408/1 June 2019	1	**25**
16.	**Q24**		7408/1 November 2020	1	**26**
17.	**Q30**		7408/1 November 2020	1	**27**
18.	**Q30**		7408/1 November 2021	1	**28**
19.	**Q31**	*also 3.4*	7408/1 November 2021	1	**29**
20.	**Q31**		7408/1 June 2022	1	**30**
21.	**Q31**	*also 3.4*	7408/1 June 2023	1	**31**
22.	**Q30**		7408/1 June 2024	1	**32**
23.	**Q32**		7408/1 June 2024	1	**33**
24.	**Q25**	*also 3.4 & 3.7*	7408/1 June 2025	1	**34**
25.	**Q31**	*also 3.4*	7408/1 June 2025	1	**35**
26.	**Q32**		7408/1 June 2025	1	**36**
27.	**Q6**	*also 3.4*	7408/1 June 2019	5	**37**
28.	**Q3**	*also 3.4*	7408/1 June 2025	5	**39**
29.	**Q6**	*also 3.4*	7408/1 June 2023	9	**40**
30.	**Q5**	*also 3.4*	7408/1 June 2022	11	**45**
31.	**Q4**	*also 3.1*	7408/3 Section A June 2025	12	**49**

	QUESTION		SOURCE	MARKS	PAGE
32.	**Q1**	*also 3.1 & 3.4*	7408/3 Section A November 2020	15	**53**
3.6.1.4	**FORCED VIBRATIONS AND RESONANCE**			1 Qs · 1 marks	**59**
33.	**Q32**		7408/1 June 2019	1	**60**
3.6.2.1	**THERMAL ENERGY TRANSFER**			8 Qs · 35 marks	**62**
34.	**Q8**		7408/2 June 2017	1	**63**
35.	**Q9**		7408/2 June 2017	1	**64**
36.	**Q7**		7408/2 November 2021	1	**65**
37.	**Q8**	*also 3.4*	7408/2 June 2023	1	**66**
38.	**Q1**	*also 3.5*	7408/2 June 2022	5	**67**
39.	**Q1**	*also 3.4*	7408/2 June 2018	7	**69**
40.	**Q1**	*also 3.4*	7408/2 June 2019	9	**71**
41.	**Q1**	*also 3.4*	7408/2 November 2020	10	**74**
3.6.2.2	**IDEAL GASES**			15 Qs · 54 marks	**77**
42.	**Q8**	*also 3.1*	7408/2 June 2018	1	**78**
43.	**Q9**		7408/2 June 2018	1	**79**
44.	**Q7**		7408/2 November 2020	1	**80**
45.	**Q8**		7408/2 November 2020	1	**81**
46.	**Q9**	*also 3.4*	7408/2 November 2020	1	**82**
47.	**Q7**		7408/2 June 2022	1	**83**
48.	**Q8**	*also 3.4*	7408/2 June 2022	1	**84**
49.	**Q9**	*also 3.8*	7408/2 June 2023	1	**85**
50.	**Q8**	*also 3.4*	7408/2 June 2024	1	**86**
51.	**Q10**		7408/2 June 2024	1	**87**
52.	**Q8**		7408/2 June 2025	1	**88**
53.	**Q10**		7408/2 June 2025	1	**89**
54.	**Q1**	*also 3.1 & 3.4*	7408/2 June 2024	9	**90**
55.	**Q3**	*also 3.4*	7408/3 Section A June 2018	14	**92**
56.	**Q4**	*also 3.1*	7408/3 Section A June 2022	19	**96**
3.6.2.3	**MOLECULAR KINETIC THEORY MODEL**			15 Qs · 70 marks	**104**
57.	**Q11**		7408/2 June 2017	1	**105**
58.	**Q10**		7408/2 June 2018	1	**106**
59.	**Q11**	*also 3.4*	7408/2 June 2018	1	**107**
60.	**Q7**		7408/2 June 2019	1	**108**
61.	**Q25**	*also 3.4*	7408/2 June 2019	1	**109**
62.	**Q10**		7408/2 November 2020	1	**110**
63.	**Q11**		7408/2 November 2020	1	**111**
64.	**Q8**		7408/2 November 2021	1	**112**
65.	**Q10**	*also 3.4*	7408/2 November 2021	1	**113**
66.	**Q1**	*also 3.4*	7408/2 June 2023	5	**114**
67.	**Q1**	*also 3.4*	7408/2 June 2017	10	**115**

	QUESTION		SOURCE	MARKS	PAGE
68.	**Q2**	*also 3.4*	7408/2 June 2022	10	**118**
69.	**Q3**		7408/2 November 2021	11	**119**
70.	**Q2**	*also 3.4*	7408/2 June 2025	11	**123**
71.	**Q2**	*also 3.4*	7408/2 June 2019	14	**125**
3.6.S	**SYNOPTIC AND CROSS-TOPIC QUESTIONS**			19 Qs · 115 marks	**127**
72.	**Q26**		7408/2 June 2018	1	**128**
73.	**Q9**	*also 3.7*	7408/2 June 2019	1	**129**
74.	**Q11**	*also 3.4 & 3.7*	7408/2 June 2019	1	**130**
75.	**Q13**	*also 3.7*	7408/2 November 2020	1	**131**
76.	**Q13**	*also 3.7*	7408/2 June 2023	1	**132**
77.	**Q24**	*also 3.4 & 3.5 & 3.7*	7408/2 June 2023	1	**133**
78.	**Q16**	*also 3.4 & 3.7*	7408/2 June 2024	1	**134**
79.	**Q21**	*also 3.4 & 3.5 & 3.7*	7408/2 June 2025	1	**135**
80.	**Q3**	*also 3.4 & 3.7*	7408/2 June 2017	6	**136**
81.	**Q5**	*also 3.4 & 3.5 & 3.7*	7408/2 June 2019	6	**138**
82.	**Q4**	*also 3.4 & 3.5 & 3.7*	7408/2 June 2018	8	**141**
83.	**Q5**	*also 3.4 & 3.7*	7408/2 June 2024	8	**144**
84.	**Q2**	*also 3.4 & 3.7*	7408/2 November 2021	10	**147**
85.	**Q7**	*also 3.4 & 3.8*	7408/2 June 2023	10	**150**
86.	**Q2**	*also 3.3*	7408/1 June 2025	10	**154**
87.	**Q3**	*also 3.4 & 3.7*	7408/2 November 2020	11	**157**
88.	**Q3**	*also 3.3*	7408/1 November 2020	12	**162**
89.	**Q6**	*also 3.4 & 3.7*	7408/2 June 2025	13	**166**
90.	**Q3**	*also 3.5*	7408/3 Section A June 2025	13	**171**

QUESTIONS

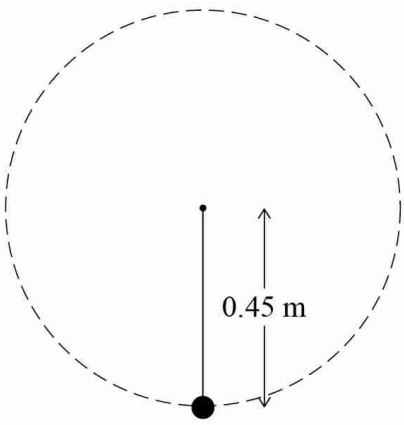
90 questions · 382 marks · 7 sub-topics

SUB-TOPIC 3.6.1.1

CIRCULAR MOTION

Sub-topic 3.6.1.1 · 7 questions · 31 marks · lowest tariff first

3 0 A bob of mass 0.50 kg is suspended from the end of a piece of string 0.45 m long.
The bob is rotated in a vertical circle at a constant rate of 120 revolutions per minute.



What is the tension in the string when the bob is at the bottom of the circle?

[1 mark]

A 5.8 N ⬭

B 31 N ⬭

C 36 N ⬭

D 40 N ⬭

1 0 The Moon orbits the Earth in 27 days.

What is the angular speed of the Moon's orbit?

[1 mark]

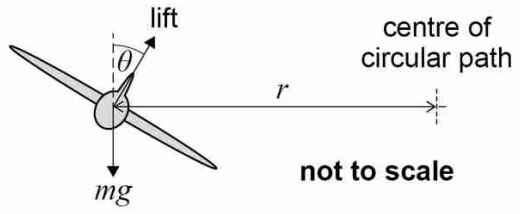
A 4.3×10^{-7} rad s^{-1} ⬭

B 2.7×10^{-6} rad s^{-1} ⬭

C 3.7×10^{-2} rad s^{-1} ⬭

D 2.3×10^{-1} rad s^{-1} ⬭

3 0 When an aircraft turns in a horizontal circular path, it banks at an angle θ.



The aircraft has mass m and travels at constant speed v in a horizontal circular path of radius r. The lift force acts at the angle θ.

What is tan θ?

[1 mark]

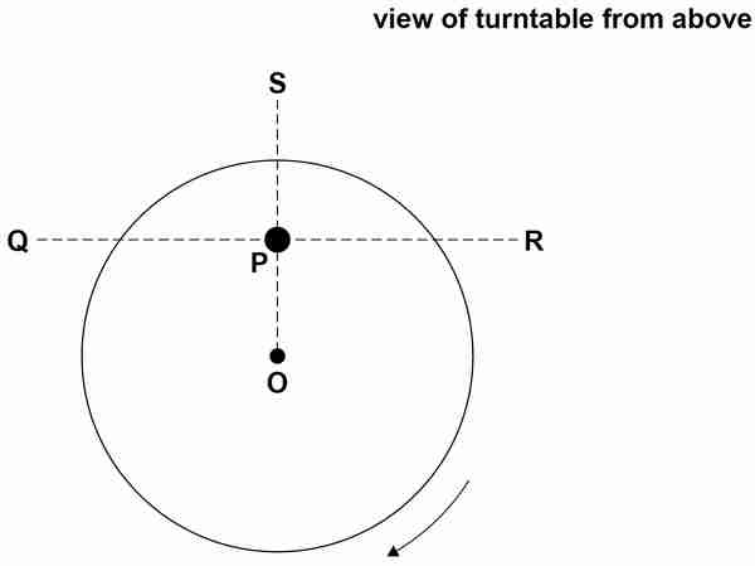
A $\frac{gv^2}{r}$ ⬭

B $\frac{rv^2}{g}$ ⬭

C $\frac{rg}{v^2}$ ⬭

D $\frac{v^2}{rg}$ ⬭

2 8 A small mass is placed at **P** on a horizontal turntable. The turntable rotates clockwise with a constant angular speed about a vertical axis through its centre **O**.



The mass remains at rest relative to the turntable.

What is the direction of the frictional force on the mass at the instant shown?

[1 mark]

A from **P** to **O** ⬭

B from **P** to **Q** ⬭

C from **P** to **R** ⬭

D from **P** to **S** ⬭

0 5 **Figure 8** shows a side view of an act performed by two acrobats. **Figure 9** shows the view from above.

Figure 8

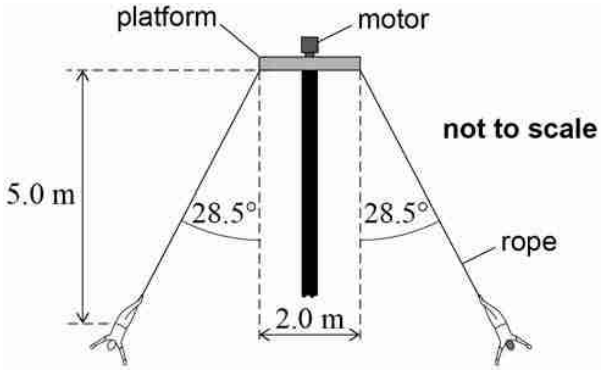
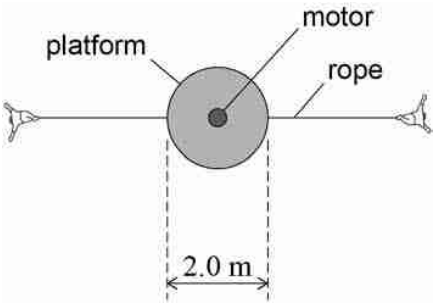


Figure 9



The acrobats, each of mass 85 kg, are suspended from ropes attached to opposite edges of a circular platform that is at the top of a vertical pole. The platform has a diameter of 2.0 m
A motor rotates the platform so that the acrobats move at a constant speed in a horizontal circle, on opposite sides of the pole.

When the period of rotation of the platform is 5.2 s, the centre of mass of each acrobat is 5.0 m below the platform and the ropes are at an angle of 28.5° to the vertical as shown in **Figure 8**.

0 5 . 1 Show that the linear speed of the acrobats is about 4.5 m s^{-1}

[2 marks]

0 5 . 2 Determine the tension in each rope that supports the acrobats.

[3 marks]

tension = _____ N

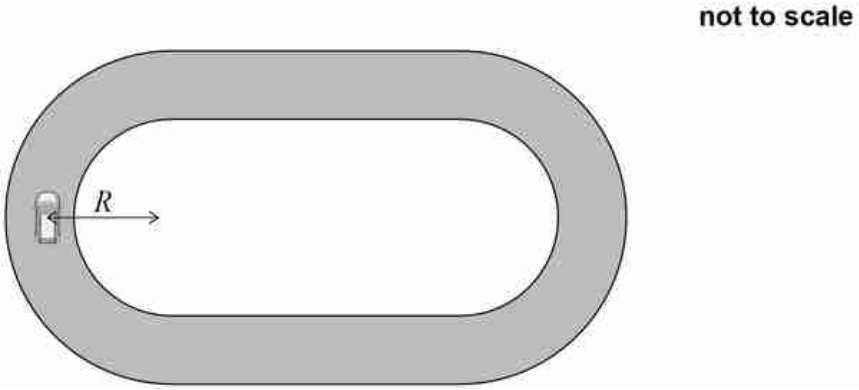
0 5 . 3 Discuss the consequences for the forces acting on the pole when one acrobat has a much greater mass than the other.

[3 marks]

0 7 A racing car of mass m travels around a horizontal oval track. The curved sections of the track are semicircles.

0 7 . 1 At the instant shown in **Figure 10** the car is moving with constant speed v in a circle of radius R.

Figure 10



The car has kinetic energy E_k.

The resultant force acting on the car is F.

Show that $R = \frac{2E_k}{F}$

[2 marks]

The maximum centripetal force that can be produced between the car's tyres and the track is $24\ \text{kN}$.

The minimum value of R is $230\ \text{m}$.

$m = 1600\ \text{kg}$

0 7 . 2 The car just starts to slip when it travels on the track in a circular path of radius $230\ \text{m}$.

Deduce the speed of the car.

[1 mark]

speed = _____ m s^{-1}

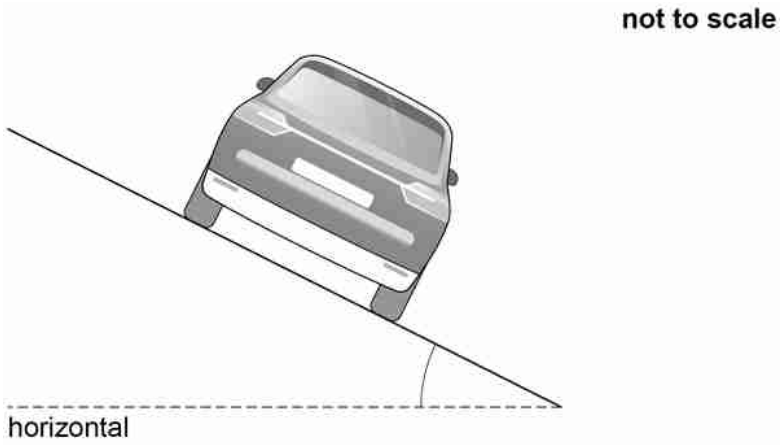
0 7 . 3 The driver wishes to drive this car around the curved section of the track, without slipping, at a speed greater than your answer to Question **07.2**.

Suggest **one** way in which the driver can achieve this.

[1 mark]

Figure 11 shows the car on the curved section of a different oval track.
The curved section of this track is a slope. This means that cars can travel at greater speeds than on the track shown in **Figure 10**.

Figure 11



0 7 . 4 The car in **Figure 11** stays at the same height on the curved section of the track.
There is no tendency for the car to slip up or down the track and therefore there is no sideways friction on the tyres.

Draw and label, on **Figure 11**, arrows to show the direction of each force that acts on the car as it travels around the curved section of the track.

[2 marks]

Question 7 continues on the next page

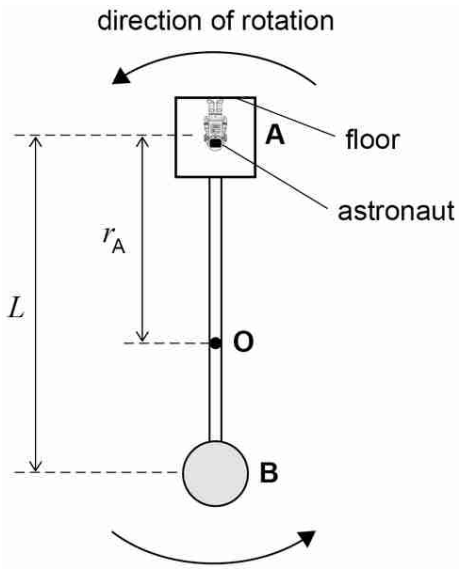
0 7 . 5 A car has a greater maximum speed on a sloped track than on a horizontal track of the same radius.

Explain why.

[2 marks]

0 4 **Figure 6** shows a rotating spacecraft that is proposed to carry astronauts to Mars.

Figure 6



The spacecraft consists of two parts **A** and **B** connected by a rigid cylindrical rod. When the spacecraft is travelling, **A** and **B** rotate at a constant angular speed about their common centre of mass **O**.

L is the distance between the centre of mass of **A** and the centre of mass of **B**.
r_A is the distance from **O** to the centre of mass of **A**.

0 4 . 1 As the spacecraft rotates, a force that imitates the effect of gravity acts on an astronaut who is in contact with the floor.

Explain why.

[2 marks]

0 4 . 2 The forces exerted on **A** and **B** by the connecting rod have the same magnitude.

m_A is the mass of **A**
m_B is the mass of **B**

Show, by considering the centripetal forces acting on **A** and **B**, that r_A is given by

$$r_A = \frac{m_B L}{m_A + m_B}$$

[2 marks]

0 4 . 3 In this spacecraft $m_A < m_B$.

Deduce whether the centre of mass of **A** or the centre of mass of **B** rotates with a greater linear speed.

[2 marks]

Question 4 continues on the next page

The astronauts live in **A** and the cargo is stored in **B**.

When loaded,

$$m_A = 1.32 \times 10^6 \text{ kg}$$

$$m_B = 3.30 \times 10^6 \text{ kg}.$$

The spacecraft imitates the gravity of Mars where $g = 3.7 \text{ m s}^{-2}$.

Figure 7 shows a stress–strain curve for the metal used for the rigid rod.

Figure 7

0 4 . 4 Suggest a suitable diameter for the rod.
Justify your answer.

[5 marks]

diameter = _____ m

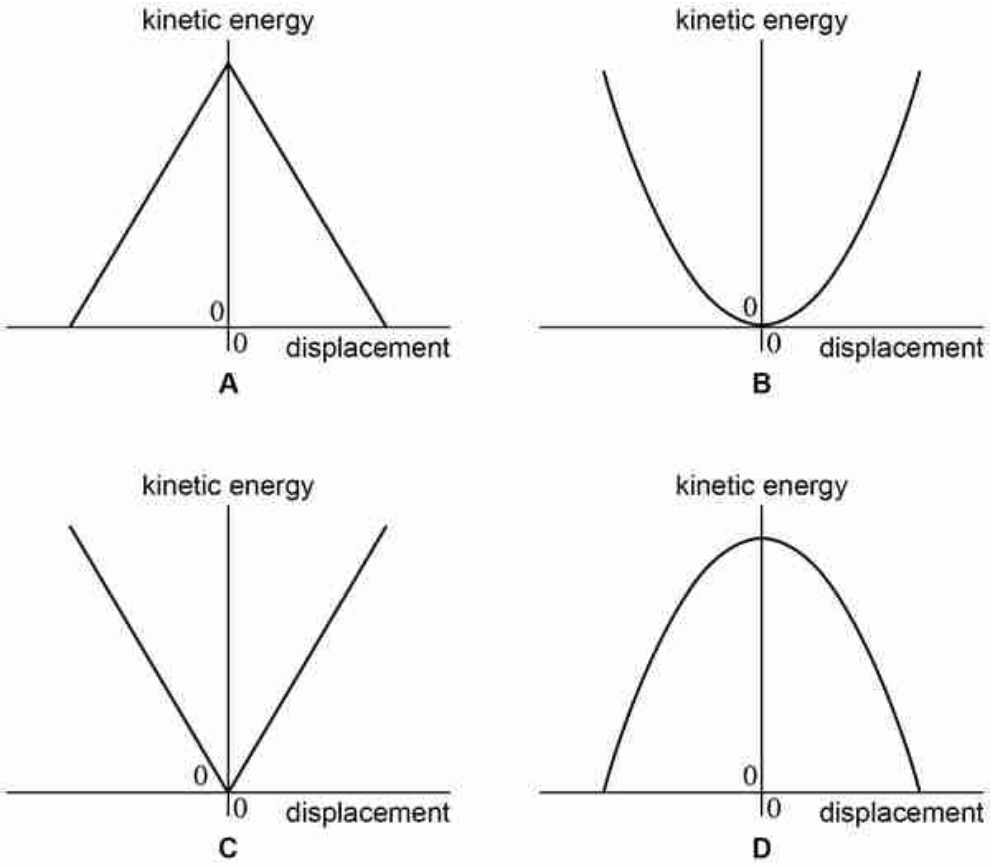
SUB-TOPIC 3.6.1.2

SIMPLE HARMONIC MOTION AND SYSTEMS

Sub-topic 3.6.1.2 · 25 questions · 76 marks · lowest tariff first

3 1 Which graph best shows how the kinetic energy of a simple pendulum varies with displacement from the equilibrium position?

[1 mark]



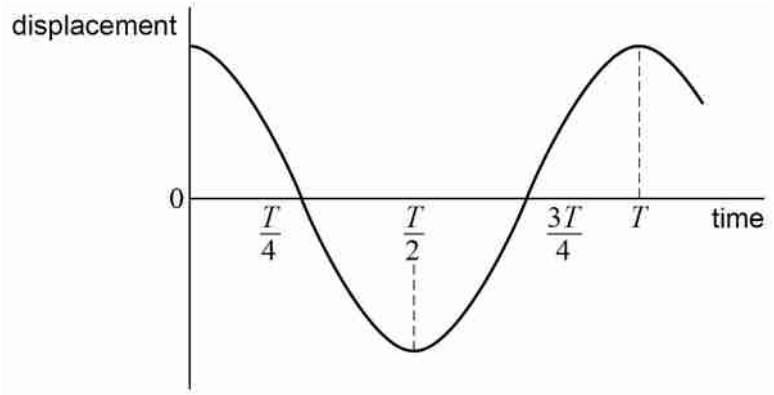
A ⬭

B ⬭

C ⬭

D ⬭

3 2 The graph shows how the displacement of a particle performing simple harmonic motion varies with time.



Which statement is **not** correct?

[1 mark]

A The speed of the particle is a maximum at time $\frac{T}{4}$ ⬭

B The potential energy of the particle is zero at time $\frac{3T}{4}$ ⬭

C The acceleration of the particle is a maximum at time $\frac{T}{2}$ ⬭

D The restoring force acting on the particle is zero at time T ⬭

END OF QUESTIONS

Copyright Information

For confidentiality purposes, from the November 2015 examination series, acknowledgements of third party copyright material will be published in a separate booklet rather than including them on the examination paper or support materials. This booklet is published after each examination series and is available for free download from www.aqa.org.uk after the live examination series.

Permission to reproduce all copyright material has been applied for. In some cases, efforts to contact copyright-holders may have been unsuccessful and AQA will be happy to rectify any omissions of acknowledgements. If you have any queries please contact the Copyright Team, AQA, Stag Hill House, Guildford, GU2 7XJ.

Copyright © 2017 AQA and its licensors. All rights reserved.

2 9 A body performs simple harmonic motion.

What is the phase difference between the variation of displacement with time and the variation of acceleration with time for the body?

[1 mark]

A 0 ⬭

B $\frac{\pi}{4}$ rad ⬭

C $\frac{\pi}{2}$ rad ⬭

D π rad ⬭

3 0 An object of mass $0.15\ \text{kg}$ performs simple harmonic motion. It oscillates with amplitude $55\ \text{mm}$ and frequency $0.80\ \text{Hz}$

What is the maximum value of its kinetic energy?

[1 mark]

A $5.7 \times 10^{-3}\ \text{J}$ ⬭

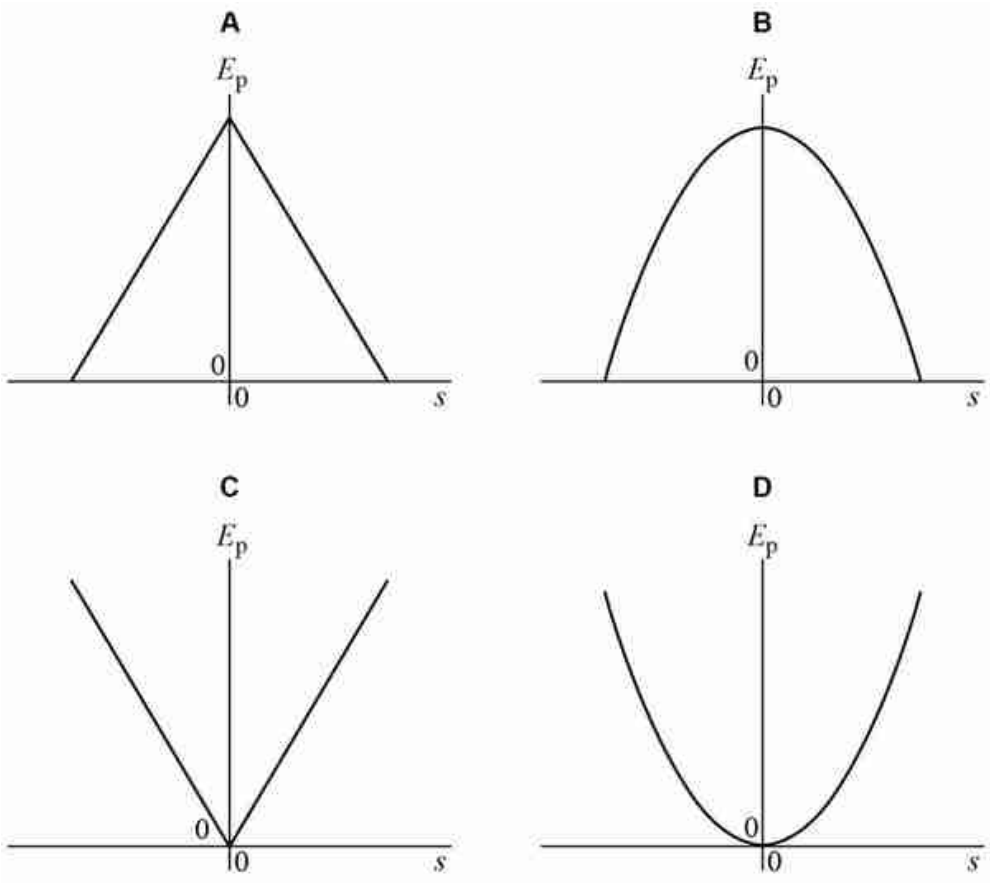
B $11 \times 10^{-3}\ \text{J}$ ⬭

C $0.57\ \text{J}$ ⬭

D $11\ \text{J}$ ⬭

3 1 Which graph shows how the gravitational potential energy E_p of a simple pendulum varies with displacement s from the equilibrium position?

[1 mark]



A ⬭

B ⬭

C ⬭

D ⬭

END OF QUESTIONS

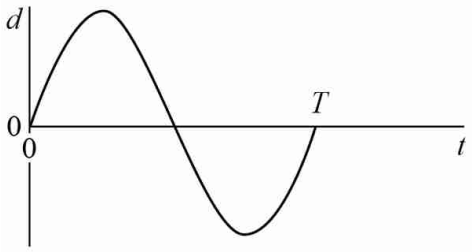
Copyright information

For confidentiality purposes, from the November 2015 examination series, acknowledgements of third party copyright material will be published in a separate booklet rather than including them on the examination paper or support materials. This booklet is published after each examination series and is available for free download from www.aqa.org.uk after the live examination series.

Permission to reproduce all copyright material has been applied for. In some cases, efforts to contact copyright-holders may have been unsuccessful and AQA will be happy to rectify any omissions of acknowledgements. If you have any queries please contact the Copyright Team, AQA, Stag Hill House, Guildford, GU2 7XJ.

Copyright © 2018 AQA and its licensors. All rights reserved.

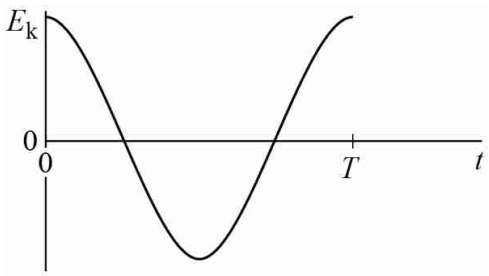
2 9 The graph shows the variation of displacement d with time t for a particle moving with simple harmonic motion of period T.



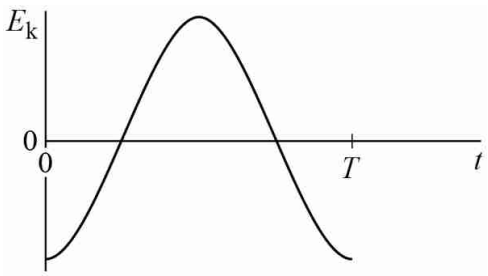
Which graph shows the variation of kinetic energy E_k of the particle with time?

[1 mark]

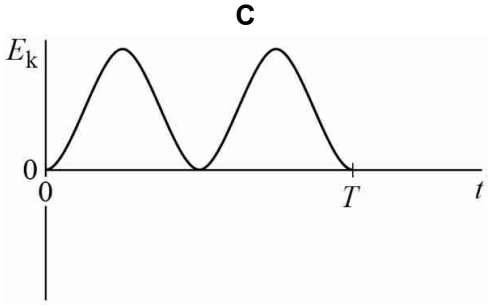
A



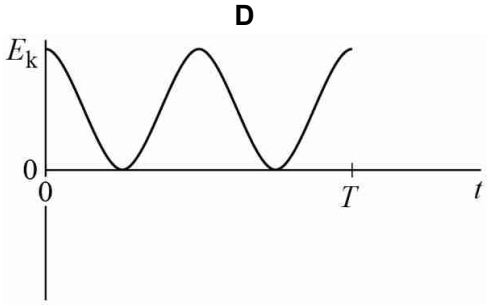
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

3 0 Two pendulums **A** and **B** oscillate with simple harmonic motion.
The time period of **A** is 2.00 s and the time period of **B** is 1.98 s.

A and **B** are released in phase.

What is the number of oscillations of **A** before **A** and **B** are next in phase?

[1 mark]

A 49 ⬭

B 50 ⬭

C 99 ⬭

D 100 ⬭

3 1 The frequency of oscillation of a vertical spring is f when the mass hanging from the spring is m.

What is the relationship between f and m?

[1 mark]

A $f \propto m^{-\frac{1}{2}}$ ⬭

B $f \propto m^{-2}$ ⬭

C $f \propto m^{\frac{1}{2}}$ ⬭

D $f \propto m^{2}$ ⬭

2 4 A particle of mass m undergoes simple harmonic motion with amplitude A and frequency f.

What is the total energy of the particle?

[1 mark]

A $2\pi mfA^2$ ⬭

B $2\pi^2 mf^2A^2$ ⬭

C $4\pi^2m^2f^2A$ ⬭

D $4\pi^2mf^2A^2$ ⬭

3 0 The period of a simple pendulum is doubled when the pendulum length is increased by 1.8 m.

What is the original length of the pendulum?

[1 mark]

A 0.45 m ⬭

B 0.60 m ⬭

C 0.90 m ⬭

D 3.6 m ⬭

END OF QUESTIONS

3 0 A simple pendulum and a mass−spring system each have a time period T on the Earth.

They are taken to the surface of a planet where the acceleration due to gravity is $\frac{g}{4}$.

What are the time periods of the pendulum and the mass−spring system on this planet?

[1 mark]

	Simple pendulum	Mass−spring system	
A	$\frac{T}{2}$	T	⬭
B	$2T$	T	⬭
C	$\frac{T}{2}$	$2T$	⬭
D	$2T$	$2T$	⬭

3 1 A particle of mass m is oscillating with simple harmonic motion.
The period of the oscillation is T and the amplitude is A.

What is the maximum kinetic energy of the particle?

[1 mark]

A $\frac{mA^2}{2T^2}$ ⬭

B $\frac{\pi^2 mA^2}{2T^2}$ ⬭

C $\frac{2mA^2}{T^2}$ ⬭

D $\frac{2\pi^2 mA^2}{T^2}$ ⬭

END OF QUESTIONS

3 1 A particle performs simple harmonic motion with a time period of 1.4 s and an amplitude of 12 mm.

What is the maximum speed of the particle?

[1 mark]

A 8.6 mm s^{-1} ⬭

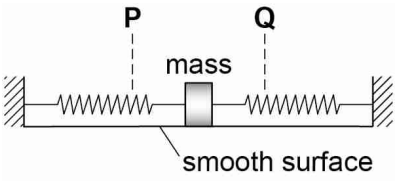
B 27 mm s^{-1} ⬭

C 54 mm s^{-1} ⬭

D 110 mm s^{-1} ⬭

END OF QUESTIONS

3 1 A mass, attached to two springs, oscillates horizontally between **P** and **Q**. The motion of the system is simple harmonic.



Which quantity has its magnitude at a minimum value when the mass is at **Q**?

[1 mark]

A the acceleration of the mass ⬭

B the kinetic energy of the mass ⬭

C the potential energy of the mass–spring system ⬭

D the resultant force of the springs on the mass ⬭

END OF QUESTIONS

3 0 A body is in simple harmonic motion of amplitude $0.60\ \text{m}$ and period 2π seconds.

What is its speed when its displacement is $0.20\ \text{m}$?

[1 mark]

A $0.32\ \text{m s}^{-1}$ ⬭

B $0.57\ \text{m s}^{-1}$ ⬭

C $0.63\ \text{m s}^{-1}$ ⬭

D $22\ \text{m s}^{-1}$ ⬭

3 2 A mass–spring system and a simple pendulum have identical periods of oscillation T when at the surface of the Earth.

Both are taken to planet **X** where the acceleration due to gravity is $\frac{g}{2}$.

What are the periods of the mass–spring system and the simple pendulum on **X**?

[1 mark]

	Period of mass–spring system	Period of simple pendulum	
A	$\frac{T}{2}$	$T\sqrt{2}$	⬭
B	T	$2T$	⬭
C	T	$T\sqrt{2}$	⬭
D	$T\sqrt{2}$	T	⬭

END OF QUESTIONS

2 5 A pendulum is oscillating with simple harmonic motion.

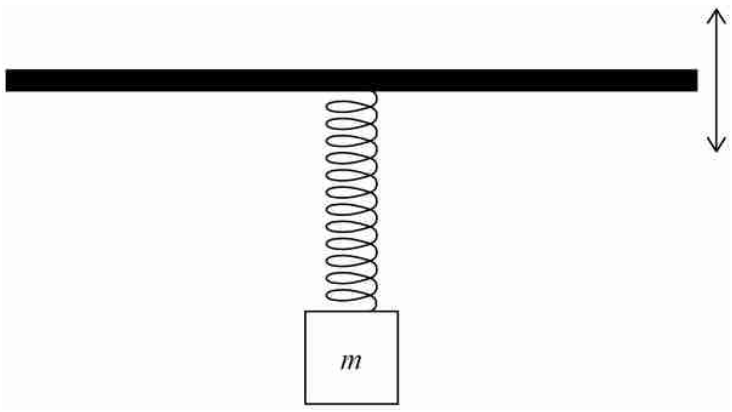
Which row gives the momentum of the pendulum bob and its gravitational potential energy (GPE) when the acceleration of the pendulum bob is zero?

[1 mark]

	Momentum	**GPE**	
A	zero	maximum	⬭
B	maximum	minimum	⬭
C	maximum	maximum	⬭
D	zero	minimum	⬭

3 1 A spring with a spring constant of $50\ \text{N m}^{-1}$ is attached to a rigid horizontal bar.
An object of mass m is attached to the bottom of the spring.

When the bar is made to move vertically up and down with a frequency of $2.6\ \text{Hz}$, the mass–spring system undergoes resonance.
Ignore the effects of damping.



What is m?

[1 mark]

A 190 g ⬭

B 370 g ⬭

C 490 g ⬭

D 590 g ⬭

3 2 A simple pendulum of length $8.0\ \text{cm}$ oscillates on Earth with a frequency f_1.
An identical pendulum on the Moon oscillates with a frequency f_2.
The acceleration due to gravity is $1.6\ \text{m s}^{-2}$ on the surface of the Moon.

What is $f_1 - f_2$?

[1 mark]

A $1.8\ \text{Hz}$ ⬭

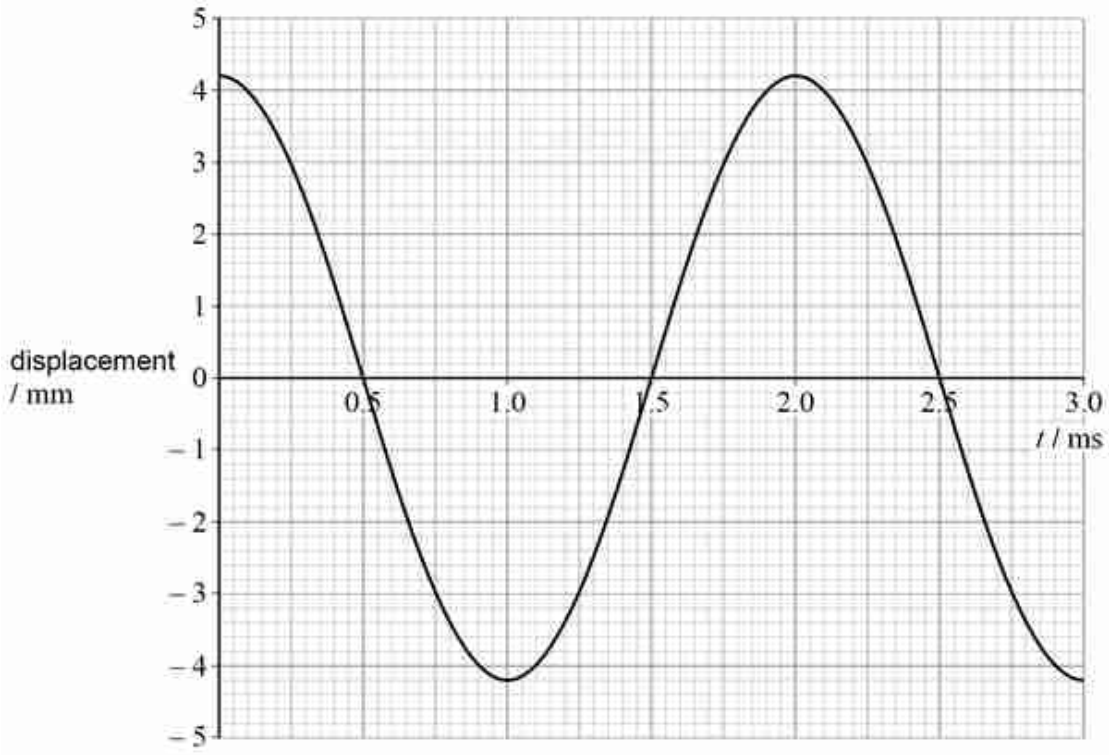
B $1.1\ \text{Hz}$ ⬭

C $0.85\ \text{Hz}$ ⬭

D $0.35\ \text{Hz}$ ⬭

0 6 A loudspeaker cone is driven by a signal generator (oscillator).
Figure 8 shows the variation of displacement with time t for a point **P** at the centre of the cone. **P** is oscillating with simple harmonic motion.

Figure 8



0 6 . 1 State the time, in milliseconds, when **P** is moving at its maximum positive velocity.
[1 mark]

time = _____ ms

0 6 . 2 Calculate the maximum acceleration of **P**.
[3 marks]

acceleration = _____ m s^{-2}

Question 6 continues on the next page

0 6 . 3 The loudspeaker creates variations in pressure and produces a sound wave in the air around it.

State the type of wave produced and describe the motion of the particles in this type of wave.

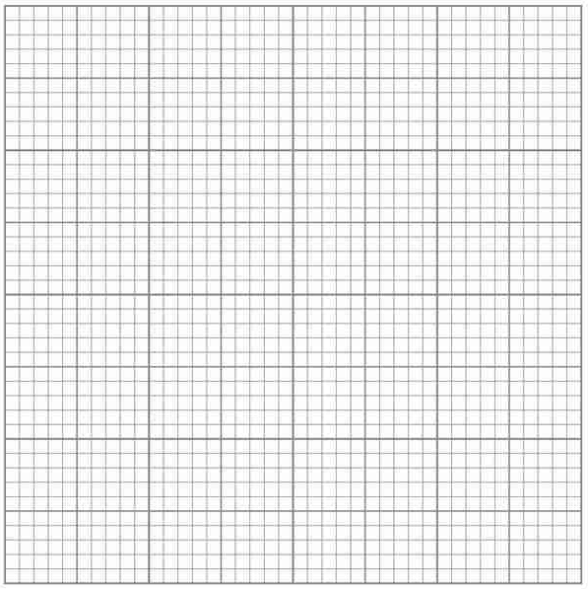
[1 mark]

0 3 A mass–spring system is undergoing simple harmonic motion (SHM).
The maximum velocity of the mass is $0.39\ \text{m s}^{-1}$ and the period of oscillation is $0.81\ \text{s}$.

0 3 . 1 Draw, on **Figure 4**, a graph of acceleration against displacement for the system.
Label each axis with a suitable unit and scale.

[4 marks]

Figure 4

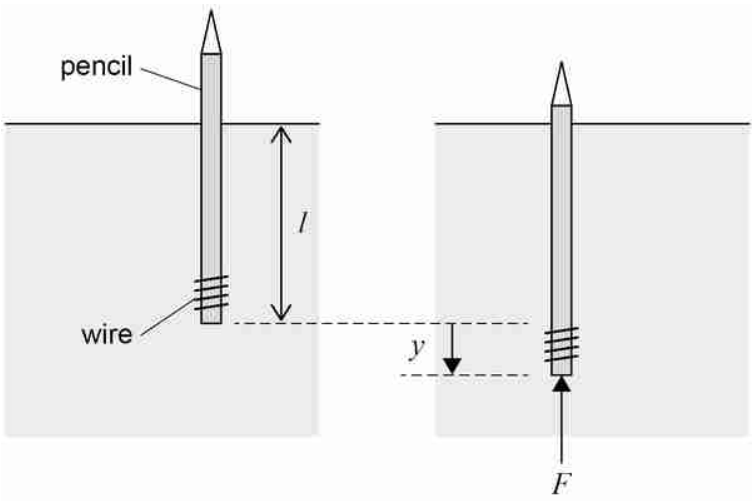


0 3 . 2 Label, with a **P**, a point on your graph where the mass has 50% of its maximum kinetic energy.

[1 mark]

0 6 A pencil is weighted with a thin coil of wire. The volume of the wire is negligible. **Figure 14** shows the pencil and wire floating in equilibrium in water.

Figure 14 **Figure 15**



In **Figure 14** the combined weight of the pencil and wire is equal to an upwards force called the buoyancy force. The length of the pencil that is submerged is l.
A student pushes the pencil down through a displacement y as shown in **Figure 15**.
The buoyancy force is now greater than the weight.
There is a resultant upward force F acting on the pencil when the student releases it.
The magnitude of F for any value of y is given by

$$F = A\rho gy$$

where A is the cross-sectional area of the pencil
ρ is the density of water
g is the acceleration due to gravity.

The pencil is pushed down and released. The pencil then oscillates vertically about the equilibrium position.

0 6 . 1 Show that the pencil moves with simple harmonic motion.

[2 marks]

0 6 . 2 The time period T of the vertical oscillations is given by

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

The measured value of l in **Figure 15** is 85 mm.
The pencil is pushed down 5.0 mm and released.

Calculate the maximum acceleration of the pencil.

[2 marks]

maximum acceleration = _____ m s^{-2}

Question 6 continues on the next page

A ship floating in the sea can be modelled by the pencil floating in water.
The ship can oscillate vertically. These oscillations are called heave oscillations.

Wave motion causes forced oscillations of the ship. Under certain conditions, heave resonance may then occur.

0 6 . 3 Explain what is meant by resonance.

[2 marks]

0 6 . 4 **Figure 16** shows a ship moving through continuous waves of wavelength $118\ \text{m}$ and velocity $14.2\ \text{m s}^{-1}$.

The ship is moving steadily at $8.0\ \text{m s}^{-1}$ relative to the seabed in the same direction as the waves.

Figure 16

The natural frequency of heave oscillations of the ship is $0.13\ \text{Hz}$.

A crew member needs an emergency operation. The ship's doctor is confident that she can do the operation if the ship remains fairly steady.

There are two options:

- stop the ship's motors and loosely anchor the ship to the seabed
- continue to sail the ship at $8.0\ \text{m s}^{-1}$ in the same direction.

Deduce which is the better option.
Support your answer with a calculation.

[3 marks]

END OF SECTION A

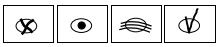
Section B

Each of Questions **07** to **31** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.
For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD 

WRONG METHODS 

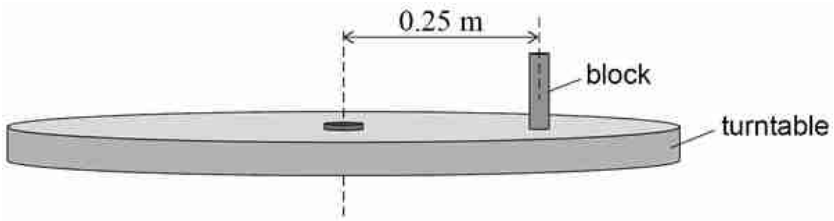
If you want to change your answer you must cross out your original answer as shown. 

If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown. 

You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.

0 5 A teacher sets up a demonstration to show the relationship between circular motion and simple harmonic motion (SHM).
She places a block on a turntable at a point $0.25\ \text{m}$ from its centre, as shown in **Figure 9**.

Figure 9



The turntable rotates with an angular speed of $1.8\ \text{rad s}^{-1}$ and the block does not slip.

0 5 . 1 Calculate the time taken for the turntable to complete one revolution.

[2 marks]

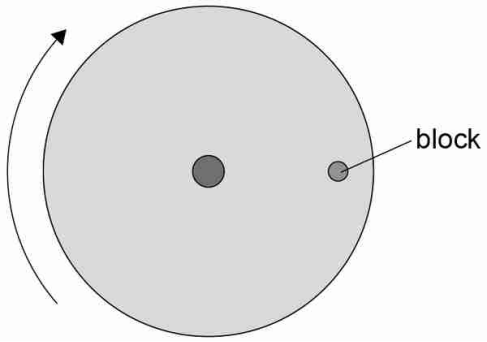
time = _____ s

0 5 . 2 **Figure 10** shows a plan view of the turntable and block.
The turntable rotates in a clockwise direction.

Draw an arrow on **Figure 10** to show the direction of the resultant force on the block.

[1 mark]

Figure 10



0 5 . 3 The mass of the block is $0.12\ \text{kg}$.

Calculate the magnitude of the resultant force on the block.

[2 marks]

magnitude of force = _____ N

Question 5 continues on the next page

0 5 . 4 Describe, with reference to one of Newton's laws of motion, the evidence that a resultant force is acting on the block.

[2 marks]

0 5 . 5 The teacher adjusts the angular speed of the turntable so that the block completes one rotation every 2.50 s.
She sets up a simple pendulum above the centre of the turntable so that it swings in phase with the movement of the block.

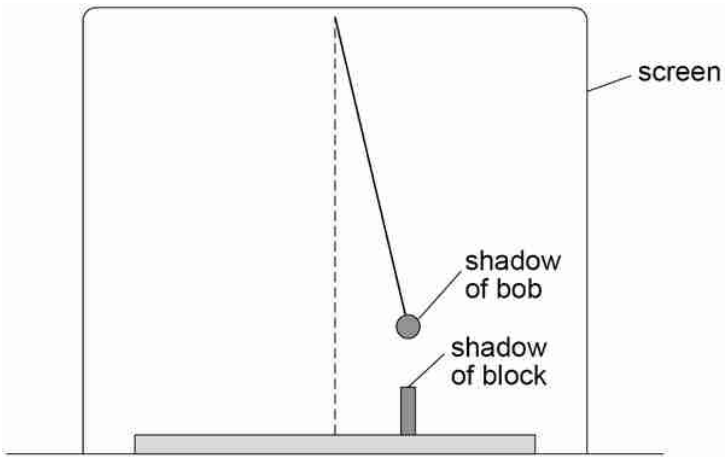
Calculate the length of the simple pendulum.

[2 marks]

length = _____ m

0 5 . 6 A lamp is used to project shadow images of the block and pendulum bob on a screen. Both shadows appear to move with SHM across the screen.
Figure 11 shows the images on the screen at one instant.

Figure 11



Initially the shadows move in phase with the same amplitude.

Air resistance affects the motion of the pendulum.

Suggest the effect this has on the amplitude relationship and the phase relationship between the moving shadows.

[2 marks]

amplitude _____

_____

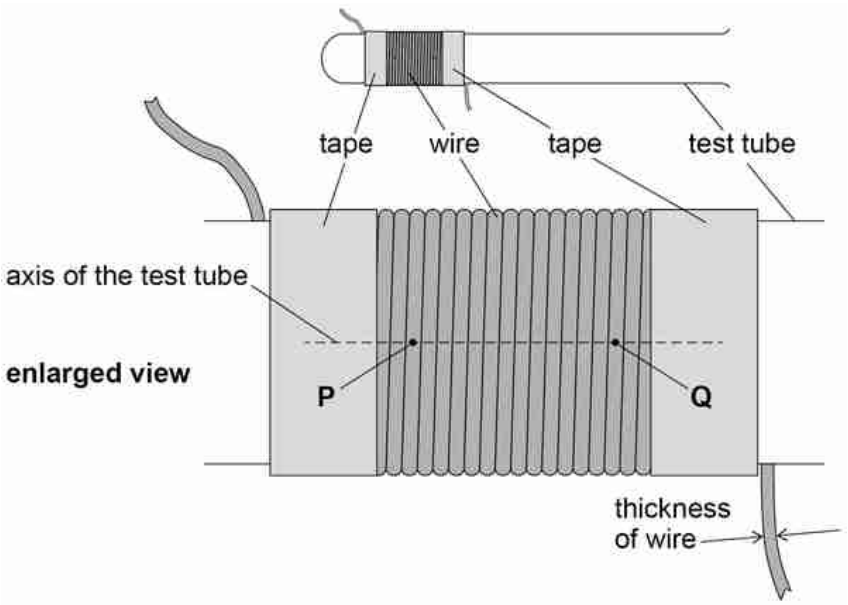
_____

phase _____

0 4 This question is about the vertical oscillations of a test tube in a liquid.

Figure 10 shows some wire wound tightly around a test tube.
The ends of the wire are secured with tape.

Figure 10



P and **Q** are points marked on the wire, as shown in the enlarged view in **Figure 10**.
A travelling microscope with a vernier scale is used to measure the distance between **P** and **Q**.
The microscope reading at **P** is $9.26\ \text{mm}$.

Figure 11 shows the microscope reading at **Q**.

Figure 11

0 4 . 1 Show that the wire has a thickness of approximately $1.2\ \text{mm}$.

[2 marks]

0 4 . 2 The external diameter of the test tube is $18.0\ \text{mm}$.

Deduce the length of wire between **P** and **Q**.

[3 marks]

length of wire = _____ mm

Question 4 continues on the next page

A student investigates vertical oscillations of the test tube in a liquid.

Figure 12 shows the test tube and wire floating at rest in a beaker of dark-coloured oil.
The part of the test tube below the surface cannot be seen clearly through the oil.

The test tube is then pushed downwards as far as possible, as shown in **Figure 13**.

Figure 12

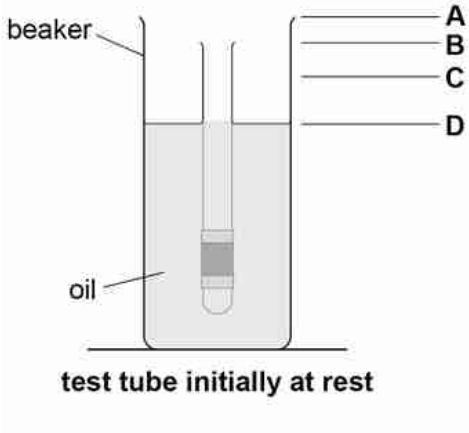


Figure 13

The test tube is now released from the position shown in **Figure 13**.
The test tube oscillates vertically with simple harmonic motion of period T.

0 4 . 3 A horizontal fiducial mark is used to reduce uncertainty in the measurement of T.
The fiducial mark is to be placed level with one of the positions **A**, **B**, **C** or **D** shown in **Figures 12** and **13**.

Identify the correct position for the fiducial mark.
Go on to explain why you chose this position.

[2 marks]

position = _____

0 4 . 4 When the total mass of the test tube, wire and tape is constant, it can be shown that:

$$T \propto \frac{1}{\sqrt{\text{density of the liquid}}}$$

When the test tube oscillates in the oil, T is 0.587 s.
The density of the oil is 8.49×10^2 kg m^{-3}.

The test tube is cleaned and placed in an identical beaker containing milk.
When the test tube oscillates in the milk, T is 0.534 s.

Determine the density of the milk.

[2 marks]

density = _____ kg m^{-3}

0 4 . 5 Due to damping, only a small number of oscillations occurs after the test tube is released.

The student wants to produce a greater number of oscillations for a particular liquid **without** changing T.

State and explain **two** ways in which the apparatus can be modified to achieve this.

[3 marks]

1 _____

_____

_____

_____

2 _____

_____

_____

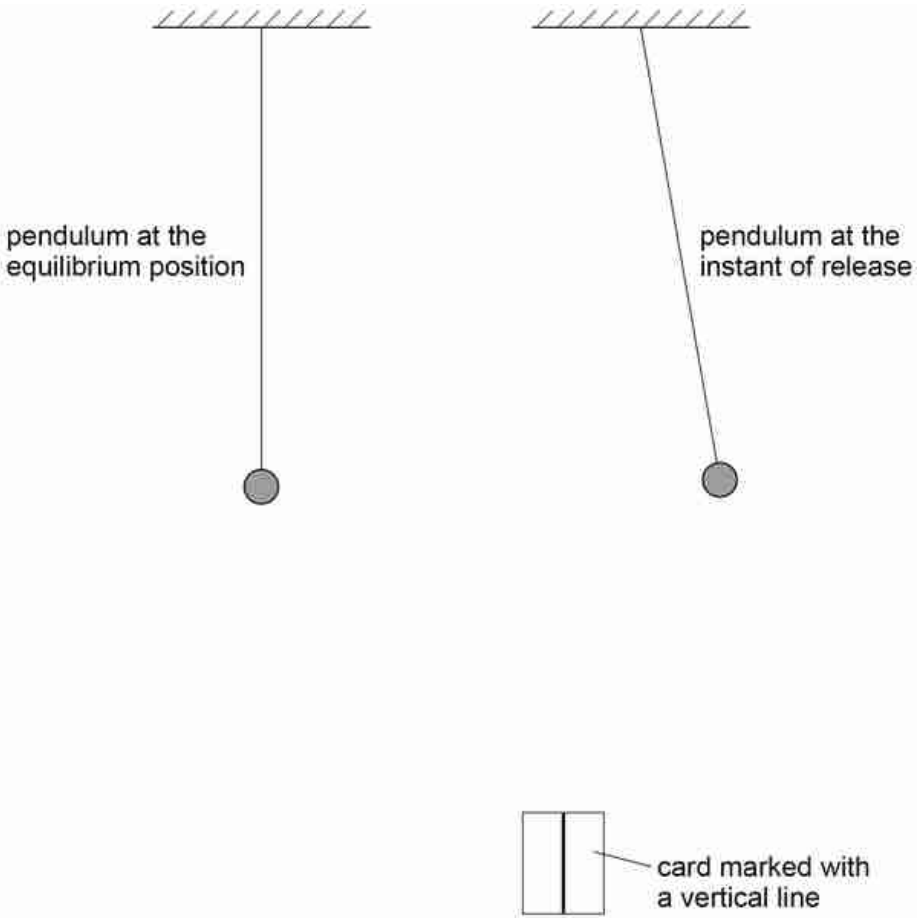
_____

END OF QUESTIONS

0 1 A simple pendulum performs oscillations of period T in a vertical plane.

Figure 1 shows views of the pendulum at the equilibrium position and at the instant of release. **Figure 1** also shows a rectangular card marked with a vertical line.

Figure 1



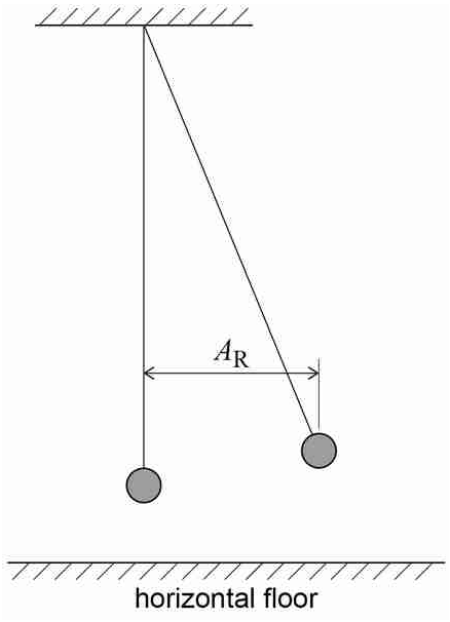
0 1 . 1 The card can be used as a fiducial mark to reduce uncertainty in the measurement of T.

Annotate **Figure 1** to show a suitable position for the fiducial mark.
Explain why you chose this position.

[2 marks]

0 1 . 2 The period of the pendulum is constant for small-amplitude oscillations.
Figure 2 shows an arrangement used to determine the maximum amplitude that can be considered to be small, by investigating how T varies with amplitude.

Figure 2



Describe a suitable procedure to determine A_R, the amplitude of the pendulum as it is released.
You may add detail to **Figure 2** to illustrate your answer.

[2 marks]

Question 1 continues on the next page

0 1 . 3 **Figure 3** shows some of the results of the experiment.

Figure 3

Estimate, using **Figure 3**, the expected percentage increase in T when A_R increases from $0.35\ \text{m}$ to $0.70\ \text{m}$.
Show your working.

[3 marks]

percentage increase = _____ %

Question 1 continues on the next page

In another experiment the pendulum is released from a fixed amplitude.
The amplitudes A_n of successive oscillations are recorded, where $n = 1, 2, 3, 4, 5...$.

Table 1 shows six sets of readings for the amplitude A_5.

Table 1

A_5 / m	0.217	0.247	0.225	0.223	0.218	0.224

0 1 . 4 Determine the result that should be recorded for A_5.
Go on to calculate the percentage uncertainty in this result.

[3 marks]

$A_5 =$ _____ m

percentage uncertainty = _____ %

0 1 . 5 **Table 2** shows results for A_n and the corresponding value of $\ln(A_n / \text{m})$ for certain values of n.

Table 2

n	A_n / m	$\ln(A_n / \text{m})$
2	0.238	−1.435
4	0.225	
7	0.212	−1.551
10	0.194	−1.640
13	0.183	−1.698

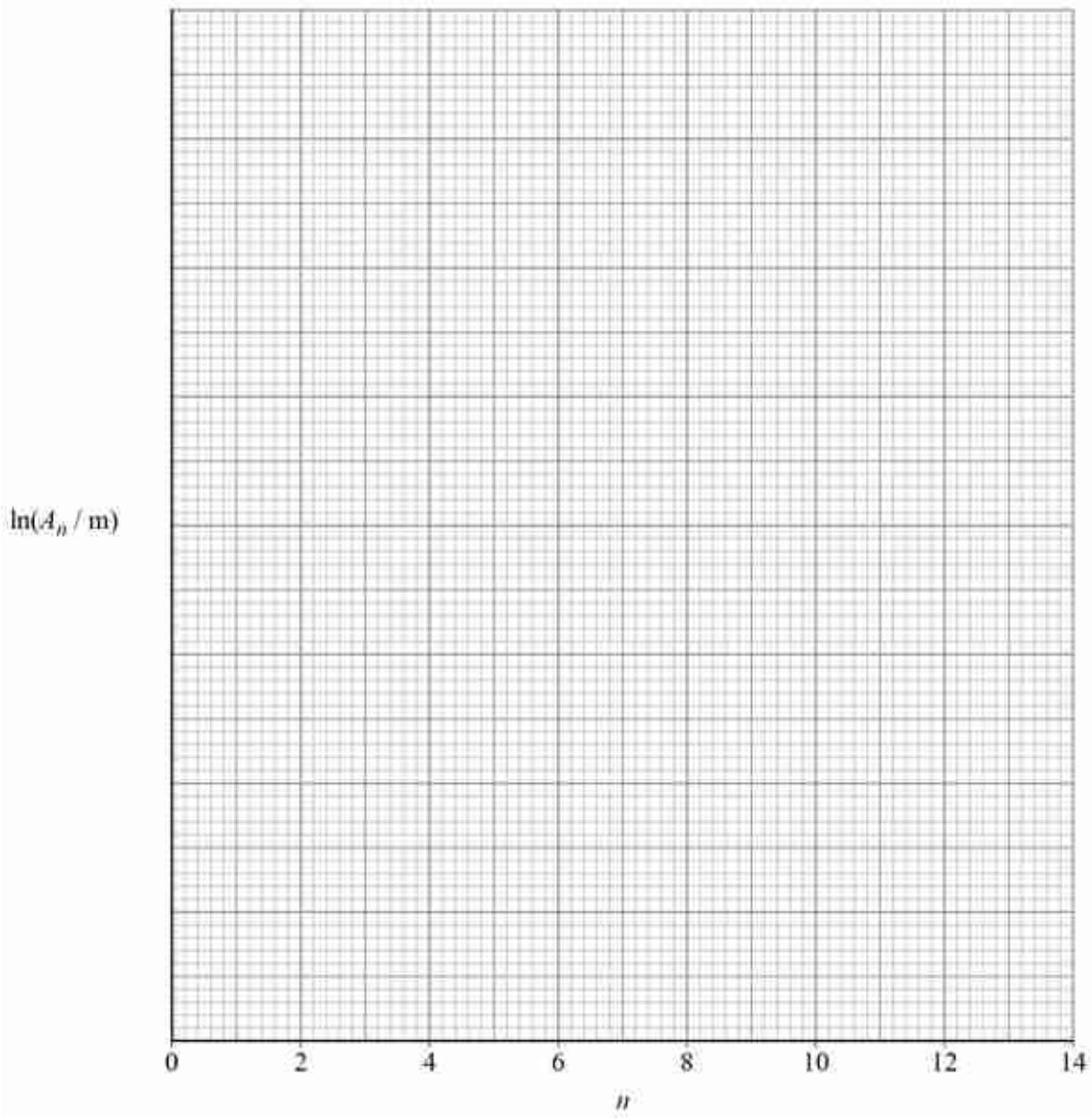
Complete **Table 2**.

[1 mark]

0 1 . 6 Plot on **Figure 4** a graph of $\ln(A_n / \text{m})$ against n.

[2 marks]

Figure 4



Question 1 continues on the next page

0 1 . 7 It can be shown that

$$A_n = A_0 \, \delta^{-n}$$

where A_0 is the amplitude of release of the pendulum
δ is a constant called the damping factor.

Explain how to find δ from your graph.
You are **not** required to determine δ.

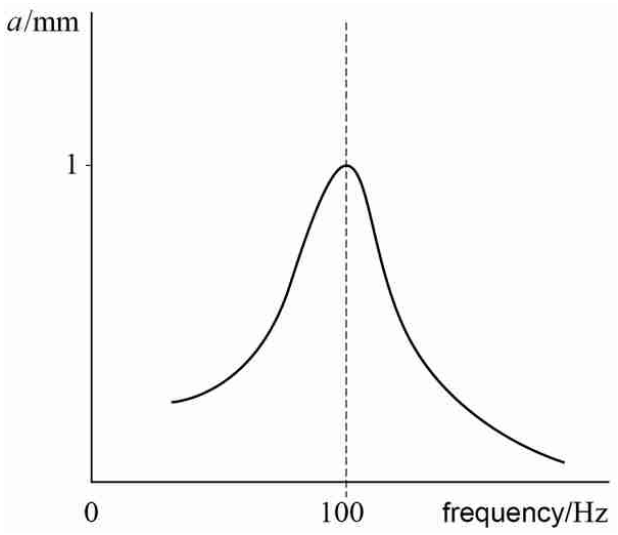
[2 marks]

SUB-TOPIC 3.6.1.4

FORCED VIBRATIONS AND RESONANCE

Sub-topic 3.6.1.4 · 1 question · 1 marks · lowest tariff first

3 2 A metal panel is driven to vibrate at different frequencies. The amplitude a of the vibration is measured at each frequency. The graph shows the variation of amplitude with driven frequency.

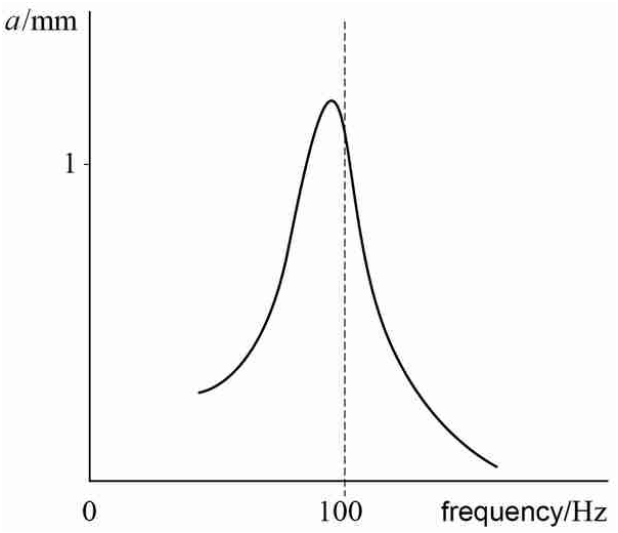


The damping of the metal panel is increased without changing the mass of the panel.

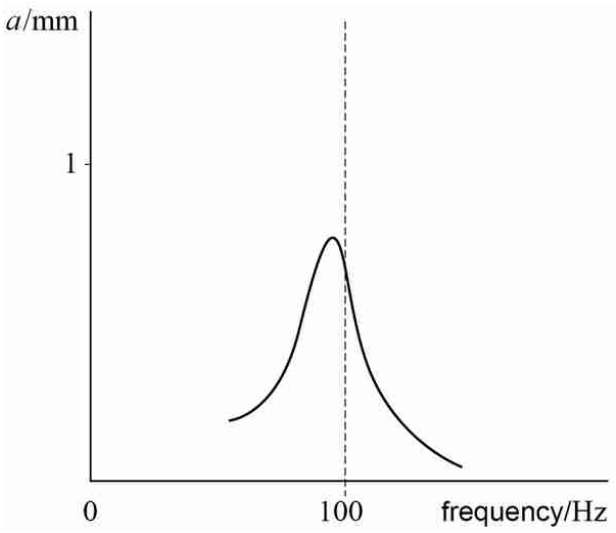
Which graph on the opposite page shows the variation of a with frequency with increased damping?

[1 mark]

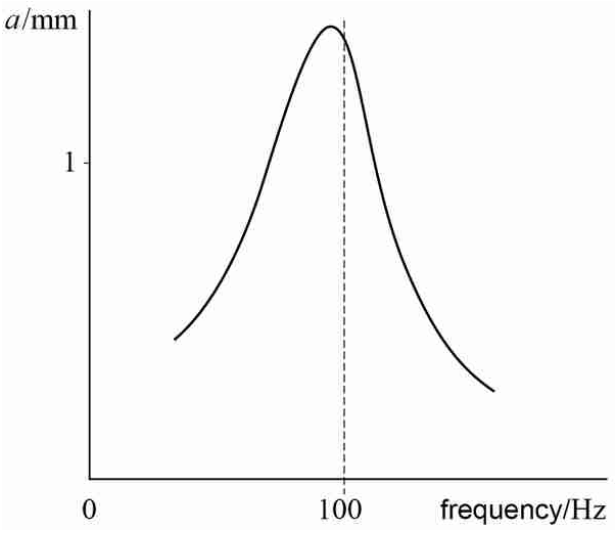
A



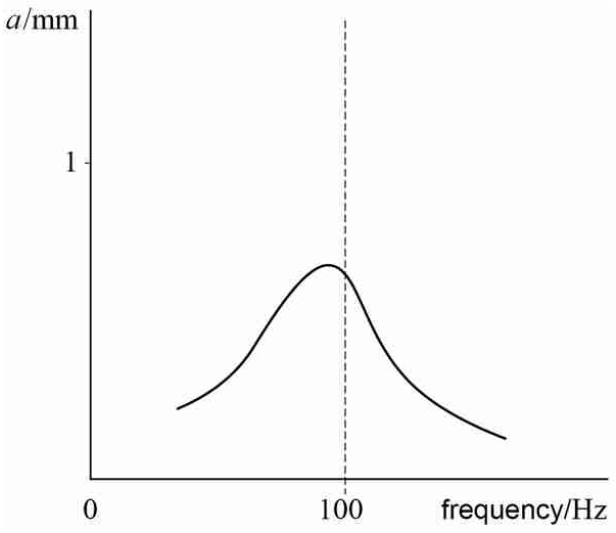
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

END OF QUESTIONS

SUB-TOPIC 3.6.2.1

THERMAL ENERGY TRANSFER

Sub-topic 3.6.2.1 · 8 questions · 35 marks · lowest tariff first

0 8 A continuous stream of water falls through a vertical distance of $100\ \text{m}$.
Assume no thermal energy is transferred to the surroundings.
The specific heat capacity of water is $4200\ \text{J kg}^{-1}\ \text{K}^{-1}$.

What is the temperature difference of the water between the top and bottom of the waterfall?

[1 mark]

A $0.023\ \text{K}$ ⬭

B $0.23\ \text{K}$ ⬭

C $2.3\ \text{K}$ ⬭

D $4.3\ \text{K}$ ⬭

0 9 A student measures the power of a microwave oven. He places 200 g of water at 23 °C into the microwave and heats it on full power for 1 minute. When he removes it, the temperature of the water is 79 °C.

The specific heat capacity of water is 4200 J kg^{-1} K^{-1}.

What is the average rate at which thermal energy is gained by the water?

[1 mark]

A 780 W ⬭

B 840 W ⬭

C 1.1 kW ⬭

D 4.6 kW ⬭

0 7 A solar panel transfers energy at a rate of $1.2\ \text{kW}$ to liquid passing through it. The liquid has a specific heat capacity of $4.0\ \text{kJ kg}^{-1}\ \text{K}^{-1}$.

When the liquid flows through the solar panel, its temperature increases by $3.0\ \text{K}$.

The flow rate of the liquid is

[1 mark]

A $0.10\ \text{kg s}^{-1}$. ⬭

B $1.1\ \text{kg s}^{-1}$. ⬭

C $10\ \text{kg s}^{-1}$. ⬭

D $100\ \text{kg s}^{-1}$. ⬭

0 8 A 1000 W heater is 75% efficient. The heater is used to increase the temperature of some water from 10 °C to 85 °C in 7 hours.

What mass of water is heated?

specific heat capacity of water = 4200 J kg^{-1} K^{-1}

[1 mark]

A 1.0 kg ⬭

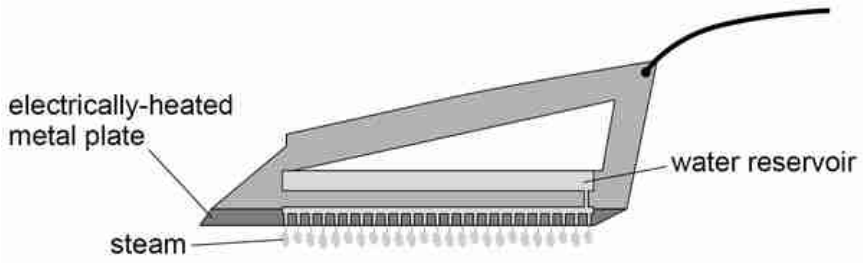
B 13 kg ⬭

C 60 kg ⬭

D 110 kg ⬭

0 1 **Figure 1** shows an electric steam iron.

Figure 1



Water from a reservoir drips onto an electrically-heated metal plate. The water boils and steam escapes through holes in the metal plate.

The electrical power of the heater inside the iron is 2.1 kW.

Assume that all the energy from the heater is transferred to the metal plate.

0 1 . 1 The metal plate has a mass of 1.2 kg and is initially at a temperature of 20 °C. The heater is switched on. After a time t the metal plate reaches its working temperature of 125 °C.

Calculate t.

specific heat capacity of the metal = 450 J kg^{-1} K^{-1}

[2 marks]

t = _____ s

0 1 . 2 The metal plate is maintained at its working temperature.
Water at 20 °C drips continuously onto the metal plate.
Steam at 100 °C emerges continuously from the iron.

The maker claims that the iron can generate steam at a rate of $60\ \text{g min}^{-1}$.

Determine whether this claim is true.

specific latent heat of vaporisation of water = $2.3 \times 10^6\ \text{J kg}^{-1}$
specific heat capacity of water = $4200\ \text{J kg}^{-1}\ \text{K}^{-1}$

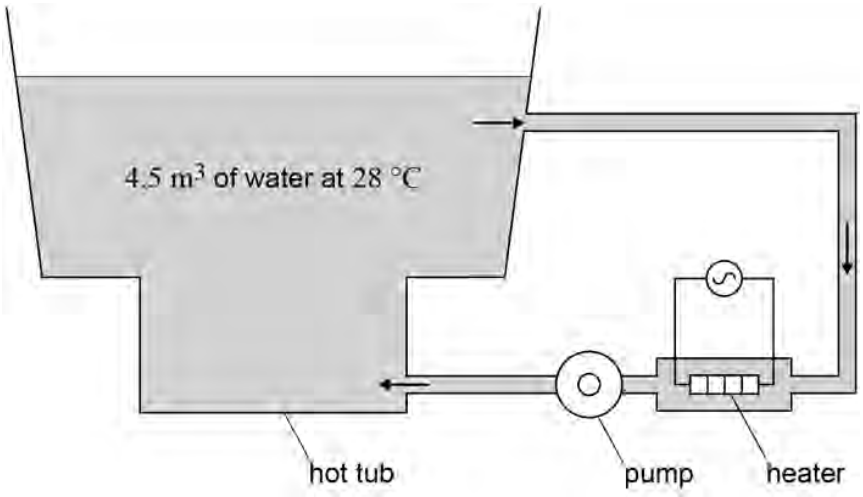
[3 marks]

0 1 . 1 Explain what is meant by specific latent heat of fusion.

[2 marks]

0 1 . 2 **Figure 1** shows how the temperature of the water is maintained in a hot tub.

Figure 1



The hot tub system has a volume of $4.5\ \text{m}^3$ and is filled with water at a temperature of $28\ °\text{C}$

The heater transfers thermal energy to the water at a rate of $2.7\ \text{kW}$ while a pump circulates the water.

Assume that no heat is transferred to the surroundings.

Calculate the rise in water temperature that the heater could produce in 1.0 hour.

density of water = 1000 kg m^{-3}
specific heat capacity of water = 4200 J kg^{-1} K^{-1}

[3 marks]

temperature rise = _____ K

0 1 . 3 The pump can circulate the water at different speeds.
When working at higher speeds the rise in temperature is greater.

Explain why.
Again assume that no heat is transferred to the surroundings.

[2 marks]

0 1

Figure 1 shows a perfectly insulated cylinder containing $0.050\ \text{kg}$ of liquid nitrogen at a temperature of $70\ \text{K}$.
A heater transfers energy at a constant rate of $12\ \text{W}$ to the nitrogen.
A piston maintains the pressure at $1.0 \times 10^5\ \text{Pa}$ during the heating process.

Figure 1

0 1 . 1 The nitrogen is heated from 70 K and is completely turned into a gas after 890 s.

Calculate the specific heat capacity of liquid nitrogen.
Give an appropriate unit for your answer.

specific latent heat of vaporisation of nitrogen = 2.0×10^5 J kg^{-1}

boiling point of nitrogen = 77 K

[5 marks]

specific heat capacity = _____ unit = _____

Question 1 continues on the next page

0 1 . 2 The work done by the nitrogen in the cylinder when expanding due to a change of state is **X**.
The energy required to change the state of the nitrogen from a liquid to a gas is **Y**.

Deduce which is greater, **X** or **Y**.

density of liquid nitrogen at its boiling temperature = $810\ \text{kg m}^{-3}$

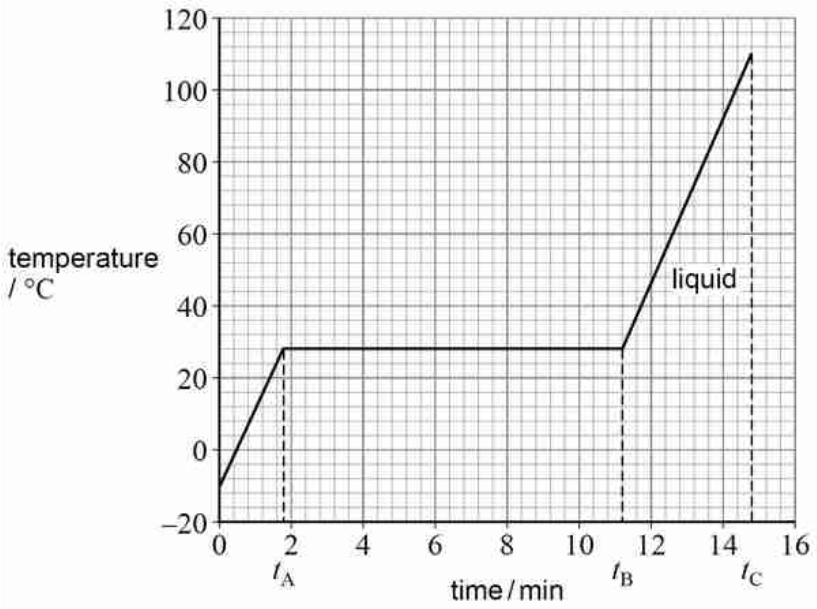
density of nitrogen gas at its boiling temperature = $3.8\ \text{kg m}^{-3}$

[4 marks]

0 1 A perfectly insulated flask contains a sample of metal **M** at a temperature of −10 °C.

Figure 1 shows how the temperature of the sample changes when energy is transferred to it at a constant rate of 35 W.

Figure 1



0 1 . 1 State the melting temperature of **M**.

[1 mark]

temperature = _____ °C

0 1 . 2 Explain how the energy transferred to the sample changes the arrangement of the atoms during the time interval t_A to t_B.

[1 mark]

0 1 . 3 State what happens to the potential energy of the atoms and to the kinetic energy of the atoms during the time interval t_A to t_B.

[2 marks]

0 1 . 4 Describe how the motion of the atoms changes during the time interval t_B to t_C.

[1 mark]

Question 1 continues on the next page

0 1 . 5 The sample has a mass of 0.25 kg.

Determine the specific heat capacity of **M** when in the liquid state.
State an appropriate SI unit for your answer.

[3 marks]

specific heat capacity = _____ unit = _____

0 1 . 6 **Table 1** shows the specific latent heats of fusion l for elements that are liquid at similar temperatures to **M**.

Table 1

Element	Caesium	Gallium	Mercury	Rubidium
l / **kJ kg^{-1}**	16	80	11	26

M is known to be one of the elements in **Table 1**.

Identify **M**.

[2 marks]

M = _____

SUB-TOPIC 3.6.2.2

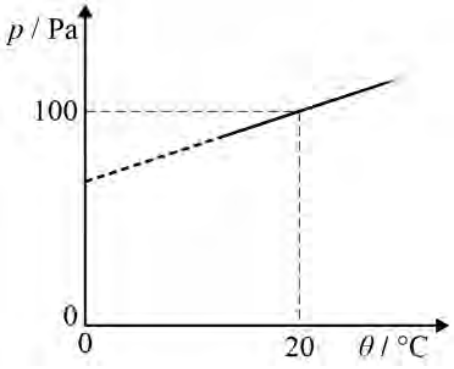
IDEAL GASES

Sub-topic 3.6.2.2 · 15 questions · 54 marks · lowest tariff first

0 8 The graph shows the variation of pressure p with temperature θ for a fixed mass of an ideal gas at constant volume.

What is the gradient of the graph?

[1 mark]



A 0.341 ⬭

B 0.395 ⬭

C 2.93 ⬭

D 5.00 ⬭

0 9 Two flasks **X** and **Y** are filled with an ideal gas and are connected by a tube of negligible volume compared to that of the flasks. The volume of **X** is twice the volume of **Y**.
X is held at a temperature of $150\ \text{K}$ and **Y** is held at a temperature of $300\ \text{K}$

What is the ratio $\frac{\text{mass of gas in } \mathbf{X}}{\text{mass of gas in } \mathbf{Y}}$?

[1 mark]

A 0.125 ⬭

B 0.25 ⬭

C 4 ⬭

D 8 ⬭

0 7 When an ideal gas at a temperature of 27 °C is suddenly compressed to one quarter of its volume, the pressure increases by a factor of 7

What is the new temperature of the gas?

[1 mark]

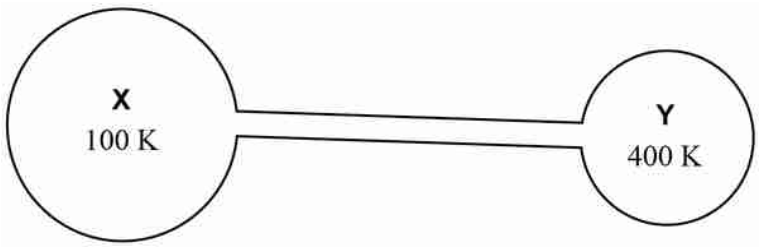
A 15 °C ⬭

B 47 °C ⬭

C 171 °C ⬭

D 252 °C ⬭

0 8 The diagram shows two flasks **X** and **Y** connected by a thin tube of negligible volume.



The flasks contain an ideal gas.

The volume of **X** is twice the volume of **Y**. When **X** is at a temperature of $100\ \text{K}$ and **Y** is at a temperature of $400\ \text{K}$ there is no net transfer of particles between the flasks.

X contains gas of mass m.

What is the mass of gas in **Y**?

[1 mark]

A $\frac{m}{8}$ ⬭

B $\frac{m}{2}$ ⬭

C $2m$ ⬭

D $8m$ ⬭

0 9 A sample **P** of an ideal gas contains $1\ \text{mol}$ at an absolute temperature T.

A second sample **Q** of an ideal gas contains $\frac{2}{3}\ \text{mol}$ at an absolute temperature $2T$.

The total molecular kinetic energy of **P** is E.

What is the total molecular kinetic energy of **Q**?

[1 mark]

A $\frac{2}{3}E$ ⬭

B $\frac{3}{4}E$ ⬭

C $\frac{4}{3}E$ ⬭

D $\frac{3}{2}E$ ⬭

0 7 An ideal gas, initially at 300 K, is compressed to half its original volume. It is then cooled at constant volume until the pressure is restored to its initial value.

What is the final temperature of the gas?

[1 mark]

A 150 K ⬭

B 200 K ⬭

C 300 K ⬭

D 600 K ⬭

0 8 A fixed volume of an ideal gas is heated.

Which row gives quantities that double when the kelvin temperature of the gas doubles?

[1 mark]

A	rms speed of the molecules	pressure of the gas	⬭
B	density of the gas	rms speed of the molecules	⬭
C	internal energy of the gas	density of the gas	⬭
D	pressure of the gas	internal energy of the gas	⬭

0 9 Which can lead to a value for the absolute zero of temperature?

[1 mark]

A Boyle's law ⬭

B Brownian motion ⬭

C Charles's law ⬭

D Rutherford scattering ⬭

0 8 In which process is work done by an ideal gas?

[1 mark]

A doubling the pressure at constant volume ⬭

B doubling the volume at constant pressure ⬭

C doubling the absolute temperature at constant volume ⬭

D doubling the pressure at constant temperature ⬭

1 0 An ideal gas is enclosed in an insulated container with a small electric heater.
The initial temperature of the gas is 300 K.
The product of pressure and volume is 5000 J.
The gas expands at constant pressure and does 1660 J of work.

What is the final temperature of the gas?

[1 mark]

A 300 K ⬭

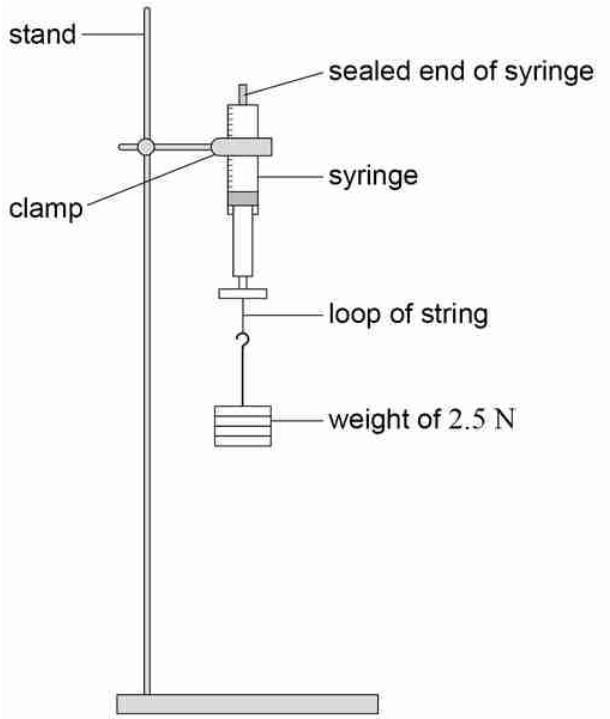
B 400 K ⬭

C 450 K ⬭

D 900 K ⬭

0 8 In an investigation of Boyle's law, a sealed syringe of cross-sectional area 1.0×10^{-4} m^2 contains 12 cm^3 of gas. The gas is initially at atmospheric pressure.

A weight of 2.5 N is then suspended from the plunger of the syringe as shown in the diagram.



The temperature of the gas in the syringe and the atmospheric pressure are constant.

atmospheric pressure = 1.0×10^5 Pa

What is the new volume of gas in the syringe?

[1 mark]

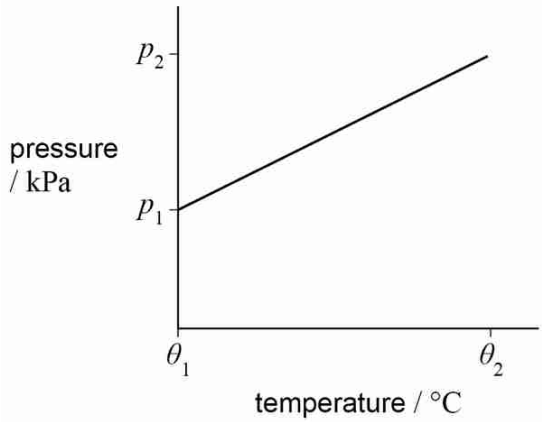
A 3 cm^3 ⬭

B 9 cm^3 ⬭

C 16 cm^3 ⬭

D 48 cm^3 ⬭

1 0 The graph shows how the pressure of a fixed mass of gas varies with temperature. The gas has a constant volume.



Which expression gives a value for absolute zero in °C?

[1 mark]

A $p_2\left(\frac{\theta_2-\theta_1}{p_2-p_1}\right)-\theta_1$ ⬭

B $\theta_1-p_1\left(\frac{\theta_2-\theta_1}{p_2-p_1}\right)$ ⬭

C $p_2-\left(\frac{p_2-p_1}{\theta_2-\theta_1}\right)\theta_2$ ⬭

D $\theta_2-p_2\left(\frac{p_2-p_1}{\theta_1-\theta_2}\right)$ ⬭

0 1 A room contains dry air at a temperature of $20.0\ °C$ and a pressure of $105\ kPa$.

0 1 . 1 Show that the amount of air in each cubic metre is about $40\ mol$.

[1 mark]

0 1 . 2 The density of the dry air is $1.25\ kg\ m^{-3}$.

Calculate c_{rms} for the air molecules.
Give your answer to an appropriate number of significant figures.

[3 marks]

$c_{rms} =$ _____ $m\ s^{-1}$

0 1 . 3 Calculate, in K, the change of temperature that will double c_{rms} for the air molecules.

[2 marks]

change of temperature = _____ K

0 1 . 4 A room contains moist air at a temperature of 20 °C.
A dehumidifier cools and then condenses water vapour from the moist air.
The final temperature of the liquid water that collects in the dehumidifier is 10 °C.
Drier air leaves the dehumidifier at a temperature of 20 °C.

Table 1 compares the air flowing into and out from the dehumidifier.

Table 1

	$\frac{\text{mass of water}}{\text{mass of air}}$
moist air flowing in	0.0057
drier air flowing out	0.0037

In one hour, a volume of 960 m^3 of air flows through the dehumidifier.
Assume that the density of the air remains constant at 1.25 kg m^{-3}.

Determine how much heat energy is removed in one hour from the water vapour by the dehumidifier.

specific heat capacity of water vapour = 1860 J kg^{-1} K^{-1}
specific latent heat of vaporisation of water = 2.3×10^6 J kg^{-1}

[3 marks]

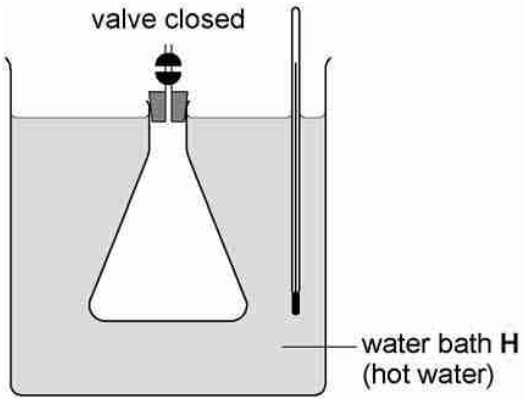
heat energy removed = _____ J

0 3 This question is about an experiment to estimate absolute zero.

Figures 9a to **9d** show the stages in the procedure carried out by a student.

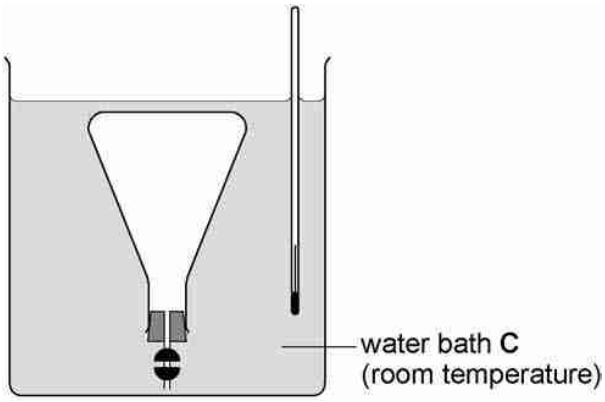
An empty flask fitted with a tube and an open valve is placed in water bath **H** containing hot water. The air inside the flask is allowed to come into thermal equilibrium with the water.
The valve is then closed, trapping a certain volume of air, as shown in **Figure 9a**.

Figure 9a



The flask is inverted and placed in water bath **C** in which the water is at room temperature.
The air inside the flask is again allowed to come into thermal equilibrium with the water, as shown in **Figure 9b**.

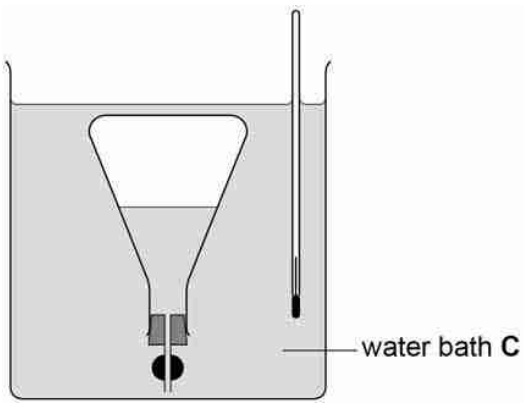
Figure 9b



Question 3 continues on the next page

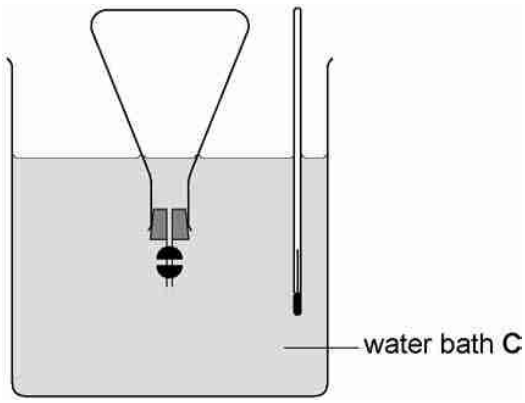
The valve is opened and some water enters the flask, as shown in **Figure 9c**.

Figure 9c



The depth of the inverted flask is adjusted until the level of water inside the flask is the same as the level in the water bath.
The valve is then closed, trapping the air and the water inside the flask, as shown in **Figure 9d**.

Figure 9d



0 3 . 1 Explain why the volume of the air in the flask in **Figure 9c** is less than the volume of the air in the flask in **Figure 9d**.

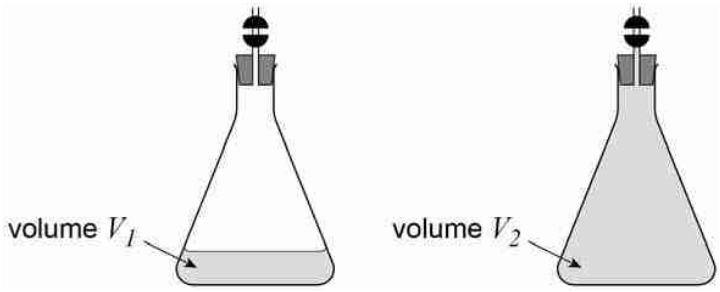
[2 marks]

0 3 . 2 Explain why Charles's Law can be applied to compare the air in the flask in **Figure 9a** with the air in the flask in **Figure 9d**.

[2 marks]

0 3 . 3 The flask is removed from water bath **C** and the valve and stopper are removed.
The volume of the water in the flask is V_1
The flask is then completely refilled with water and the valve and stopper replaced.
The volume of the water now in the flask is V_2
The volumes V_1 and V_2 are shown by the shaded parts in **Figure 10**.

Figure 10



Explain how V_1 and V_2 can be determined.

In your answer you should

- identify a suitable measuring instrument
- explain a suitable procedure to eliminate possible systematic error.

[3 marks]

Question 3 continues on the next page

0 3 . 4 Plot on **Figure 11** points to show the volume V and the temperature θ of the air in the flask when

- the flask is as shown in **Figure 9a**
- the flask is as shown in **Figure 9d**.

The temperature of the hot water bath is 86 °C
Room temperature is 19 °C

$V_1 = 48\ \text{cm}^3$
$V_2 = 255\ \text{cm}^3$

[3 marks]

Figure 11

0 3 . 5 Add a best fit line to your graph in **Figure 11** to show how V should vary with θ according to Charles's Law.

[1 mark]

0 3 . 6 Determine the value of absolute zero in °C using your graph in **Figure 11**.

[3 marks]

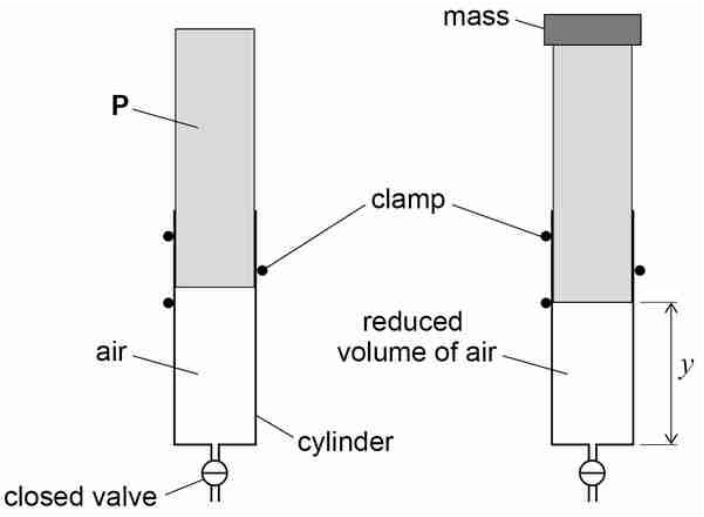
value of absolute zero = _____ °C

END OF QUESTIONS

0 4 **Figure 9** shows air trapped in a vertical cylinder by a valve and a piston **P**.
The valve remains closed throughout the experiment.

A mass is placed on top of **P**.
P moves downwards and the volume of the trapped air decreases.
There are no air leaks and there is no friction between the cylinder and **P**.

Figure 9

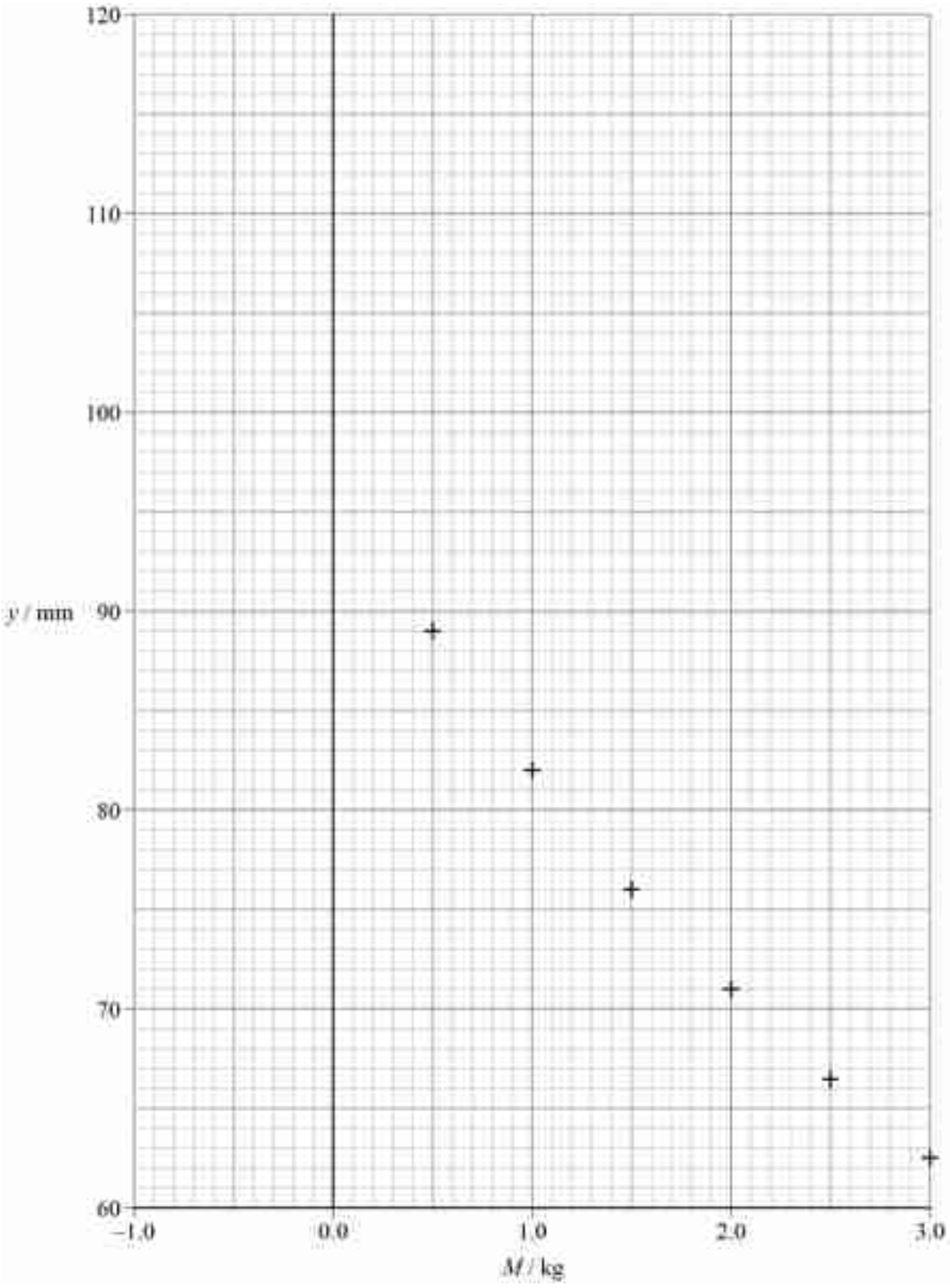


The vertical distance y between the end of **P** and the closed end of the cylinder is measured.
Additional masses are used to find out how y depends on the total mass M placed on top of **P**.
Figure 10 shows a graph of these data.

0 4 . 1 Show that y is **not** inversely proportional to M.
Use data points from **Figure 10**.

[2 marks]

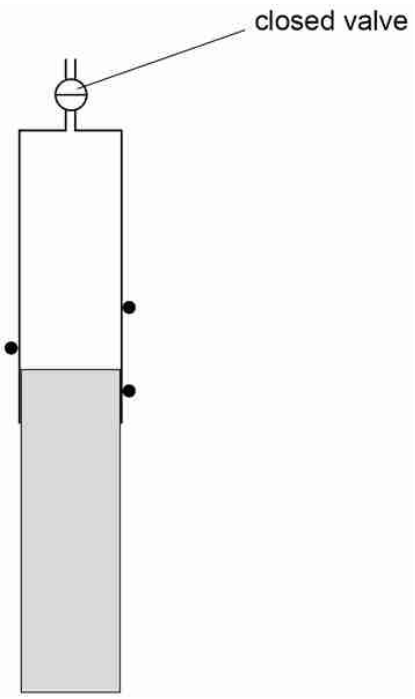
Figure 10



Question 4 continues on the next page

0 4 . 2 The masses are removed and the cylinder is inverted.
P moves downwards without friction before coming to rest, as shown in **Figure 11**.

Figure 11



Explain why **P** does not fall out of the cylinder unless the valve is opened.

[3 marks]

0 4 . 3 The mass of **P** is $0.350\ \text{kg}$.

Deduce y when the cylinder is in the inverted position shown in **Figure 11**.

Draw a line of best fit on **Figure 10** to arrive at your answer.

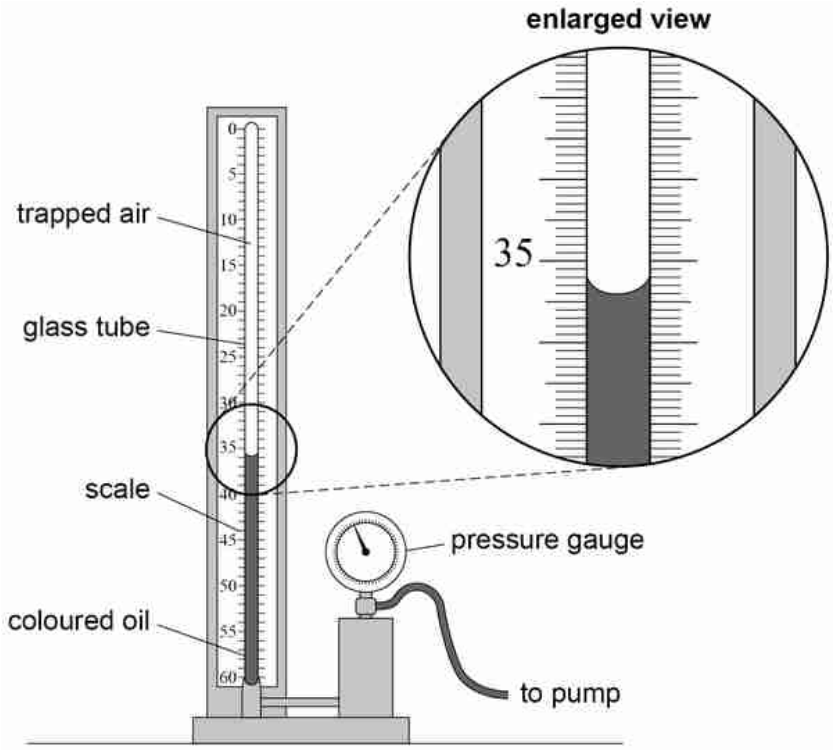
[4 marks]

$y =$ _____ mm

Question 4 continues on the next page

Figure 12 shows apparatus used in schools to investigate Boyle's law.

Figure 12



A fixed mass of air is trapped above some coloured oil inside a glass tube, closed at the top.
A pump applies pressure to the oil and the air.
The trapped air is compressed and its pressure p is read from the pressure gauge.

0 4 . 4 A scale, marked in $0.2\ \text{cm}^3$ intervals, is used to measure the volume V of the air.
A student says that the reading for V shown in **Figure 12** is $35.4\ \text{cm}^3$.

State:

- the error the student has made
- the correct reading, in cm^3, of the volume.

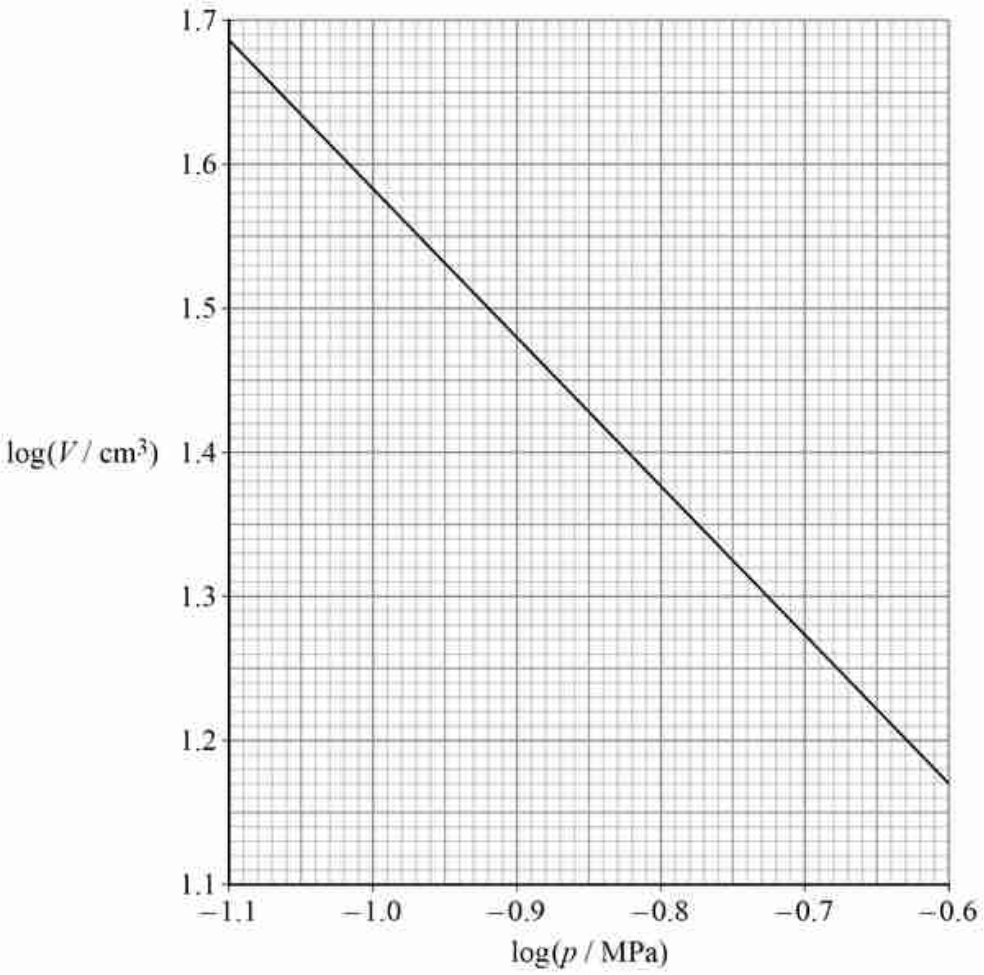
[2 marks]

volume = _____ cm^3

Question 4 continues on the next page

0 4 . 5 **Figure 13** shows data obtained using the apparatus in **Figure 12**.

Figure 13



Explain why the gradient of the graph in **Figure 13** confirms that the air obeys Boyle's law.

[3 marks]

0 4 . 6 The largest pressure that can be read from the pressure gauge is 3.4×10^5 Pa.

Determine, using **Figure 13**, the volume V corresponding to this pressure.

[3 marks]

$V =$ _____ cm^3

0 4 . 7 State **one** property of the air that must not change during the experiment.
Go on to suggest how this can be achieved.

[2 marks]

END OF QUESTIONS

SUB-TOPIC 3.6.2.3

MOLECULAR KINETIC THEORY MODEL

Sub-topic 3.6.2.3 · 15 questions · 70 marks · lowest tariff first

1 1 What is the total internal energy of $2.4\ \text{mol}$ of an ideal gas which has a temperature of $15\ °\text{C}$?

[1 mark]

A $6.0 \times 10^{-21}\ \text{J}$ ⬭

B $1.4 \times 10^{-20}\ \text{J}$ ⬭

C $4.5 \times 10^{2}\ \text{J}$ ⬭

D $8.6 \times 10^{3}\ \text{J}$ ⬭

1 2 Show that the root-mean-square speed of ^{1}

1 0 The average mass of an air molecule is 4.8×10^{-26} kg

What is the mean square speed of an air molecule at 750 K?

[1 mark]

A 3.3×10^5 m^2 s^{-2} ⬭

B 4.3×10^5 m^2 s^{-2} ⬭

C 6.5×10^5 m^2 s^{-2} ⬭

D 8.7×10^5 m^2 s^{-2} ⬭

1 1 A transparent illuminated box contains small smoke particles and air.
The smoke particles are observed to move randomly when viewed through a microscope.

What is the cause of this observation of Brownian motion?

[1 mark]

A Smoke particles gaining kinetic energy by the absorption of light ⬭

B Collisions between smoke particles and air molecules ⬭

C Smoke particles moving in convection currents caused by the air being heated by the light ⬭

D The smoke particles moving randomly due to their temperature ⬭

0 7 Brownian motion

[1 mark]

A makes it possible to see the motion of air molecules. ⬭

B is caused by the collisions of smoke particles. ⬭

C is caused by collisions between air molecules and smoke particles. ⬭

D occurs because air is a mixture of gases and the molecules have different masses. ⬭

2 5 Which is **not** an assumption about gas particles in the kinetic theory model for a gas?

[1 mark]

A They collide elastically with the container walls. ⬭

B They have negligible size compared to the distance between the container walls. ⬭

C They travel between the container walls in negligibly short times. ⬭

D They collide with the container walls in negligibly short times. ⬭

1 0 An ideal gas is contained in a cubical box of side length a.
The gas has N molecules each of mass m.

What is the pressure exerted by the gas on the walls of the box?

[1 mark]

A $\frac{mNa^3}{2} \times c_{\text{rms}}^2$ ⬭

B $\frac{mNa^2}{2} \times c_{\text{rms}}^2$ ⬭

C $\frac{mN}{3a^2} \times c_{\text{rms}}^2$ ⬭

D $\frac{mN}{3a^3} \times c_{\text{rms}}^2$ ⬭

1 1 Which statement is true about an experiment where Brownian motion is demonstrated using smoke particles in air?

[1 mark]

A The experiment makes it possible to see the motion of air molecules. ⬭

B The motion is caused by the collisions of smoke particles with each other. ⬭

C The motion is caused by collisions between air molecules and smoke particles. ⬭

D The motion occurs because air is a mixture of gases and the molecules have different masses. ⬭

0 8 A gas occupies a volume V. Its particles have a root mean square speed (c_{rms}) of u. The gas is compressed at constant temperature to a volume $0.5V$.

What is the root mean square speed of the gas particles after compression?

[1 mark]

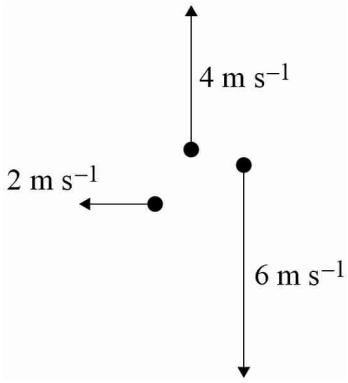
A $\frac{u}{2}$ ⬭

B u ⬭

C $2u$ ⬭

D $4u$ ⬭

1 0 Three particles are travelling in the same plane with velocities as shown in the vector diagram.



What is the root mean square speed of the particles?

[1 mark]

A 4.3 m s^{-1} ⬭

B 7.5 m s^{-1} ⬭

C 19 m s^{-1} ⬭

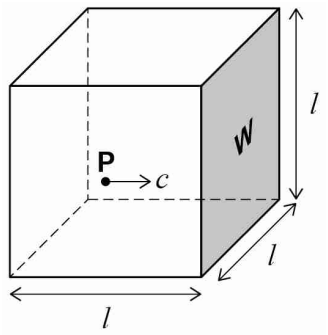
D 56 m s^{-1} ⬭

0 1 . 1 State what is meant by the internal energy of an ideal gas.

[1 mark]

Figure 1 shows a single gas particle **P** of an ideal gas inside a hollow cube.

Figure 1



The cube has side length l and volume V.
P has mass m and is travelling at a velocity c perpendicular to side **W**.

0 1 . 2 Explain why **P** has a change in momentum of $-2mc$ during one collision with **W**.

[1 mark]

0 1 . 3 **P** collides repeatedly with **W**.

Show that the frequency f of collisions is $\frac{c}{2l}$.

[1 mark]

0 1 . 4 Deduce an expression, in terms of m, c and V, for the contribution of **P** to the pressure exerted on **W**.
Refer to appropriate Newton's laws of motion.

[2 marks]

0 1 . 1 A number of assumptions are made when explaining the behaviour of a gas using the molecular kinetic theory model.

State **one** assumption about the size of molecules.

[1 mark]

Figure 1 shows how the pressure changes with volume for a fixed mass of an ideal gas.

At **A** the temperature of the gas is 27 °C. The gas then undergoes two changes, one from **A** to **B** and then one from **B** to **C**.

Figure 1

0 1 . 2 Calculate the number of gas molecules trapped in the cylinder using information from the initial situation at **A**.

[2 marks]

number of molecules = _____

0 1 . 3 Calculate, in K, the change in temperature of the gas during the compression that occurs between **A** and **B**.

[2 marks]

change in temperature = _____ K

0 1 . 4 Deduce whether the temperature of the gas changes during the compression from **B** to **C**.

[2 marks]

_____

_____

Question 1 continues on the next page

0 1 . 5 Compare the work done on the gas during the change from **A** to **B** with that from **B** to **C** on **Figure 1**.

[3 marks]

0 2 . 1 In the kinetic theory model, it is assumed that there are many identical particles moving at random.

State **two** other assumptions made in deriving the equation $pV = \frac{1}{3}Nm\,(c_{\text{rms}})^2$.

[2 marks]

1 _____

_____

_____

2 _____

_____

_____

0 2 . 2 Explain why molecules of a gas exert a force on the walls of a container.
Refer to Newton's laws of motion in your answer.

[3 marks]

0 2 . 3 A sealed flask of volume $0.35\ \text{m}^3$ contains an ideal gas at a pressure of $220\ \text{kPa}$.
The mean kinetic energy of the gas molecules is $6.7 \times 10^{-21}\ \text{J}$.

Calculate the amount of gas in the container.

[3 marks]

amount of gas = _____ mol

0 2 . 4 **Figure 2** shows the variation of pressure with volume for a fixed mass of an ideal gas at constant absolute temperature T.

Draw, on **Figure 2**, the graph for the same gas at temperature $2T$.

[2 marks]

Figure 2

0 3 **Figure 4** and **Figure 5** show apparatus used in an experiment to confirm the distribution of atom speeds in a gas at a particular temperature.

Figure 4

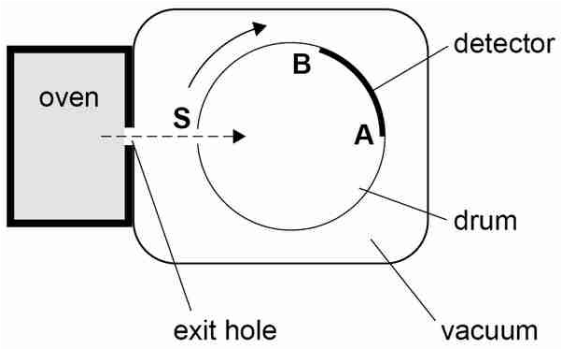
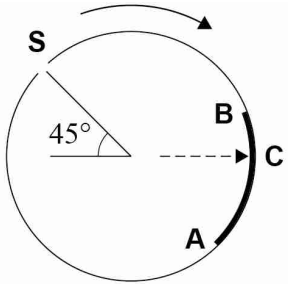


Figure 5



The oven contains an ideal gas kept at a constant temperature. Atoms of the gas emerge from the oven and some pass through the narrow slit **S** in a rapidly rotating drum. The drum is in a vacuum.

0 3 . 1 Explain why the drum must be in a vacuum.

[1 mark]

One atom leaves the oven, enters the drum through **S** and travels in a straight line across the drum.
In the time taken for the atom to move from **S** to the detector **AB**, the drum rotates through $45°$. The atom hits the detector at point **C**, as shown in **Figure 5**.

drum diameter = distance from **S** to **A** = $0.500\ \text{m}$
drum rotational speed = 120 revolutions per second

0 3 . 2 Show that the atom is moving at a speed of about $500\ \text{m s}^{-1}$.

[2 marks]

0 3 . 3 The speed of the atom in Question **03.2** is equal to c_{rms}, the root mean square speed of the atoms of the gas in the oven.
The molar mass of the gas is $0.209\ \text{kg mol}^{-1}$.

Calculate the temperature of the gas in the oven.

[3 marks]

temperature = _____ K

Question 3 continues on the next page

0 3 . 4 The oven temperature is kept constant during the experiment but the pressure in the oven decreases as atoms leave through the exit hole.

Explain, using the kinetic theory, why the pressure decreases.

[2 marks]

0 3 . 5 The pressure of gas in the oven is initially 5.0×10^4 Pa.
The volume of the oven is 2.7×10^{-2} m^3.
During the experiment the pressure in the oven decreases to 4.5×10^4 Pa.

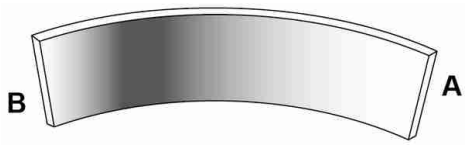
Calculate, in mol, the amount of gas that has emerged from the oven.

[1 mark]

amount of gas = _____ mol

0 3 . 6 Atoms enter the drum every time **S** passes the exit hole. The detector darkens at the point where an atom strikes it.
After a time, the detector is removed from the drum.
Figure 6 shows the appearance of the detector.

Figure 6



A new detector is placed in the drum and the experiment is repeated with a new sample of the same gas at a higher temperature.

Describe and explain the appearance of this detector when the experiment is repeated.

[2 marks]

0 2 The derivation of the equation $pV = \frac{1}{3}Nm(c_{rms})^2$ is based on several assumptions.

0 2 . 1 One of these assumptions is that particle motion is random.

State what is meant by random particle motion.

[2 marks]

0 2 . 2 State **two** other assumptions required for this derivation.

[2 marks]

1

2

Question 2 continues on the next page

0 2 . 3 When the temperature of a fixed mass of an ideal gas increases at constant pressure, the gas must expand.

Explain this expansion using the kinetic theory model.

[3 marks]

The average kinetic energy of the particles of an ideal gas is equal to $\frac{3}{2}kT$.

This is **not** true for a real gas.

0 2 . 4 Helium behaves as an ideal gas.
The temperature of a sample of helium gas is increased from $27\ °C$ to $77\ °C$.

Calculate the change in the average kinetic energy of a helium atom in the sample.

[1 mark]

change in average kinetic energy = _____ J

0 2 . 5 When an ideal gas is heated at constant volume, all of the energy supplied by heating is used to increase the average kinetic energy of the particles.

When water vapour is heated at constant volume, its specific heat capacity is $1400\ J\ kg^{-1}\ K^{-1}$.

Deduce whether water vapour behaves as an ideal gas when heated at constant volume.

mass of a water molecule = $3.0 \times 10^{-26}\ kg$

[3 marks]

0 2 . 1 State what is meant by the internal energy of a gas.

[2 marks]

0 2 . 2 Absolute zero of temperature can be interpreted in terms of the ideal gas laws or the kinetic energy of particles in an ideal gas.

Describe these two interpretations of absolute zero of temperature.

[2 marks]

Question 2 continues on the next page

0 2 . 3 A mixture of argon atoms and helium atoms is in a cylinder enclosed with a piston. The mixture is at a temperature of 310 K.

Calculate the root mean square speed (c_{rms}) of the argon atoms in the mixture.

molar mass of argon = 4.0×10^{-2} kg mol^{-1}

[3 marks]

c_{rms} = _____ m s^{-1}

0 2 . 4 Compare the mean kinetic energy of the argon atoms and the helium atoms in the mixture.

[1 mark]

_____

_____

_____

0 2 . 5 Explain, in terms of the kinetic theory model, why a pressure is exerted by the gas on the piston.

[3 marks]

0 2 . 6 The mixture of gases in the cylinder stays the same.

Explain, using the kinetic theory model, **two** changes that can be made independently to reduce the pressure exerted by the gas.

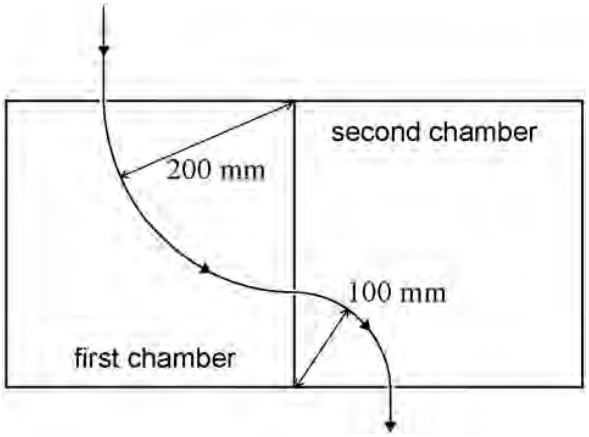
[3 marks]

SUB-TOPIC 3.6.S

SYNOPTIC AND CROSS-TOPIC QUESTIONS

Sub-topic 3.6.S · 19 questions · 115 marks · lowest tariff first

2 6 Different magnetic fields are present in the two chambers shown. A particle enters the first chamber at a velocity of $80\ \text{m s}^{-1}$ and is deflected into a circular path of radius $200\ \text{mm}$
In the second chamber it follows a circular path of radius $100\ \text{mm}$



The particle leaves the second chamber at a speed of

[1 mark]

A $20\ \text{m s}^{-1}$ ⬭

B $40\ \text{m s}^{-1}$ ⬭

C $80\ \text{m s}^{-1}$ ⬭

D $160\ \text{m s}^{-1}$ ⬭

0 9 What is the angular speed of a satellite in a geostationary orbit around the Earth?

[1 mark]

A 1.2×10^{-5} rad s^{-1} ⬭

B 7.3×10^{-5} rad s^{-1} ⬭

C 4.2×10^{-3} rad s^{-1} ⬭

D 2.6×10^{-1} rad s^{-1} ⬭

1 1 Satellites **N** and **F** have the same mass and are in circular orbits about the same planet. The orbital radius of **F** is greater than that of **N**.

Which is greater for **F** than for **N**?

[1 mark]

A gravitational force on the satellite ⬭

B angular speed ⬭

C kinetic energy ⬭

D orbital period ⬭

1 3 What is the angular speed of a satellite in a geostationary orbit around the Earth?

[1 mark]

A 1.2×10^{-5} rad s^{-1} ⬭

B 7.3×10^{-5} rad s^{-1} ⬭

C 4.4×10^{-3} rad s^{-1} ⬭

D 2.6×10^{-1} rad s^{-1} ⬭

1 3 Which statement is **not** true for a satellite in a geostationary orbit?

[1 mark]

A The satellite orbits in the plane of the Earth's equator. ⬭

B The satellite has the same angular velocity as a point on the Earth's surface. ⬭

C The satellite takes 24 hours to orbit the Earth. ⬭

D Signals from the satellite can be sent to any point on the Earth's surface during one orbit. ⬭

2 4 A circular coil with a radius of $0.10\ \text{m}$ has 200 turns.
The coil rotates at 50 revolutions per second about an axis which is perpendicular to a uniform magnetic field and in the plane of the coil.
The magnetic flux density of the field is $0.20\ \text{T}$.

What is the maximum emf induced in the coil?

[1 mark]

A 63 V ⬭

B 126 V ⬭

C 195 V ⬭

D 395 V ⬭

1 6 An electron enters a uniform magnetic field at right angles to the field.
The flux density of the field is B.
The electron moves with a non-relativistic speed v in a circular path of radius r.

What is the number of circuits completed by the electron in one second?

[1 mark]

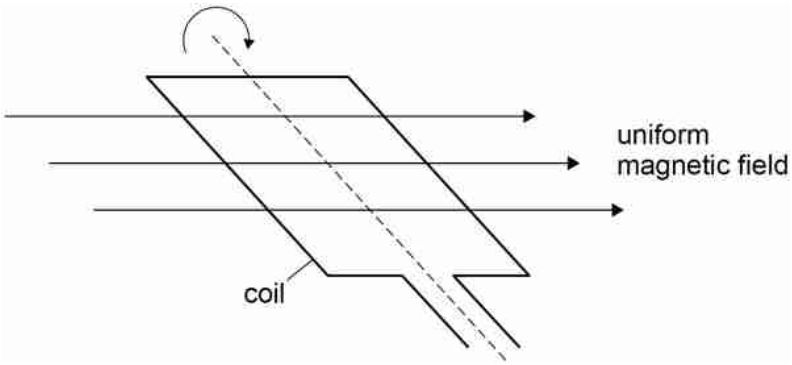
A $\frac{2\pi m_e}{Be}$ ⬭

B $\frac{2\pi r}{v}$ ⬭

C $\frac{v}{\pi r}$ ⬭

D $\frac{Be}{2\pi m_e}$ ⬭

2 1 A coil rotates at a constant angular speed in a uniform horizontal magnetic field.
The diagram shows the instant when the plane of the coil is horizontal.



cross-sectional area of coil = 20×10^{-3} m^2
number of turns in coil = 500 turns
magnetic flux density = 50 mT
frequency of rotation = 50 Hz

What is the mean induced emf, in V, as the coil rotates through π rad from the position shown?

[1 mark]

A 0 ⬭

B 0.50 ⬭

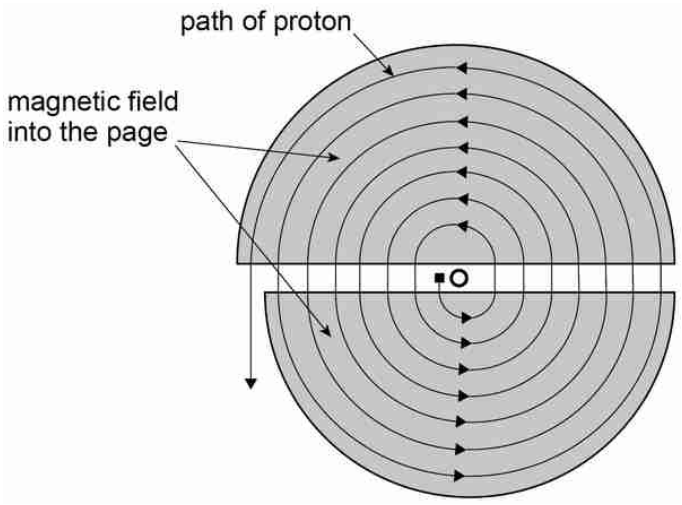
C 100 ⬭

D 157 ⬭

0 3 A cyclotron has two D-shaped regions where the magnetic flux density is constant. The D-shaped regions are separated by a small gap.
An alternating electric field between the D-shaped regions accelerates charged particles. The magnetic field causes the charged particles to follow a circular path.

Figure 4 shows the path followed by a proton that starts from **O**.

Figure 4



0 3 . 1 Explain why it is **not** possible for the magnetic field to alter the speed of a proton while it is in one of the D-shaped regions.

[1 mark]

0 3 . 2 Derive an expression to show that the time taken by a proton to travel round one semi-circular path is independent of the radius of the path.

[3 marks]

0 3 . 3 The maximum radius of the path followed by the proton is $0.55\ \text{m}$ and the magnetic flux density of the uniform field is $0.44\ \text{T}$.

Ignore any relativistic effects.

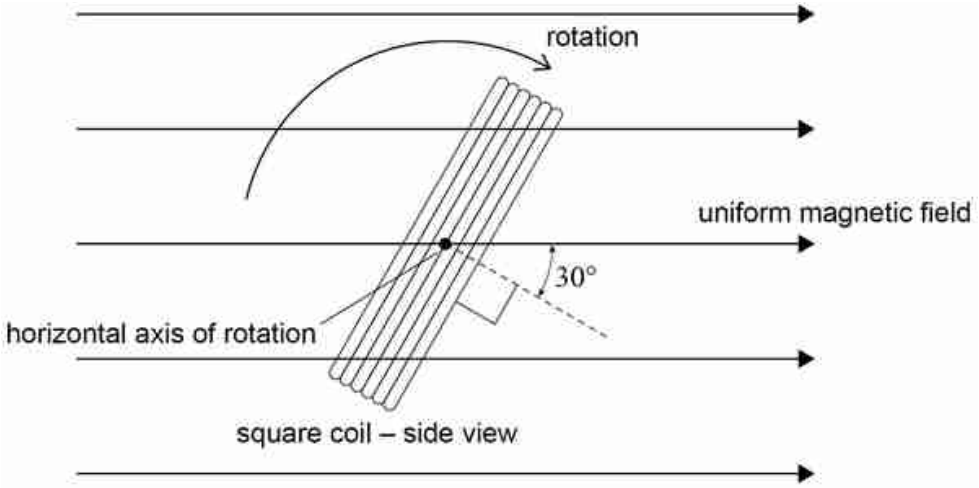
Calculate the maximum speed of a proton when it leaves the cyclotron.

[2 marks]

maximum speed = _____ m s^{-1}

0 5 A square coil of wire is rotating at a constant angular speed about a horizontal axis. **Figure 4** shows the coil at one instant when the normal to the plane of the coil is at $30°$ to a magnetic field.

Figure 4



The area of the coil is 5.0×10^{-4} m^2 and the flux density of the uniform magnetic field is 2.5×10^{-2} T.

0 5 . 1 The maximum flux linkage of the coil during its rotation is 1.5×10^{-3} Wb turns.

Calculate the number of turns in the coil.

[2 marks]

number of turns = _____

0 5 . 2 Calculate the flux linkage of the coil at the instant shown in **Figure 4**.

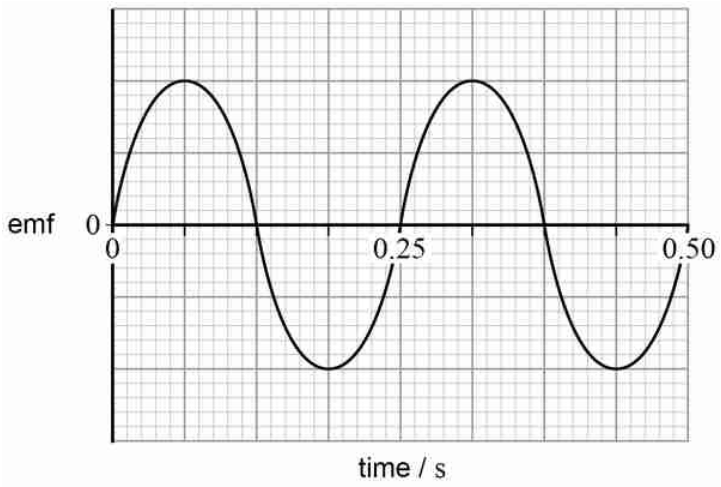
[1 mark]

flux linkage = _____ Wb turns

Question 5 continues on the next page

0 5 . 3 The coil forms part of an electrical generator. **Figure 5** shows the emf generated by the coil.

Figure 5



Calculate the peak value of the emf generated.

[2 marks]

emf = _____ V

0 5 . 4 Sketch on **Figure 6** the variation with time of flux linkage for the same time interval as **Figure 5**.

[1 mark]

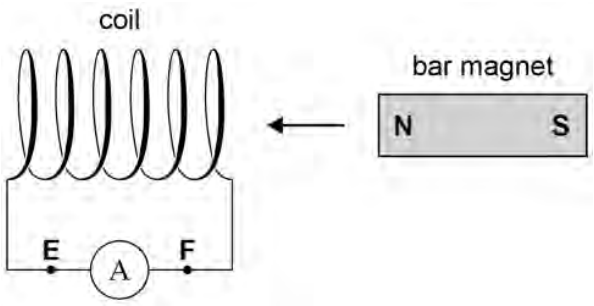
Figure 6

0 4 . 1 State Lenz's law.

[1 mark]

0 4 . 2 Lenz's law can be demonstrated using a bar magnet and a coil of wire connected to a sensitive ammeter as shown in **Figure 6**.

Figure 6



The bar magnet is moved towards the coil and is then brought to a halt.

State how the reading on the ammeter changes during this process.

[1 mark]

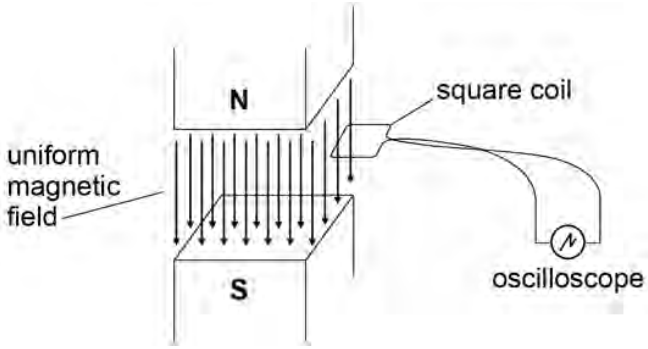
0 4 . 3 During the demonstration an induced current is detected by the ammeter. The induced current is in the direction **E** to **F**.

Explain how this demonstrates Lenz's law.

[2 marks]

0 4 . 4 **Figure 7** shows an arrangement for investigating induced emf.

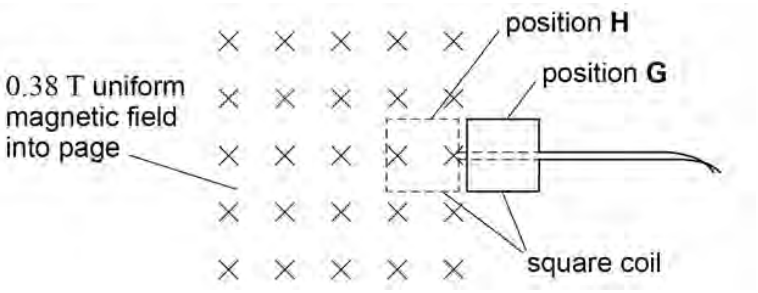
Figure 7



As shown, the uniform vertical magnetic field is confined to the gap between the poles of the magnet. The plane of the square coil is horizontal and is made of conducting wire. The coil consists of a single turn and is attached by flexible wire to an oscilloscope.

The oscilloscope gives a reading of 2.9×10^{-4} V when the coil is moved at uniform speed from position **G** outside the field to position **H** inside the field, as shown in **Figure 8**.

Figure 8



Length of side of square coil = 32 mm

Magnetic flux density of uniform magnetic field = 0.38 T

Calculate the time taken to move the coil from position **G** to position **H**.

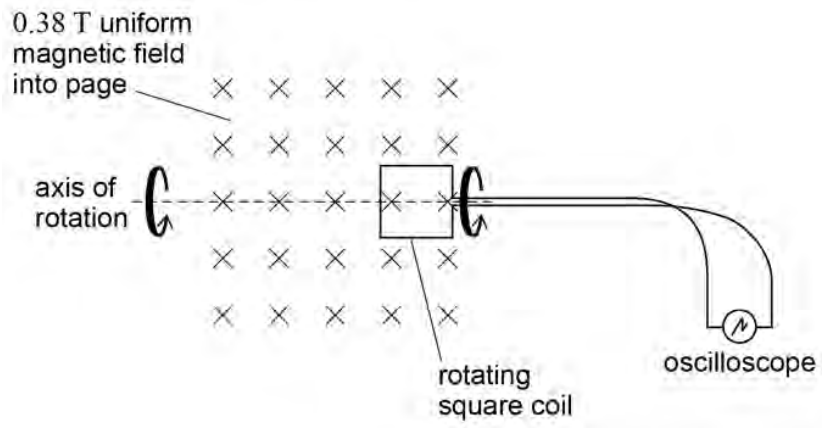
[2 marks]

time = _____ s

Question 4 continues on the next page

0 4 . 5 The square coil is rotated through 360° at a constant angular speed about the horizontal axis shown in **Figure 9**.

Figure 9



Calculate the angular speed of the coil when the maximum reading on the oscilloscope is 5.1 mV

[2 marks]

angular speed = _____ rad s^{-1}

0 5 A satellite $\mathbf{S_1}$ is placed in a circular orbit around the Earth so that observations of the far side of the Moon can be made continuously.

$\mathbf{S_1}$ has the same angular speed as the Moon so that the centres of the Earth, the Moon and $\mathbf{S_1}$ are always in a straight line.

Figure 7 shows two positions of the Moon and $\mathbf{S_1}$ as they orbit the Earth.

Figure 7

0 5 . 1 The resultant force on $\mathbf{S_1}$ is due to the gravitational forces from the Earth and the Moon.
The magnitude of the Earth's gravitational field strength at the orbital radius of $\mathbf{S_1}$ is 1.98×10^{-3} N kg^{-1}.
The magnitude of the Moon's gravitational field strength at the orbital radius of $\mathbf{S_1}$ is g_M.

Show that g_M is approximately 1.2×10^{-3} N kg^{-1}.

period of the Moon's orbit = 27.3 days
orbital radius of $\mathbf{S_1}$ = 4.489×10^5 km

[3 marks]

0 5 . 2 Calculate the distance from $\mathbf{S_1}$ to the centre of the Moon.

mass of the Moon = 7.35×10^{22} kg

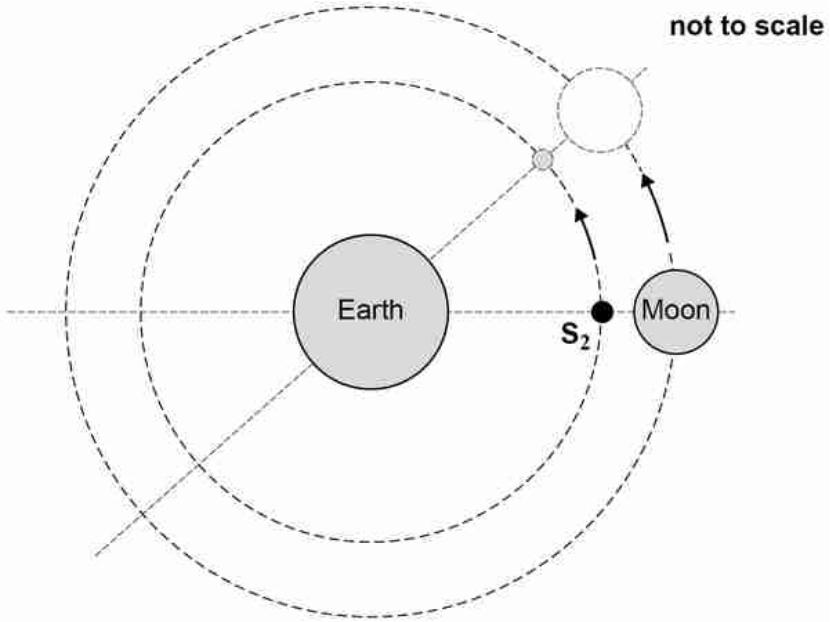
[2 marks]

distance = _____ m

Question 5 continues on the next page

0 5 . 3 Another satellite S_2 is placed in a circular orbit between the Earth and the Moon.
S_2 always views the near side of the Moon.
S_2 also has the same angular speed as the Moon so that the centres of the Earth, the Moon and S_2 are always in a straight line.
Figure 8 shows two positions of the Moon and S_2 as they orbit the Earth.

Figure 8



Explain how the resultant force on S_2 due to the gravitational fields of the Earth and the Moon causes S_2 to orbit with the same angular speed as the Moon.
No calculations are required.

[3 marks]

0 2 The Global Positioning System (GPS) uses satellites to support navigation on Earth.

0 2 . 1 One GPS satellite is in a circular orbit at a height h above the surface of the Earth. The Earth has mass M and radius R.

Show that the angular speed ω of the satellite is given by

$$\omega = \sqrt{\frac{GM}{(R+h)^3}}$$

[2 marks]

0 2 . 2 Calculate the orbital period of the satellite when h equals 2.02×10^7 m.

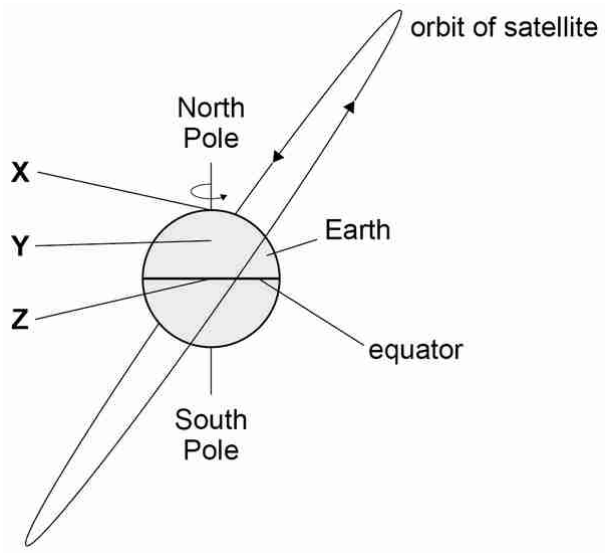
[2 marks]

orbital period = _____ s

0 2 . 3 **Figure 3** shows the orbital plane of the satellite inclined at an angle to the equator. **X**, **Y** and **Z** are locations on the Earth.

X is at the North Pole, **Y** is on a high mountain and **Z** is on the equator.

Figure 3



The satellite is to be launched from one of the locations.

State and explain which launch site **X**, **Y** or **Z** minimises the amount of fuel required to send the satellite into its orbit.

[2 marks]

Question 2 continues on the next page

0 2 . 4 The satellite has a mass of 1630 kg.

Calculate the gravitational potential energy of the satellite when in the orbit in Question **02.2**.

[2 marks]

gravitational potential energy = _____ J

0 2 . 5 A different satellite is in a higher circular orbit.

Explain how the linear speed of this satellite compares with the linear speed of the satellite in Question **02.1**.

[2 marks]

0 7 . 1 Carbon is used as the moderator in some thermal nuclear reactors.

Identify **one** other material commonly used as a moderator.

[1 mark]

_____

0 7 . 2 State **two** benefits of slowing down the neutrons released during fission.

[2 marks]

1 _____

_____

2 _____

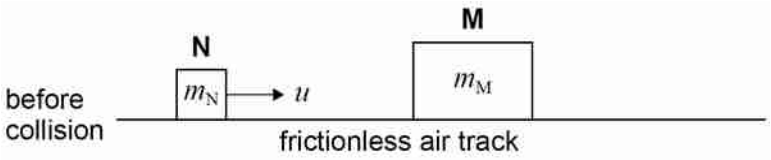
_____

0 7 . 3 The collision of a neutron with the nucleus of a moderator atom is modelled using two gliders on a horizontal frictionless air track.

In **Figures 13** and **14** the glider **N** of mass m_N represents the neutron and the glider **M** of mass m_M represents the moderator nucleus.

Figure 13 shows glider **N** travelling with initial speed u towards the stationary glider **M**.

Figure 13

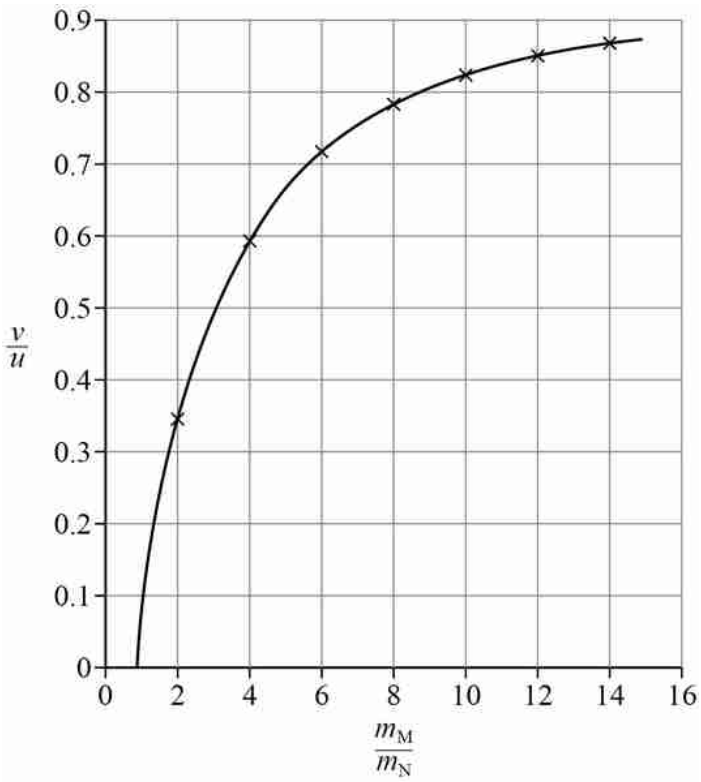


The gliders collide. **N** rebounds with speed v as shown in **Figure 14**.

Figure 14

Figure 15 shows the variation of the ratio $\frac{v}{u}$ with the ratio $\frac{m_M}{m_N}$.

Figure 15



Show that when $\frac{m_M}{m_N}$ is 12, **N** loses about 30% of its initial kinetic energy in the collision.

[2 marks]

Question 7 continues on the next page

0 7 . 4 In a reactor, the speed of a fast-moving neutron is reduced by a series of y random collisions with carbon-12 nuclei.

The final kinetic energy E_f of the neutron is

$$E_f = E_0 e^{-by}$$

where E_0 is the initial kinetic energy of the neutron and $b = 0.73$

A thermal neutron has kinetic energy equivalent to that of the average particle of an ideal gas with a temperature of $350\ \text{K}$.

One neutron has an initial kinetic energy of $1.0\ \text{MeV}$.

Calculate the minimum value of y required so that this neutron becomes a thermal neutron.

[3 marks]

$y =$ _____

0 7 . 5 Explain, with reference to **Figure 15**, why elements with a small nucleon number are preferred as moderator materials.

[2 marks]

END OF SECTION A

Section B

Each of Questions **08** to **32** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.
For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD ● WRONG METHODS ⊗ ◉ ≋ √

If you want to change your answer you must cross out your original answer as shown. ⊠

If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown. ⊗

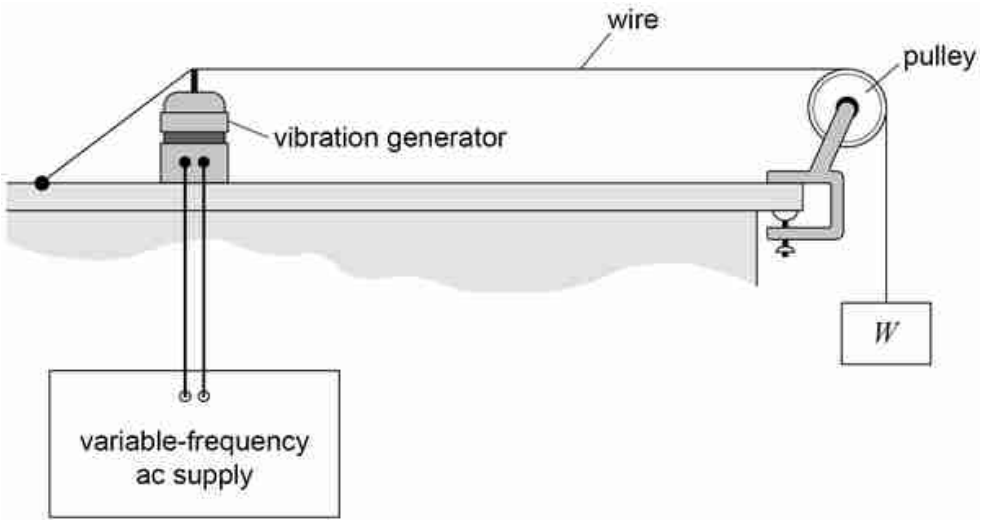
You may do your working in the blank space around each question but this will not be marked. Do **not** use additional sheets for this working.

0 2 . 1 State what is meant by a transverse wave.

[2 marks]

Figure 2 shows apparatus that is used to investigate stationary waves on a stretched wire.

Figure 2



A block of weight W is used to keep the wire under tension.

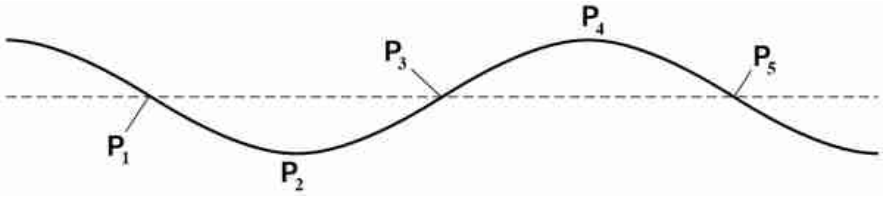
The frequency of the ac supply is varied until a stationary wave is produced on the wire.

0 2 . 2 Explain how a stationary wave is produced on the wire.

[1 mark]

0 2 . 3 **Figure 3** shows a small section of the wire at one instant.
Five points on the wire are labelled P_1 to P_5.
The dashed line represents the position of the wire when the ac supply is turned off.

Figure 3



Describe how the phase of the oscillating particles varies along the wire between P_1 and P_5.

[2 marks]

Question 2 continues on the next page

0 2 . 4 A student investigates stationary waves on a wire using the apparatus in **Figure 2**.
The investigation requires the student to produce the first five harmonics on the wire.

The student needs to choose **one** of two wires, **A** or **B**, for the investigation.

The mass of a $2.00\ \text{m}$ length of wire **A** is $1.32\ \text{g}$.
The mass of a $2.00\ \text{m}$ length of wire **B** is $2.94\ \text{g}$.

The ac supply can produce signals in the range $1\ \text{Hz}$ to $50\ \text{Hz}$.
The length of the wire that vibrates between the vibration generator and the pulley is $1.50\ \text{m}$.

The student needs to choose **one** value for weight W for the investigation.
W can be either $1.0\ \text{N}$ or $5.0\ \text{N}$.

Determine, in kg m^{-1}, the mass per unit length of each wire.
Go on to suggest which wire and which value of W the student should use to produce the first five harmonics.

[5 marks]

mass per unit length of **A** = _____ kg m^{-1}

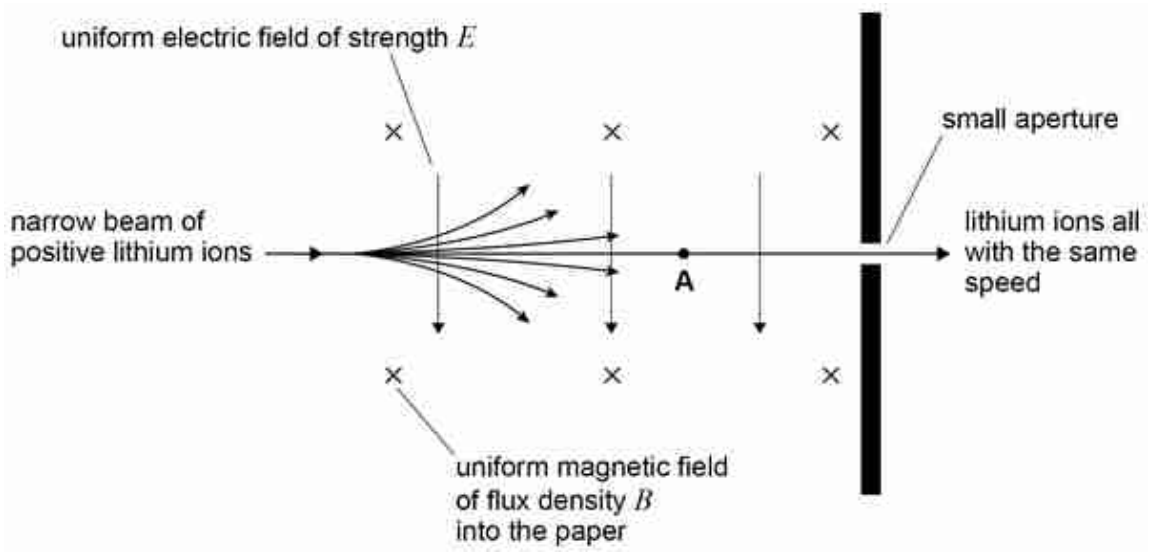
mass per unit length of **B** = _____ kg m^{-1}

wire = _____ W = _____ N

0 3 Mass spectrometers are used to measure the masses of ions.

Figure 3 shows one part of a mass spectrometer.

Figure 3



A narrow beam consists of positive lithium ions travelling at different speeds.
The beam enters a region where there is an electric field and a magnetic field.
The directions of the uniform electric field of strength E and the uniform magnetic field of flux density B are shown on **Figure 3**.

Most ions are deflected from their original path.
Lithium ions that travel at one particular speed are not deflected, and pass through the small aperture.

0 3 . 1 The positive lithium ion **A** in **Figure 3** moves at a speed v.

Draw **two** labelled arrows on **Figure 3** to show the directions of the electric force F_E and the magnetic force F_M acting on **A**.

[1 mark]

0 3 . 2 Lithium ions travelling at 1.5×10^5 m s^{-1} pass through the small aperture.

Calculate E.

$B = 0.12$ T

[2 marks]

$E =$ _____ V m^{-1}

Question 3 continues on the next page

0 3 . 3 Ions that pass through the small aperture enter a second uniform magnetic field of flux density B.
Ions of different mass are separated because they follow different paths as shown in **Figure 4**.

Figure 4

Ions of mass m and charge q travelling at speed v follow a circular path in the uniform magnetic field.

Show that the radius r of the circular path is given by

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

[1 mark]

0 3 . 4 The ions of different mass are deflected and strike the detector surface at different distances from the small aperture as shown in **Figure 4**.

A singly-charged lithium ion ($^{6}_{3}\mathrm{Li}^{+}$) passes through the small aperture.

Calculate the distance between the small aperture and the point where this ion strikes the detector surface.

$v = 1.5 \times 10^{5}\ \mathrm{m\ s^{-1}}$

$B = 0.12\ \mathrm{T}$

mass of $^{6}_{3}\mathrm{Li}^{+}$ ion $= 1.0 \times 10^{-26}\ \mathrm{kg}$

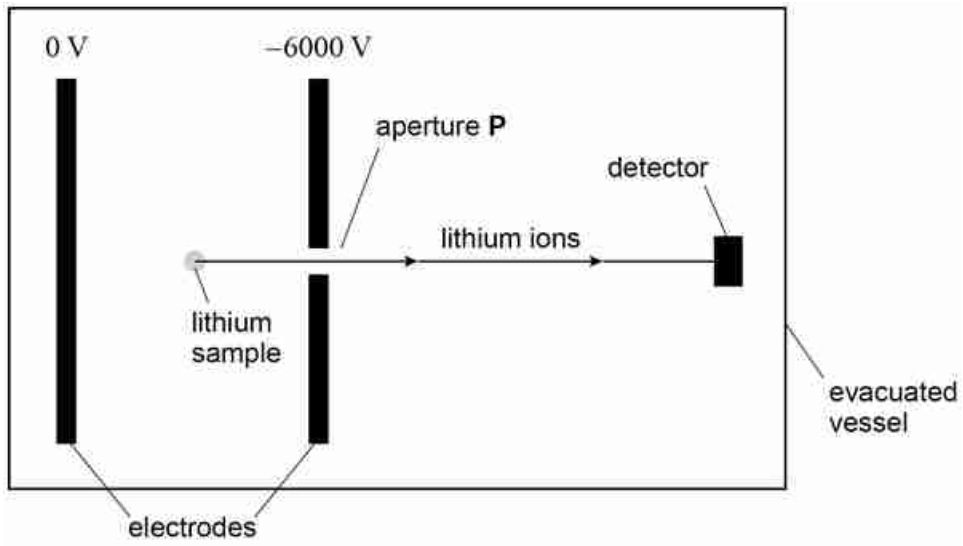
[2 marks]

distance = _____ m

Question 3 continues on the next page

0 3 . 5 **Figure 5** shows a different type of mass spectrometer working with lithium ions.

Figure 5



A stationary $^{7}_{3}Li^{+}$ ion in the lithium sample is at the mid-point between the parallel electrodes. The $^{7}_{3}Li^{+}$ ion accelerates towards aperture **P**.

Determine the speed of the ion when it emerges through aperture **P**.

mass of $^{7}_{3}Li^{+}$ ion $= 1.2 \times 10^{-26}$ kg

[3 marks]

speed = _____ m s^{-1}

0 3 . 6 $^{6}_{3}\mathrm{Li}^{+}$ and $^{7}_{3}\mathrm{Li}^{+}$ ions are produced in the sample simultaneously and travel a distance L from aperture **P** to the detector.
For each type of ion, the time interval between production and detection is measured.

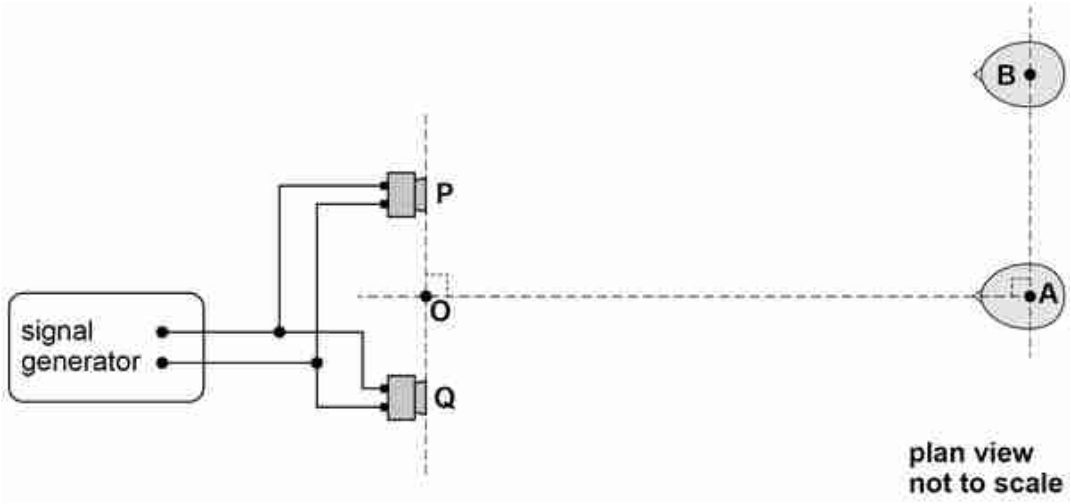
Discuss how the masses of the ions can be deduced from the measurement of these time intervals.

[2 marks]

0 3 A student investigates the interference of sound waves using two loudspeakers, **P** and **Q**, connected to a signal generator (oscillator). Each loudspeaker acts as a point source of sound.

Figure 3 shows the arrangement.

Figure 3



Point **O** is the midpoint between **P** and **Q**.

0 3 . 1 Explain why the two loudspeakers are coherent sources of sound waves.

[2 marks]

0 3 . 2 The student faces the two loudspeakers at point **A**. Point **A** is at equal distances from **P** and **Q**.
He then moves to point **B**, at right angles to the line **OA**, still facing the two loudspeakers.
As his head moves from **A** to **B** the amplitude of the sound wave he hears decreases and then increases. The amplitude starts to decrease again as he moves beyond **B**.

Explain why the variation in amplitude occurs as he moves from **A** to **B**.

[3 marks]

Question 3 continues on the next page

0 3 . 3 The student records the following data:

separation of the two loudspeakers = 0.30 m
distance **OA** = 2.25 m
distance from **A** to **B** = 0.95 m

Show that the path difference for the sound waves from the two loudspeakers to point **B** is about 0.1 m.

[3 marks]

0 3 . 4 The frequency of the sound wave is 2960 Hz.

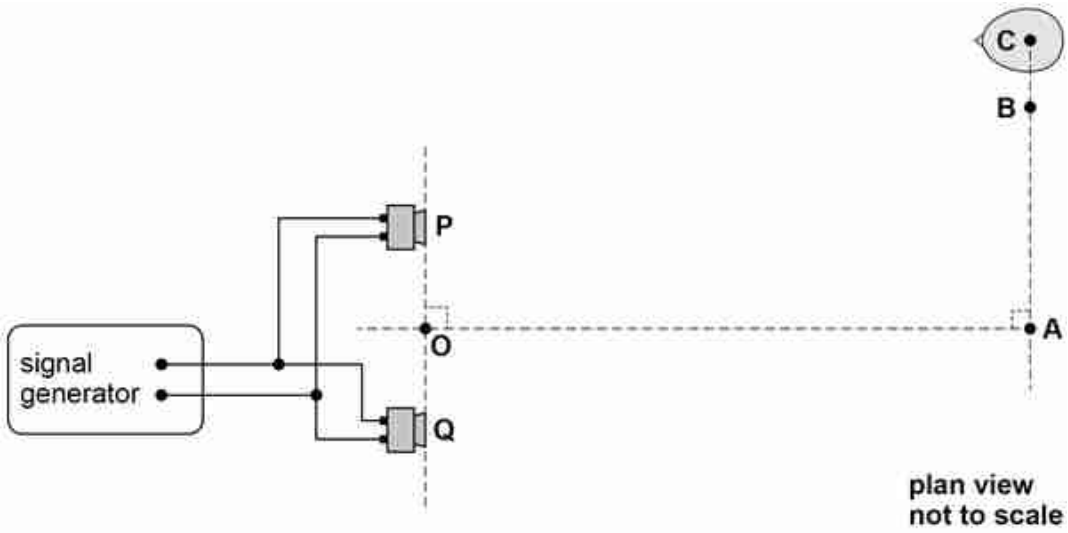
Calculate the speed of sound from the student's data.

[1 mark]

speed of sound = _____ m s^{-1}

0 3 . 5 The student moves his head to point **C** as shown in **Figure 4**. The emitted frequency of the sound from the loudspeakers is then gradually decreased.

Figure 4

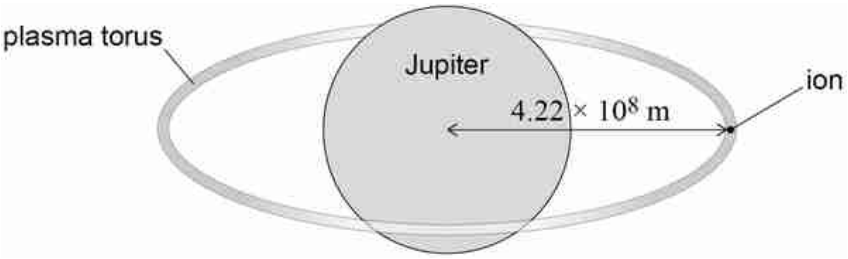


Discuss the effect that this decrease in frequency has on the amplitude of the sound wave heard by the student.

[3 marks]

0 6 Ions orbit Jupiter in a ring called a plasma torus as shown in **Figure 6**.
This question is about applying gravitational, magnetic and electric fields to a particle in the plasma.

Figure 6



An ion travels in a circular path at a speed of $74.2\ \text{km s}^{-1}$ and at a distance of $4.22 \times 10^8\ \text{m}$ from the centre of Jupiter.

0 6 . 1 Student **A** suggests that the gravitational force acting on the ion due to Jupiter provides the centripetal acceleration of the ion.

Deduce whether this suggestion is correct.

mass of Jupiter = $1.90 \times 10^{27}\ \text{kg}$

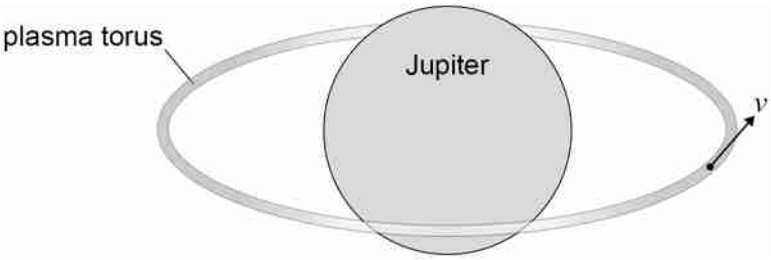
[3 marks]

Question 6 continues on the next page

Student **B** suggests that the magnetic field of Jupiter alone can cause the ion to move in the circular path.

Figure 7 shows the direction of the velocity v of the ion in the plasma torus.
v is tangential to the plasma torus.

Figure 7



The ion has a positive charge.

Student **B**'s suggestion requires a magnetic field to act at the position of the ion.

0 6 . 2 Draw an arrow on **Figure 7** to show the direction of this magnetic field.

[1 mark]

The ion has a charge of $+3.20 \times 10^{-19}$ C and a mass of 5.31×10^{-26} kg.

0 6 . 3 The ion moves with a speed of 74.2 km s^{-1} in a circle of radius 4.22×10^{8} m.

Calculate the magnitude of the magnetic flux density required for this motion.
State, in fundamental (base) units, the unit for your answer.
Ignore any contribution from the gravitational field.

[3 marks]

magnetic flux density = _____ unit = _____

0 6 . 4 An electric field of strength 371 μV m^{-1} can also accelerate the ion.

Calculate the acceleration of the ion due to this electric field.

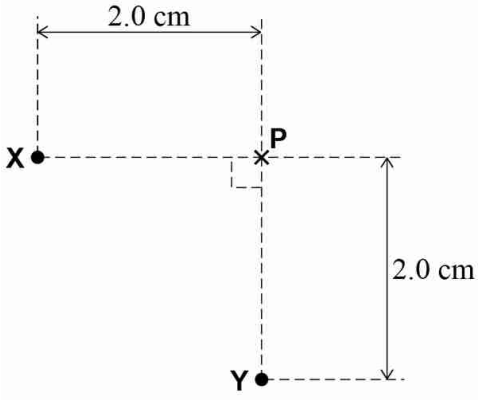
[3 marks]

acceleration = _____ m s^{-2}

Question 6 continues on the next page

0 6 . 5 The plasma torus contains two ions **X** and **Y** as shown in **Figure 8**.
X has a charge of $+2e$.
Y has a charge of $+1e$.
Assume that each ion acts as a point charge.

Figure 8



Calculate the magnitude of the resultant electric field strength at point **P** in **Figure 8** due to the two ions.

[3 marks]

resultant electric field strength = _____ $\mathrm{V\ m^{-1}}$

END OF SECTION A

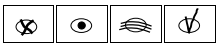
Section B

Each of Questions **07** to **31** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.
For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD 

WRONG METHODS 

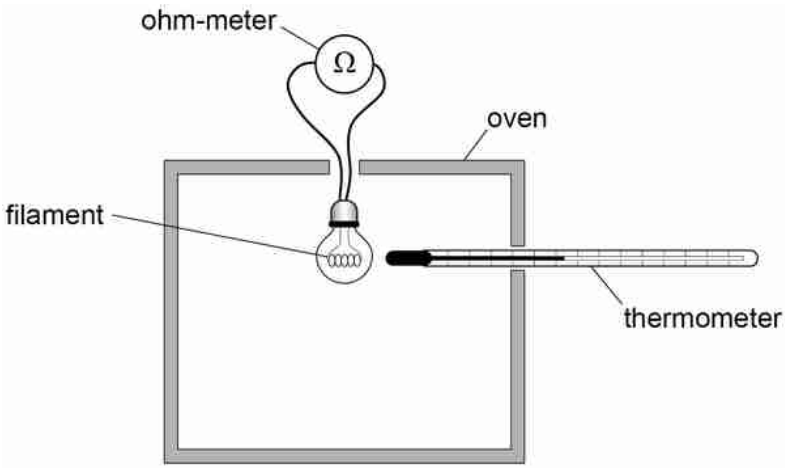
If you want to change your answer you must cross out your original answer as shown. 

If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown. 

You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.

0 3 **Figure 5** shows apparatus to investigate how the resistance R of a lamp filament varies with the absolute temperature T of the filament.

Figure 5



The lamp is inside an oven.

The oven temperature is increased to a steady value.
The filament is at the same temperature as the inside of the oven.

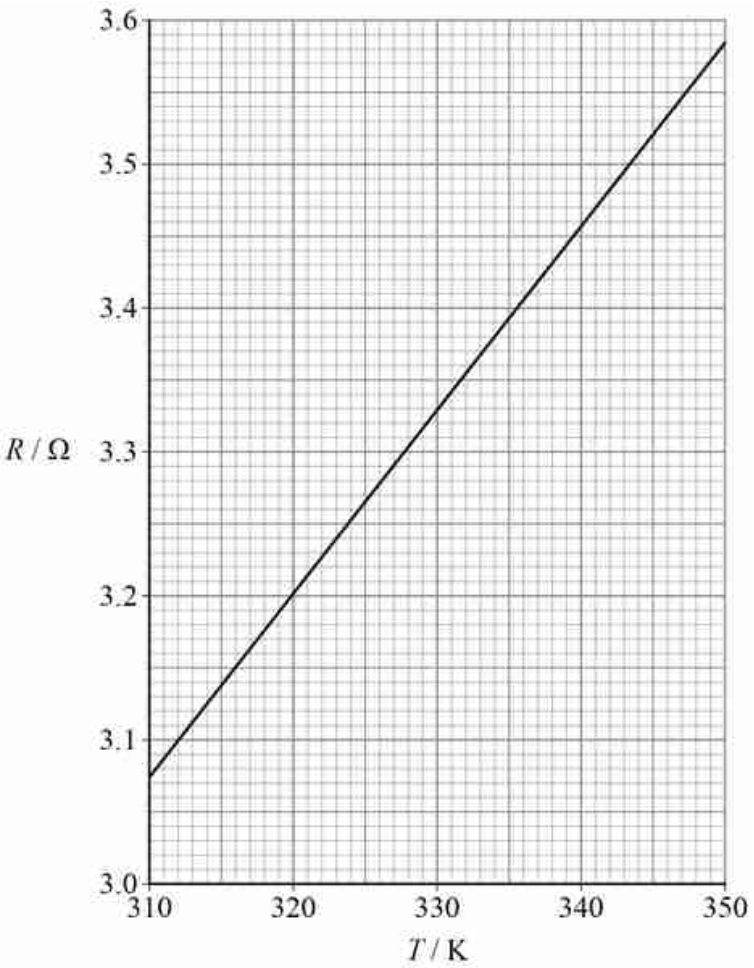
The temperature T in kelvin is determined using the thermometer.
An ohm-meter is connected to the filament to determine R at temperature T.

The oven temperature is increased to new steady values and further readings of T and R are recorded.

Question 3 continues on the next page

Figure 6 shows the variation of R with T.

Figure 6



It can be shown that:

$$\frac{R - R_0}{R_0} = \alpha(T - T_0)$$

where:

R_0 is the resistance of the filament at temperature T_0

α is a constant.

0 3 . 1 Determine α using the graph in **Figure 6**.
State an appropriate SI unit for your answer.

$R_0 = 2.83\ \Omega$ when $T_0 = 291\ \text{K}$

[3 marks]

$\alpha =$ _____ unit = _____

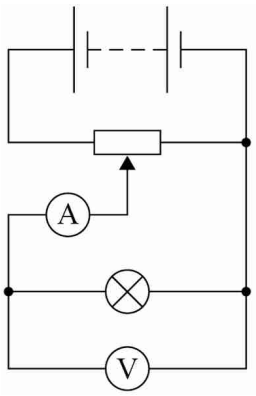
Question 3 continues on the next page

In a different investigation, a student investigates how the electrical power P transferred in the same filament lamp varies for values of T greater than $800\ \text{K}$.

The student assumes that α is constant for all values of T.

Figure 7 shows the circuit that the student uses.
The temperature of the filament is controlled by the energy supplied to it from the battery.

Figure 7



0 3 . 2 Explain how the ammeter and voltmeter readings are used to determine values of P and T.

[2 marks]

P

T

Question 3 continues on the next page

For a steady value of T, $P = P_1 + P_2$
where:

P_1 is the rate of heat transfer from the filament by radiation

P_2 is the rate of heat transfer from the filament by all other processes.

In **Figure 8**:

- the solid line shows how P varies with T
- the dashed line shows how P_2 varies with T.

Figure 8

0 3 . 3 Complete **Table 2**.

[3 marks]

Table 2

T / K	P / W	P_1 / W	P_2 / W
960	3.7	1.2	2.5
1100		2.0	3.0
1370			
1680	16.2	11.0	

Question 3 continues on the next page

0 3 . 4 It can be shown that $P_1 \propto T^n$ where n is an integer.

Determine n.

In your answer you should:
- use **Table 3** to organise the data you will plot
- plot a suitable graph on **Figure 9**.

[5 marks]

Table 3

T / K	P_1 / W		
960	1.2		
1100	2.0		
1370			
1680	11.0		

$n =$ _____

Figure 9

MARK SCHEMES

official mark schemes

D

10	B (AO1)	2.7×10^{-6} rad s^{-1}

30	D	$\frac{r}{rg}$	

28	A	from **P** to **O**	AO1
		$\frac{2}{3}$ $\frac{2}{3}$	

05.1		Forgets to add 1 giving radius 2.71 and speed 3.27 m s^{-1}	

05.2	Centripetal force = $85 \times 4.49^2/3.71 = 460$ N ✓ Centripetal force = $T \sin 28.5$✓ T = 950 - 970 N✓ **OR** Weight = 85 x 9.8(1) 0r 834 N seen✓ Weight = $T \cos 28.5$ ✓ T = 950 (949) (N) ✓ **OR** Centripetal force = 85 x $4.5^2/3.71$ = 464 N✓ Weight = 834 N✓ $T = \sqrt{464^2 + 834^2}$ = 950 - 970 N✓ Allow ecf for incorrect weight or centripetal force	470 N if using 4.5 m s^{-1} leads to 1000 N **Allow the following as ecf:** forgetting to add the 1 m (using r = 2.71 m) leads to centripetal force = 630 N T = 1300 N) Using r =3.39 m as ecf from 5.1 which leads to Centripetal force = 510 N giving T = 1070 N **Allow the following as ecf:** forgetting to add the 1 m (using r = 2.71 m) leads to centripetal force = 630 N, T = 1050 N using r =3.39 m leads to Centripetal force = 510 N giving T = 980N	1 1 1

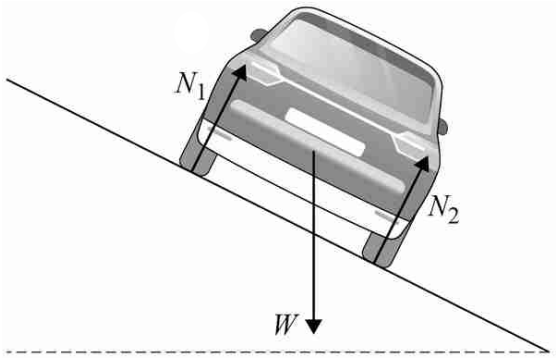
05.3	Vertical (compressive) force **on the pole** increases✓ Increases mass <u>increases weight</u> and hence tension in the rope(for the same angle) ✓ <u>Centripetal Force</u> on the acrobats/masses would be different/not equal Or would be greater <u>on the more massive acrobat</u>(travelling at the same speed/same angle to vertical) ✓ Unbalanced (horizontal) forces/resultant force exists (on the pole) ✓ **or** Unbalanced moments acting (on pole)/resultant torque acting (on pole)✓ Causing the pole to sway/bend/move/ or tilt/topple the platform <u>toward more massive acrobat</u>✓		Max 3 1 1 1
Total			**8**

06.	(Total) kinetic energy ✓		1
	Attempt to apply conservation of momentum ✓	NB This is a 'show that' so all stages must be seen Must see substitution	1 1

07.1	$E_k = \frac{1}{2}mv^2$ AND $F = \frac{mv^2}{R}$ ✓ Combines two equations correctly ✓ (To give $R = \frac{2E_k}{F}$)	In MP1 do not condone use of r for R unless explicitly equated. E.g.r =R Do not allow use of r for R in MP2. In MP2 allow r becoming R without explanation. Eg for MP2: $F = \frac{m2E_k}{mR}$ (need to see m or ~~m~~) OR $mv^2 = FR = 2E_k$	2	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
07.2	$v = 58.7$ (m s^{-1}) ✓	Calculator value: 58.73670062 Accept 59 Do not accept rounding error.	1	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
07.3	Idea that the radius of the path of the car can be increased OR Idea that friction between tyres and track can be increased ✓	eg Start at the outside of the track and drive to the inside of the curve Condone 'reduce mass of car' Treat banking answer as neutral.	1	AO3

Question	Answers	Additional comments/Guidance	Mark	AO
07.4	 W ✓ N_1 and N_2 ✓	W must be straight and vertically downwards with a line of action that passess approximately through the centre of mass Normal reaction forces with lines of action through tyres at right angles to slope Condone any symbols for W, N_1 and N_2 Award **max 1** if centripetal force appears. Treat components as neutral	2	1 × AO1 1 × AO2

Question	Answers	Additional comments/Guidance	Mark	AO
07.5	(with the slope) there is a (horizontal) component of the normal reaction force that increases the (maximum) centripetal force ✓ Idea that v can be greater (for same R) when centripetal force greater ✓		2	AO3
Total			**8**	

Question	Answers	Additional comments/Guidance	Mark	AO
	1			

04.1	Centripetal force acts inwards / towards the centre of rotation ✓ Links reaction force to centripetal force ✓		2	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	Equates forces AND states **either** centripetal force with correct symbols✓ cancelling ω✓ $m_A r\cancel{\omega^2} = m_B(L-r)\cancel{\omega^2}$ $r = \frac{m_B L}{m_A + m_B}$	E.g. $F = m_A r\omega^2$ $F = m_B(L-r)\omega^2$ In MP1 condone: equations containing v; use of ω_A and ω_B for the angular velocities. In MP2 it must be clear that the angular velocity and not the velocity.	2	AO2 L2 Maths 2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.3	The angular speed is the same for A & B or Rotational radius for B less than that for A ✓ Both of these points AND $v = r\omega$ so velocity of A is greater.✓	Alternative for MP2: Both of points in MP1 AND A travels greater distance in the same time.	2	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
04.4	Use of safety factor e.g. maximum stress << 0.300 GPa ✓ $F = ma = 1.32 \times 10^6 \times 3.7$✓ $(= 4.9 \times 10^6$ N) $A = \frac{F}{\sigma}$ valid substitution ✓ $d = \sqrt{\frac{4A}{\pi}}$ ✓ (expect > 0.144 m) Valid justification for selection of maximum stress used e.g. using a stress that is from the linear / elastic section of the graph or reference to either safety factor or trying to limit weight of cable. ✓	Alternative for MP1: they can work through for a stress of 0.3 GPa and then increase the diameter, if justified as a safety factor. Do not allow use of stress ≈0.3 GPa for full marks. Allow ecf for stress and force	5	AO3 L2 Maths 2
Total			**11**	

Question	Answers	Additional comments/Guidelines	Mark	AO

D

D

D

A

D

D

C

A

24	B

30	B

17

30	B	$2T$ T

31	D	$\frac{2\pi^2 mA}{T^2}$

20

31	C (AO2)	54 mm s^{-1}

31	B	the kinetic energy of the mass

30	B	$0.57\ \text{m s}^{-1}$	AO1
		T	

32	C	T $T\sqrt{2}$	AO2

25

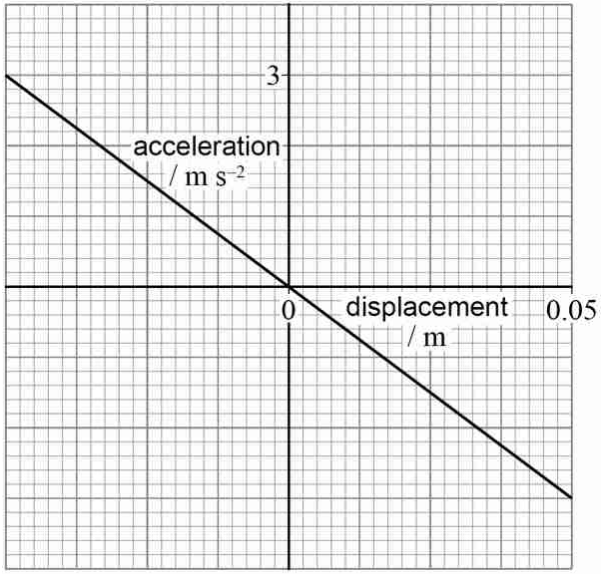
25	B		maximum	minimum		AO1	

31	A	190 g	AO2

32	B	1.1 Hz	AO2

06.1	1.5 (ms) ✓		1
06.2	A = 4.2 (mm) read from graph ✓ T = 2.0 (ms) read from graph ✓ ($a_{max} = 4.2 \times 10^{-3} \times (2 \times \pi / (2 \times 10^{-3}))^2$ $4.1(5) \times 10^4$ (m s^{-2}) ✓ (Do not allow 4.2)	Condone power of ten error in A and/or T but not in final answer. Evidence for T might be seen in equation, as 500 (f). Only allowed ecf for max 2 is use of 4.1 mm for A, giving 4.0×10^4 (m s^{-2})	3
06.3	longitudinal (they) oscillate along direction of energy transfer ✓	Both required for 1 mark Condone "vibrate" for oscillate. Condone 'travel' for transfer	1
Total			**5**

Question	Answers	Additional Comments/Guidelines	Mark
	Mention of increase in lost volts/ pd across internal resistance (in cell)✓ (because) current has increased	Accept reverse arguments Do not accept terminal pd has decreased Treat comments about resistance of lamp as	

03.1	Evidence of $\omega = \frac{2\pi}{T}$ OR 0.05 m seen OR $A = \frac{V}{\text{their } \omega}$ $_1$✓ Use of $a = -\omega^2 x$ OR 3.0 m s^{-2} seen $_2$✓ Straight line through origin with negative gradient featuring all four quadrants $_3$✓ Single straight line ends at (0.05,-3.0) OR Single straight line ends at (0.05, 3.0) $_4$✓	Expect to see:  Condone axes either way round Award **4** for correct graph with correct values Evidence for $_1$✓ and $_2$✓ can be seen on the graph. In $_3$✓ (0,0) must be in centre of line. $_4$✓there is no ecf from $_1$✓ or $_2$✓.	4	2 × AO1 2 × AO2

Question	Answers	Additional comments/Guidance	Mark	AO
03.2	**P** at $\frac{\text{their max displacement}}{\sqrt{2}}$ (judge by eye)	Accept on either quadrant Expect to see 3.54 x 10^{-2} m **AND** 2.1 m s^{-2}	1	AO1
Total			**5**	

Question	Answers	Additional comments/Guidance	Mark	AO

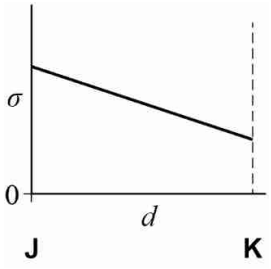
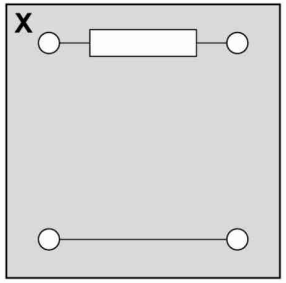
06.1	Equates resultant force to ma and shows a proportional to y, as $A\rho mg$ are all constant✓ Minus sign included and explained: (restoring) force/acceleration directed to centre of oscillation ✓ (hence SHM)	In MP1: Condone upthrust/buoyancy force for resultant force $F = ma = -A\rho yg$ $a = -\frac{A\rho yg}{m}$ Condone missing minus signs in MP1. In MP2: Minus because force/acceleration is in opposite direction to y OWTTE	2	AO1× 1 AO2× 1

Question	Answers	Additional comments/Guidelines	Mark	AO
06.2	$(T = 2\pi/\omega)$ so $\omega = \sqrt{\frac{g}{l}}$ ✓ $(= 10.74 \text{ rad s}^{-1})$ $(a_{max} = -\omega^2 y_{max} = \frac{g}{l} \times y_{max} = (9.81 \div 0.085) \times 0.005)$ $0.58 \text{ (m s}^{-2})$ ✓ from some correct working	Alternative for MP1: calculates time $(0.58(5) \text{ s})$ AND then uses ω from this time MP2 for correct calculation of acceleration.	2	AO1 × 1 AO2 × 1

Question	Answers	Additional comments/Guidelines	Mark	AO
06.3	Idea that (at resonance) frequency of forced vibrations equals natural/resonant frequency $_1$✓ Idea that amplitude (of vibrations/oscillations) is at a maximum $_2$✓	Accept fully labelled graph of amplitude vs driving frequency with resonance frequency clearly labelled$_1$✓ and an amplitude peak. $_2$✓ Condone ‘wave frequency’ for ‘driving frequency’ Ignore references to phase	2	AO1 × 2

Question	Answers	Additional comments/Guidelines	Mark	AO
06.4	stopped: wave frequency (= $\frac{v}{\lambda}$) = 0.12 Hz $_1$✓ moving: when ship continues at $8\ \text{m s}^{-1}$, forcing frequency will be further from resonant frequency $_2$✓ Moving option is better with reason, eg for stopped option wave/forcing frequency very close to natural frequency, (so amplitude of oscillations will be high) **OR** for moving option resonance does not occur $_3$✓	$_1$✓is for calculation of (driving) frequency when stopped. Condone reference to 'frequency of waves'. If no reference to ship being stopped, evidence can come from the substitution. Reject simple "0.12 (Hz)" $_2$✓ is for a relevant comment about the moving situation OR calculation of forcing frequency with the ship moving (giving 0.05 Hz) For $_2$✓ accept incorrect calculation from adding speeds provided comment that this frequency is further from resonant frequency. $_3$✓ is for statement of why moving is the better option Allow answer for $_3$✓ that mentions that damping will be highly likely, so amplitudes may not reach high enough values to prevent operation	3	AO3× 3
Total			**9**	

Question	Key	Answer
07	A	$10\ \mu m\ s^{-1}$ $100\ s$
08	B	$4\ m\ s^{-1}$
09	B	8 7
10	D	They decay into electrons.
11	B	down quark up quark β^-
12	C	$2.8 \times 10^5\ m\ s^{-1}$
13	A	decreasing the kinetic energy of the electrons
14	C	1.2 0.17
15	B	They have a constant phase relationship.
16	A	$0.22s$ 0.66λ
17	C	decreases increases
18	C	45 m
19	D	force mass × displacement
20	C	displacement and momentum
21	B	A current in it causes no heating effect.
22	B	B

23	A	$\frac{mg}{k}$
24	C	The acceleration is unchanged.
25	C	$7.50\ \text{m s}^{-1}$
26	D	
27	D	
28	A	19

29	B	36
30	D	$\frac{v^2}{rg}$
31	B	the kinetic energy of the mass

05.1	Use of time = angle ÷ angular speed ✓ To get 3.5 (s) ✓	Alternative for MP1: Accept distance÷speed when circumference has been calculated. Accept answers that round to 3.49	2	2 x AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	Arrow towards centre of turntable . ✓		1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
05.3	Use of $F = mrw^2$ OR determination of centripetal acceleration and then $F=ma$ ✓ To give 0.097 N ✓	Shown by substitution. Condone use of diameter or radius halved in MP1. Accept negative answer. Calculator value: 0.0972	2	2 x AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
05.4	States block is (constantly) changing direction ✓ Uses appropriate Newton law of motion to link evidence (to show that a force acts) ✓ *Alternative 1* Block constantly changing direction (at constant speed) ✓ Uses N1 to show that a force must apply ✓ *Alternative 2* Changing direction shows (centripetal) acceleration ✓ Uses N2 to show that a force must apply ✓	Reference can be to the name of the law or to a description of what the law says. Condone lack of “resultant force” in N1 and N2. Use of “changing velocity” without reference to direction is not enough for MP1.	2	2 x AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
05.5	Use of pendulum equation by substitution or manipulation ✓ To give 1.55 m ✓	Allow 2+ sf Allow answer that rounds to 1.55 Use of $g = 10$ N kg^{-1} gives 1.58 – do not allow for MP2	2	2 x AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
05.6	*Amplitude* – the pendulum shadow amplitude becomes less than the block shadow amplitude ✓ *Phase* – time period decreases/changes OR frequency increases/changes (as pendulum amplitude gets less) therefore phase changes ✓	Must see a comparison for MP1 Condone: the time periods/ frequencies remain identical therefore the shadows remain in phase	2	2 x AO3
Total			**11**	

Question	Answers	Additional comments/Guidelines	Mark	AO
	As angle of refraction greater than angle of incidence with			

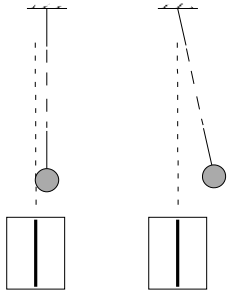
04.1	working to determine t: EITHER $\frac{24.73 - 9.26}{n}$ where n is their number of turns between **P** and **Q** OR $\frac{x - 9.26}{13}$ where x is their vernier reading from **Figure 11** $_1$✓ $t = 1.19$ (mm) $_2$✓	for $_1$✓ n must be an integer AND x must be 2 dp; allow $\frac{15.47}{n}$ for $_2$✓ must see some correct working; accept >3 sf that rounds to 1.19	2	AO3

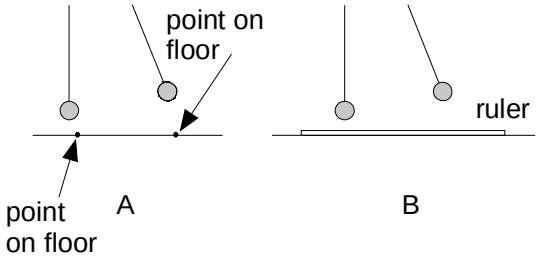
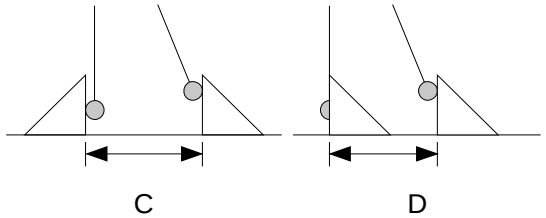
Question	Answers	Additional comments/Guidance	Mark	AO
04.2	MAX $_1$✓$_2$✓ from • diameter $= 18(.0) + (2 \times)$ their t from **04.1** $_A$✓ • circumference = $\pi \times$ their diameter $_B$✓ • length = their circumference $\times$ their n from **04.1** $_C$✓ **correctly** calculates L using their $n \times \pi \times (18 +$ their $t)$ OR using their $n \times \pi \times (18 + (2 \times$ their $t))$ $_3$✓	for $_A$✓ accept $t = 1.2$ (mm) for $_B$✓ allow $(18 + t)$ OR $(18 + 2t)$ for their diameter; condone $(18 + \frac{t}{2})$ OR 18 the award of $_3$✓ is contingent on the award of $_A$✓ $_B$✓ and $_C$✓ for $_3$✓ L must be given to 3 sf ie a **whole number** of millimetres condone the award of $_1$✓$_2$✓$_3$✓ if working is missing but recognisable values of n and t are seen	3	AO3

Question	Answers	Additional comments/Guidance	Mark	AO
04.3	identifies **B** $_1$✓ where (the top of the test tube) is moving fastest / has maximum kinetic energy / where the transit time is least $_2$✓	for $_1$✓ must reject **A** and **D**; allow **C only** if an additional mark added **to the tube** at this height when the tube is **at the equilibrium position** OWTTE $_2$✓ is contingent on $_1$✓ for $_2$✓ comments about the equilibrium position / equilibrium point / centre of oscillation / rest position are neutral; the idea that 'the (top of the) test tube will always pass point' is neutral; explaining why **A**, **C** and **D** are not suitable is neutral	2	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
04.4	derives an expression that can be used to determine ρ for milk OR evaluates $T^2\rho$ OR $T\sqrt{\rho}$ (for oil) $_1$✓	award $_1$✓ and $_2$✓ independently for $_1$✓ accept a valid expression, any subject, without full substitution, eg $\rho_{\text{milk}} = \rho_{\text{oil}} \frac{T_{\text{oil}}^2}{T_{\text{milk}}^2}$ OR $0.587^2 \times 849$ seen / 293 seen OR $0.587 \times \sqrt{849}$ seen / 17.1 seen	2	1 × AO1 1 × AO2
	density of liquid $= \left(849 \times \frac{0.587^2}{0.534^2}\right) = 1.03 \times 10^3$ (kg m^{-3}) $_2$✓	for $_2$✓ 3 sf only but condone 4 sf answer in the range 1025 to 1030 only		

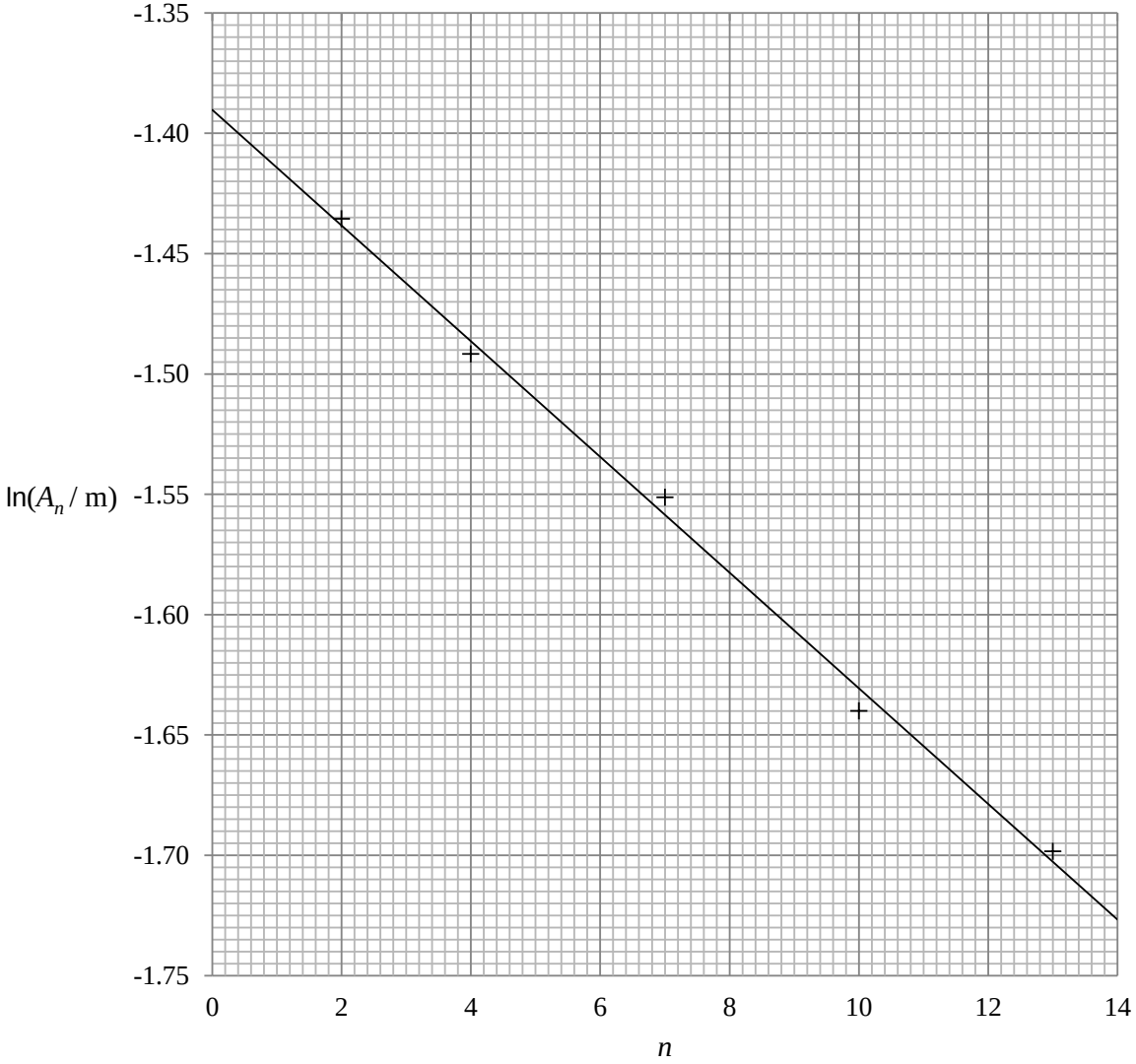
<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidance</th><th>Mark</th><th>AO</th></tr>
<tr><td>04.5</td><td>MAX 3 from
a valid modification $_1$✓
a rationale for the modification $_2$✓
an additional valid modification $_3$✓
a rationale for the second modification $_4$✓</td><td>
<table>
<tr><td>$_1$✓ (idea of) increasing the depth of the oil,
eg add (more) oil to the beaker
do not accept ‘use a narrower beaker’ as this increases drag</td><td>$_2$✓ (idea of) increasing the (initial) displacement / amplitude / height of the test tube
OR
increasing the (initial) energy of the system
allow ‘to produce larger / bigger oscillations’</td></tr>
<tr><td>$_3$✓ (idea of) increasing the distance between the test tube and the beaker walls,
eg use a wider / larger diameter beaker AND add oil to (at least) the original depth (to maintain the initial amplitude)</td><td>$_4$✓ (idea of) reducing the drag / (fluid) resistance / (fluid) friction / velocity gradient;
condone (idea of) ‘reducing the damping)</td></tr>
</table>
for $_1$✓ ‘use a taller / deeper / larger beaker’ is neutral;
for $_2$✓ (idea of) ‘obtain greater oscillations’ is neutral;
for $_3$✓treat as neutral any changes to the test tube, wire or oil;
condone ‘water’ / ‘liquid’ for oil
for $_4$✓ ‘reduce the effect of damping’ is neutral</td><td>3</td><td>AO3</td></tr>
<tr><td>Total</td><td></td><td></td><td>12</td><td></td></tr>
</table>

01.1	annotates **Figure 1** to identify equilibrium position; some (or all) of the mark should be below the bob **or** (bottom of mark) should be level with bottom of bob $_1$✓ this is where (the pendulum / bob) is moving fastest / (pendulum has) maximum kinetic energy **or** this is where the transit time is least $_2$✓	for $_1$✓ condone a poorly-annotated sketch if intention is clarified in $_2$✓; do not allow talkout do not insist on seeing the outline of the card as long as the vertical line is seen; condone arrows ↑ ↕ etc; blobs ●+✖ are neutral allow vertical line of the mark to be aligned with either edge of the bob in the left-hand view or marked directly below point of suspension (within one-quarter of bob radius) in the right-hand view, eg  if marks are shown on each view of the pendulum, then each separately must satisfy the criteria for $_1$✓ **$_2$✓ is contingent on award of $_1$✓** for $_2$✓comments about why the mark is not aligned with bob in right-hand view are neutral (at equilibrium) 'acceleration is zero' is neutral	2	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	use of appropriate <u>horizontal</u> scale or wtte 1✓ use of set-square with edge made vertical or other suitable equipment to eliminate parallax error in A_R 2✓ measures A_R from (either) edge of displaced bob 3✓	any of 1✓2✓or 3✓can be earned by suitable annotation to **Figure 2** for 1✓ruler or 'mm scale' only; 'measuring with a ruler between points marked on the floor' is acceptable (see A below) or use of a 'ruler placed on floor' (see B)  for 2✓allow use of plumb line, spirit level, video or photographic equipment; reject clamp stand any use of the fiducial mark or the idea that the supporting beam is horizontal are neutral withhold 3✓unless candidates explains that allowance is being made for radius / diameter of bob (see C and D below) 	MAX 2	AO3.2b

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	extrapolation of curve to (at least) $x = 0.70$ m $_1$✓ consistently-recorded min 3 dp values for $T_{0.35}$ and $T_{0.70}$ $_2$✓ evidence of valid calculation (check denominator correct); percentage increase in range 1.4(0) % to 1.8(0) % $_3$✓	for $_1$✓extrapolation must be continuous and smooth; allow (ruled) straight line; reject hairy, thick or dashed lines for $_2$✓allow values seen in working; $T_{0.35}$ must round to 2.322; condone $T_{0.70}$ by eye don't insist on horizontal or vertical lines between curve and vertical axis on **Figure 3** for $_3$✓expected answer is 1.51%	1 2	AO3.1a AO2.1h
01.4	rejects anomalous 0.247; average $A_5 \geq$ 3 sf (that rounds to) 0.221 (s) $_1$✓ correct uncertainty calculation or 0.004(0) (s) seen $_2$✓ **or** does not reject 0.247; average A_5 = (rounds to) 0.226 (s); correct uncertainty calculation or 0.015 (s) seen $_{12}$✓ correct % uncertainty from $\frac{\textit{their half range}}{\textit{their average}} \times 100 \geq$ 2 sf $_3$✓	0.221 and 1.8 % on answer lines earn $_{123}$✓✓✓ $_1$✓ (0.247 rejected) full answer 0.2214 (s) $_2$✓ from half range; can be inferred from working $_3$✓ if $_{12}$✓✓full answer 1.81 %; allow 1.8 % or 1 sf 2 % when 0.247 is not rejected $_{12}$✓full answer 0.2257 (s) $_3$✓ full answer 6.647 %; allow 6.64 / 6.65 % or 2 sf 6.6 / 6.7 % for $_3$✓ allow ECF only if uncertainty is from half range	3	AO2.1h

Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	$\ln(A_4 / \text{m}) = -1.492$ ✓	CAO 3 dp only	1	AO1.1b
01.6	vertical scale with one major (cm) grid square = 0.02 **or** 0.025; maximum spacing of values marked on the scale = 5 cm 1✓ points plotted for n = 2, 4, 7, 10 and 13; suitable continuous ruled line of negative gradient from n = 2 to (at least) n = 13; line must pass above n = 4 **and** n = 10 points **and** must pass below n = 7 point 2✓	withhold both marks for false plot for 1✓scale might go (down page) from −1.40 to −1.72 (1 square = 0.02) or from −1.30 to −1.70 (1 square = 0.025); scale must cover range of plotted points; do not insist on use of broken scale convention no credit for reversed values leading to graph with 'positive' gradient; no credit for missing / inconsistent minus signs or for inconsistent dp in labelled values for 2✓allow ECF acceptable line based on accurate plot of incorrect n = 4 point allow ECF for graph with 'positive' gradient due to reversed scale, eg line must pass **below** n = 4 **and** n = 10 points **and** must pass **above** n = 7 point accept only 4 points if n = 4 is not tabulated; line must pass **between** n = 7 and n = 10 ignore any plot of $\ln(A_5 / \text{m})$ based on 01.4 data; withhold mark for poor points eg blobs or for thick / faint / non-continuous line	2	AO2.1h



10

Question	Answers	Additional comments/Guidelines	Mark	AO
01.7	(any) correct expression with ln A_n as subject $_1$✓ $\delta = e^{-gradient}$ or wtte $_2$✓	for $_1$✓ $y = mx + c$ idea is required **either** ln $A_n = -n \ln \delta + \ln A_0$ $(y = mx + c)$ **or** ln $A_n = \ln A_0 - n \ln \delta$ $(y = c + mx)$ **not** ln $A_n = \ln A_0 - \ln \delta^n$ treat 'lg A' as a slip allow use of 'log A' for $_1$✓ but no ECF in $_2$✓ for $_2$✓ δ must be the subject, reject ln $\delta = -$ gradient etc allow ECF if $_1$✓ is withheld for missing – sign; if gradient is evaluated accept $\delta = e^{(+)0.024}$ or $\delta = 1.02(4)$ etc an explanation that δ can be found using $A_n = A_0 \delta^{-n}$ must rely on values of A_n, A_0 and n that are determined using the line in **Figure 4**	2	AO3.2a
Total			**15**	

Question	Answers	Additional comments/Guidelines	Mark	AO

D

B

A

7	A	0.10 kg s^{-1}.

8	C	60 kg

01.1	Combining and making use of $Q = Pt$ and $Q = mc\Delta\theta$ equations without the need to make t the subject. ✓1 t = 27 (s) ✓2	✓1 numerical errors are ignored for this mark. Provided the temperature difference is correct then subsequent changes that involve 273 ^{0}C can be ignored. ✓2 $t = (1.2 \times 450)\frac{(125-20)}{2100}$ No ecf for the second mark but correct answer gains both marks Condone use of c_{water} for c_{metal}.	2	2 x AO2 3.6.2.1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	(The power supplied in time t raises the temperature of m kg of water and converts it to steam) Use of appropriate equation. ✓1 Correct evaluation of Δm or P. No ecf. ✓2 Deduction that claim is false (consistent with their value) supported by their calculated quantity OR Deduction that their calculated quantity is greater / smaller than required ✓3	The award of MP3 is dependent on the award of MP1 OR MP2. Evidence for MP1 can be seen in MP2 via the correct answers in the exemplars below. Condone error in time / temperature change / POT for MP1. Use of m from the metal is not condoned ✓1 $Pt = mc_w\Delta\theta + ml$ OR $P = \frac{mc_w\Delta\theta + ml}{t}$ ✓2 Several methods can be followed including in 1 minute 2100×60 $= \Delta m \times 4200 \times (100 - 20) + \Delta m \times 2.3 \times 10^6$ $\Delta m = 0.048$ kg min^{-1} OR in one second 2100 $= \Delta m \times 4200 \times (100 - 20) + \Delta m \times 2.3 \times 10^6$ $\Delta m = 0.00080$ kg s^{-1} OR $P = \frac{0.060 \times 4200 \times (100 - 20) + 0.060 \times 2.3 \times 10^6}{60}$ $P = 2.6(4) \times 10^3$ W OR Comparing the energy supplied in time eg in a minute (126000 J) with energy needed (138000 + 20160 = 158000 J) OR	3	2 x AO3 1 x AO1 3.6.2.1

		= 75.3 s. ✓3 So claim is not true. 0.048 kg min^{-1} is smaller than 60 g min^{-1} OR 0.00080 kg s^{-1} = 48 g min^{-1} is smaller than 60 g min^{-1} OR 2.6×10^3 W is greater (than 2.1 kW / power available) OR time to generate 60 g of steam is too long. (The most common ecf will be to leave out the raising of the water temperature before changing the water to steam giving calculated values of Δm = 0.055 kg min^{-1}, or Δm = 0.00091 kg s^{-1} or $P = 2.3 \times 10^3$ W)		
Total			**5**	

Question	Answers	Additional comments/Guidelines	Mark	AO

01.1	liquid state or melt/fuse ✓ Without a change of temperature or at the freezing/melting temperature/point ✓	state (if energy to change is given then required or needed is implied) 2nd mark stands alone.	2	AO1

01.2	(Dividing both sides of the equation $\Delta Q = m\,c\,\Delta\theta$ by Δt gives $\Delta Q/\Delta t = m\,c\,\Delta\theta/\Delta t$ or $\Delta\theta = (\Delta Q/\Delta t) \times \Delta t/m\,c$ where $m = \rho V$) $\Delta\theta = 2700 \times (60 \times 60) / (4.5 \times 1000 \times 4200)$ ✓ Full substitution correct✓ temperature rise = $\Delta\theta = 0.51$ (K) ✓ (= 0.514 K)	Working must be seen as there is a self-cancelling error with two 1000 factors. So answer alone gains the 3rd mark only. Firs mark can be gained if (60x 60) is absent even if not re-arranged. The change of temperature may be written as a difference between 28 °C and an unknown temperature (allow in kelvin written either way round ie with incorrect sign) 1 sig fig is **not** acceptable. Useful numbers: $4.5 \times 1000 \times 4200 = 1.89 \times 10^{7}$ $2700/(4500\times4200) = 1.4 \times 10^{-4}$ Max 2 if: Omits (60 x 60) giving 1.43×10^{-4} K Omits 60 giving 8.57×10^{-3}	3	AO2

01.3	(When the pump is working at speed) the pump is <u>doing work</u> (on the water) ✓ work (and heat both) can raise the temperature of a body (as stated in the 1st Law of thermodynamics) (this may be expressed as work is converted to thermal energy) OWTTE **OR** The pump increases the randomness / turbulence of the water/molecules **OR** The <u>mean</u> square speed/*mean* kinetic energy is proportional to the (absolute) temperature. ✓ (this may be given in the form on an equation) OWTTE	(Lenient mark – a reference to random motion or more collisions may gain this mark but a simple increase in kinetic energy is not enough) Do not penalise answers that go nowhere unless they directly contradict a marked answer.	2	2 AO3
Total			**7**	

Question	Answers	Additional Comments/Guidance	Mark	ID details
	(The electric field strength at a point) is the force per unit charge ✓	An equation is not sufficient unless the symbols are defined. Unit charge can be replaced by coulomb. (Reference to a point is not needed as it is in		

01.1	Attempt to use $c = \left(\frac{\quad}{m \times \Delta\theta}\right) = \frac{\quad}{0.050 \times (77-70)}$ ✓3 specific heat capacity of liquid nitrogen = $c = 1.9 \times 10^3$ ✓4 (allow 1 sig fig due to the small temperature difference) $J\ kg^{-1}\ K^{-1}$ or $J\ kg^{-1}\ ^oC^{-1}$ ✓5 {taken from the answer line but if not present can come from the body of the answer space}	✓4 Allow 1 sig fig due to the small temperature difference. No ecf – correct answer only. ✓5 Correct answer Consistent with 4th mark and only in the form shown ie no double or single solidus/oblique lines. Only penalise the kelvin unit if it has an obvious loop at the top – allow if simply small.	5	AO2-1d-3 Math2-4
01.2	(Use of volume = $\frac{m}{\rho}$) nitrogen gas = $\frac{0.050}{3.8}$ = 0.013 (m^3) ✓1 {if both given both must be correct} nitrogen liquid = $\frac{0.050}{810}$ = 0.000062 (m^3) OR a reference to the volume being negligible ✓2 Work done in expanding (= X = $p\Delta V$) = $1.0 \times 10^5 \times 0.013 = 1.3 \times 10^3$ (J) ✓3	✓1 Substitution or answer and can be seen without label or explanation. ✓2 Substitution or answer or words. ✓3 Evidence of ΔV or calculation introduced with 'work done =' is required for the mark. For an ecf the product must be shown in full with the substitution of the ecf being clear. ✓4 Allow ecf from 01.1 for this mark provided	4	AO1-1a-1 AO2-1f-1 AO3-1b-2 Math2-1

	which is less than 1.0×10^4 J/the energy to change state =Y (ie X<Y) ✓4	the statement is consistent with the figures. OR If the ecf comes from the 3rd mark above then the work done in expanding must be clearly labelled for the comparison or have units of J i.e it cannot be compared with a number that just happens to be on the page.		

Total			**9**	

Question	Answers	Additional Comments/Guidance	Mark	ID details
	It is the <u>sum/total</u> of the (kinetic and potential) energies of the particles/atoms/molecules (that move at random in the gas) ✓1	✓1 Cannot be an average or a rms energy. Nor a vague reference to an energy of or in the gas.		AO1-1a-

01.1	28 (°C) ✓		1	
01.2	The energy transferred reduces the number of nearest atomic neighbours OR allows atoms to move their centre of vibration OR breaks some of the (atomic) bonds OR crystalline to amorphous ✓ (owtte)	First alternative must not imply total loss of intermolecular forces or neighbours. A reference to 'breaking <u>the</u> bonds' implies all the bonds and does not gain the mark. No mark for saying bonds weaken. However these errors in discussing the bonds does not prevent a mark coming from another point Last alternative might be expressed as 'atoms change from fixed positions to them being able to slide around each other'. Ignore any references to changes in separation. An explanation that involves increasing the kinetic energy will lose the mark. So will any description that implies it becomes a gas.	1	
01.3	The (total or mean) kinetic energy remains constant. ✓ The (total or mean) potential energy increases. ✓		2	

01.4	The mean speed/mean kinetic energy increases ✓	Ignore references to larger separation (because it's not always true): collisions (as it is not a gas) or measures of randomness (which are usually too vague). Condone use of average for mean. Don't allow velocity instead of speed. During this time interval the atoms are all in the liquid form so no credit for references that indicate a change of state.	1	
01.5	Using both $\Delta Q = mc\Delta\theta$ **and** $\Delta Q = P\Delta t$ ✓ $\left(c = \frac{P\Delta t}{m\Delta\theta} = \frac{35 \times (14.8 - 11.2) \times 60}{0.25 \times (110 - 28)} = 369\right)$ c = 370 ✓ (allow 365–375) J kg^{-1} K^{-1} ✓ (or J kg^{-1} C^{-1})	First mark can be given by seeing the substitution which may have some errors for example not using exactly 28. These will be penalised in the second mark. Correct answer gains first two marks NB 400 J kg^{-1} K^{-1} shows candidate has wrongly made calculations for the solid. No mark for the unit if a solidus is used because of the uncertainty of whether the K is on the top or bottom line. (which is correct J / kg / K or J / kg K ?) However allow a prefix if kilojoules are used for example.	3	

Question	Answers	Additional comments/Guidelines	Mark	AO
01.6	(Using both $\Delta Q = ml$ and $\Delta Q = P\Delta t$) $l \left(= \frac{P\Delta t}{m}\right) = \frac{35 \times ((11.2-1.8) \times 60)}{0.25} = 79$ kJ kg^{-1} ✓ hence M = gallium ✓ (condone an ecf consistent with the calculation provided a comment is made if the value falls outside the range of the table)	The calculation yields1.3 kJ kg^{-1} if the 60 seconds is omitted. Interim stage heat supplied = 19.7 kJ A valid calculation must be shown to gain this second mark.	2	

Total			10

8

Question	Answers	Additional comments/Guidelines	Mark	AO

A

C

D

A

C

07	A (AO2)	150 K	

08	D (AO2)		pressure of the gas	internal energy of the gas

9	C	Charles's Law

8	B	doubling the volume at constant pressure

10	B	400 K

8	C	$16\ cm^3$	AO2

10	B	$\theta_1 - p_1\left(\frac{\theta_2 - \theta_1}{p_2 - p_1}\right)$	AO2

01.1	$n = 43.1$ ✓ (≥ 2 SF)	$n = \frac{105\times10^3\times1}{8.31\times(273+20.0)}$	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	Use of $m = \frac{\rho V}{nN_A}$ OR $m = \rho V$ OR use of $m_{\text{molecule}} = \frac{m_{\text{gas}}}{N_A}$ OR $N = nN_A$ OR $(c_{\text{rms}})^2 = \frac{3p}{\rho}$ seen in any form OR use of their mass with $pV = \frac{1}{3}Nm(c_{\text{rms}})^2$ OR use of $\frac{1}{2}m(c_{\text{rms}})^2 = \frac{3}{2}kT$ ✓1 Correct answer see table ✓2 Correct SF see table ✓3	Allow ecf for incorrect T and/or n in 1.1 Several approaches are possible $m = \frac{pV}{nN_A} = \frac{1.25\times1.00}{43.1\times6.02\times10^{23}} = 4.82\times10^{-26}$ (5.1×10^{-26} if 40 used) $c_{\text{rms}} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3\times1.38\times10^{-23}\times293}{4.82\times10^{-26}}} = 502$ OR $pV = \frac{1}{3}Nm(c_{\text{rms}})^2$ $p\frac{Nm}{\rho} = \frac{1}{3}Nm(c_{\text{rms}})^2$ $(c_{\text{rms}})^2 = \frac{3p}{\rho}\left(= \frac{3pV}{Nm} = \frac{3p\times1}{\rho}\right)$ $c_{\text{rms}} = \sqrt{\frac{3\times105\times10^3}{1.25}} = 502$	3	AO2

n	✓2 c_{rms} / m s^{-1}	✓3 SF
Without n	500 – 503	3 SF (501 – 503)
n more than 3SF	500 – 503	3 SF (501 – 503)
43.1	500 – 503	3 SF (501 – 503)
43	500 – 503	2 SF (500)
40 (no evidence of $n = 43$ in 1.1)	482 – 484 or 500	2 or 1 SF (480 or 500)
40 (evidence of $n = 43$ in 1.1)	482 – 484 or 500	1 SF (500)

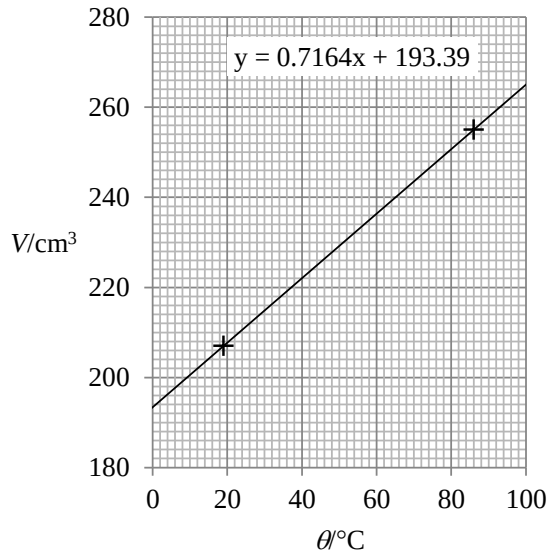
Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	$T = 4 \times 293$ or 4 times the starting temperature in K ✓ change in temperature = 879 (K) ✓ (correct answer gains both marks) **Alternative** $T = \frac{m(2c_{rms})^2}{3k}$ correctly calculated for their m, c_{rms} ✓ Their calculated $T - 293$ ✓ 7709	mp1 Using $\frac{1}{2}m(c_{rms})^2 = \frac{3}{2}kT$ so $(c_{rms})^2 \propto T$ $\frac{(c_{rms})^2}{293} = \frac{(2\times c_{rms})^2}{T}$ $T = 293 \times 4 = 1172$ K mp2 change in temperature = $1172 - 293 = 879$ K Allow answer that rounds to 880 (K) If no other marks awarded award max 1 when T is 4 times original and $\Delta\theta = 60$	2	AO2f

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	Max 2 from: ✓✓ • Calculation of mass of water condensed in one hour $1.25 \times 960 \times (0.0057 - 0.0037) = 2.4$ (kg) • use of their mass with $mc\Delta\theta$ (expect 4.5×10^4 (J)) • use of their mass with mL (expect $5.5(2) \times 10^6$ (J)) heat energy removed = 5.6×10^6 (J) ✓		3	2 × AO2.2f 1 × AO3.1a
Total			**9**	

Question	Answers	Additional comments/Guidelines	Mark	AO

03.1	**OR** Boyle's Law applies **OR** PV = constant; $_2$✓ any suggestion that pressure is constant **OR** the volume is constant **OR** the temperature changes **OR** the amount of air in the flask increases as flask is raised loses both marks	reject 'pressure released (in **9d**)' for $_2$✓ allow <u>mean</u> KE of molecules is the same accept $P \propto \frac{1}{V}$; allow nRT = constant; reject $PV = k$ (unless k = constant is also seen)	**2**
03.2	same (air) pressure $_1$✓ same mass of air $_2$✓ any suggestion that temperature is constant **OR** that volume is constant **OR** that pressure has changed **OR** the amount of air in the flask decreases as flask is moved from H to C loses both marks	for $_1$✓ and $_2$✓ accept constant/unchanged = same and condone 'assume same pressure/mass of gas' for $_2$✓accept same (number of) moles or same amount of gas no credit for stating 'volume increases as temperature increases' 'temperature is in equilibrium' is neutral	**2**

Question	Answers	Additional Comments/Guidelines	Mark
03.3	relevant quantity and instrument seen: volume(s) (of liquid) measured using a measuring cylinder **OR** graduated beaker $_1$✓ reject 'measuring beaker' and 'burette' eye level with the bottom of the meniscus (allow suitable sketch showing eye) $_2$✓ 'measure at eye level' **OR** 'eye level with graduation' **OR** 'eye perpendicular to graduation' are not enough to avoid parallax error $_3$✓ see alternative opposite; if both approaches are given record the mark to whichever scores most	alternative for $_1$✓mass (of liquid/flask) measured using a balance reject 'scales' and reject 'weigh/find weight/weigh the mass' for $_2$✓valid method to account for the mass of flask eg tare/zero balance (ECF 'scales') with (same) empty flask on balance and then measure mass of flask with liquid **OR** subtract mass of empty flask from mass of flask containing liquid; don't penalise 'weigh' twice **OR** ensure the balance is on a horizontal surface for $_3$✓find volume(s) using $V = \frac{m}{\rho}$; V must be subject	**3**
03.4	suitable vertical scale for their data points covering at least half the grid; false origin on the vertical scale correctly marked; vertical scale marked at sensible intervals, based around intervals of 1, 2, 4 or 5 etc; graduations no further than 2 major divisions apart $_1$✓ 19, 207 plotted to nearest ½ grid square $_2$✓ 86, 255 plotted to nearest ½ grid square $_3$✓	for $_1$✓ the two correct data points a suitable scale is 10 cm^3 for each major division an unmarked origin is be assumed to be (0, 0); if a broken scale symbol is not used and the V scale becomes non-linear, withhold the mark award $_{23}$✓ = 1 MAX for thick or poorly-marked points eg thicker than half a grid square; reject blobs, dots and circles	**3**
03.5	**continuous ruled** best-fit line of positive gradient through intersection of cross-hairs of their points ✓	apply same criteria for judging line quality as in **02.3**; don't penalise thick line if thick points are penalised in **03.4**	**1**

Question	Answers	Additional Comments/Guidelines	Mark
03.6	legitimate method to <u>calculate</u> horizontal intercept eg gradient calculated from ΔV divided by $\Delta\theta$ ie <u>numerical</u> evidence of 2 steps required; don't penalise read off errors or small steps reads (to within 1 grid square) **OR** uses a point on the line to calculate (with correct use of $y = mx + c$) the vertical intercept; sensible values are shown on the right $_1$✓ correct use of their vertical intercept and their gradient to calculate the horizontal intercept using $-1 \times$ vertical intercept divided by gradient $_2$✓ **OR** similar triangles, eg $\frac{255-207}{86-19} = \frac{207-0}{19-\theta}$ or similar seen $_1$✓ minimum $\Delta\theta = 86 - 19$ (= 67as in example above) $_2$✓ result in range $-260°C$ to $-285°C$ $_3$✓ withhold mark for missing sign; no credit for unsupported answer	 in $_1$✓ condone V changed to m^3 when calculating gradient and finding intercept values for a graph with a negative gradient allow credit for $_1$✓ only = 1 MAX no credit for non-linear graph = 0 MAX data which may be seen in working include $V = 193\ cm^3$, $\theta = 0\ °C$; $V = 265\ cm^3$, $\theta = 100\ °C$; $V = 207\ cm^3$, $\theta = 19\ °C$; $V = 255\ cm^3$, $\theta = 86°\ C$	**3**
Total			**14**

04.1	attempts two calculations that would lead to a conclusion $_1$✓ a reasoned judgement explaining why y not inversely proportional to M $_2$✓ **M / kg** | **y / mm** | **acceptable $M \times y$** | **min sf** 0.5 | 89(.0) | 44.5 / 45 | 2 1.0 | 82(.0) | 82(.0) 1.5 | 76(.0) | 114(.0) | 3 2.0 | 71(.0) | 142(.0) 2.5 | 66.5 | 166(.3) 3.0 | 62.5 | 187.5 / 188	for $_1$✓ the result of at least one calculation of $M \times y$ must be correct (see table) otherwise withhold both marks; allow use of y in m but reject POT error; allow use of correct read-offs from valid BFL; condone use of two rows of data to show that when M doubles, y does not halve; award of $_2$✓ is contingent on valid $_1$✓ for $_2$✓ two correct calculations of $M \times y$; see table for min sf in result for $M \times y$ OR one correct calculation of $M \times y$ and an appropriate reverse-working calculation; statement rejecting inverse-proportion supported by suitable quantitative reasoning, eg calculation of the percentage difference between the results of their calculations; condone ‘large’ / ‘significant differences’ (between calculation results) / use of >> etc; reject ‘values are different’ / ‘not same’ / ‘not constant’ / ‘not close enough’ use of > etc; reasoning must be based on the data points, eg reject ‘best-fit line crosses y-axis’	1 1	1 x AO1 1 x AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	(as **P** moves down trapped air expands so) pressure (of trapped air) is reduced $_1$✓ pressure less than atmospheric pressure $_2$✓ this leads to an upwards force balancing the weight of **P** OR pressure difference across **P** × area of piston = weight of piston $_3$✓ why **P** falls when the valve is opened $_4$✓	must address situation in Figure 11 for $_1$✓ allow 'pressure reaches lower value' reject 'pressure is low' for $_2$✓ allow 'there is a pressure difference across **P** ' / 'external pressure > pressure of trapped air' award $_1$✓$_2$✓ for pressure of air reduced below atmospheric'' for $_3$✓ allow any **correct** idea about how two opposing forces act to produce equilibrium; 'no resultant force' is not enough reject 'weight = gravity' / ideas about 'suction' / equating pressure with force for $_4$✓ idea of external and internal pressures equalising; reject 'pressure released / returns to normal'	Max 3	3 x AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
04.3	smooth curve of decreasing negative gradient through all 6 points $_1$✓ line with negative gradient extrapolated (backwards) to $M \leq -0.35$ $_2$✓ records y corresponding to $M = -0.7$ $_3$✓ y in range 108 mm to 116 mm $_4$✓ OR for incorrect M (3 MAX) smooth curve etc $_1$✓ line with negative gradient extrapolated (backwards) to $M \leq -0.35$ $_2$✓ records y corresponding to $M = -0.35$; y in range 101 mm to 107 mm $_{34}$✓ OR for linear graph (2 MAX) ruled line with negative gradient extrapolated (backwards) to $M \leq -0.35$ $_{12}$✓ records y corresponding to $M = -0.7$; y in range 97 mm to 103 mm $_{34}$✓	for $_1$✓ must be a single continuous line for $M \geq 0.5$ that overlaps with all 6 **+**; condone poorly-marked line (note that poor line quality may only be penalised in **Question 03.4**) for $_2$✓ condone linear extension of curve with negative gradient for $M < +0.5$ for $_3$✓ curve must extend to where read off is being made award of $_4$✓ is contingent on valid $_3$✓ for $_4$✓ answers that round to nearest mm are acceptable	1 1 1 1	1 × AO1 2 × AO2 1 × AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
04.4	correctly identifies error $_1$✓	for $_1$✓ reading has been taken at / from the top of the **meniscus** / top of coloured oil / top of liquid OR should have taken / did not take reading from the bottom / lowest point of the **meniscus** / lowest point on **surface** of coloured oil OR '(student thinks) sub-divisions are $0.1\ cm^3$ and not (as question states) $0.2\ cm^3$' reject 'should have read from bottom of coloured oil' / 'failed to read meniscus properly' / 'read at the top of the air' / 'has read divisions incorrectly' or wtte	1	1 x AO1 1 x AO2
	correct reading is 35.8 $_2$✓	for $_2$✓ CAO	1	

Question	Answers	Additional comments/Guidelines	Mark	AO
04.5	gradient from $\Delta \log(V / \text{cm}^3)$ divided by $\Delta \log(p / \text{MPa})$;	don't insist on large steps / read off accuracy	1	1 x AO2
	evaluated to ≥ 3 sf result between -1.05 and -1.01 $_1$✓	accept result that rounds to 3sf between -1.05 and -1.01; sign essential		2 x AO3
	relevant algebra enabling comparison with $y = mx + c$ $_2$✓	for $_2$✓ (eg Boyle's Law written as)	1	
		$\log V = -\log p +$ constant		
		condone variation based on Ideal Gas Law in which case must establish that $(nR)T$ / $(Nk)T$ is constant (which then implies Boyle's Law) (recognisable data book symbols only)		
		OR		
		(Figure 13 shows)		
		$\log V$ = gradient × $\log p$ + constant;		
		accept (log) k, (log) c etc as recognisable symbols for the constant;		
		condone (any) numerical value given for the constant eg $10^{1.685}$;		
		accept m as recognisable symbol for the gradient		
	why gradient ≈ $\underline{-1}$ confirms Boyle's Law $_3$✓	for $_3$✓ allow gradient is / equals / should be -1	1	
		if $_2$✓ not given accept 'gradient ≈ $\underline{-1}$ demonstrates inverse proportion or wtte		

Question	Answers	Additional comments/Guidelines	Mark	AO
04.6		V_2 in range 10.5 to 11.5 (cm^3) earns $_1$✓$_2$✓$_3$✓		1 x AO2
	reads off and attempts to make use of log p_1 AND log V_1 for any point on the line $_1$✓	for $_1$✓ check log V_1 is within half a grid square of correct position for their log p_1 or vice-versa; 'make use of' excludes use in a gradient calculation	1	2 x AO3
	applies a workable method $_2$✓	for $_2$✓ creditworthy examples are a calculation of the intercept in **Figure 13** eg log V + log p = 0.585 OR use of gradient = $\frac{\Delta \log V}{\Delta \log p}$ (eg similar triangles idea) OR a calculation of $p \times V$ (by any means) OR use of log $V = -1 \times$ log 0.34 + their intercept no credit for claiming 1.685 (or 1.170) are intercepts; this cannot earn $_2$✓	1	
	further manipulation to determine unknown V_2 $_3$✓	for $_3$✓ accept result that rounds to 10.5 or 11.5; accept 2sf 11 (cm^3)	1	

Question	Answers	Additional comments/Guidelines	Mark	AO
04.7	temperature (of air) $_1$✓	for $_1$✓ accept ‘mean ke of air molecules’ (or wtte) / ‘vapour pressure of air’ ‘keep mass of air constant’ is neutral (this information is given below **Figure 13**)	1	1 x AO1 1 x AO2
	change the pressure of the gas slowly or wtte OR wait (after a change) between taking readings / until the oil level stabilises $_2$✓	award of $_2$✓ is contingent on valid $_1$✓ for $_2$✓ condone ‘keep lab temperature constant’; ‘use a water bath’ is neutral reject ‘do the experiment slowly’ / ‘do not heat the apparatus’ / ‘keep windows closed’ etc	1	
Total			**19**	

D

C

B

C

C

D

C

8	B	u

10	A	$4.3\ \text{m s}^{-1}$

01.1	total kinetic energy of the particles ✓	Condone “molecules” or “atoms” for “particles” Kinetic energy will be taken to mean total kinetic energy but do not accept use of mean kinetic energy or reference to kinetic energy of a single particle. Do not allow any reference that implies there is potential energy or any other energy added to the kinetic energy.	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	(the speed before and after a collision is the same in the elastic collision) $\Delta p\ (= p_f - p_i) = -mc - mc = -2mc$ ✓	Use of subscripts i and f or before and after do not need explanation. Δ will be assumed to mean (final – initial). Either the initial momentum or the final momentum must be described clearly enough to justify the negative final answer	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	Time between colliding with **W** $(=\frac{s}{c}) = \frac{2l}{c}$ $f = \frac{1}{T}\left(=\frac{c}{2l}\right)$ ✓	Must show evidence of a time calculation using distance and speed Do not allow any attempted use of $v = f\lambda$	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	Reference to a Newton law **AND** $P = \frac{F}{A}$ ✓1 $P\left(= \frac{F}{A} = \frac{mc^2}{l} \times \frac{1}{l^2}\right) = \frac{mc^2}{V}$ ✓2	The reference to Newton law could be a simple link between Newton's name and an equation.	2	AO1 ×2
Total			**5**	

8

Question	Answers	Additional comments/Guidelines	Mark	AO

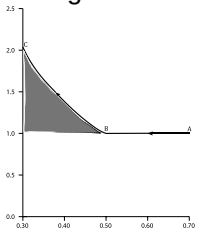
01.1	The volume/size of the gas molecules is negligible/point mass or point molecule Or molecules are point masses Or small compared to the volume/size occupied by of the gas ✓ owtte	No mark for all the same size or spherical. Without the comparison the word used must suggest extremely small. Zero volume is wrong.	1

01.2	(using $N = PV/kT$) $N = (1.0 \times 10^5 \times 0.70 \times 10^{-3}/(1.38 \times 10^{-23} \times 300)$ ✓ (first mark is for converting the temperature to kelvin and using it in a valid equation) $N = 1.7 \times 10^{22}$ molecules ✓ (1.69×10^{22} molecules) Alternatively (using $n = PV/RT$) $n = (1.0 \times 10^5 \times 0.70 \times 10^{-3} / 8.31 \times 300) = 0.028$ mol ✓ (first mark is for converting the temperature to kelvin and using it in a valid equation) N (= $n N_A = 0.028 \times 6.02 \times 10^{23}$) = 1.7×10^{22} molecules ✓ (1.69×10^{22} molecules)	Correct answer scores both marks. Power of 10 issue = AE Temperature conversion = PE	2

01.3	(using $T_B = T_A V_B / V_A$) $T_B = 300 \times 0.50 / 0.70 = 214$ (K) ✓ Change in temperature (= 214 – 300) = (–) 86 (K)✓ Or T_B (= PV/Nk) = $1.0 \times 10^5 \times 0.50 \times 10^{-3}/(1.38 \times 10^{-23} \times 1.69 \times 10^{22})$ = 214 (K) ✓ Change in temperature (= 214 – 300) = (–) 86 (K)✓ (± 1 K) Or T_B = (PV/nR) = $1.0 \times 10^5 \times 0.50 \times 10^{-3}$ /(0.028 × 8.31) = 215 (K) ✓	Correct answer scores both marks. Let the last mark stand-alone provided an attempt at calculating T_B is made. Also allow working in Celsius for this last stand-alone mark.	2

	Change in temperature (= 215 – 300) = (–) 85 (K)✓		

Question	Answers	Additional Comments/Guidelines	Mark
01.4	An appropriate calculation might be: (If the temperature remained constant $P_C = P_B V_B / V_C$) $P_C = 1.0 \times 10^5 \times 0.50 \times 10^{-3} / 0.30 \times 10^{-3} = 1.7 \times 10^5$ (Pa) ✓ (but the pressure at C is higher than this so) the temperature at C is different / higher / not constant ✓ Or (If the temperature remained constant $P_C V_C$ would equal $P_B V_B$) $P_B V_B = 1.0 \times 10^5 \times 0.50 \times 10^{-3} = 50$ $P_C V_C = 2.05 \times 10^5 \times 0.30 \times 10^{-3} = 61$ ✓ (*P V* is not equal) the temperature at C is different / higher / not constant ✓ Or a full calculation can be given using *P V* / *T* = constant. $P_B V_B / T_B = 1.0 \times 10^5 \times 0.5 \times 10^{-3} / 214 = (0.234\ J\ K^{-1})$ $T_C = P_C V_C$ / constant $= 2.05 \times 10^5 \times 0.30 \times 10^{-3} / 0.234$ $T_C = 263$ K ✓ the temperature at C is different / higher / not constant ✓	On its own higher temperature scores 0. **Additionally there must be a reference to a correct calculation to obtain the last mark.** The question only requires the candidate to spot a change. The two marks are for each side of a comparison. Complete figures are not always required. For example in the last alternative the common factor 10^5 could be missing. 2nd alternative may come from a ratio. Depending on the sig figs used in the substitution of data the temperature has a range 256 – 270 K *PV* = *NkT* may be used as another alternative. On a few occasions the full paper may be required to view.	2

Question	Answers	Additional Comments/Guidelines	Mark
01.5	work done on gas from **A** to **B** (using $W = P\Delta V$ or W = area under the graph = $1.0 \times (0.70 - 0.50) \times 10^{-3}$) = 20 (J) ✓ giving a reference to the work done being the area under the graph ✓ The third mark can be obtained in the following ways: calculating the area indicated corresponds to the <u>additional work</u> done on the gas from **B** to **C**  (166 mm^2 where 1 mm^2 = 0.05 J) = 8.3 J √ (allow 8.0 – 10.0 J) Or The total work done (566 mm^2 where 1 mm^2 = 0.05 J) = 28.3 (J) ✓ (allow 28.0 – 30.0 J)	This second mark can be obtained from an attempt at an area calculation that involves the curved section of the graph. NB '<u>additional</u> work' must be quoted to give mark for 8 – 10 J. This 3rd mark is for a correct evaluation and not for details of the process.	3
Total			**10**

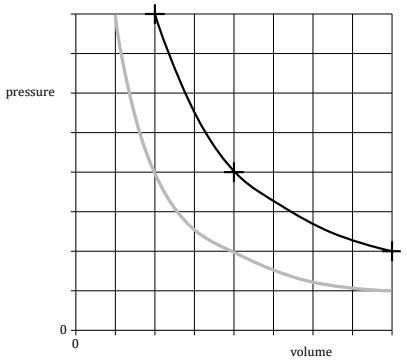
Question	Answers	Additional Comments/Guidelines	Mark

02.1	Any two from ✓✓ • Volume of molecules/particles is negligible/small compared to the volume of the container • Collision time is negligible/small compared to the time between collisions • Collisions are elastic or kinetic energy is conserved • There are negligible/no forces between molecules/particles except during collisions	Reference to the volume occupied by the gas must be clear for the first point. So 'volume of gas' is not enough. Condone missing reference to "except during collisions" in bullet 4. Condone "Newtonian mechanics apply"	2	2 x AO1 3.6.2.3

Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	There is a change in velocity/momentum for the molecules (at the wall) because the direction has changed ✓1 Relates MP1 to Newton I OR II ✓2 (Uses Newton III to) link the force on the wall and the force on the molecule ✓3	The essence of the Newton law must be given in the context of the gas. Just quoting a Newton law is not enough for a mark. Do not accept "rate of change of momentum" in MP1. Condone "bounces from wall" for "changes direction". Collision is not a change in direction. Accept reference to changing velocity/momentum/direction in MP2.	3	3 x AO2 3.6.2.3

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	Use of $E_k = \frac{3}{2}kT$ to find a temperature OR Using $pV = \frac{1}{3}Nm(c_{rms})^2$ with $E_k = \frac{1}{2}m(c_{rms})^2$ to find N ✓1 Correct substitution into $PV = nRT$ to find n OR Correct substitution into $N = \frac{3}{2}\frac{PV}{E_k}$ to find N (= 1.7 x10^{25})✓2	✓1 $T = \frac{2\times 6.7\times10^{-21}}{3\times 1.38\times10^{-23}} = 324\ \text{K}$ ✓2 for use of the equation. $n = \left(\frac{PV}{RT} = \frac{220\times10^3\times0.35}{8.31\times324}\right)$ or $N = \frac{3}{2}\times\frac{220\times10^3\times0.35}{6.7\times10^{-21}}$	3	1 x AO1 2 x AO2 3.6.2.2 3.6.2.3

	amount of gas = 29 (mol) ✓3 (28.6 mol)	✓3 no ecf, correct answer only If no other marks are awarded, award one mark: for an unsupported final answer of 1.7 x 10^{25} which is the number of molecules. OR for converting a number of molecules into moles using their $n = \frac{N}{N_A}$		

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	Drawn graph with concave shape always above existing graph passing through at least one of the data points. (data points are shown as crosses on the graph) ✓ Passing through coordinates (2,8), (4,4) and (8,2) ✓ (coordinates refer to cm intervals on the graph)	Drawn line must be ± 1 small square (2 mm) of a data point to count.  Condone a poor quality line.	2	2 x AO2 3.6.2.2
Total			**10**	

Question	Answers	Additional comments/Guidelines	Mark	AO

03.1	(If not in a vacuum) gas atoms will collide with air atoms, changing their direction or speed distribution. ✓	There must be some indication of a change of the oven gas molecules associated with collisions If temperature change is mentioned this must be related to speed distribution for the mark	1	AO1.1a ×1

Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	Finds time taken for one rev AND/OR time for 1/8 rev ✓ (Uses speed = distance/time to get) $= 0.500 / 1.04 \times 10^{-3} = 480\ \text{m s}^{-1}$ ✓ (so about $500\ \text{m s}^{-1}$)	1 rev in 1/120 s or 0.00833 s Time for 45º or 1/8 rev = 1.04×10^{-3} s Must have 2 or more sf answer but $500\ \text{m s}^{-1}$ is acceptable as a final answer provided the calculated time for 45º or 1/8 rev is shown and rounded down to 2 sf	2	AO2.1h ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	Mass of one atom = $m = 0.209/N_A = 3.47 \times 10^{-25}$ kg ✓$_1$ Substitutes m and answer **03.2** in $\frac{1}{2}m(c_{rms})^2 = \frac{3}{2}kT$ and rearranges ✓$_2$ $T = 1930$ K ✓$_3$	✓$_1$ May be seen in the substitution of the equation that follows ✓$_2$ $T = \frac{m}{3k}$(answer **03.2**)^2 ✓$_3$ Accept 2095 K or 2100 K if $500\ \text{m s}^{-1}$ used A correct answer also gains the second mark	3	AO1.1b ×1 AO2.1c ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	(Pressure is due to collisions of atoms with oven walls) With fewer atoms fewer collisions <u>per second</u> ✓1a but average momentum change per collision stays the same or therefore the total momentum change per second falls (so pressure drops) ✓2a OR Reference to $pV = \frac{1}{3}Nm(c_{rms})^2$ ✓1b c_{rms} is constant as *T* is constant hence $p \propto N$ (so pressure drops) ✓2b	✓1a There must be a reference to frequency or rate of collision ✓1b The equation may be in any equivalent kinetic theory form *pV=nRT* is not acceptable unless a connection is made between *T* and c_{rms}	2	AO1.1b ×1 AO2.1c ×1

Question	Answers	Additional comments/Guidelines	Mark	AO
03.5	$(pV = nRT)$ leaked $n = \frac{V((p_1 - p_2)}{RT}$ ✓ $= 8.42 \times 10^{-3}$ mol	ecf for T from **03.3**	1	AO2.1h ×1

Question	Answers	Additional comments/Guidelines	Mark	AO
03.6	At higher temp atoms will be faster (so drum will not have turned as far) ✓1a Darkest area will be closer to A ✓2a	✓1 Accept drawing but allow any degree of maximum darkness. The drawing may be flat or curved.  Allow more atoms will pass through S as it passes the oven, for the first mark making the dark patch darker, for the second mark. This must be linked to the more atoms	2	AO3.1a ×2
Total			11	

Question	Answers	Additional comments/Guidelines	Mark	AO

02.1	There is a range of speeds / kinetic energies ✓ Idea of no preferred direction ✓	Any suggestion that particles do not follow Newton's laws, are not deterministic, or the motion is unpredictable, is incorrect and restricts to **MAX 1.** Ignore references to Brownian motion and collisions. Allow velocity for speed in MP1. A reference to average speed is not enough for MP1. Must express the idea that all directions are equally likely not just that there is a range of directions. Allow $\overline{v}_x = \overline{v}_y = \overline{v}_z$ or similar for MP2	2	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
02.2	Any **two** from: ✓✓ • particle volume << gas volume / particle volume is negligible / point masses • time for collisions << time between collisions / collisions are instantaneous • no non-contact / intermolecular forces between the particles • all collisions (between particles / between particles and wall) are elastic • the particles follow Newton's laws / have no wave behaviour	Mark using list principle Particles are (very) small is insufficient Time for collisions is (very) short/small is insufficient Ignore (as included in assumption given in **02.1**): • there is no preferred direction • there is a range of speeds	2	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
02.3	**Any two from** ✓✓ • greater **mean** speed / c_{rms} / **mean** kinetic energy • (mean) change in momentum / Δmv (per collision) increases • more frequent collisions (with walls, for the same volume) • force increases because force is the rate of change of momentum / $F = \frac{\Delta(mv)}{(\Delta)t}$ Larger volume increases the (surface) area **and** pressure $= \frac{\text{force}}{\text{area}}$ (if the force increases so must the area to keep pressure the same) **OR** Larger volume increases the (mean) time between collisions or decreases the number of collisions per second / frequency of collisions ✓ (decreasing the total rate of change of momentum and hence force)	Ignore reference to equations of state. Do **not** allow greater mean velocity in bullet point 1. Other marks can be awarded. Ignore references to particles colliding with each other. **Alternative route** (all marks must come from same route) (Increase in temperature means) c_{rms} increases ✓ Use of $pV = \frac{1}{3}Nm(c_{rms})^2$ to justify increase of V ✓ p N and m named and stated as constant ✓	3	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
02.4	$\Delta E_k \left(= \frac{3}{2}k\Delta T = \frac{3}{2} \times 1.38 \times 10^{-23} \times (77-27) \right) = 1.0(35) \times 10^{-21}$ (J) ✓		1	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
02.5	Calculation of number N of water molecules in $1\ \text{kg}$ **or** use of $\frac{3}{2}kT$ **or** use of $\frac{3}{2}RT$ for their ΔT ✓	$N = \frac{1}{3.0\times10^{-26}}$ Allow $N = \frac{N_A}{0.018}$ Allow MP1 for **quoting** their answer to **02.4** if $\Delta\theta = 50\ \text{K}$ in MP2.	3	AO3
	Use of $mc\Delta\theta$ for their $\Delta\theta$ ✓	Allow for MP2: $c = \frac{3}{2}k\Delta T \times N = \frac{3}{2}\times1.38\times10^{-23}\times1\times$ their N **Max 1** when different ΔT and $\Delta\theta$ used for MP1 and MP2.		
	Valid comparison of quantities leading to no ✓	e.g. $c = 690\ (\text{J kg}^{-1}\ \text{K}^{-1}) \neq 1400$ so no, water vapour does not behave as an ideal gas e.g. for change in temperature of **50 K**: $Q = 2.1\times10^{-21}\ (\text{J})$ and $\Delta E_k = 1.0(35)\times10^{-21}(\text{J})$ Condone comparison involving 1 sf **Alternative method** $mc\Delta\theta = \frac{3}{2}k\Delta T$ ✓ $c = \left(\frac{3k}{2m} =\right)\frac{3\times1.38\times10^{-23}}{2\times3.0\times10^{-26}}$ ✓ Comparison of quantities leading to no ✓		
Total			**11**	

Question	Answers	Additional comments/Guidance	Mark	AO

02.1	particles/atoms/molecules (that move at random in the gas) ✓1 For reference to kinetic energy of the gas or molecules ✓2	✓2 This is independent of the first mark provided energy of the gas is given in some form. So here an average kinetic energy would be acceptable.	2	2

02.2	(Using) the gas laws it is the temperature at which the volume/pressure of a gas extrapolates to zero OR (Using $pV = nRT$ or $pV = NRT$) it is the temperature when pV or V or p is zero OR Plotting data of volume (or pressure) against temperature the plot extrapolates and crosses the temperature axis at absolute	✓1first Condone 'becomes/is zero' or phrases like 'said to be zero' or 'thought to be zero'. ✓1second Just quoting Charles' law or the Pressure law is not enough. ✓1third Allow the information in the form of a sketch.	2	AO1-1a-2

	(whereas) using the kinetic energy it is the temperature at which the (random) motion stops or can be extrapolated to stop or the kinetic energy (of the particles) is zero. ✓2	✓2 The zero must be very explicit e.g. not just very very small. Allow reference to zero point energy/residual kinetic energy at 0 K/uncertainty at 0 K		

Question	Answers	Additional Comments/Guidance	Mark	ID details
02.3	Mass of argon atom = $\frac{\text{molar mass}}{N_A}$ $= \frac{4.0\times10^{-2}}{N_A} = \frac{4.0\times10^{-2}}{6.02\times10^{23}} = 6.6(4)\times10^{-26}$ (kg) ✓1 $c_{rms} = \left(\frac{3kT}{m}\right)^{1/2}$ $= \left(\frac{3\times1.38\times10^{-23}\times310}{6.64\times10^{-26}}\right)^{1/2}$ ✓2 {*k* can be in form of a symbol} = 440 (m s^{-1}) ✓3 Alternative 1 $\frac{m(c_{rms})^2}{2}$ or $(E_k)_{average} = \left(\frac{3kT}{2}\right) = \frac{3RT}{2N_A}$ ✓1Alt1 $c_{rms} = \left(\frac{3RT}{mN_A}\right)^{1/2} = \left(\frac{3\times8.31\times310}{4.0\times10^{-2}}\right)^{1/2}$ ✓2Alt1 {*R* can be in form of a symbol} = 440 (m s^{-1}) ✓3Alt1	✓1 Substitution of the molar mass or the answer gains the mark. Also the numbers may be seen in the equation of the second mark. ✓2 Give a mark for this rearrangement and substitution even if the mass is incorrect. c_{rms} must be the only unknown in the equation, data and constants to be shown. ✓3 Only allow a correct answer so no ecf from the second mark. A correct answer gains all three marks ✓1Alt1 The Mark is for introducing $\frac{R}{N_A}$ in the mean energy equation. ✓2Alt1 The mark is for the use of the molar mass. c_{rms} must be the only unknown in the equation, data and constants to be shown. ✓3Alt1 Only allow a correct answer so no ecf	3	AO1-1b-1 AO2-1f-2 Math2-3

	Alternative 2 $(E_k)_{average} = \frac{3kT}{2} = \frac{3 \times 1.38 \times 10^{-23} \times 310}{2} = 6.42 \times 10^{-21}$ (J) OR $(E_k)_{total} = (E_k)_{average} \times N_A = 6.42 \times 10^{-21} \times 6.02 \times 10^{23}$ $(E_k)_{total} = 3.86 \times 10^3$ (J) ✓1Alt2 $c_{rms} = \left(\frac{2 \times (their\ energy)}{\text{molar mass}}\right)^{1/2} = \left(\frac{2 \times (E_k)_{total}}{\text{molar mass}}\right)^{1/2}$ $= \left(\frac{2 \times 3.86 \times 10^3}{4.0 \times 10^{-2}}\right)^{1/2}$ ✓2Alt2 = 439 (m s^{-1}) ✓3Alt2	from the second mark. A correct answer gains all three marks {On most occasions answer 5.7×10^{-10} m s^{-1} yields 2 marks as the wrong mass has been used} ✓1Alt2 The mark can be given for evaluating either the average or the total kinetic energy. ✓2Alt2 Give a mark for this rearrangement and substitution even if the energy is incorrect. c_{rms} must be the only unknown in the equation, data and constants to be shown. ✓3Alt2 Only allow a correct answer so no ecf from the second mark. A correct answer gains all three marks {On most occasions answer 5.7×10^{-10} m s^{-1} yields 2 marks as the wrong mass has been used} Note the slightly different answers for the third mark which depends on the route taken.		

02.4	(In equilibrium at the same temperature) both gases have the same <u>mean or average</u> kinetic energy ✓	Allow 'they are the same' as a bold statement. However if this is not an opening statement following the question then 'mean or average' must be used.	1	AO2-1d-1 Math2-1

02.5	Particles/atoms/molecules collide with the piston/walls and change momentum ✓1 (The piston provides the) force = <u>rate of change</u> of momentum	✓1 Ignore any reference to particles colliding with each other.	3	AO1-1b-2 AO2-1b-1

	(The particles give a force on the piston producing a pressure) A relevant reference to pressure = force divided by/over area or *F*/*A* ✓3	✓3 Relevant = reference to Piston or arising from the particles. (ie where or what) If no mark is scored give a mark for *P* = *F*/*A* alone		

Question	Answers	Additional Comments/Guidance	Mark	ID details
02.6	**change** the volume could be increased **explanation** which increases the time between collisions OR results in less frequent collisions (with the piston/wall so reducing the rate of change of momentum) OR which increases the area of the piston/wall (and so reduces the pressure) **change** the temperature could be reduced **explanation** which reduces the momentum (change at the wall) OR (and) increases the time between collisions or reduces the frequency of collisions (reducing the rate of change of momentum) ✓✓✓	An explanation in terms of the gas laws is not acceptable. **3 marks** for 2 changes and 2 explanations **2 marks** for 2 changes and 1 explanation **1 mark** for 1 change with corresponding explanation OR 2 changes with no adequate explanation If a wrong change is given, eg. reduce the mass, then only one mark is available for one change with corresponding explanation.	3	AO2-1h-2 AO3-1a-1
Total			**14**	

Question	Answers	Additional Comments/Guidance	Mark	ID details
	the work done/energy required in bringing 1 kg/unit mass from	A test mass should not be taken to be a unit		AO1-1a-

C

B

D

B

13	D	Signals from the satellite can be sent to at any point on the Earth's surface during one orbit.

24	D	395 V

16	D	$\frac{}{2\pi m_e}$

21	A	0	AO2

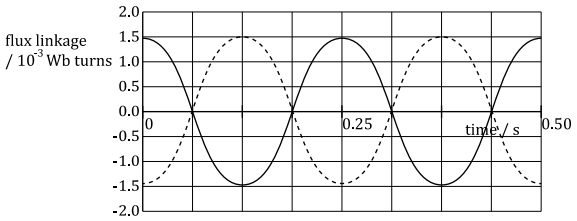
03.1	It is not possible as the force (due to the magnetic field) is perpendicular to the motion/direction of travel/velocity ✓ (it can only change the charged particle's direction or alternatively no work is done on the proton) Or No component of force in the direction of motion.	The main part being examined is the reference to the force being perpendicular to the motion.	1

03.2	$B Q v = m v^2 / r$ ✓ $t_{\text{semi-circle}}$ (= distance / speed) = $\pi r / v$ Or use of t_{circle} (= distance / speed) = $2 \pi r / v$ ✓(this mark can only be awarded if it follows an attempt to answer the first mark) combining gives ($t_{\text{circle}} = 2\pi m / B Q$ so) $t_{\text{semi-circle}} = \pi m / B Q$ (which does not contain r / is independent of r) ✓	Accept 'e' if used instead of 'Q' Alternatives can be given for the first two marks. 1st needs a centripetal force term. 2nd is a circular motion expression to enable r to be removed.	3

03.3	(rearranging first equation in 03. 2 or from data booklet $v = B Q r / m$) $v = 0.44 \times 1.6 \times 10^{-19} \times 0.55 / 1.67 \times 10^{-27}$ ✓ $v = 2.3 \times 10^{7}$ (m s^{-1}) ✓	Correct answer scores both marks.	2

Total			**6**

Question	Answers	Additional Comments/Guidelines	Mark
	(moderator) - the neutron undergoes an elastic collision/bounces off	Must have the idea that the neutron slow because	

05.1	AB 2.5 x 10 x 3.0 x 10 N = 120 (turns) ✓2	✓2 A correct answer gains both marks. If no mark is awarded a single mark can be given for $\Phi = BAN\cos 30^o$ being used to find N =139.	2	1 AO2-1f-1 Math2-1
05.2	$\Phi\left(= \text{NAB}\cos\theta = 1.5 \times 10^{-3}\cos 30^o\right)$ Flux linkage = 1.3×10^{-3} (Wb turns) ✓		1	AO2-1f-1 Math2-1
05.3	$f = \frac{1}{T} = \frac{1}{0.25}$ = 4.0 (Hz) or ω = 25.1 or 8π (rad s^{-1}) ✓1 Peak emf (= $BAN\frac{2\pi}{T}$= $1.5 \times 10^{-3} \times \frac{2\pi}{0.25}$) = 0.038 (volt) ✓2 (0.0377 volt)	✓1 Condone using 1 sig fig for f but not ω or T. The mark can be gained from seeing f or ω or T given explicitly or from a substitution in the peak emf equation in the second mark. ✓2 A correct answer gains both marks.	2	AO1-1a-1 AO2-1h-1 Math2-2
05.4	 Either solid or dashed line gains mark ✓	The mark is dependent on the exact crossing of the time axis which has a tolerance of ± 1 small square. The vertical axis figures is not expected. Also ignore errors in height and the exact positions of the peaks. Only a rough sinusoidal shape is expected. A	1	AO3-1a-1 Math2-1

		triangular shape with very slightly rounded edges would be acceptable.		

Total			**6**

Question	Answers	Additional Comments/Guidance	Mark	ID details
	To increase the probability/chance of fission (when neutron collides with fissile material/ U-235)	Condone because thermal/slow moving neutrons are needed for fission to take place 'fuel' but not 'fuel rod' to be used in the		AO2-1a-

04.1	flux linkage) is such that it will (try) to oppose the change (of flux) that is producing it ✓ owtte	induced current as this is dependent on a circuit. Ignore reference to current if emf is given.	1	AO1

04.2	(The reading shows a dc) current flow which then becomes zero (when the magnet stops moving) ✓	The reading does not have to be steady. So reading increasing or pulsing up before falling to zero is okay. There should be no hint that the reading changes direction.	1	AO2
04.3	(The induced current produces) a north pole on the right hand side of the coil. ✓ which opposes the motion of the bar magnet **OR** and the two north poles repel each other **OR** to try to maintain the (small) magnetic field as the magnet approaches the coil (without this the magnet would increase the magnetic field beside the coil) ✓	The polarity of the coil may be shown on the diagram. The two marks are independent but the second mark does not stand completely alone as it has to be said in context. EG 'Two North poles repel' on its own will not gain a mark.	2	AO1 AO2
04.4	(Use of $\varepsilon = BlV$ as the straight leading edge of the coil is the only conductor that cuts the magnetic flux lines. Also using $v = s / t$) $t = Bls/\varepsilon$ ✓ (There must be some evidence of use for the mark but the mark can come from substituting numbers, eg $t = 0.38 \times 0.032 \times 0.032 / 2.9 \times 10^{-4}$) $t = 1.3(4)$ (s)✓ **OR** (Using $\varepsilon = (-)N\,\Delta\phi/\Delta t$ then $\Delta t = \Delta(BA)/\varepsilon$) $t = BA/\varepsilon$ ✓ (There must be some evidence of use for the mark but the	Useful numbers $BA = 3.89 \times 10^{-4}$ Although the first mark can come from substituting numbers the equation mark may be lost if it is obvious that the equation is not understood by the way substitutions are made (this does not include a simple AE slip). This loss of a mark is directed at the candidate who quotes several equations and happens to hit on the correct equation but fails to use it properly. Failure to square the side length is a PE. Answer only gains 2 marks.	2	AO2

	mark can come from substituting numbers, eg. $t = 0.38 \times .032^2 / 2.9 \times 10^{-4}$) t = 1.3(4) (s) ✓			

04.5	(using $\varepsilon = BAN\omega \sin \omega t$ which give a maximum value of $\varepsilon_{max} = BAN\omega$) ω (= ε_{max} / BAN) = $5.1 \times 10^{-3} / (0.38 \times (0.032)^2$ ✓ ω = 13(.1) (rad s^{-1}) ✓	Candidates who cannot maximise/remove sin ωt gain no marks. {may see $\omega = 5.1 \times 10^{-3} / 3.9 \times 10^{-4}$}	2	AO2

Total			**8**

Question	Answers	Additional Comments/Guidance	Mark	ID details
	γ radiation because it is very / the most penetrating **OR** γ radiation because it is penetrating enough to irradiate all sides of the instruments	The quoted radiation must be gamma only and not a mixture.		

05.1	Max 2 ✓ ✓ • $\omega = \frac{2\pi}{T} = \frac{2\pi}{27.3\times24\times60\times60} = 2.664 \times 10^{-6}$ (rad s^{-1}) or $v = \frac{2\pi r}{T} = \frac{2\pi\times4.489\times10^{8}}{27.3\times24\times60\times60} = 1196$ (m s^{-1}) Substitution or value • Idea (resultant) gravitational field strength is equal to centripetal acceleration e.g. $g_R = a$ or $g_R = r\omega^2$ or $g_R = \frac{v^2}{r}$ (= 3.19 × 10^{-3} m s^{-2}) • Idea that $g_M = g_R - g_E$ $1.21 \times 10^{-3} \geq 3$ SF from correct working ✓ (N kg^{-1})	MP1 may be part of MP2 Ignore PoT, rounding errors and minor copy errors for MP1 and MP2 A substitution into $T^2 = \frac{4\pi^2 r^3}{GM}$ or equivalent is not accepted for the first bullet. In the second bullet point do not allow g_m MP3 must follow from correct working	3	AO2f

Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	$r = \sqrt{\frac{GM}{g_M}} = \sqrt{\frac{6.67\times10^{-11}\times7.35\times10^{22}}{1.21\times10^{-3}}}$ ✓ 6.37×10^{7} (m) ✓	Allow ecf from **05.1** Allow 6.38×10^{7} or 6.39×10^{7} or 6.4×10^{7} (m)	2	AO2b

Question	Answers	Additional comments/Guidelines	Mark	AO
05.3	Idea that the force from the Moon is in the opposite direction to the force from the Earth ✓$_1$ **An expression of why S_2 can't orbit Earth at this ω and r without the moon.** Idea that the Earth's gravitational force is too great or that it causes an angular velocity that is too great (without the presence of the Moon) OR Application of the idea that orbital period decreases with radius ✓$_2$ **An expression of how the moon enables S_2 to orbit Earth with this ω and r.** Idea that the Moon and the Earth reduce the resultant or centripetal force (causes the angular speed of S_2 and the Moon to be the same) OR Effect of the moon's gravitational force or field is to reduce the (angular) speed or increase period ✓$_3$	✓$_1$ Allow gravitational field strength from the Moon is in the opposite direction to the gravitational field strength from the Earth. Condone balanced forces for ✓$_1$ but not ✓$_3$. ✓$_2$ Alternatives (Without the Moon's gravitational influence) • the force or gravitational field (strength) from the Earth is too large • the force or gravitational field is larger as it is closer to the Earth (than **S_1** or the moon) • the required centripetal force is smaller as it closer to the Earth (than **S_1** or the moon, at the same angular velocity) • satellite's angular velocity is greater than the Moon • satellite's period is less than the moons • satellite's angular velocity would be too large. ✓$_3$ The resultant/total centripetal force/centripetal acceleration/gravitational field strength is less (because of the Moon's presence and so orbits at the same angular velocity as the Moon). Reject the idea that the centripetal force on the moon and S_2 are the same. Do not credit arguments based around being closer to moon	3	AO2e
Total			**8**	

Question	Answers	Additional comments/Guidelines	Mark	AO

02.1	Relating the gravitational force to mass × acceleration with the acceleration being centripetal in any form ✓1 show the working leading to answer $\omega = \sqrt{\frac{GM}{(R+h)^3}}$ ✓2	✓1 $\frac{GMm}{r^2} = (ma) = \frac{mv^2}{r}$ or $mr\omega^2$ or $mv\omega$ and r can be replaced by $R + h$	2	3.7.2.4 AO2 1e ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	$\left(\omega = \sqrt{\frac{GM}{(R+h)^3}} = \sqrt{\frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{\left(2.02 \times 10^{7} + 6.37 \times 10^{6}\right)^3}}\right)$ $= 1.45 \times 10^{-4}$ (rad s^{-1}) ✓1 $T = \frac{2\pi}{\omega} = \frac{2\pi}{1.45 \times 10^{-4}} = 4.3(1) \times 10^{4}$ (s) ✓2	✓1 A full substitution in the equation can gain this mark even if ω is incorrectly calculated A final correct answer for T gains both marks	2	3.7.2.4 AO2 1b ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	Launch from **Z** with some speed or energy argument ✓1 At this position the satellite has the largest initial speed/kinetic energy from the Earth's rotation. ✓2	✓1 Condone ref. to equator rather than Z Consider answer Y only if extremely well explained in terms of different potentials and fuel use.	2	3.7.2.4 AO1 1b AO3 1b

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	gravitational potential energy $= (-)\frac{GMm}{r}$ OR $(-)\frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 1630}{2.66 \times 10^{7}}$ ✓1 gravitational potential energy = -2.44×10^{10} (J) ✓2	✓1 for the equation or substitution without the need for the negative sign only allow ecf for $r = 6.37 \times 10^{6}$ giving gpe = -1.02×10^{11}J ✓2 the minus is necessary for the mark Correct answer gains both marks	2	3.7.2.3 AO1 1b ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
02.5	In a higher orbit the linear speed is smaller using $v = \sqrt{\frac{GM}{r}}$ or $v \propto \frac{1}{\sqrt{r}}$ ✓1 Suitable justification of $v \propto \frac{1}{\sqrt{r}}$ ✓2	✓2 example $v = r\omega = r\sqrt{\frac{GM}{(R+h)^3}} = r\sqrt{\frac{GM}{(r)^3}} = \sqrt{\frac{GM}{r}}$ Or derivation from basics	2	3.7.2.4 AO2 1e ×2
Total			10	

Question	Answers	Additional comments/Guidelines	Mark	AO
		There must be some indication of a change of		

07.1	Heavy water **OR** Beryllium / Be **OR** (normal) Water ✓	Accept D_2O and H_2O	1	AO1

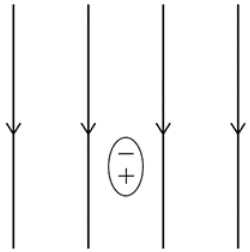
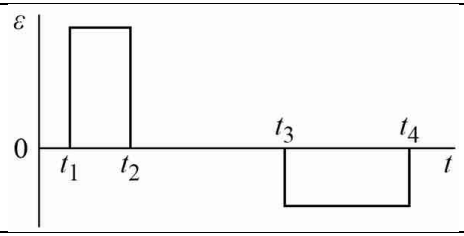
Question	Answers	Additional comments/Guidelines	Mark	AO
07.2	Any **two** points from: ✓✓ • U-235/Uranium fuel will (be more likely to) absorb the neutron • slow neutrons are less damaging **OR** cause less fatigue to the structure of the reactor/shielding/etc • slow neutrons (spend longer within the fissionable material and) increase the chance of causing fission • slowing neutrons transfers heat energy to the moderator (which can make heat easier to extract) all points OWTTE	Condone the answer: As an alternative to the first point Fission of U-236 is much more likely. Condone the answer: Absorption by U-238 is less likely.	2	AO1 AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
07.3	$\frac{\text{final kinetic energy}}{\text{initial kinetic energy}} = \left(\frac{\frac{1}{2}m_N v^2}{\frac{1}{2}m_N u^2}\right) = \left(\frac{v}{u}\right)^2 = 0.85^2 = 72\%$ ✓1 (Hence) proportion of kinetic energy lost = 28% ✓2	✓1 can be for any of the terms shown equating to the kinetic energy ratio. ✓2 can be an ecf but only for an arithmetic error.	2	AO2 AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
07.4	final kinetic energy $= (\frac{3}{2}kT =) 7.2 \times 10^{-21}$ (J) ✓1 initial kinetic energy $= (W = QV) = 1.6 \times 10^{-13}$ (J) ✓2 **OR** final kinetic energy $= 0.045$ (eV) ✓1 initial kinetic energy $= 1.0 \times 10^{6}$ (eV) ✓2 (Rearranging equation $y = \frac{\ln\left(\frac{E_0}{E_f}\right)}{b}$) $y = 23.(2)$ ✓3	✓1+2 Both marks must come from the same alternative route and have consistent units (which may not be seen). ✓1 Initial kinetic energy = $\frac{3}{2} \times 1.38 \times 10^{-23} \times 350 = 7.245 \times 10^{-21}$ J $= \frac{7.245 \times 10^{-21}}{1.60 \times 10^{-13}} = 0.045$ eV ✓2 Using the eV unit alternative the second mark cannot be given without an attempt at the first mark. The 1.0×10^{6} eV can be seen in a later substitution provided eV is used throughout. ✓3 $y = \frac{\ln\left(\frac{1.0 \times 10^{6}}{0.045}\right)}{0.73} = 23.2$ Condone answer 24 provided it is given as an integer.	3	AO2 ×3

Question	Answers	Additional comments/Guidelines	Mark	AO
07.5	Idea that the model/**Figure 15** shows that low nucleon number (and so low mass) gives a greater change/reduction in speed/KE (in a collision) ✓ Idea that fewer collisions needed (with a low mass number so moderator can be thinner) ✓	Condone the use of nuclear mass instead of mass number.	2	AO2 ×2
Total			**10**	

Question	Key	Answer
8	C	$60\ \text{kg}$
9	C	Charles's Law
10	C	10^{36}
11	B	$\left(\frac{M}{R}\right)^{\frac{1}{2}}$
12	B	$\sqrt{\frac{GM}{(R+h)}}$
13	D	Signals from the satellite can be sent to at any point on the Earth's surface during one orbit.
14	C	$\frac{2Q}{\pi\varepsilon_0 d^2}$
15	A	$20\ \mu\text{N}$
16	A	vertically down the plane.
17	C	the electric potential of the sphere.

18	A	
19	C	4.0×10^{-14} m
20	B	6.0×10^{-3} T
21	B	The radius of the path followed by an ion is different for each isotope.
22	A	
23	D	600 μV
24	D	395 V
25	D	gamma radiation from nuclides with a small decay constant.
26	C	The number of alpha particles deflected backwards is greater than the number that pass straight through the foil.
27	C	0.174 A

28	A	when a particular nucleus will decay.
29	B	β^-
30	C	16 MBq
31	B	1.0×10^8 W
32	D	6.1×10^8

32

02.1	Idea that the oscillations (of particles in the wave) are at right angles $_1$✓ to the direction of energy transfer $_2$✓	Allow 'oscillates' for 'oscillations'. Do not accept 'vibrations'. Allow 'displacement' for 'oscillations' Credit a correctly labelled diagram Do not allow a contradiction in $_1$✓ $_2$✓ is contingent on $_1$✓. Do not allow direction of (wave) motion/travel Treat any reference to polarisation as neutral. If no other mark given: award **max 1** when answer suggests that <u>amplitude</u> is perpendicular to the direction of energy transfer.	2	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
02.2	Idea that waves (from vibration generator and reflected wave) travel in opposite directions (along the wire) and superpose ✓	If a reflected wave is referred to, the presence of an incident wave can be assumed. Do not accept 'interfere' for 'superpose' Do not accept reference to 'phase (difference)'unless correct, ie a valid comment would be 'phase difference is time dependent'.	1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
02.3	Idea that particles in wave between $\mathbf{P_1}$ and $\mathbf{P_3}$ are in phase OR between $\mathbf{P_3}$ and $\mathbf{P_5}$ are in phase $_1$✓ Idea that particles between $\mathbf{P_1}$ and $\mathbf{P_3}$ are in antiphase with particles between $\mathbf{P_3}$ and $\mathbf{P_5}$ OR idea that $\mathbf{P_2}$ and $\mathbf{P_4}$ are in antiphase $_2$✓	If no other mark given: award **max 1** for 'P1 and P3 and P5 are nodes' **and** 'P2 and P4 are antinodes' provided that there is no reference to a phase relationship between the nodes. Reject: 'completely out of phase' or 'out of phase' for antiphase; allow 'π out of phase' or '180 degrees out of phase'.	2	AO2

<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidance</th><th>Mark</th><th>AO</th></tr>
<tr>
<td>02.4</td>
<td>Determines mass per unit length for either wire and answer seen on answer line $_1$✓

Determines frequency of first harmonic f_1 for one wire and value of W $_2$✓

Evidence of use of $5f_1$ to determine the frequency range
OR
evidence of required frequency ≤ 10 Hz $_3$✓

Comparison between the fifth-harmonic (frequency) and 50 Hz. $_4$✓

Wire B and $W = 1.0$ N $_5$✓</td>
<td>A $\mu = 6.60 \times 10^{-4}$ kg m^{-1}
B $\mu = 1.47 \times 10^{-3}$ kg m^{-1}
Allow incorrect values of mass per unit length to be carried forward from $_1$✓ to the rest of the answer except $_5$✓.
Expect to see values from:
<table>
<tr><th>W / N</th><th>A f_1 / Hz</th><th>A $5f_1$/Hz</th><th>B f_1 / Hz</th><th>B $5f_1$ / Hz</th></tr>
<tr><td>1.0</td><td>13.0</td><td>65.0</td><td>8.7</td><td>43.5</td></tr>
<tr><td>5.0</td><td>29.0</td><td>145</td><td>19.4</td><td>97.0</td></tr>
</table>
For $_4$✓, look for some idea that their selected fifth-harmonic frequency is the greatest that does not exceed 50 Hz or that first-harmonic is greatest that does not exceed 10 Hz.
Allow reference to ‘range’ for values of frequency.
$_4$✓ does not require a value for the fifth harmonic.

B can be identified by its mass or mass per unit length.
MP5 is a standalone mark and can be awarded without further evidence.</td>
<td>5</td>
<td>1 × AO1
4 × AO3</td>
</tr>
</table>

	Alternative $_2$✓ , $_3$✓ and $_4$✓ $_2$✓ Calculates a wavelength (or half wavelength) for 50 Hz and any one combination of wire and weight. $_3$✓ Evidence of maximum wavelength (or half wavelength) of fifth harmonic is 1.5/(5/2) or 0.6m (or 1.5/2 or 0.3 m). $_4$✓ compares between their combination wavelength and their fifth harmonic maximum wavelength.	For alternative $_2$✓ expect to see one from: **W / N** | **A** wavelength / **m** | **B** ***wavelength / m*** **1.0** | 0.78 | 0.52 **5.0** | 1.74 | 1.17 If alternative methods are used: $_2$✓ is for using the frequency formula, $_3$✓ is for a calculation that allows the comparison; $_4$✓ is for the comparison.		
Total			**10**	

Question	Answers	Additional comments/Guidance	Mark	AO

03.1	Arrow pointing up labelled magnetic force or F_M and arrow pointing down labelled electric force or F_E ✓	As location A is given in the question the base of the arrows do not need to sit exactly on A but arrows, if extended, should pass through A. Care – in some cases A can look like an arrow head.	1	AO1.1b
03.2	Statement that electric and magnetic forces balance OR $qE = Bqv$ OR $E = vB$ OR $1.5 \times 10^5 \times 0.12$ ✓ electric field strength = $E = 1.8 \times 10^4$ (V m^{-1}) ✓	A correct final answer gains both marks	2	AO1.1b AO2.1b M2
03.3	(centripetal force or $F_c = \frac{mv^2}{r}$, equals force due to the magnetic field or $F_m = Bqv$) $F = \frac{mv^2}{r} = Bqv$ and hence $r = \frac{mv}{Bq}$ ✓	Condone use of F to represent both F_c and F_m Allow an interchange between use of q and Q. Note F = is required	1	AO2.1c
03.4	$r \left(= \frac{mv}{Bq} = \frac{1.0\times10^{-26}\times1.5\times10^5}{0.12\times1.6\times10^{-19}}\right) = 0.078(1)$ ✓ distance (= $2r$) = 0.16 (m) ✓ (0.156 m)	ecf on second mark. second mark given only if mv/Bq used.in an calculation.	2	AO1.1b ×2 M2

Question	Answers	Additional comments/Guidelines	Mark	AO
03.5	(using an energy approach) work done by field equals gain in KE $qV = \frac{1}{2}mv^2$ ✓1a (so $v = \sqrt{\frac{2qV}{m}} = \left(\frac{2\times1.6\times10^{-19}\times\frac{6000}{2}}{1.2\times10^{-26}}\right)^{1/2}$) mark for using the $V/2$ either in an equation or via a substitution ✓2a $= 2.8(3) \times 10^5$ (m s^{-1}) ✓3a OR (using a force approach) Force on ion = $ma = qE$ ✓1b ($E = V/d$ $a = \frac{6000 \times 1.6 \times 10^{-19}}{1.2 \times 10^{-26} \times d} = 8.0 \times 10^{10}/d$ Using $v^2 = u^2 + 2as$) Mark for using equation for E and equation of motion either in symbols or via a substitution ✓2b $v = 2.8 \times 10^5$ (m s^{-1}) ✓3b	1a in words or equation which can be awarded even if the ion is not singly charged (candidates can wrongly think it has a charge of 3e) 2a for making use of half the pd ie 3000 V 3a Only allow ecf using 6000V giving $v = 4.0 \times 10^5$ m s^{-1}	3	AO1.1b AO2.1f ×2 M2 ×2

03.6	A smaller mass gives a smaller time interval ✓1 (The explanation can come from a Force or a Work done approach) The ions are given the same force ✓2a (so) smaller mass has higher acceleration and smaller time interval ✓3a OR Work done on ions or kinetic energy gained is the same ✓2b (so) smaller mass is given greater speed and smaller time interval ✓3b Award any two of the three marks	condone use of 'lighter' for 'smaller mass'	3 max 2	AO3.1b ×2

Total			**11**

Question	Answers	Additional comments/Guidelines	Mark	AO

03.1	Understanding that for coherence sources must have same frequency/wavelength AND constant phase difference. ✓ And that this achieved by both speakers being connected to same signal (generator). ✓		2	AO1a AO1b
03.2	The sound waves from the two speakers <u>superpose</u> (at a point) ✓ At A (and B) the two waves are in phase/ have zero phase difference (and a maximum is produced)✓ Moving away from A introduces a path difference/phase difference/waves are out of phase (and amplitude decreases) ✓ (Moving on towards B the waves move back in phase)	Do **not** accept 'interfere' or 'superimpose' for 'superpose' Accept for MP1 waves adding together/combine at a point (e.g. point A) for 'superpose'. Do not accept diagram. Award MP3 for formation of minimum/destructive interference due to (odd number of) half wavelength path difference/ π/ 180° phase difference/ antiphase.	3	2 × AO2.1g 1 × AO2.1c
03.3	Clear evidence of use of Pythagoras ✓ Correct calculation of either length PB or QB ✓ PB = $(2.25^2 + (0.95 - 0.3/2)^2)^{½} = 2.39$ m QB = $(2.25^2 + (0.95 + 0.3/2)^2)^{½} = 2.50$ m (Path difference =) QB – PB either numerically or algebraically✓ (= 0.11 (0.12) m)	If ws/D used to give 0.13 (m) reward with 1 mark	3	AO2.1h

Question	Answers	Additional comments/Guidelines	Mark	ID details
03.4	(Path difference = one wavelength) Use of speed = frequency × wavelength to give Speed = 2960 × 0.12 = 360 m s^{-1}✓	Working or equation must be seen. Condone use of 0.10 m or 0.11 m or 0.127m or 0.13 m 0.10 gives 300 (296) m s^{-1} 0.11 gives 330 (325.6) m s^{-1} 0.127 gives 376 m s^{-1} 0.13 gives 380 (385) m s^{-1}	1	AO2.1h
03.5	Wavelength (gradually) increases. ✓ So that path difference at C gets closer to one wavelength✓ (Amplitude of) sound will get larger/louder as waves move in phase (then smaller/quieter).✓	 Alternative for MP2: Separation of maxima (along line AB) increases✓ Alternatives for MP3: Maximum moves (from B) towards C so amplitude of sound gets larger/louder (then quieter). OR Maximum moves further along path/beyond C so amplitude of sound gets quieter✓	3	AO3.1a
Total			**12**	

Question	Answers	Additional comments/Guidelines	Mark	ID details
	Evidence of distance travelled = area under graph			

06.1	$a = \frac{v^2}{r} = \frac{(74.2\times10^3)^2}{4.22\times10^8}$ **OR** $13.0\ (\text{m s}^{-2})$ seen ✓ $g = \frac{GM}{r^2} = \frac{6.67\times10^{-11}\times1.90\times10^{27}}{(4.22\times10^8)^2}$ **OR** $0.712\ (\text{m s}^{-2})$ seen ✓ (for ballistic objects $ma = mg$ so $a = g$ and) $0.71\ \text{m s}^{-2} \neq 13\ \text{m s}^{-2}$ so the suggestion is not correct ✓	POT must be correct in MP1 and MP2 If no working, correct units must be seen somewhere for MP3 Allow calculation and comparison of centripetal force and weight if consistent mass used. Condone 1SF answers. Correct answers to calculations required for MP3. **Alternative** Evidence of $T^2 = \frac{4\pi^2 r^3}{GM}$ **or** $v^2 = \frac{GM}{r}$ **or** $\omega^2 = \frac{GM}{r^3}$ ✓ Calculation of any relevant quantity or combination of quantities e.g. $v = 17.3\ \text{km s}^{-1}$ ✓ Comparison of a relevant quantity to conclude that suggestion is not correct ✓	3	AO3

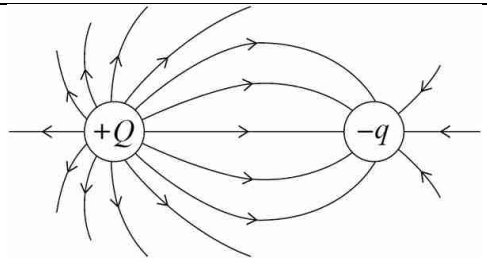
Question	Answers	Additional comments/Guidance	Mark	AO
06.2	Arrow starting at dot, pointing vertically down the page ✓	Condone a downwards vertical arrow where the line of action passes through the point. The line of action of the arrow must travel through the plasma torus near to the ion. Ignore arrows that are outside this area. When more than one arrow is drawn within the scoring area, then which arrow is B must be indicated unambiguously. Allow a line that looks vertical taking into account the 3D nature of the diagram.	1	AO2

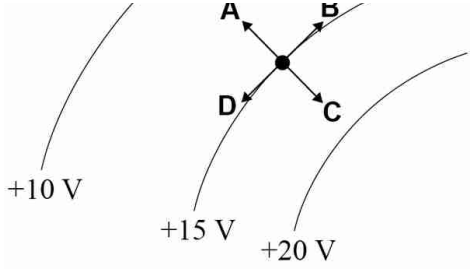
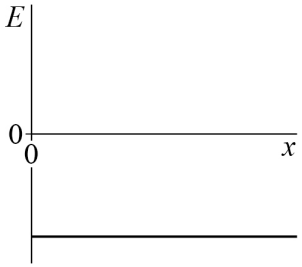
Question	Answers	Additional comments/Guidance	Mark	AO
06.3	$BQv = \frac{mv^2}{r}$ ✓ $B(= \frac{5.31\times10^{-26}\times74.2\times10^{3}}{3.2\times10^{-19}\times4.22\times10^{8}}) = 2.9\times10^{-11}$ ✓ $\text{kg A}^{-1}\text{ s}^{-2}$ ✓	Evidence for MP1 can come from substitution of candidates centripetal force as their magnetic force in second equation. Do **not** accept e for Q in MP1 when correct answer not seen. Allow ecf for use of their centripetal acceleration (expect 13.0) from question **06.1** e.g. $BQV = ma$ MP3 can be awarded with no working.	3	1 × AO1 2 × AO2

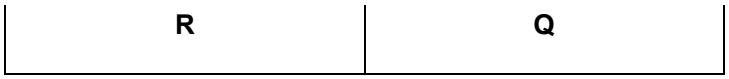
Question	Answers	Additional comments/Guidance	Mark	AO
06.4	Use of $F = ma$ / $a = \frac{v^2}{r}$ **OR** use of $F = QE$ ✓ $a\left(=\frac{QE}{m}\right)=\frac{3.2\times10^{-19}\times371\times10^{-6}}{5.31\times10^{-26}}$ ✓ 2.24×10^3 (m s^{-2}) ✓	Ignore PoT in MP1 and MP2 Condone in MP1 **and** MP2 the use of **one** of either • e for 3.2×10^{-19} C or • m_e / m_p for mass Allow use of $F = QE$ **and** $F = ma$ with same F	3	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
06.5	Any **two** from: ✓✓ • Correct charges for both ions • Use of $E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$ for either charge • use of Pythagoras with their E values **or** $E_T = \sqrt{E_Y^2 + 4E_Y^2}$ 8.0 or 8.1×10^{-6} (V m^{-1}) ✓	Do **not** condone POT error in MP1. $2 \times 1.60 \times 10^{-19} (= 3.2 \times 10^{-19})$ (C) **and** 1.60×10^{-19} (C) $E_X = 7.2 \times 10^{-6}$ V m^{-1} $E_Y = 3.6 \times 10^{-6}$ V m^{-1} Condone use of $+1$ or $+2$ for Q in bullet 2 Correct values seen for E_X and E_Y gains bullets 1 and 2 Allow appropriate trigonometry with 63° or 27° for bullet 3. Do **not** allow use of Pythagoras with distances.	3	AO2

Total			13

Question	Key	Answer	AO
7	B	$\frac{\sqrt{2}}{3}v$	AO2
8	C	$16\ \text{cm}^3$	AO2
9	C	is constant as the pressure increases.	AO2
10	B	$\theta_1 - p_1\left(\frac{\theta_2 - \theta_1}{p_2 - p_1}\right)$	AO2
11	B		AO2
12	A	$4F$	AO2
13	A	qV	AO1

14	C		AO1
15	D		AO2
16	D		AO1
17	C	600 μF	AO2
18	C	233 Ω	AO2

19	B		AO2
20	D	$4I$	AO2
21	A	0	AO2
22	D	6.25 μV	AO2
23	A	80%	AO2
24	A	34 kHz	AO2
25	D	64 cm	AO2
26	C	0.103 MeV	AO2
27	D	$^{123}_{53}\mathrm{I} + \mathrm{e}^- \rightarrow {}^{123}_{52}\mathrm{Te} + \nu_e$	AO1
28	C	4.7 MeV	AO2
29	A	to absorb neutrons released from fission	AO1
30	D	slow neutrons to thermal speeds.	AO1
31	D	**R** only	AO1

Total: 25 marks

03.1		for $_1$✓ and $_2$✓ allow ≥ 4 sf rounding to 3 sf in range	3	2 × AO2
	α in range with correct POT $_1$✓$_2$✓	for $_1$✓ α in range 4.45 to 4.57		1 × AO1
	α in range with incorrect OR missing POT $_1$✓	for $_1$✓ $_2$✓ α in range 4.45 to 4.57×10^{-3} allow $_{12}$✓ for α in range 4.39 to 4.63×10^{-3} OR allow $_{12}$✓ for 2 sf $\alpha = 4.5 \times 10^{-3}$		
	K^{-1} $_3$✓	for $_3$✓ condone $°K^{-1}$ OR $\frac{1}{K}$ OR $\frac{1}{{}^{o}K}$ do **not** accept $(°)C^{-1}$ do **not** accept k for K		

Question	Answers	Additional comments/Guidance	Mark	AO
03.2		allow valid work in 'wrong' answer space	2	AO1
	determines P using $V \times I$ in some form OR determines R using $\frac{V}{I}$ in some form $_1$✓	for $_1$✓ AND / OR $_2$✓ accept formulae in symbols or in words eg 'power = current × voltage'; accept 'voltmeter reading' for V / 'ammeter reading' for I; treat as neutral the idea of plotting an IV graph to find P and / or to find R		
	determines P using $V \times I$ AND R using $\frac{V}{I}$ in some form AND determines T using (their) R $_1$✓$_2$✓	for $_2$✓ allow 'use the equation with R'; any rearranged equation must be correct eg $T = \frac{R - R_0}{\alpha R_0} + T_0$; treat the following as neutral: (unqualified) 'use the equation' / 'use $T \propto R$ to determine T'/ 'use (extrapolate) **Figure 6**' / 'use **Figure 8**'		

<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidance</th><th>Mark</th><th>AO</th></tr>
<tr><td>03.3</td><td>2nd row of Table 2 P correct
AND
4th row of Table 2 P_2 correct $_1$✓

3rd row of Table 2:
P correct $\pm$ 0.2
AND
P_2 correct $\pm$ 0.2 $_2$✓

their P_1 = their P – their P_2
AND
all the data added to Table 2 is to 1 dp $_3$✓

<table>
<tr><th>T / K</th><th>P / W</th><th>P_1 / W</th><th>P_2 / W</th></tr>
<tr><td>960</td><td>3.7</td><td>1.2</td><td>2.5</td></tr>
<tr><td>1100</td><td>5.0</td><td>2.0</td><td>3.0</td></tr>
<tr><td>1370</td><td>8.8</td><td>4.8</td><td>4.0</td></tr>
<tr><td>1680</td><td>16.2</td><td>11.0</td><td>5.2</td></tr>
</table>
</td><td>only penalise dp in $_3$✓
for $_1$✓ (2nd row) P = 5.0 (W)
AND
(4th row) P_2 = 5.2 (W)

for $_2$✓ (3rd row) P = 8.6 to 9.0 (W)
AND
P_2 = 3.8 to 4.2 (W)

for $_3$✓ expect P_1 = 4.4 to 5.2 (W)</td><td>3</td><td>2 × AO2

1 × AO3</td></tr>
</table>

<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidelines</th><th>Mark</th><th>AO</th></tr>
<tr><td>03.4</td><td>intention to use a logarithmic plot to test power law:

suitable headings in Table 3
OR
suitable graph axis labels in Figure 9 $_1$✓

their P_1 data in Table 2 transferred to 3rd row / their P_1 used to complete 3rd row
AND
4 sets of $\log T$ and $\log P_1$ recorded in columns 3 and 4 of Table 3 $_2$✓

<table><tr><th>T / K</th><th>P_1 / W</th><th>log (T / K)</th><th>log (P_1 / W)</th></tr><tr><td>960</td><td>1.2</td><td>2.98</td><td>0.08</td></tr><tr><td>1100</td><td>2.0</td><td>3.04</td><td>0.30</td></tr><tr><td>1370</td><td>4.8</td><td>3.14</td><td>0.68</td></tr><tr><td>1680</td><td>11.0</td><td>3.23</td><td>1.04</td></tr></table></td><td>award $_1$✓ for use of bracket, solidus AND unit eg $\log (T / \mathrm{K})$ AND $\log (P_1 / \mathrm{W})$;

can be shown EITHER in the Table 3 headings OR for the Figure 9 axis labels;

accept $\lg (T / \mathrm{K})$ / $\log (T / \mathrm{k})$ for $\log (T / \mathrm{K})$;

accept columns interchanged / axes reversed

for $_2$✓ check that the $\log T$ AND $\log P_1$ values are correct to at least 2 dp;

all $\log T$ values to the same (minimum 2) dp;

all $\log P_1$ values to same (minimum 2) dp OR all to same (minimum 3) sf

ECF wrong P_1;

allow 4 sets of $\ln (T / \mathrm{K})$ and $\ln (P_1 / \mathrm{W})$

<table><tr><th>T / K</th><th>P_1 / W</th><th>ln (T / K)</th><th>ln (P_1 / W)</th></tr><tr><td>960</td><td>1.2</td><td>6.87</td><td>0.18</td></tr><tr><td>1100</td><td>2.0</td><td>7.00</td><td>0.69</td></tr><tr><td>1370</td><td>4.8</td><td>7.22</td><td>1.57</td></tr><tr><td>1680</td><td>11.0</td><td>7.43</td><td>2.40</td></tr></table></td><td>MAX 5</td><td>2 × AO1

2 × AO2

1 × AO3</td></tr>
</table>

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4 (cont)	**Figure 9 and processing**: suitable scales for their data; each axis labelled with (at least) their plotted quantity; allow interchanged axes $_3$✓	for $_3$✓ each scale must • accommodate all **their** data • have at least 4 evenly-spaced values marked along each axis • be linear, avoiding 'difficult' intervals • allow points to cover ≥ half the grid in both directions (expect use of a false origin) condone a suitably scaled and labelled **non-logarithmic** plot including P_1 against T		
	4 points plotted and a **ruled** line that is **continuous** (at least) from 1st point to 4th point $_4$✓	for $_4$✓ the 1st, 2nd and 4th points should lie on a straight line (by eye); check possible errant point(s) but allow minor plotting errors (≤ 2 minor squares); do **not** allow blobs, thick or faint points; allow a ruled line that is not the best line but do **not** allow a thick / faint / discontinuous line		
	an unrounded gradient result in the range 3.6 to 4.4 OR a gradient result correctly rounded to the nearest integer $_5$✓	for $_5$✓ do not penalise small steps; condone **one** read off error for reversed axes unrounded gradient range is 0.23 to 0.28 or inverse of gradient rounded		
	$n = 4$ CAO $_6$✓	$_6$✓ is contingent on $_5$✓		
	if the plot is not log-log or ln-ln award $_{12}$✗$_3$✓$_{456}$✗ = 1 MAX if plot is T^4 against P_1 allow up to $_1$✓$_2$✓$_3$✓$_4$✗$_5$✗$_6$✗ = 3 MAX			

Question	Answers	Additional comments/Guidelines	Mark	AO

03.4 (cont)

Figure 9 with log (P_1 / W) against log (T / K)

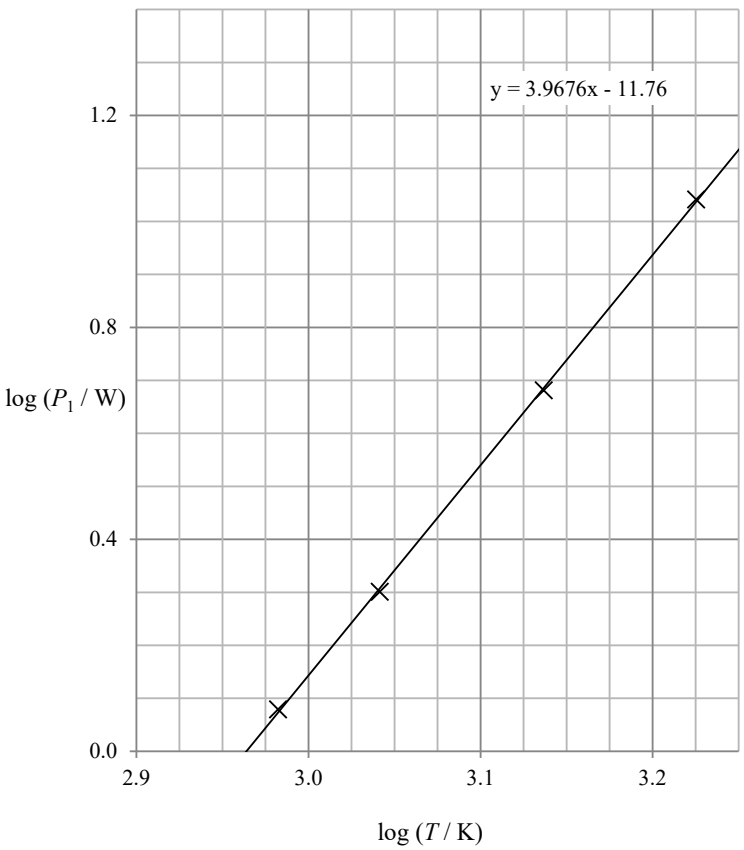
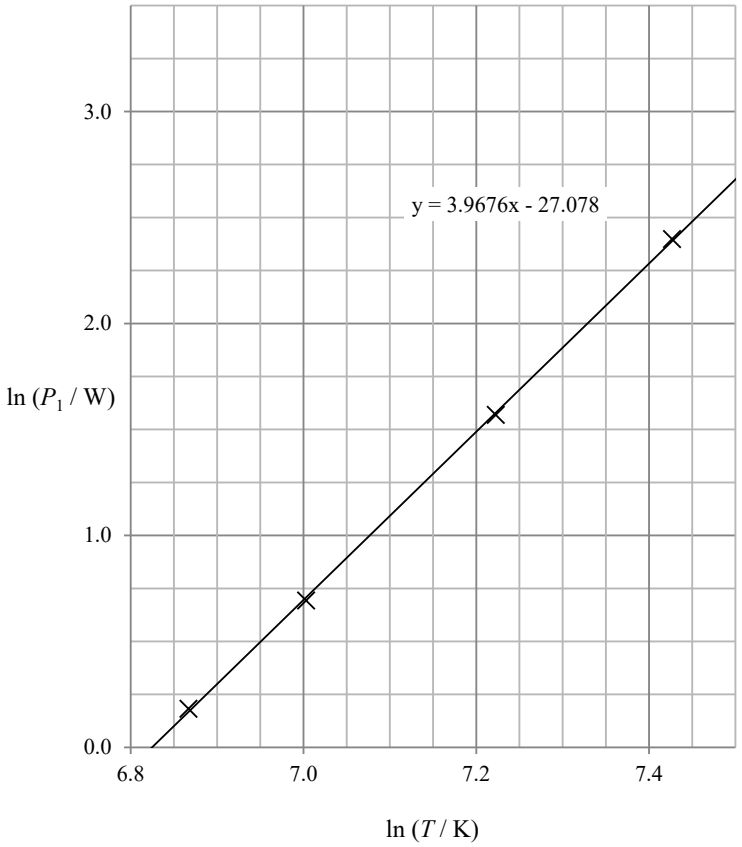


Figure 9 with ln (P_1 / W) against ln (T / K)



	typical graphs using the14 cm × 14 cm grid on **Figure 9**: grid lines shown are at the semi-major (1 cm) intervals note the false origin is required for a suitable $\log T$ scale for these scales a minimum of 4 evenly-spaced values on each axis are expected for $_3$✓

Total			**13**

Question	Answers	Additional comments/Guidance	Mark	AO