GuideMyGrades

YOUR GOALS. OUR EXPERTISE.

AQA A LEVEL PHYSICS (7408): QUESTIONS BY TOPIC

Fields and their consequences (3.7)

A Level Physics (7408) · Section 3.7

159 questions · 526 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
3.7.2	**GRAVITATIONAL FIELDS AND ORBITS**		38 Qs · 128 marks		7
1.	**Q12**		7408/2 June 2017	1	8
2.	**Q13**		7408/2 June 2017	1	9
3.	**Q13**		7408/2 June 2018	1	10
4.	**Q14**		7408/2 June 2018	1	11
5.	**Q15**		7408/2 June 2018	1	12
6.	**Q16**	*also 3.4*	7408/2 June 2018	1	13
7.	**Q17**	*also 3.4*	7408/2 June 2018	1	14
8.	**Q18**		7408/2 June 2018	1	15
9.	**Q8**	*also 3.4*	7408/2 June 2019	1	16
10.	**Q9**	*also 3.6*	7408/2 June 2019	1	17
11.	**Q11**	*also 3.4 & 3.6*	7408/2 June 2019	1	18
12.	**Q12**		7408/2 June 2019	1	19
13.	**Q12**	*also 3.1*	7408/2 November 2020	1	20
14.	**Q13**	*also 3.6*	7408/2 November 2020	1	21
15.	**Q9**		7408/1 November 2021	1	22
16.	**Q11**		7408/2 November 2021	1	23
17.	**Q12**	*also 3.4*	7408/2 November 2021	1	24
18.	**Q13**	*also 3.4*	7408/2 November 2021	1	25
19.	**Q9**		7408/2 June 2022	1	26
20.	**Q10**	*also 3.6*	7408/2 June 2022	1	27
21.	**Q11**		7408/2 June 2022	1	28
22.	**Q13**	*also 3.4*	7408/2 June 2022	1	29
23.	**Q11**		7408/2 June 2023	1	30
24.	**Q13**	*also 3.6*	7408/2 June 2023	1	31
25.	**Q21**		7408/2 June 2024	1	32
26.	**Q22**	*also 3.1*	7408/2 June 2024	1	33
27.	**Q23**	*also 3.4*	7408/2 June 2024	1	34
28.	**Q7**	*also 3.4*	7408/2 June 2025	1	35
29.	**Q3**		7408/2 June 2019	6	36
30.	**Q5**	*also 3.4 & 3.6*	7408/2 June 2024	8	38
31.	**Q4**		7408/2 June 2025	8	41
32.	**Q6**		7408/2 June 2017	9	44

	QUESTION		SOURCE	MARKS	PAGE
33.	**Q7**	*also 3.1 & 3.5*	7408/2 June 2017	10	**46**
34.	**Q2**	*also 3.4 & 3.6*	7408/2 November 2021	10	**50**
35.	**Q3**	*also 3.4*	7408/2 June 2023	10	**53**
36.	**Q4**		7408/2 June 2022	12	**56**
37.	**Q6**	*also 3.4 & 3.6*	7408/2 June 2025	13	**61**
38.	**Q2**		7408/2 November 2020	14	**66**
3.7.3	**ELECTRIC FIELDS**			35 Qs · 85 marks	**69**
39.	**Q15**		7408/2 June 2017	1	**70**
40.	**Q17**	*also 3.4*	7408/2 June 2017	1	**71**
41.	**Q20**		7408/2 June 2018	1	**72**
42.	**Q21**		7408/2 June 2018	1	**73**
43.	**Q22**		7408/2 June 2018	1	**74**
44.	**Q15**		7408/2 June 2019	1	**75**
45.	**Q16**		7408/2 June 2019	1	**76**
46.	**Q15**		7408/2 November 2020	1	**77**
47.	**Q16**		7408/2 November 2020	1	**78**
48.	**Q17**		7408/2 November 2020	1	**79**
49.	**Q18**		7408/2 November 2020	1	**80**
50.	**Q15**		7408/2 November 2021	1	**81**
51.	**Q16**		7408/2 November 2021	1	**82**
52.	**Q17**		7408/2 November 2021	1	**83**
53.	**Q18**		7408/2 November 2021	1	**84**
54.	**Q19**	*also 3.2 & 3.4*	7408/2 November 2021	1	**85**
55.	**Q16**		7408/2 June 2022	1	**86**
56.	**Q10**		7408/2 June 2023	1	**87**
57.	**Q16**		7408/2 June 2023	1	**88**
58.	**Q17**		7408/2 June 2023	1	**89**
59.	**Q18**		7408/2 June 2023	1	**90**
60.	**Q24**	*also 3.4*	7408/2 June 2024	1	**91**
61.	**Q26**		7408/2 June 2024	1	**92**
62.	**Q27**	*also 3.2*	7408/2 June 2024	1	**93**
63.	**Q28**	*also 3.2*	7408/2 June 2024	1	**94**
64.	**Q11**		7408/2 June 2025	1	**95**
65.	**Q13**		7408/2 June 2025	1	**96**
66.	**Q14**		7408/2 June 2025	1	**97**
67.	**Q15**		7408/2 June 2025	1	**98**
68.	**Q16**		7408/2 June 2025	1	**99**
69.	**Q4**	*also 3.4 & 3.8*	7408/2 June 2023	8	**100**
70.	**Q2**	*also 3.4*	7408/2 June 2018	9	**103**
71.	**Q3**		7408/2 June 2022	12	**106**

	QUESTION		SOURCE	MARKS	PAGE
72.	**Q6**	*also 3.4*	7408/2 June 2024	12	**109**
73.	**Q4**	*also 3.4*	7408/2 June 2019	14	**113**
3.7.4	**CAPACITANCE**			30 Qs · 84 marks	**116**
74.	**Q18**		7408/2 June 2017	1	**117**
75.	**Q19**		7408/2 June 2017	1	**118**
76.	**Q20**		7408/2 June 2017	1	**119**
77.	**Q21**		7408/2 June 2017	1	**120**
78.	**Q23**	*also 3.5*	7408/2 June 2018	1	**121**
79.	**Q24**		7408/2 June 2018	1	**122**
80.	**Q25**	*also 3.5*	7408/2 June 2018	1	**123**
81.	**Q19**		7408/2 June 2019	1	**124**
82.	**Q20**		7408/2 June 2019	1	**125**
83.	**Q21**	*also 3.5*	7408/2 June 2019	1	**126**
84.	**Q22**		7408/2 June 2019	1	**127**
85.	**Q19**		7408/2 November 2020	1	**128**
86.	**Q20**		7408/2 November 2020	1	**129**
87.	**Q21**		7408/2 November 2020	1	**130**
88.	**Q22**	*also 3.5*	7408/2 November 2020	1	**131**
89.	**Q20**		7408/2 November 2021	1	**132**
90.	**Q17**	*also 3.5*	7408/2 June 2022	1	**133**
91.	**Q18**	*also 3.5*	7408/2 June 2022	1	**134**
92.	**Q19**		7408/2 June 2022	1	**135**
93.	**Q20**		7408/2 June 2022	1	**136**
94.	**Q21**		7408/2 June 2022	1	**137**
95.	**Q11**		7408/2 June 2024	1	**138**
96.	**Q17**		7408/2 June 2025	1	**139**
97.	**Q18**	*also 3.5*	7408/2 June 2025	1	**140**
98.	**Q5**	*also 3.5*	7408/2 June 2025	8	**141**
99.	**Q3**	*also 3.5*	7408/2 June 2018	9	**144**
100.	**Q2**	*also 3.1 & 3.5*	7408/2 June 2024	9	**147**
101.	**Q5**	*also 3.5*	7408/2 June 2023	10	**151**
102.	**Q1**		7408/2 November 2021	12	**155**
103.	**Q2**	*also 3.1*	7408/3 Section A June 2025	12	**157**
3.7.5a	**MAGNETIC FIELDS: FORCES ON WIRES AND CHARGED PARTICLES**			20 Qs · 95 marks	**161**
104.	**Q27**		7408/2 June 2018	1	**162**
105.	**Q13**	*also 3.4*	7408/2 June 2019	1	**163**
106.	**Q23**		7408/2 June 2019	1	**164**
107.	**Q24**	*also 3.4*	7408/2 June 2019	1	**165**
108.	**Q23**	*also 3.4*	7408/2 November 2020	1	**166**
109.	**Q21**		7408/2 November 2021	1	**167**

	QUESTION		SOURCE	MARKS	PAGE
110.	**Q14**	*also 3.4*	7408/2 June 2022	1	**168**
111.	**Q22**	*also 3.4*	7408/2 June 2022	1	**169**
112.	**Q26**		7408/2 June 2022	1	**170**
113.	**Q20**	*also 3.4*	7408/2 June 2023	1	**171**
114.	**Q21**	*also 3.4 & 3.8*	7408/2 June 2023	1	**172**
115.	**Q16**	*also 3.4 & 3.6*	7408/2 June 2024	1	**173**
116.	**Q20**	*also 3.4*	7408/2 June 2025	1	**174**
117.	**Q2**	*also 3.4*	7408/2 June 2017	5	**175**
118.	**Q3**	*also 3.4 & 3.6*	7408/2 June 2017	6	**177**
119.	**Q5**	*also 3.4 & 3.8*	7408/2 November 2021	10	**179**
120.	**Q3**	*also 3.4 & 3.6*	7408/2 November 2020	11	**182**
121.	**Q3**	*also 3.4*	7408/3 Section A June 2024	15	**187**
122.	**Q3**	*also 3.1 & 3.4*	7408/3 Section A June 2023	16	**193**
123.	**Q1**	*also 3.4*	7408/3 Section A June 2018	19	**200**
3.7.5b	**ELECTROMAGNETIC INDUCTION, AC AND TRANSFORMERS**			29 Qs · 85 marks	**207**
124.	**Q22**	*also 3.4 & 3.5*	7408/2 June 2017	1	**208**
125.	**Q25**	*also 3.4 & 3.5*	7408/2 June 2017	1	**209**
126.	**Q28**	*also 3.4*	7408/2 June 2018	1	**210**
127.	**Q28**	*also 3.5*	7408/2 June 2019	1	**211**
128.	**Q29**		7408/2 June 2019	1	**212**
129.	**Q24**	*also 3.5*	7408/2 November 2020	1	**213**
130.	**Q25**	*also 3.3 & 3.5*	7408/2 November 2020	1	**214**
131.	**Q26**	*also 3.4 & 3.5*	7408/2 November 2020	1	**215**
132.	**Q22**	*also 3.5*	7408/2 November 2021	1	**216**
133.	**Q23**		7408/2 November 2021	1	**217**
134.	**Q24**	*also 3.5*	7408/2 November 2021	1	**218**
135.	**Q25**	*also 3.4*	7408/2 November 2021	1	**219**
136.	**Q23**	*also 3.5*	7408/2 June 2022	1	**220**
137.	**Q24**	*also 3.5*	7408/2 June 2022	1	**221**
138.	**Q22**	*also 3.5*	7408/2 June 2023	1	**222**
139.	**Q23**	*also 3.4 & 3.5*	7408/2 June 2023	1	**223**
140.	**Q24**	*also 3.4 & 3.5 & 3.6*	7408/2 June 2023	1	**224**
141.	**Q27**	*also 3.4*	7408/2 June 2023	1	**225**
142.	**Q12**	*also 3.4*	7408/2 June 2024	1	**226**
143.	**Q21**	*also 3.4 & 3.5 & 3.6*	7408/2 June 2025	1	**227**
144.	**Q22**	*also 3.4 & 3.5*	7408/2 June 2025	1	**228**
145.	**Q23**	*also 3.4 & 3.5*	7408/2 June 2025	1	**229**
146.	**Q5**	*also 3.4 & 3.5 & 3.6*	7408/2 June 2019	6	**230**
147.	**Q3**	*also 3.4 & 3.5*	7408/2 June 2024	7	**233**
148.	**Q4**	*also 3.4 & 3.5 & 3.6*	7408/2 June 2018	8	**235**

	QUESTION		SOURCE	MARKS	PAGE
149.	**Q4**	*also 3.4 & 3.5*	7408/2 November 2021	8	**238**
150.	**Q4**		7408/2 November 2020	9	**241**
151.	**Q5**	*also 3.4*	7408/2 June 2022	11	**246**
152.	**Q2**	*also 3.1*	7408/3 Section A June 2017	14	**249**
3.7.S	**SYNOPTIC AND CROSS-TOPIC QUESTIONS**			7 Qs · 49 marks	**257**
153.	**Q31**	*also 3.4 & 3.6*	7408/1 June 2018	1	**258**
154.	**Q16**	*also 3.4*	7408/1 June 2019	1	**259**
155.	**Q25**	*also 3.4*	7408/1 June 2022	1	**260**
156.	**Q25**	*also 3.4 & 3.6*	7408/1 June 2025	1	**261**
157.	**Q2**	*also 3.1 & 3.4*	7408/3 Section A June 2019	13	**262**
158.	**Q3**	*also 3.3*	7408/3 Section A June 2019	13	**269**
159.	**Q3**	*also 3.1 & 3.5*	7408/3 Section A November 2021	19	**275**

QUESTIONS

159 questions · 526 marks · 6 sub-topics

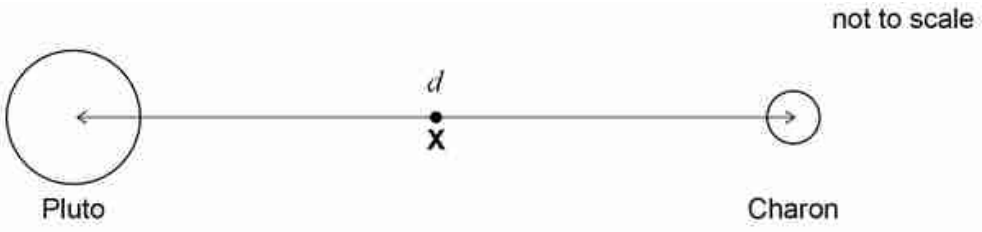
SUB-TOPIC 3.7.2

GRAVITATIONAL FIELDS AND ORBITS

Sub-topic 3.7.2 · 38 questions · 128 marks · lowest tariff first

1 2 Charon is a moon of Pluto that has a mass equal to $\frac{1}{9}$ that of Pluto.

The distance between the centre of Pluto and the centre of Charon is d.
X is the point at which the resultant gravitational field due to Pluto and Charon is zero.



What is the distance of **X** from the centre of Pluto?

[1 mark]

A $\frac{2}{9}d$ ⬭

B $\frac{2}{3}d$ ⬭

C $\frac{3}{4}d$ ⬭

D $\frac{8}{9}d$ ⬭

1 3 The distance between the Sun and Mars varies from 2.1×10^{11} m to 2.5×10^{11} m.
When Mars is closest to the Sun, the force of gravitational attraction between them is F.

What is the force of gravitational attraction between them when they are furthest apart?

[1 mark]

A $0.71F$ ⬭

B $0.84F$ ⬭

C $1.2F$ ⬭

D $1.4F$ ⬭

1 3 The distance between the Sun and the Earth is 1.5×10^{11} m

What is the gravitational force exerted on the Sun by the Earth?

[1 mark]

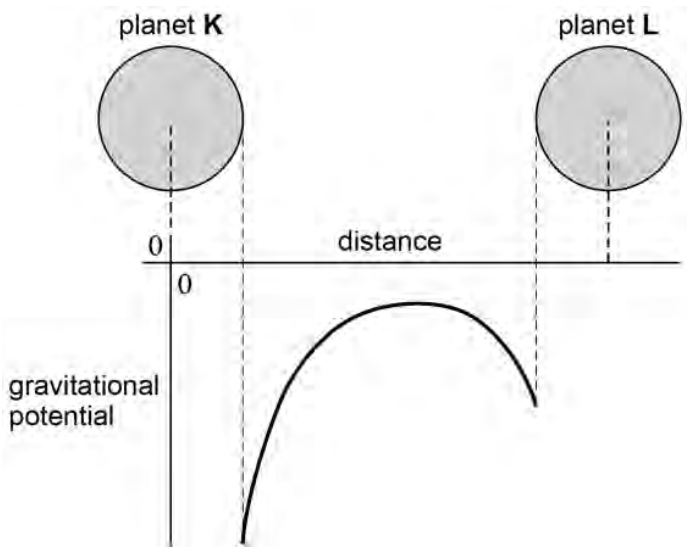
A 3.5×10^{22} N ⬭

B 1.7×10^{26} N ⬭

C 5.3×10^{33} N ⬭

D 8.9×10^{50} N ⬭

1 4 The graph shows how the gravitational potential varies with distance between two planets, **K** and **L**, that have the same radius.



Which statement is correct?

[1 mark]

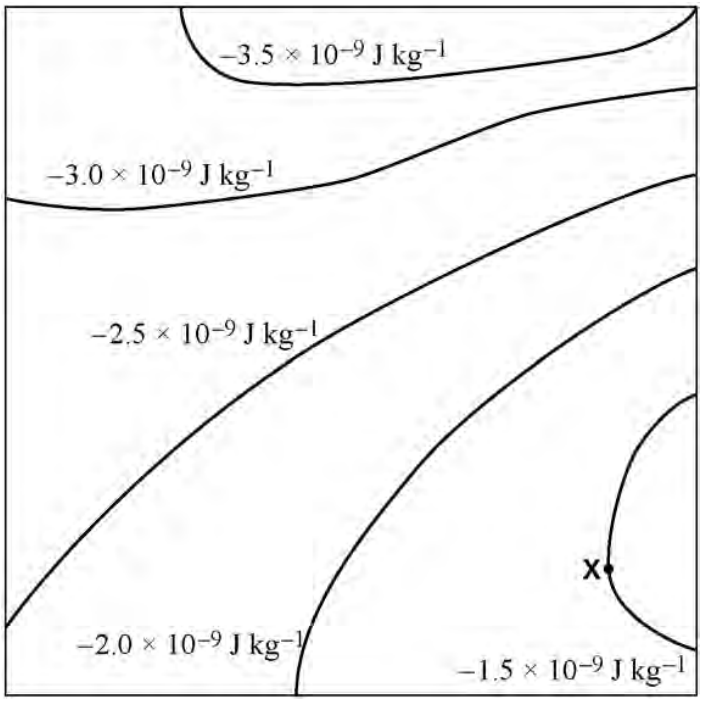
A The mass of **L** is greater than the mass of **K**. ⬭

B The gravitational field strength at the surface of **L** is greater than that at the surface of **K**. ⬭

C The escape velocity from planet **L** is greater than that from planet **K**. ⬭

D More work must be done to move a mass of $1\ \text{kg}$ from the surface of **K** to a distant point, than $1\ \text{kg}$ from the surface of **L**. ⬭

1 5 The diagram shows equipotential lines near a group of asteroids.



Which arrow shows the direction of the gravitational field at **X**?

[1 mark]

A ↑ ⬭

B ↓ ⬭

C ← ⬭

D → ⬭

1 6 Planet **N** has a gravitational potential $-V$ at its surface. Planet **M** has double the density and double the radius of planet **N**. Both planets are spherical and have uniform density.

What is the gravitational potential at the surface of planet **M**?

[1 mark]

A $-16V$ ⬭

B $-8V$ ⬭

C $-4V$ ⬭

D $-0.2V$ ⬭

1 7 A spacecraft of mass 1.0×10^{6} kg is in orbit around the Sun at a radius of 1.1×10^{11} m
The spacecraft moves into a new orbit of radius 2.5×10^{11} m around the Sun.

What is the total change in gravitational potential energy of the spacecraft?

[1 mark]

A -6.76×10^{14} J ⬭

B -3.38×10^{14} J ⬭

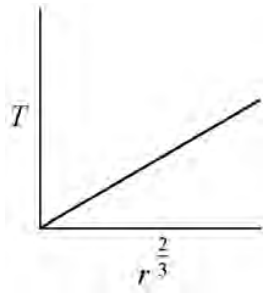
C 3.38×10^{14} J ⬭

D 6.76×10^{14} J ⬭

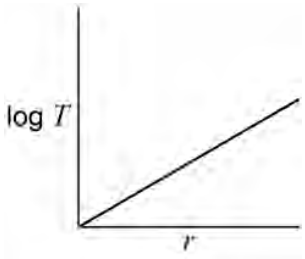
1 8 Which graph shows the relationship between the time period T and the orbital radius r of a planet in orbit around the Sun?

[1 mark]

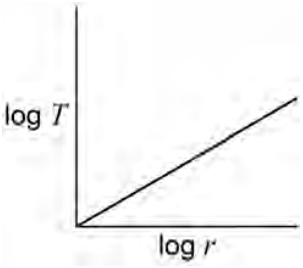
A



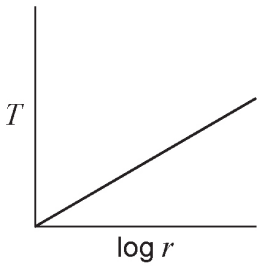
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

0 8 Which row shows two scalar quantities?

[1 mark]

A	gravitational potential	gravitational field strength	⬭
B	mass	gravitational potential	⬭
C	gravitational field strength	weight	⬭
D	weight	gravitational potential	⬭

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 2 An object moves freely at $90°$ to the direction of a gravitational field.

The acceleration of the object is

[1 mark]

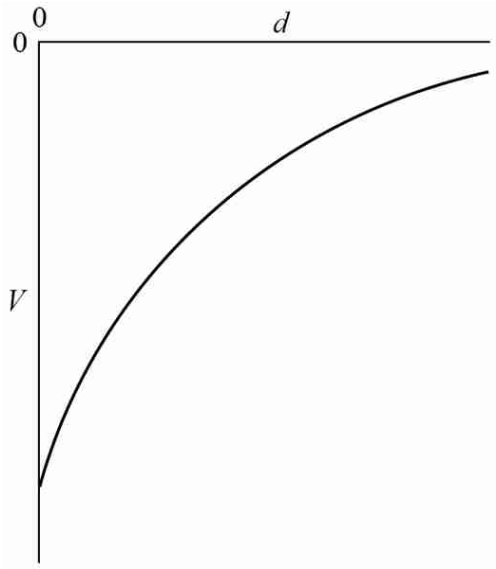
A zero. ⬭

B opposite to the direction of the gravitational field. ⬭

C in the direction of the gravitational field. ⬭

D at $90°$ to the direction of the gravitational field. ⬭

1 2 The graph shows how the gravitational potential V varies with the vertical distance d from the surface of the Earth.



What does the gradient of the graph represent at the surface of the Earth?

[1 mark]

A potential energy ⬭

B mass of the Earth ⬭

C magnitude of the gravitational constant ⬭

D magnitude of the gravitational field strength ⬭

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} ⬭

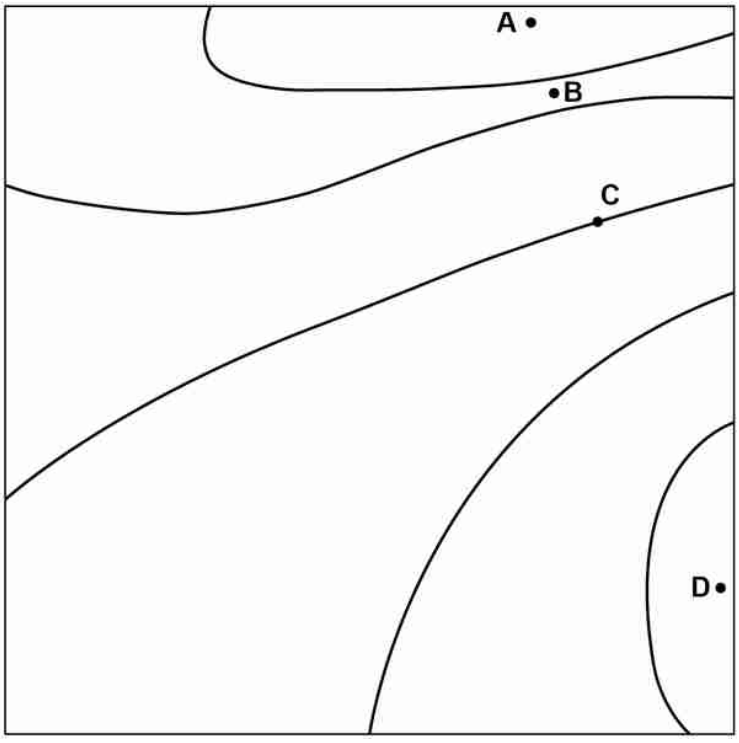
0 9 The gravitational force is one of the four fundamental forces.
The ticks in the table match particles with the other fundamental forces.

In which row is the particle matched to the only other fundamental forces it experiences?

[1 mark]

	Particle	Electromagnetic force	Weak nuclear force	Strong nuclear force	
A	μ^+	✓	✓		⬭
B	$\overline{p}$	✓		✓	⬭
C	π^0	✓	✓	✓	⬭
D	ν_e		✓	✓	⬭

1 1 The diagram shows gravitational equipotentials. Adjacent equipotentials are separated by an equal gravitational potential difference V.



Which point has the greatest gravitational field strength?

[1 mark]

A ⬭

B ⬭

C ⬭

D ⬭

1 2 A planet has radius R and density ρ. The gravitational field strength at the surface is g.

What is the gravitational field strength at the surface of a planet of radius $2R$ and density 2ρ?

[1 mark]

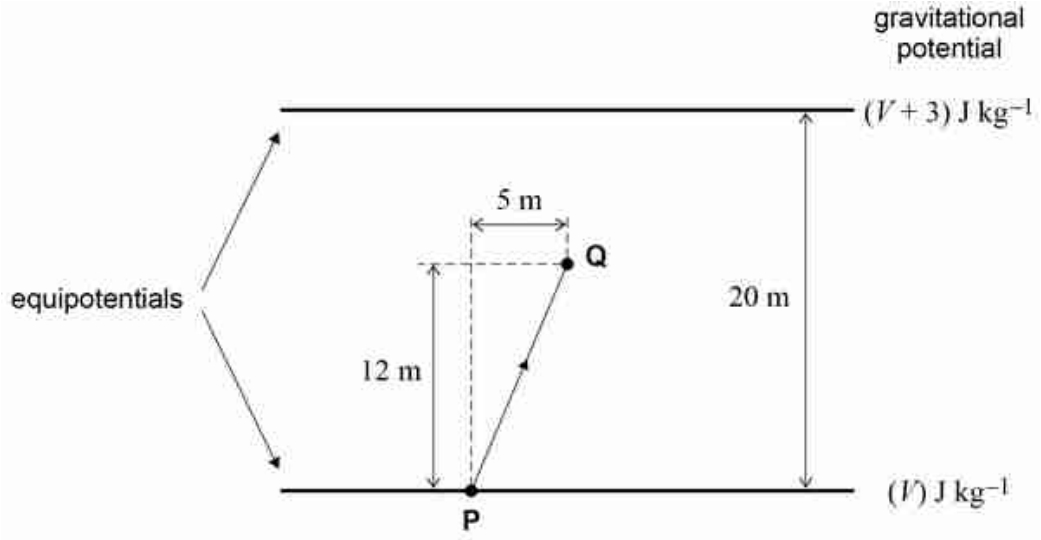
A $2g$ ⬭

B $4g$ ⬭

C $8g$ ⬭

D $16g$ ⬭

1 3 The diagram shows equipotential lines for a uniform gravitational field. The lines are separated by 20 m.



An object of mass 4 kg is moved from **P** to **Q**.

What is the work done against gravity to move the object?

[1 mark]

A 7.2 J ⬭

B 7.8 J ⬭

C 10.2 J ⬭

D 36 J ⬭

0 9 A planet of radius R and mass M has a gravitational field strength of g at its surface.

Which row describes a planet with a gravitational field strength of $4g$ at its surface?

[1 mark]

	Radius of planet	Mass of planet	
A	$2R$	$2M$	⬭
B	$R\sqrt{2}$	$\frac{M}{2}$	⬭
C	$\frac{R}{\sqrt{2}}$	$\frac{M}{2}$	⬭
D	$\frac{R}{\sqrt{2}}$	$2M$	⬭

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} ⬭

1 1 The radius of the Earth is R and the acceleration due to gravity at the surface of the Earth is g.

What is the escape velocity for a mass m at the surface of the Earth?

[1 mark]

A $\sqrt{gR}$ ⬭

B $\sqrt{2gR}$ ⬭

C $\sqrt{2mgR}$ ⬭

D $\sqrt{\frac{2gR}{m}}$ ⬭

1 3 Satellites **N** and **F** have the same mass and move in circular orbits about the same planet. The orbital radius of **N** is less than that of **F**.

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

[1 mark]

A the gravitational force on the satellite ⬭

B the speed of the satellite ⬭

C the kinetic energy of the satellite ⬭

D the orbital period of the satellite ⬭

1 1 Data are collected for the mass M, radius R and escape velocity u for each planet in the Solar System.

The data show that u is directly proportional to

[1 mark]

A $\left(\frac{M}{R}\right)^{-\frac{1}{2}}$ ⬭

B $\left(\frac{M}{R}\right)^{\frac{1}{2}}$ ⬭

C $\frac{M}{R}$ ⬭

D $\left(\frac{M}{R}\right)^{2}$ ⬭

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 1 A synchronous orbit of the Earth has a radius R.
A planet has a mass twice the mass of the Earth. A day on the planet is one quarter of an Earth day.

What is the radius of a synchronous orbit for this planet?

[1 mark]

A $\frac{R}{\sqrt[3]{2}}$ ⬭

B $\frac{R}{\sqrt[3]{16}}$ ⬭

C $\frac{R}{2}$ ⬭

D $\frac{\sqrt{2}R}{8}$ ⬭

2 2 An asteroid has a mass of 2×10^{17} kg and an escape velocity of 40 m s^{-1}.

What is the order of magnitude of the radius of the asteroid?

[1 mark]

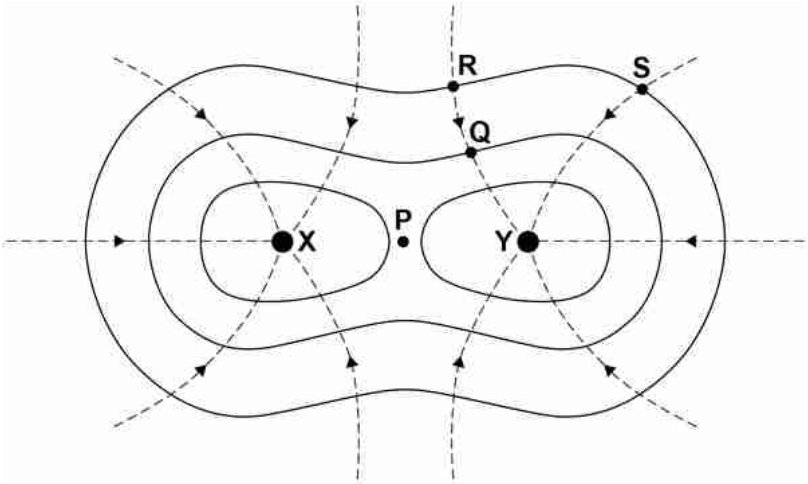
A 10^3 m ⬭

B 10^4 m ⬭

C 10^5 m ⬭

D 10^6 m ⬭

2 3 The diagram shows the gravitational field for a binary star system consisting of two stars **X** and **Y** of equal mass.



Equipotential lines are shown as solid lines.
Gravitational field lines are shown as dashed lines.

Which statement is correct?

[1 mark]

A More work is done moving from **Q** to **S** to **R** than moving directly from **Q** to **R**. ⬭

B No work is done moving from **Q** to **R**. ⬭

C The gravitational field strength is the same at **R** and **S**. ⬭

D The work done moving from **Q** to **R** and moving from **Q** to **S** is the same. ⬭

0 7 An object on the surface of a moon has an escape velocity v. The moon has a density ρ and radius R.

Another moon **X** has a density 2ρ and radius $\frac{R}{3}$.

What is the escape velocity for an object on the surface of **X**?

[1 mark]

A $\frac{2}{9}v$ ⬭

B $\frac{\sqrt{2}}{3}v$ ⬭

C $\sqrt{\frac{2}{3}}v$ ⬭

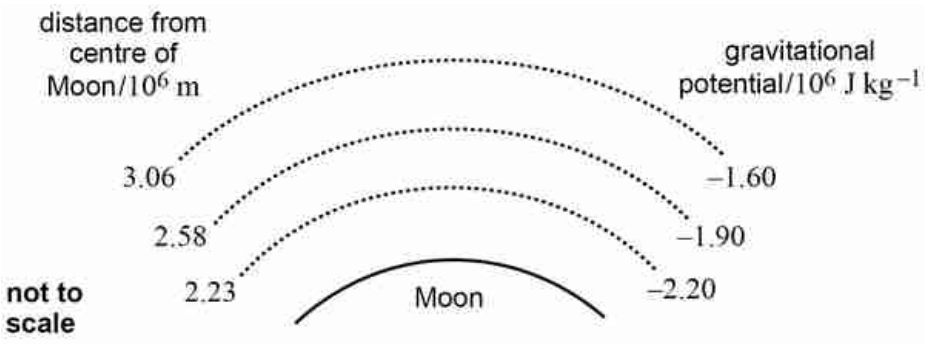
D $\frac{2}{\sqrt{3}}v$ ⬭

0 3 . 1 Define gravitational potential at a point.

[1 mark]

0 3 . 2 **Figure 2** shows the positions of equipotential surfaces at different distances from the centre of the Moon.

Figure 2



Explain how the equipotential surfaces in **Figure 2** show that the gravitational field is **not** uniform.

[1 mark]

0 3 . 3 Calculate, using **Figure 2**, the escape velocity at the surface of the Moon.

radius of Moon = 1.74×10^6 m

[4 marks]

escape velocity = _____ m 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

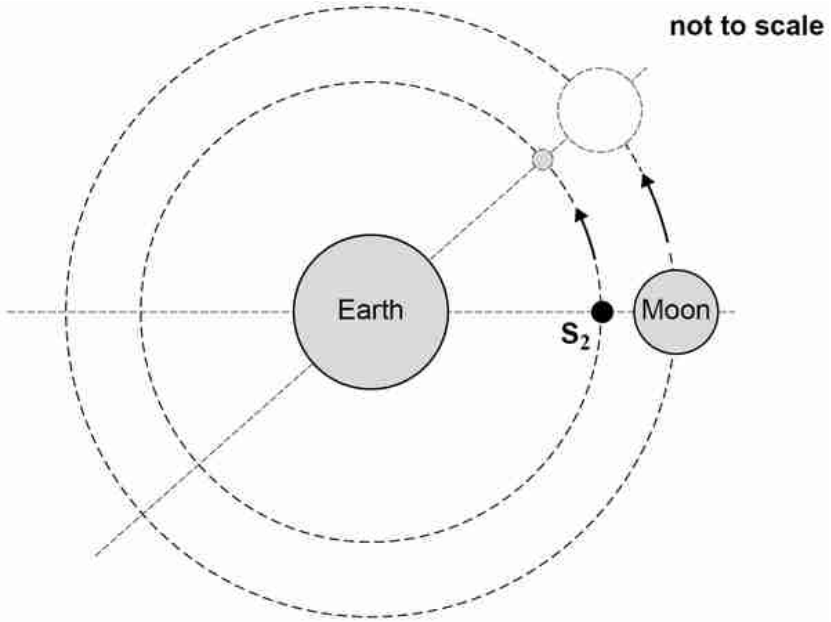
[2 marks]

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 4 . 1 Mimas and Enceladus are moons of Saturn.

Mimas orbits at a height of 1.28×10^8 m above the surface of Saturn.
The orbital period of Mimas is 0.94 Earth days.

Enceladus orbits at a height of 1.80×10^8 m above the surface of Saturn.

Calculate, in Earth days, the orbital period of Enceladus.

radius of Saturn = 5.8×10^7 m

[3 marks]

orbital period = _____ Earth days

Question 4 continues on the next page

Titan is the largest moon of Saturn.

Figure 2 shows the variation of gravitational potential with distance from the centre of Saturn in the direction of Titan.

The dashed line shows the gravitational potential due to the mass of Saturn alone.

The solid line shows the total gravitational potential due to Saturn and Titan.
The solid line ends at the surface of Titan.

Figure 2

0 4 . 2 A student suggests that, over the range of distances shown in **Figure 2**, the gravitational field strength due to the mass of Saturn alone is approximately constant.

Explain why the suggestion is correct.

[1 mark]

0 4 . 3 At a point **P**, the resultant gravitational field strength due to Saturn and Titan is zero.

Determine, using the solid line in **Figure 2**, the distance from Saturn to **P**.

[1 mark]

distance = _____ m

0 4 . 4 The centre of Titan is 12.22×10^8 m from the centre of Saturn.

Show that the gravitational potential due to the mass of Titan at a distance of 12.08×10^8 m from Saturn is about -7×10^5 J kg^{-1}.
Go on to determine the mass of Titan.

[3 marks]

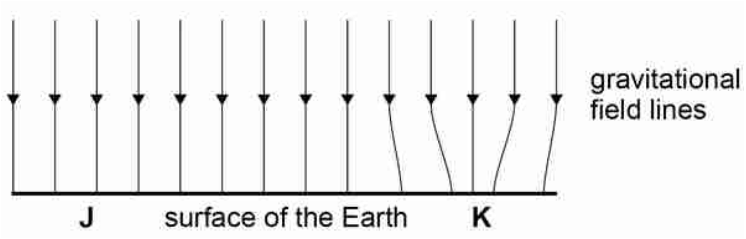
mass = _____ kg

0 6 . 1 State what is represented by gravitational field lines.

[1 mark]

0 6 . 2 **Figure 6** shows the gravitational field above a small horizontal region on the surface of the Earth.

Figure 6



Suggest why the field lines converge over a small area at **K**.

[2 marks]

0 6 . 3 A ball travelling at constant speed passes position **J** moving towards position **K** in **Figure 6**.

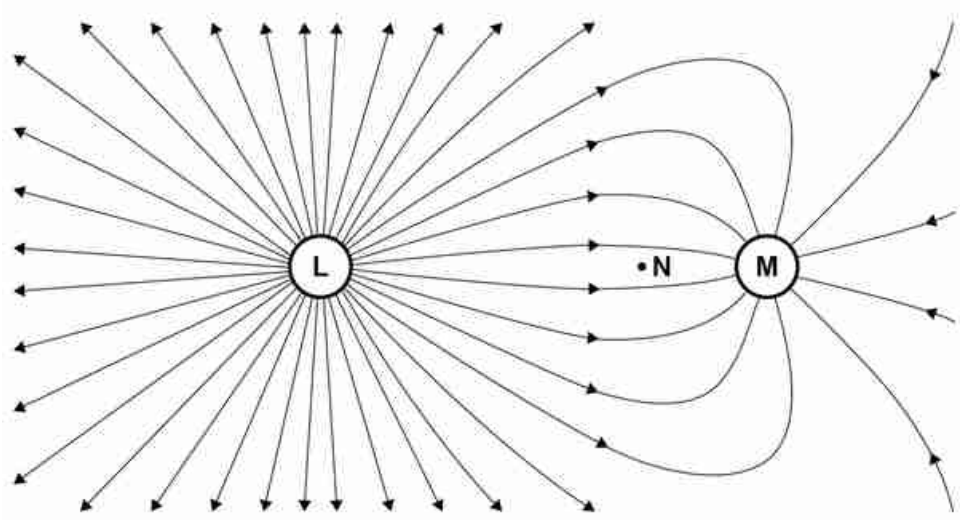
Assume friction is negligible.

Explain any change in the speed of the ball as it approaches **K**.

[2 marks]

0 6 . 4 **Figure 7** shows lines of force for the electric field surrounding two charged objects **L** and **M**.

Figure 7



Explain why the lines of force shown in **Figure 7** cannot represent a gravitational field.

[1 mark]

0 6 . 5 State which object **L** or **M** has a charge with the greater magnitude.

object _____

State which object **L** or **M** has a positive charge.

object _____

[1 mark]

0 6 . 6 Draw, on **Figure 7**, an equipotential line that passes through point **N**.
Do **not** extend your line beyond the given field lines.

[2 marks]

0 7 . 1 Derive an expression to show that for satellites in a circular orbit

$$T^2 \propto r^3$$

where T is the period of orbit and r is the radius of the orbit.

[2 marks]

0 7 . 2 Pluto is a dwarf planet. The mean orbital radius of Pluto around the Sun is 5.91×10^9 km compared to a mean orbital radius of 1.50×10^8 km for the Earth.

Calculate in years the orbital period of Pluto.

[2 marks]

orbital period of Pluto = _____ yr

0 7 . 3 A small mass released from rest just above the surface of Pluto has an acceleration of $0.617\ \text{m s}^{-2}$.

Assume Pluto has no atmosphere that could provide any resistance to motion.

Calculate the mass of Pluto.

Give your answer to an appropriate number of significant figures.

radius of Pluto = $1.19 \times 10^{6}\ \text{m}$

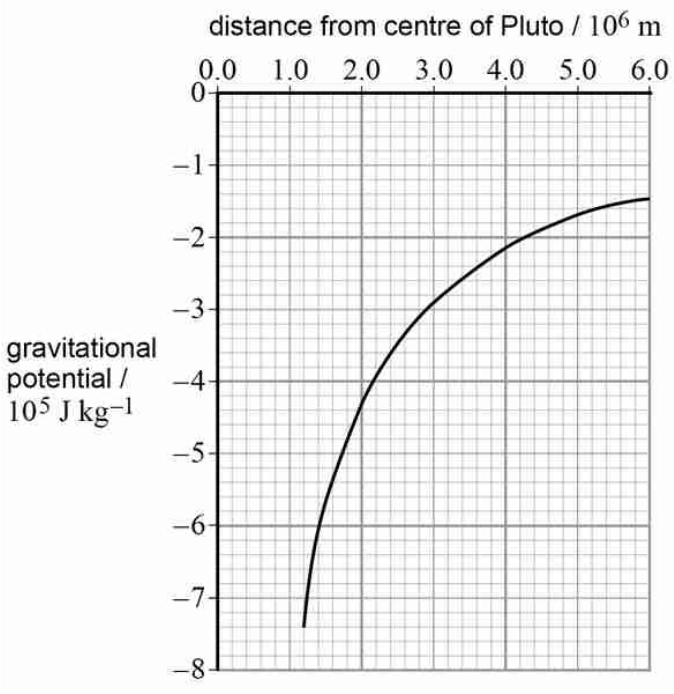
[3 marks]

mass of Pluto = _____ kg

Question 7 continues on the next page

0 7 . 4 **Figure 8** shows the variation in gravitational potential with distance from the centre of Pluto for points at and above its surface.

Figure 8



A meteorite hits Pluto and ejects a lump of ice from the surface that travels vertically at an initial speed of $1400\ \text{m s}^{-1}$.

Determine whether this lump of ice can escape from Pluto.

[3 marks]

END OF SECTION A

Section B

Each of Questions **8** 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 answer 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.

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.

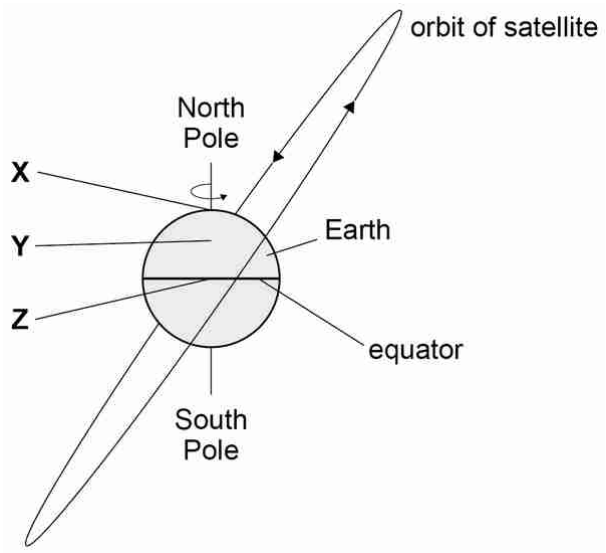
[2 marks]

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 3 . 1 Describe **two** properties of a radial gravitational field.

[2 marks]

1 _____

_____

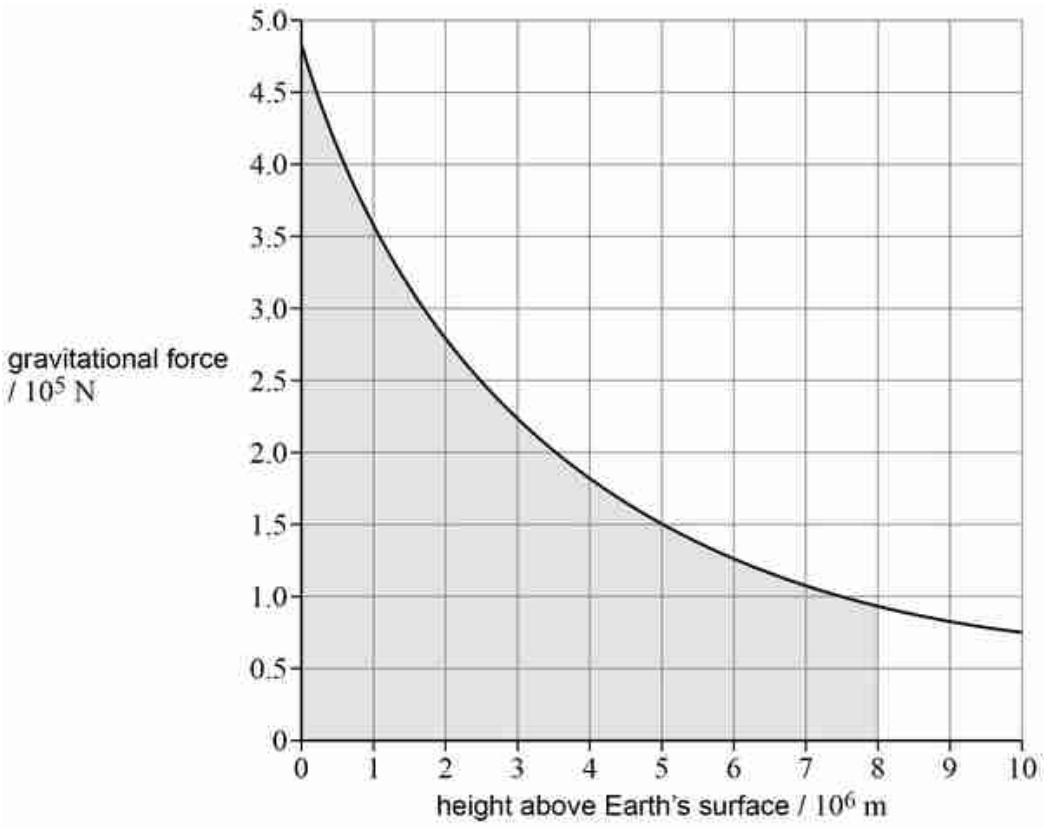
2 _____

_____

A space probe is launched from the Earth's surface.

Figure 3 shows how the gravitational force acting on the space probe varies with height above the Earth's surface.

Figure 3



0 3 . 2 State the physical significance of the shaded area in **Figure 3**.

[1 mark]

At the Earth's surface,

- the gravitational field strength of the Sun is g_S
- the gravitational field strength of the Earth is g_E.

0 3 . 3 Calculate $\frac{g_S}{g_E}$.

distance from the Earth to the Sun $= 1.50 \times 10^{11}$ m

[2 marks]

$\frac{g_S}{g_E} =$ _____

0 3 . 4 Explain why g_S is more important than g_E in predicting the motion of the space probe as it escapes from the Solar System.

[1 mark]

_____

_____

_____

Question 3 continues on the next page

0 3 . 5 The space probe eventually reaches a point where the gravitational influence of the Solar System is negligible.
The probe is unpowered as it approaches an isolated interstellar body **X**.
The gravitational field of **X** changes the kinetic energy of the space probe.

Table 2 shows the distance of the space probe from the centre of mass of **X** and the speed for two positions **A** and **B** of the space probe.

Table 2

	Distance of space probe from centre of mass of X / 10^6 m	Speed of space probe / 10^3 m s^{-1}
A	6.0	1.1
B	0.17	1.3

The space probe has a mass of 4.9×10^4 kg.

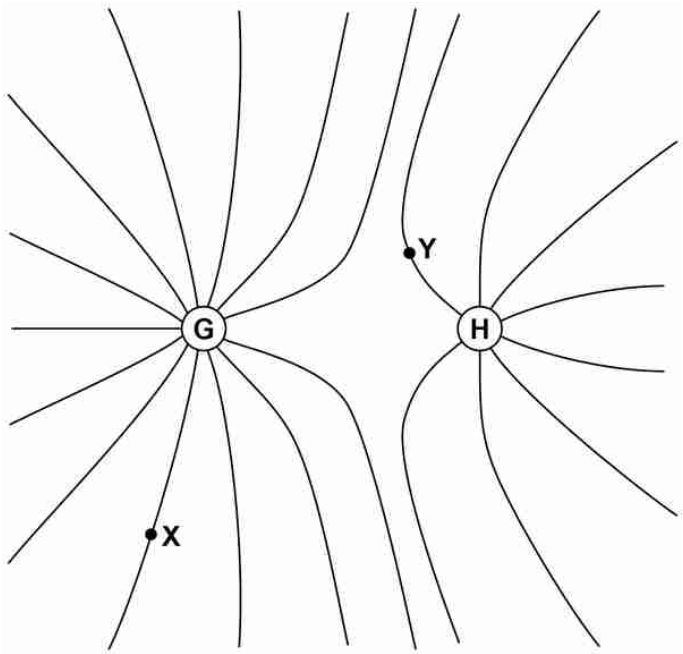
Calculate the mass of **X**.

[4 marks]

mass of **X** = _____ kg

0 4 The lines in **Figure 4** show the shape of the gravitational field around two stars **G** and **H**.

Figure 4



0 4 . 1 Compare, with reference to **Figure 4**, the masses of **G** and **H**.

[2 marks]

0 4 . 2 **X** and **Y** are two points in the field.

Annotate **Figure 4** to show the field direction at **X** and the field direction at **Y**.

[1 mark]

Question 4 continues on the next page

0 4 . 3 A spherical asteroid **P** has a mass of 2.0×10^{20} kg.

The gravitational field strength at its surface is 0.40 N kg^{-1}.

Calculate the radius R of **P**.

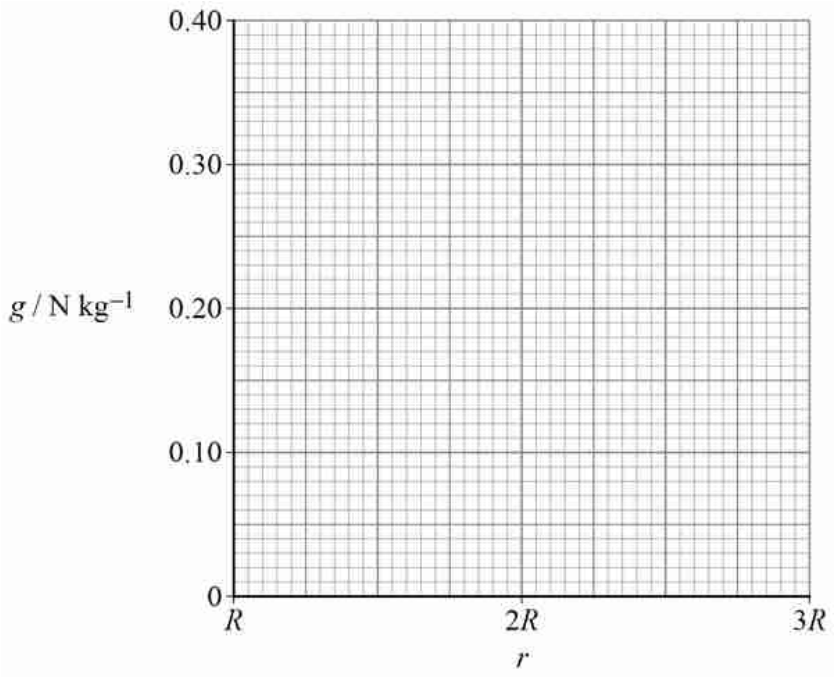
[1 mark]

$R =$ _____ m

0 4 . 4 Sketch, on **Figure 5**, the variation of the gravitational field strength g with distance r. The distance r is measured from the centre of **P**.

[1 mark]

Figure 5



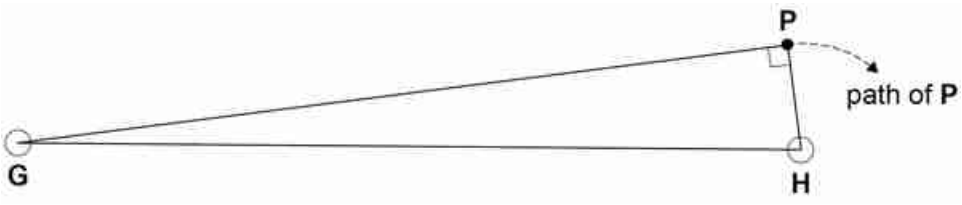
0 4 . 5 Explain what is represented by the area under the graph between $r = R$ and $r = 2R$ on **Figure 5**.

[2 marks]

Question 4 continues on the next page

Asteroid **P** approaches the two stars **G** and **H**.
Figure 6 shows one position of **P** close to **H**.

Figure 6



0 4 . 6 The gravitational force on **P** from **G** is 6.38×10^{12} N.
The mass of **H** is 3.00×10^{25} kg and the mass of **P** is 2.00×10^{20} kg.
The distance **HP** is 1.50×10^{11} m.

Calculate the magnitude of the acceleration of **P**.

[4 marks]

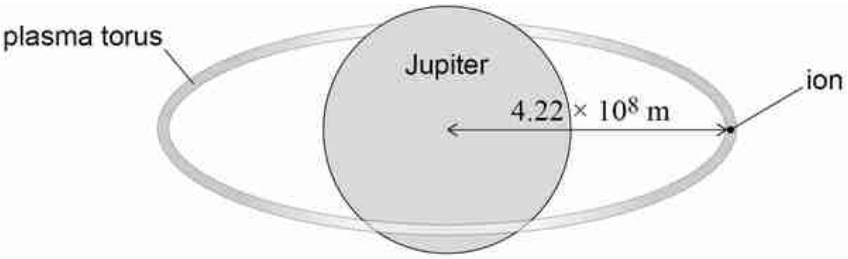
magnitude of acceleration = _____ m s^{-2}

0 4 . 7 Explain why **P** cannot have a circular orbit around **H**.

[1 mark]

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

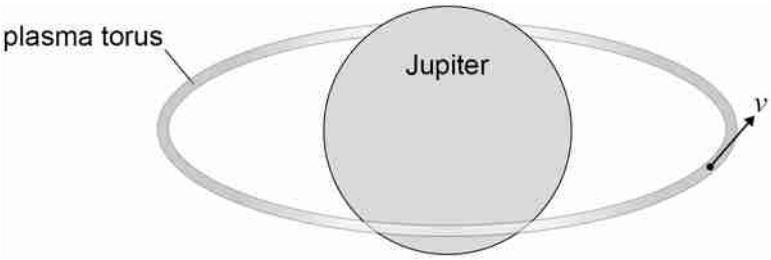
[3 marks]

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.

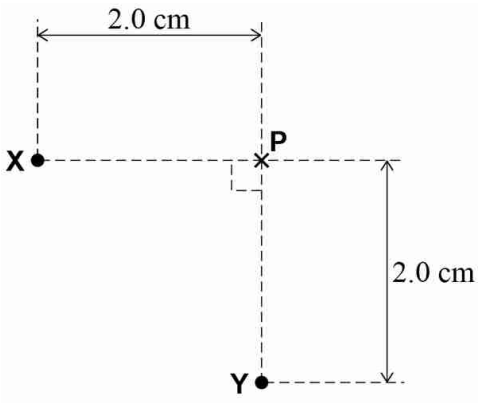
[3 marks]

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

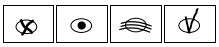
Section B

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 

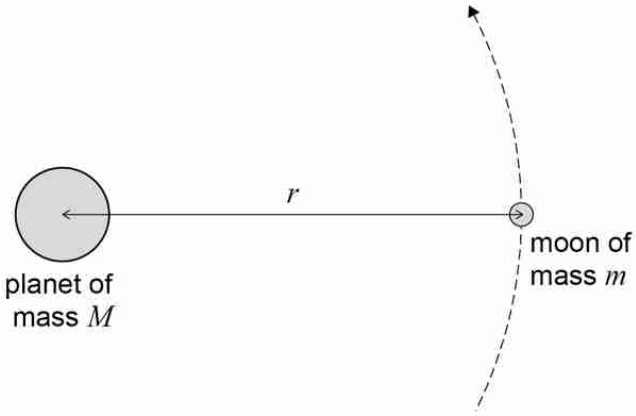
If you want to change your answer you must cross out your original answer as shown. 

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 2 **Figure 2** shows a moon of mass m in a circular orbit of radius r around a planet of mass M, where $m << M$.

Figure 2



The moon has an orbital period T.
T is related to r by

$$T^2 = kr^3$$

where k is a constant for this planet.

0 2 . 1 Show that $k = \dfrac{4\pi^2}{GM}$

[3 marks]

Table 2 gives data for two of the moons of the planet Uranus.

Table 2

Name	T / days	r / m
Miranda	1.41	1.29×10^8
Umbriel	4.14	**X**

0 2 . 2 Calculate the orbital radius **X** of Umbriel.

[2 marks]

orbital radius = _____ m

0 2 . 3 Calculate the mass of Uranus.

[3 marks]

mass = _____ kg

Question 2 continues on the next page

Table 3 gives data for three more moons of Uranus.

Table 3

Name	Mass / kg	Diameter / m
Ariel	1.27×10^{21}	1.16×10^{6}
Oberon	3.03×10^{21}	1.52×10^{6}
Titania	3.49×10^{21}	1.58×10^{6}

0 2 . 4 Deduce which moon in **Table 3** has the greatest escape velocity for an object on its surface.
Assume the effect of Uranus is negligible.

[3 marks]

0 2 . 5 A spring mechanism can project an object vertically to a maximum height of 1.0 m from the surface of the Earth.

Determine whether the same mechanism could project the same object vertically to a maximum height greater than 100 m when placed on the surface of Ariel.

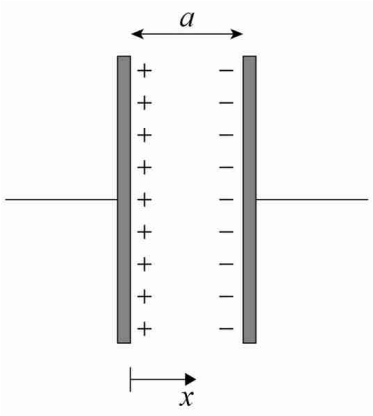
[3 marks]

SUB-TOPIC 3.7.3

ELECTRIC FIELDS

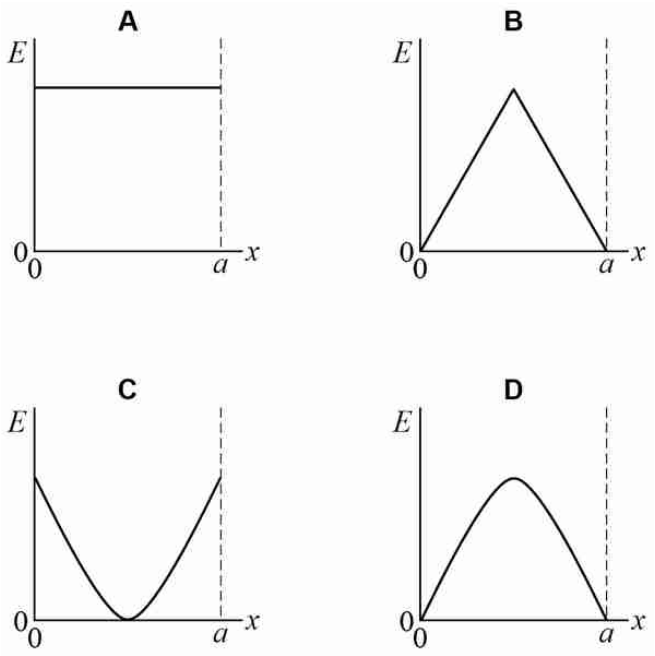
Sub-topic 3.7.3 · 35 questions · 85 marks · lowest tariff first

1 5 Two parallel metal plates of separation a carry equal and opposite charges.



Which graph best represents how the electric field strength E varies with the distance x in the space between the two plates?

[1 mark]



A ⬭

B ⬭

C ⬭

D ⬭

1 7 An electron moves through a distance of $0.10\ \text{m}$ parallel to the field lines of a uniform electric field of strength $2.0\ \text{kN C}^{-1}$.

What is the work done on the electron?

[1 mark]

A zero ⬭

B $1.6 \times 10^{-17}\ \text{J}$ ⬭

C $3.2 \times 10^{-17}\ \text{J}$ ⬭

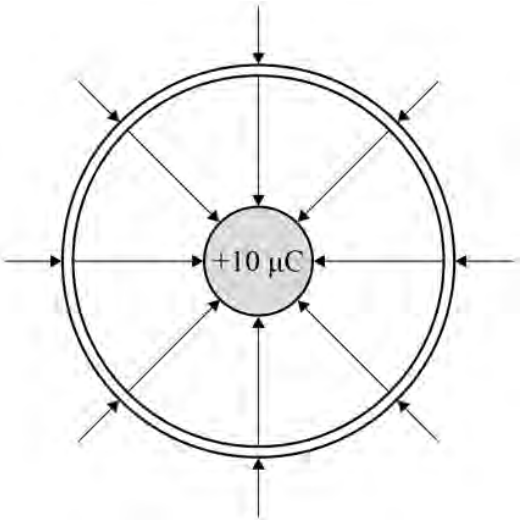
D $1.6 \times 10^{-21}\ \text{J}$ ⬭

2 0 A conducting sphere holding a charge of +10 μC is placed centrally inside a second uncharged conducting sphere.

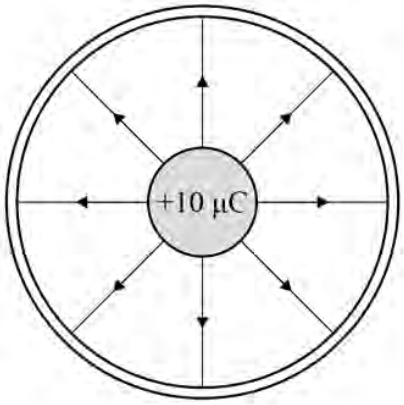
Which diagram shows the electric field lines for the system?

[1 mark]

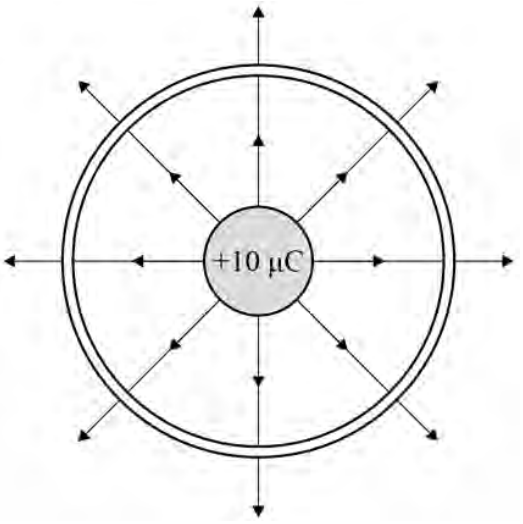
A



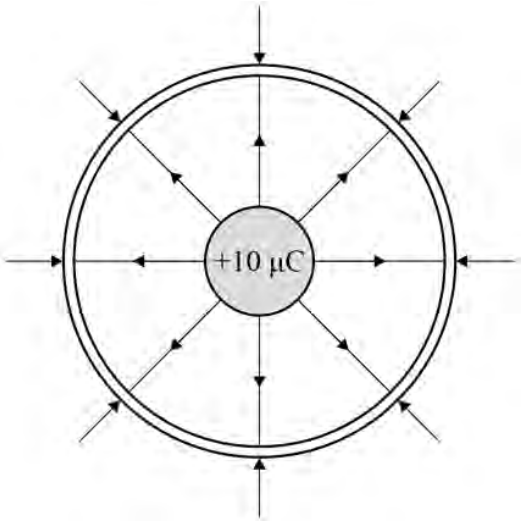
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

2 1 A charged spherical conductor has a radius r. An electric field of strength E exists at the surface due to the charge.

What is the potential of the spherical conductor?

[1 mark]

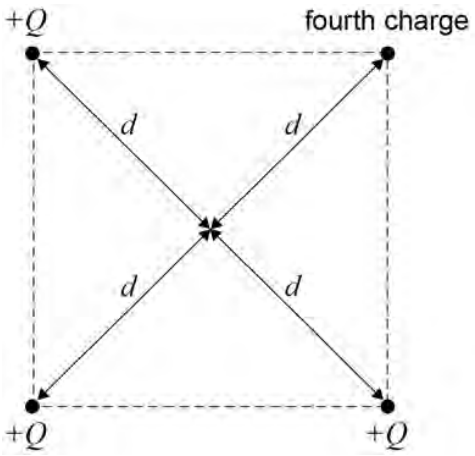
A r^2E ⬭

B $r\,E^2$ ⬭

C $\frac{E}{r}$ ⬭

D $r\,E$ ⬭

2 2 Four positive charges are fixed at the corners of a square as shown.



The total potential at the centre of the square, a distance d from each charge, is $\frac{5Q}{4\pi\varepsilon_o d}$. Three of the charges have a charge of $+Q$.

What is the magnitude of the fourth charge?

[1 mark]

A $-\frac{7Q}{4}$ ⬭

B Q ⬭

C $\sqrt{2}Q$ ⬭

D $2Q$ ⬭

1 5 $1.5\ \text{mJ}$ of work is done when a charge of $30\ \mu\text{C}$ is moved between two points, **M** and **N**, in an electric field.

What is the potential difference between **M** and **N**?

[1 mark]

A $20\ \text{mV}$ ⬭

B $20\ \text{V}$ ⬭

C $45\ \text{V}$ ⬭

D $50\ \text{V}$ ⬭

1 6 An electric field acts into the plane of the paper. An electron enters the field at $90°$ to the field lines.

The force on the electron is

[1 mark]

A zero. ⬭

B along the direction of the field. ⬭

C at $90°$ to the field. ⬭

D opposite to the direction of the field. ⬭

1 5 At a distance L from a fixed point charge, the electric field strength is E and the electric potential is V.

What are the electric field strength and the electric potential at a distance $3L$ from the charge?

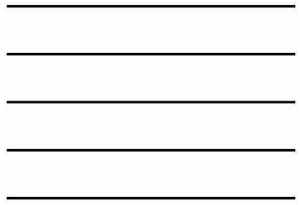
[1 mark]

	Electric field strength	Electric potential	
A	$\frac{E}{3}$	$\frac{V}{9}$	⬭
B	$\frac{E}{3}$	$\frac{V}{3}$	⬭
C	$\frac{E}{9}$	$\frac{V}{3}$	⬭
D	$\frac{E}{9}$	$\frac{V}{9}$	⬭

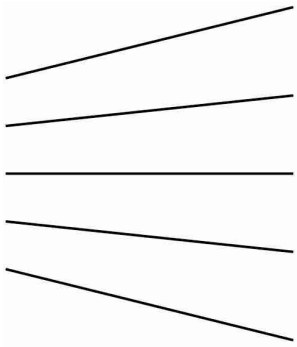
1 6 Which diagram shows lines of equipotential in steps of equal potential difference near an isolated point charge?

[1 mark]

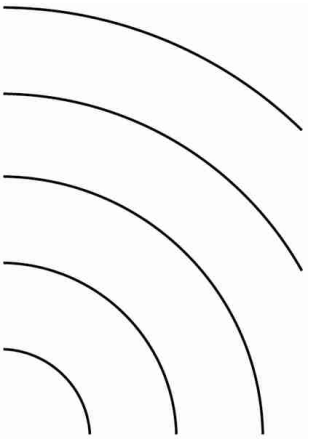
A



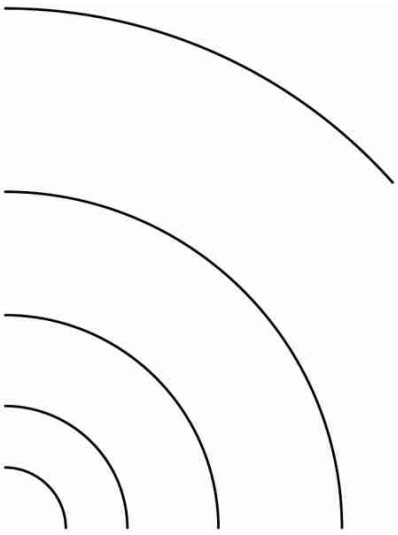
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

1 7 A positive charge of 2.0×10^{-4} C is placed in an electric field at a point where the potential is +500 V.

What is the potential energy of the system?

[1 mark]

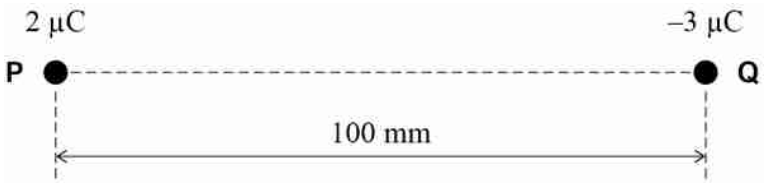
A 1.0×10^{-1} J ⬭

B 1.0×10^{-1} J C^{-1} ⬭

C 4.0×10^{-7} J ⬭

D 4.0×10^{-7} J C^{-1} ⬭

1 8 Two charges **P** and **Q** are 100 mm apart.
X is a point on the line between **P** and **Q** where the electric potential is 0 V.



What is the distance from **P** to **X**?

[1 mark]

A 33 mm ⬭

B 40 mm ⬭

C 60 mm ⬭

D 67 mm ⬭

1 5 Two protons are separated by distance r.
The electrostatic force between the two protons is **X** times the gravitational force between them.

What is the best estimate for **X**?

[1 mark]

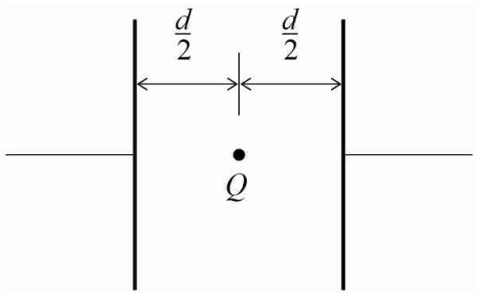
A 10^{20} ⬭

B 10^{28} ⬭

C 10^{36} ⬭

D 10^{42} ⬭

1 6 Two parallel metal plates separated by a distance d have a potential difference V across them. A particle with charge Q is placed midway between the plates.



What is the magnitude of the electrostatic force acting on the particle?

[1 mark]

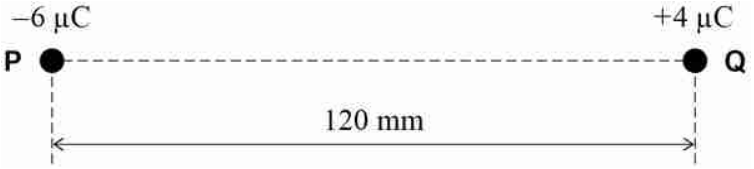
A zero ⬭

B $\frac{QV}{2d}$ ⬭

C $\frac{QV}{d}$ ⬭

D $\frac{2QV}{d}$ ⬭

1 7 Two charged particles **P** and **Q** are separated by a distance of 120 mm.
X is a point on the line between **P** and **Q** where the electric potential is zero.



What is the distance from **P** to **X**?

[1 mark]

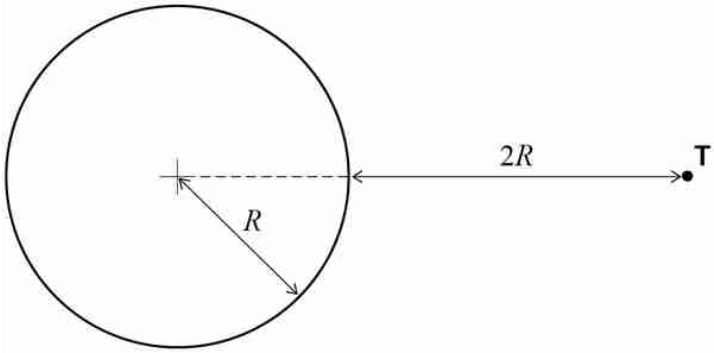
A 40 mm ⬭

B 48 mm ⬭

C 60 mm ⬭

D 72 mm ⬭

1 8 An isolated spherical conductor is charged.
The conductor has a radius R and an electric potential V. The electric field strength at its surface is E.



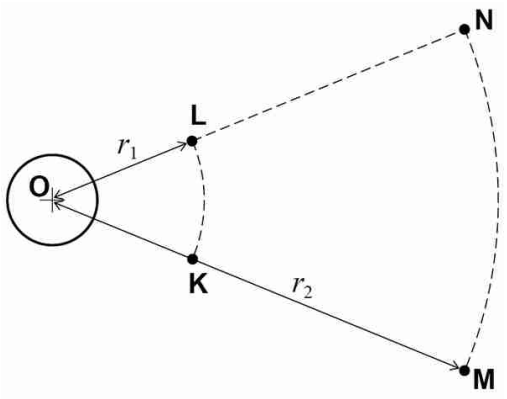
Point **T** is a distance $2R$ from the surface.

What are the electric field strength and electric potential at **T**?

[1 mark]

	Electric field strength	Electric potential	
A	$\frac{E}{2}$	$\frac{V}{4}$	⬭
B	$\frac{E}{3}$	$\frac{V}{9}$	⬭
C	$\frac{E}{4}$	$\frac{V}{2}$	⬭
D	$\frac{E}{9}$	$\frac{V}{3}$	⬭

1 9 **O** is the centre of a negatively charged sphere.



K and **L** are two points at a distance r_1 from **O**.
M and **N** are two points at a distance r_2 from **O**.

Which statement is true?

[1 mark]

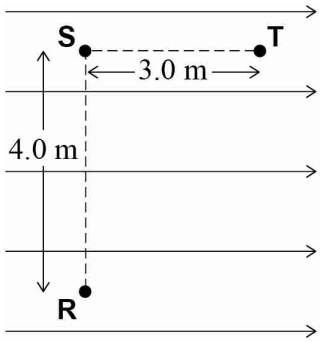
A The work done moving an electron from **M** to **K** is the same as that done moving an electron from **K** to **L**. ⬭

B The work done moving a positron from **K** to **M** is the same as that done moving an electron from **K** to **M**. ⬭

C No work is done moving an electron from **M** to **N**. ⬭

D No work is done moving a positron from **L** to **N**. ⬭

1 6 The diagram shows a uniform electric field of strength $15\ \text{V m}^{-1}$.
The length **RS** is perpendicular to the field and the line **ST** is parallel to the field.



What is the total change in electrical potential energy for a charge of $3.0\ \mu\text{C}$ moving from **R** to **T**?

[1 mark]

A $135\ \mu\text{J}$ ⬭

B $180\ \mu\text{J}$ ⬭

C $225\ \mu\text{J}$ ⬭

D $315\ \mu\text{J}$ ⬭

1 0 Two protons are separated by a distance of 1×10^{-9} m.

Which is an estimate of $\frac{\text{electric repulsion force}}{\text{gravitational attraction force}}$ for these two protons?

[1 mark]

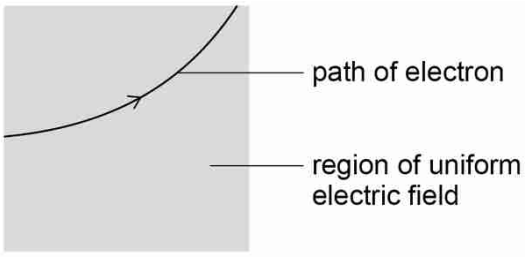
A 10^{18} ⬭

B 10^{28} ⬭

C 10^{36} ⬭

D 10^{45} ⬭

1 6 The diagram shows the path of an electron in a uniform electric field.
The electron moves in a vertical plane.



The direction of the electric field is

[1 mark]

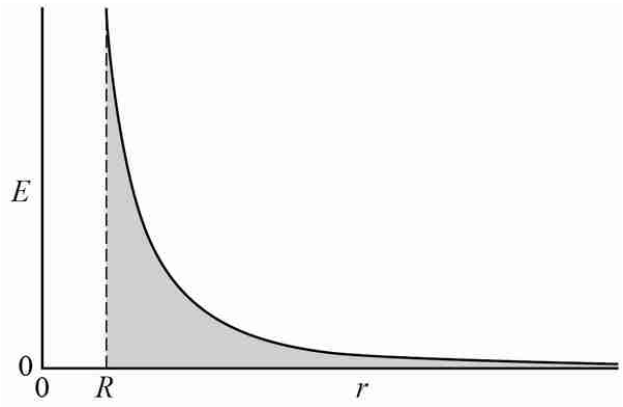
A vertically down the plane. ⬭

B vertically up the plane. ⬭

C horizontally into the plane. ⬭

D horizontally out of the plane. ⬭

1 7 The graph shows the variation of electric field strength E surrounding a charged sphere of radius R. The distance from the centre of the sphere is r.



The total area under the curve from R to infinity is

[1 mark]

A the capacitance of the sphere. ⬭

B the charge held on the sphere. ⬭

C the electric potential of the sphere. ⬭

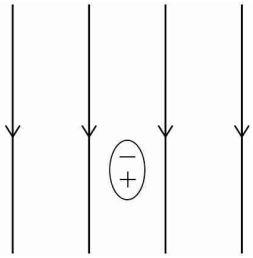
D the energy needed to remove an electron from the sphere. ⬭

1 8 A polar molecule is in an external electric field.

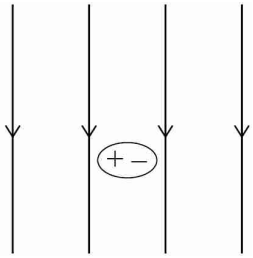
Which diagram shows the orientation of the polar molecule?

[1 mark]

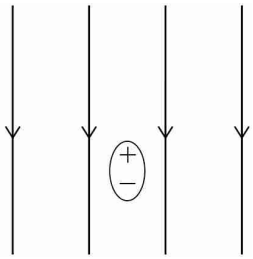
A



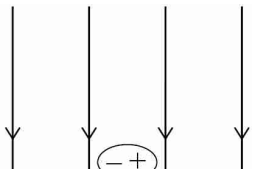
B



C



D



2 4 Which is equal to ε_0?

[1 mark]

A the relative permittivity of a vacuum ⬭

B the charge stored on a capacitor consisting of two parallel plates of area $1\ \text{m}^2$ separated by $1\ \text{m}$ when the potential difference between the plates is $1\ \text{V}$ ⬭

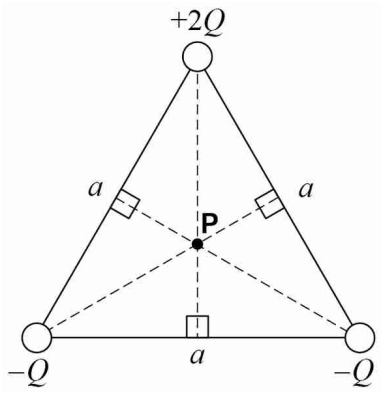
C the work done when moving a $2\ \text{C}$ charge from infinity to a distance of $\pi\ \text{m}$ from the centre of a metal sphere that carries $2\ \text{C}$ of charge ⬭

D the charge on a metal sphere which experiences a force of $1\ \text{N}$ when its centre is placed $1\ \text{m}$ from the centre of a metal sphere that carries $1\ \text{C}$ of charge ⬭

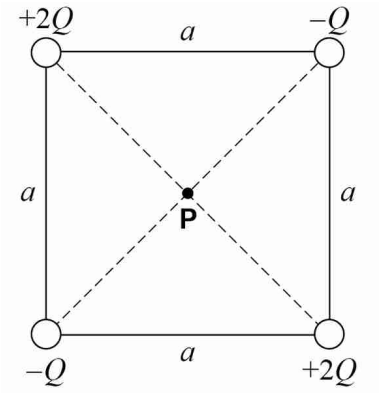
2 6 Which diagram shows a distribution of charge where the electric potential at **P** and the electric field at **P** are both zero?

[1 mark]

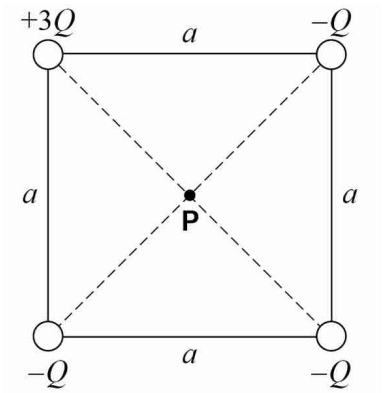
A



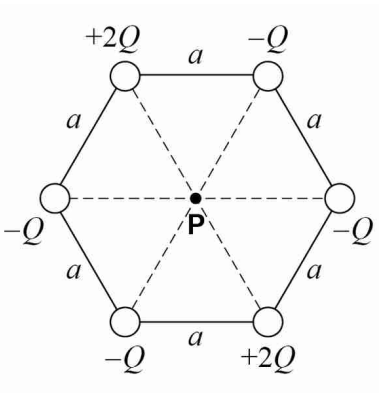
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

2 7 An ion has a specific charge of $-7.1 \times 10^{7}\ \text{C kg}^{-1}$.
It is held stationary in a vertical electric field on the surface of the Earth.

What are the magnitude and direction of the electric field?

[1 mark]

A $1.38 \times 10^{-7}\ \text{V m}^{-1}$ upwards ⬭

B $1.38 \times 10^{-7}\ \text{V m}^{-1}$ downwards ⬭

C $7.24 \times 10^{6}\ \text{V m}^{-1}$ upwards ⬭

D $7.24 \times 10^{6}\ \text{V m}^{-1}$ downwards ⬭

electrostatic force

2 8 Which particle pair has the largest magnitude of $\frac{\text{electrostatic force}}{\text{gravitational force}}$ when separated by the same distance?

[1 mark]

A an electron and a positive pion ⬭

B a helium nucleus and a proton ⬭

C a proton and a positive pion ⬭

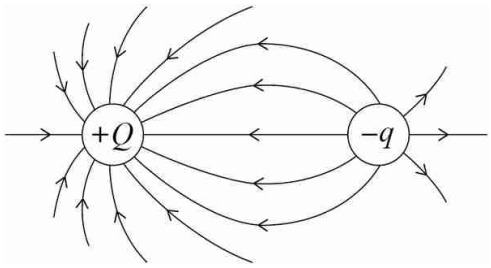
D a proton and an electron ⬭

1 1 Two charged metal spheres have charges $+Q$ and $-q$.
The magnitude of $+Q$ is greater than the magnitude of $-q$.

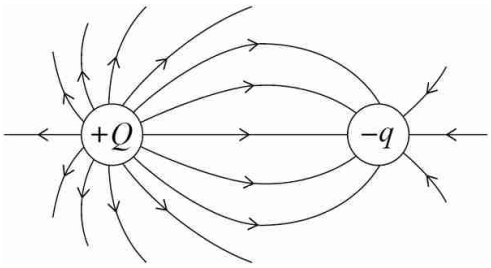
In which diagram are the electric field lines correct?

[1 mark]

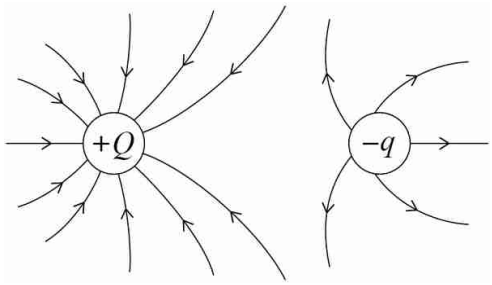
A



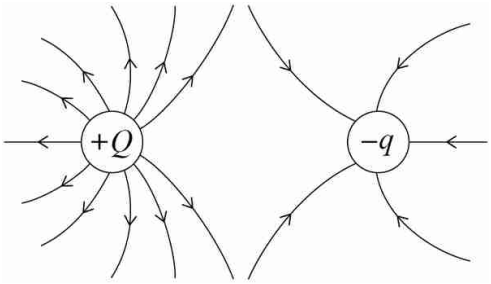
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

1 3 A particle has mass m and charge q.

The particle is moved a distance d through a potential difference V.

What is the change in electric potential energy?

[1 mark]

A qV ⬭

B $\frac{V}{q}$ ⬭

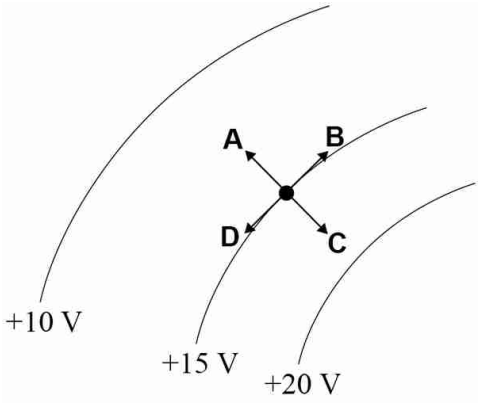
C $\frac{qV}{d}$ ⬭

D $\frac{V}{qm}$ ⬭

1 4 The diagram shows an electron in an electric field represented by equipotentials.

Which arrow shows the direction of the electric force on the electron?

[1 mark]



A ⬭

B ⬭

C ⬭

D ⬭

1 5 The diagram shows point charges **Q** and **q**.

Q and **q** have charges of opposite sign.

The magnitude of the charge of **Q** is greater than the magnitude of the charge of **q**.



The electric field strength is zero at one of the points **A**, **B**, **C** or **D**.

At which point is the electric field strength zero?

[1 mark]

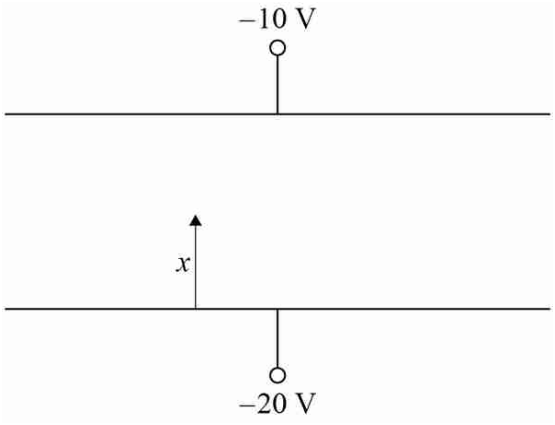
A ⬭

B ⬭

C ⬭

D ⬭

1 6 The diagram shows two parallel conducting plates at potentials of -20 V and -10 V.

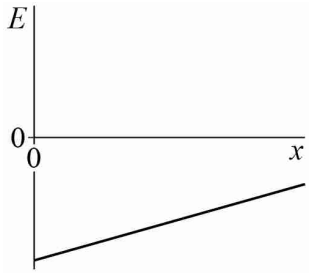


The displacement x is measured from the bottom (-20 V) plate.

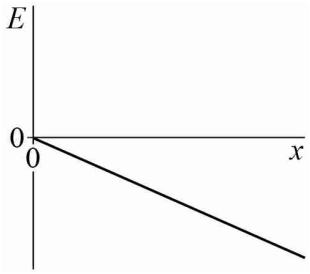
Which graph shows how the electric field strength E varies with x?

[1 mark]

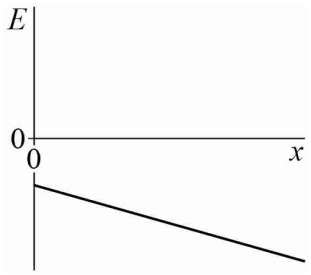
A



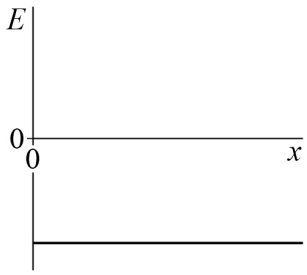
B



C



D



A ⬭

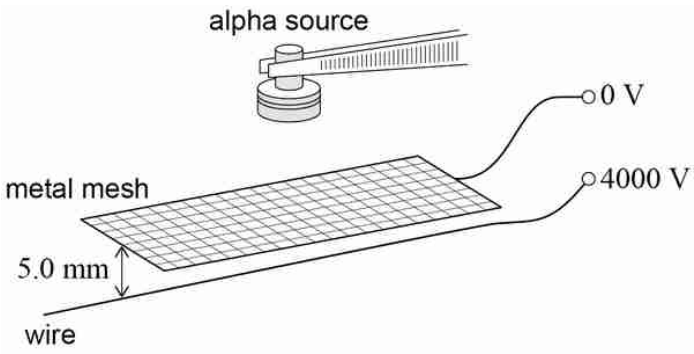
B ⬭

C ⬭

D ⬭

0 4 **Figure 4** shows a spark detector used to detect alpha particles.

Figure 4



The detector consists of a metal mesh placed $5.0\ \text{mm}$ above a wire.
A potential difference of $4000\ \text{V}$ is applied between the mesh and the wire.

Molecules in the air between the mesh and the wire are ionised by an alpha particle and a spark is produced.

Figure 5 shows equipotentials between the mesh and the wire.

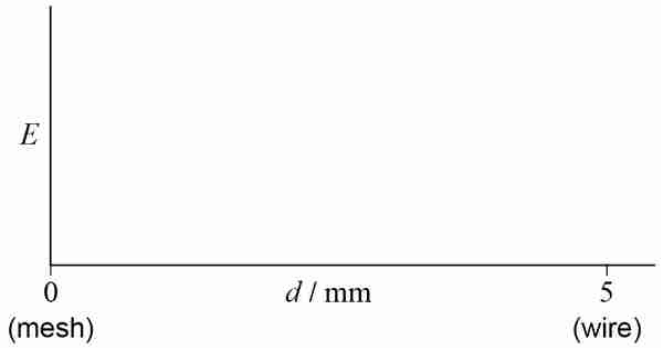
Figure 5

0 4 . 1 **Figure 5** shows a dashed line between the mesh and the wire.

Sketch on **Figure 6** a graph to show how the magnitude E of the electric field strength varies with the distance d from the mesh along this dashed line.
No values are required on the E axis.

[2 marks]

Figure 6



An alpha particle passes through the mesh.
The alpha particle ionises an argon atom at **P** on **Figure 5**, releasing one electron.
The electron and the argon ion have no kinetic energy at **P**.
The electron then travels to the wire and the argon ion travels to the mesh.

0 4 . 2 Calculate the ratio $\frac{\text{speed of electron when it reaches the wire}}{\text{speed of argon ion when it reaches the mesh}}$.

Assume that the air has no effect on the motion of the electron or on the motion of the argon ion.

mass of argon ion $= 6.64 \times 10^{-26}$ kg

[2 marks]

ratio = _____

Question 4 continues on the next page

0 4 . 3 In practice, the air **does** affect the motion of the electron and the motion of the argon ion.

Suggest how the presence of air between the mesh and the wire changes the ratio in Question **04.2**.
No numerical detail is required.

[1 mark]

0 4 . 4 The alpha source in **Figure 4** is moved to different heights h above the mesh.

Figure 7 shows how the number of sparks N produced in 10 minutes varies with h.
No sparks are produced when the source is not present.

Figure 7

Student **A** suggests that the spark rate obeys an inverse-square law.
Student **B** suggests that the spark rate decreases exponentially with h.

Determine whether either student is correct.

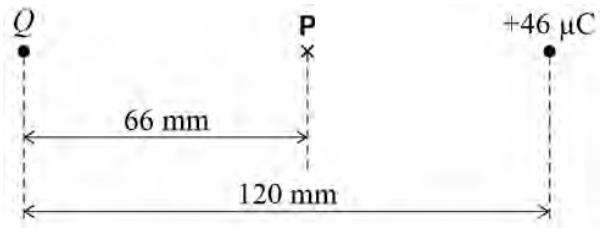
[3 marks]

0 2 . 1 Define the electric field strength at a point in an electric field.

[2 marks]

0 2 . 2 **Figure 2** shows a point charge of +46 μC placed 120 mm from a point charge Q.

Figure 2



Position **P** is on the line joining the charges at a distance 66 mm from charge Q.
The resultant electric field strength at position **P** is zero.

Calculate the charge Q.

[3 marks]

Q = _____ C

0 2 . 3 Explain, without calculation, whether net work must be done in moving a proton from infinity to position **P** in **Figure 2**.

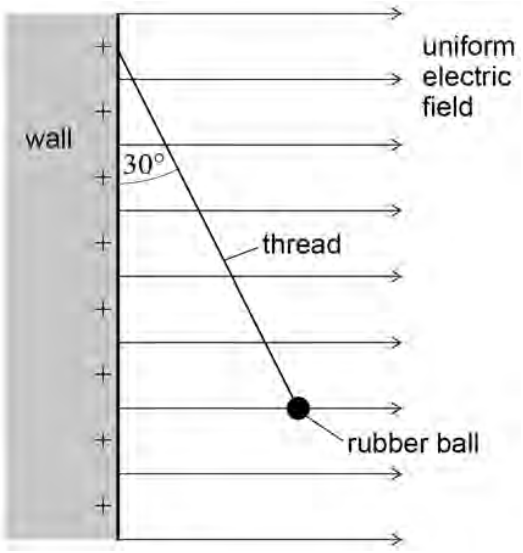
[2 marks]

Question 2 continues on the next page

0 2 . 4 A small rubber ball coated with a conducting paint carries a positive charge. The ball is suspended in equilibrium from a vertical wall by an uncharged non-conducting thread of negligible mass. The wall is positively charged and produces a horizontal uniform electric field perpendicular to the wall along the whole of its length.

Figure 3 shows that the thread makes an angle of 30° to the wall.

Figure 3



The thread breaks.

Explain the motion of the ball.

[2 marks]

0 3 An isolated solid conducting sphere is initially uncharged.
Electrons are then transferred to the sphere.

0 3 . 1 State and explain the location of the excess electrons.

[2 marks]

Figure 3 shows how the electric potential V varies with distance r from the centre of the sphere.
The radius of the sphere is 0.10 m.

Figure 3

0 3 . 2 The magnitude of the electric field strength E is related to V by $E = \frac{\Delta V}{\Delta r}$.

Determine, using this relationship, the magnitude of the electric field strength at a distance $0.30\ \text{m}$ from the centre of the sphere.

State an appropriate SI unit for your answer.

[4 marks]

electric field strength = _____ unit _____

0 3 . 3 The sphere acts as a capacitor because it stores charge at an electric potential.

Show that the capacitance of the sphere is approximately $1 \times 10^{-11}\ \text{F}$.

[3 marks]

Question 3 continues on the next page

0 3 . 4 Electrons leak away from the sphere with time and the amount of energy stored by the sphere decreases. At one instant, the magnitude of the electric potential of the sphere has fallen to 1.0×10^6 V.

Calculate, for this instant, the change in the energy stored by the sphere.

[3 marks]

change in energy = _____ J

0 6 . 1 The electric potential at a point in an electric field is $-4.0\ \text{V}$.

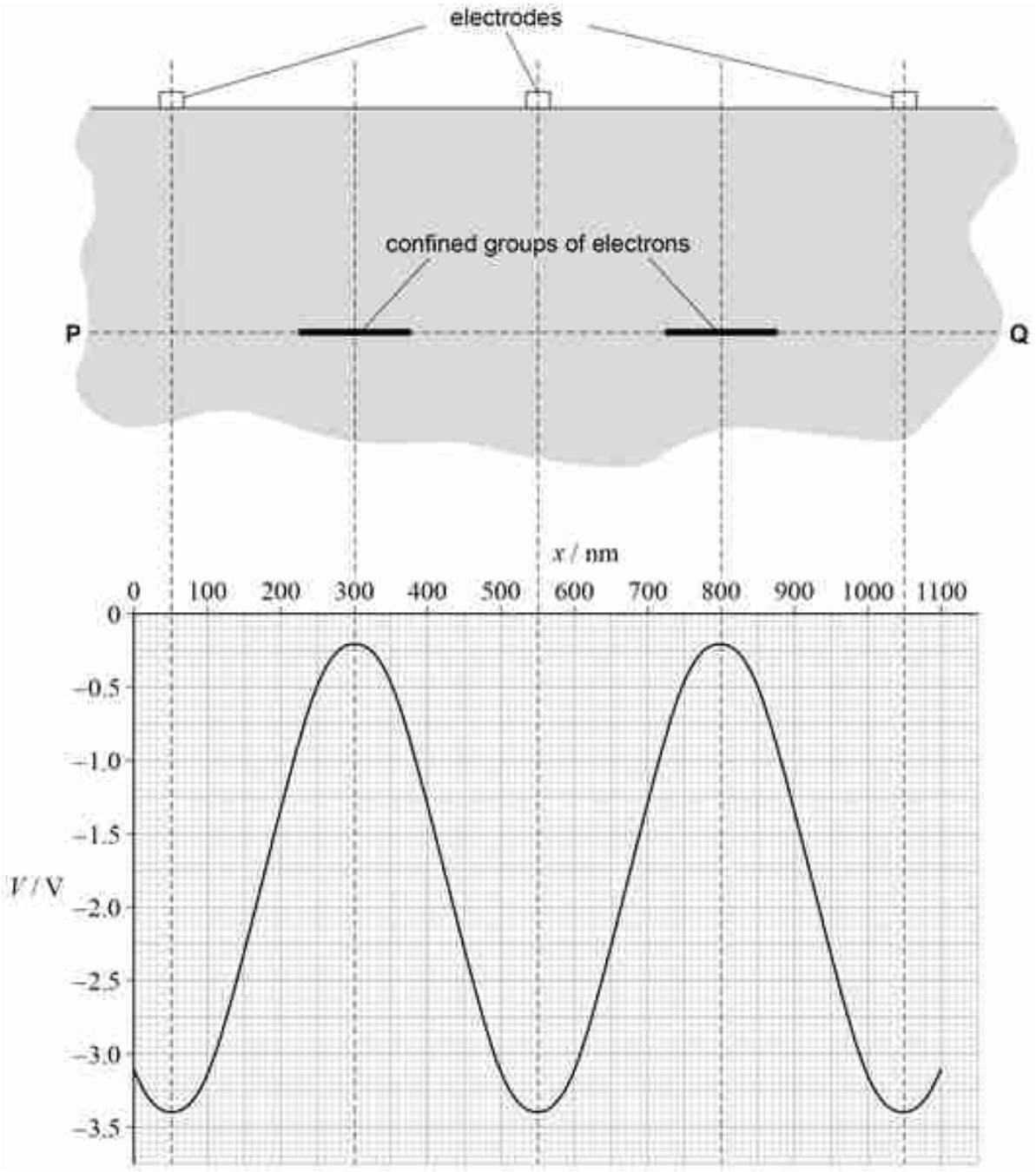
Explain what is meant by this statement.

[3 marks]

Question 6 continues on the next page

Figure 9 shows an arrangement for confining groups of electrons to small regions inside a block of gallium arsenide.

Figure 9



Electrons can only move along the line **PQ** in the block.

When a suitable electric potential is applied to the electrodes, the electrons are confined to the regions shown in **Figure 9**.

The graph in **Figure 9** shows how the electric potential V varies with distance x along **PQ**.

0 6 . 2 Determine, using the graph in **Figure 9**, the maximum magnitude of the electric field. State an appropriate unit for your answer.

[4 marks]

maximum magnitude = _____ unit _____

0 6 . 3 An electron at rest at $x = 300$ nm gains kinetic energy and moves to $x = 800$ nm.

Determine the minimum kinetic energy required by the electron.

[2 marks]

minimum kinetic energy = _____ J

Question 6 continues on the next page

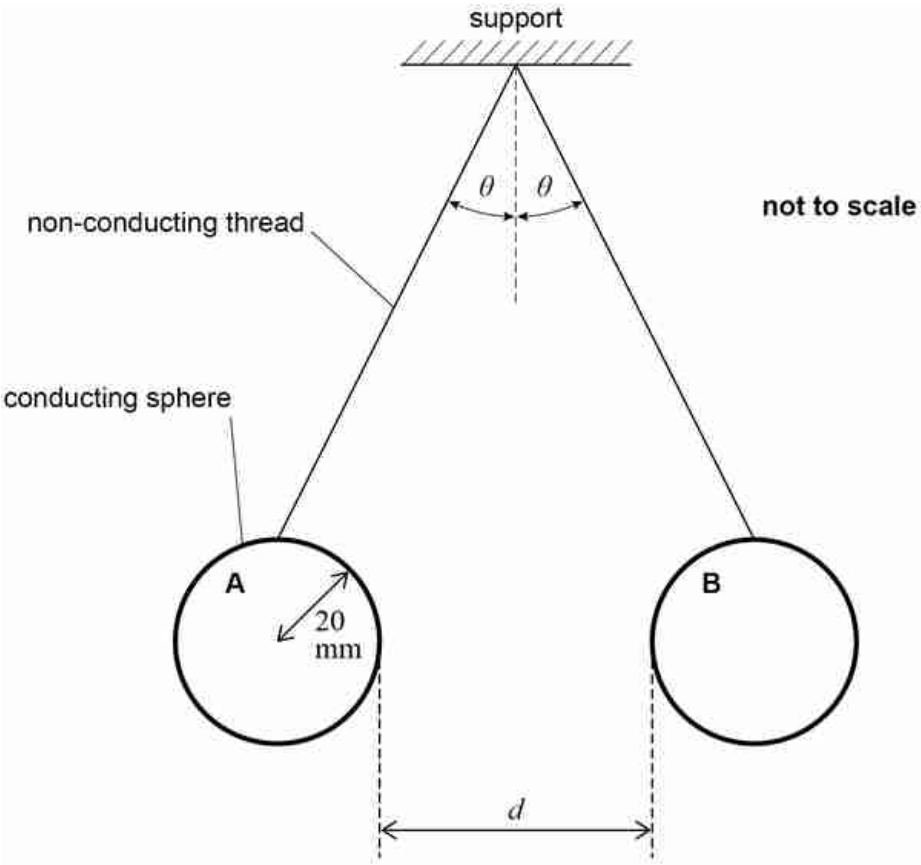
0 6 . 4 One of the confined electrons is at $x = 350$ nm.

Discuss the subsequent motion of this electron due to the variation in electric potential shown in **Figure 9**.
Assume that the electron starts from rest.

[3 marks]

0 4 **Figure 3** shows an arrangement used to investigate the repulsive forces between two identical charged conducting spheres.
The spheres are suspended by non-conducting thread.

Figure 3



Each sphere has a mass of 3.2×10^{-3} kg and a radius of 20 mm.
The distance d is 40 mm.

The capacitance of a sphere of radius r is $4\pi\varepsilon_0 r$.

Each sphere is charged by connecting it briefly to the positive terminal of a high-voltage supply, the other terminal of which is at 0 V.
After this has been done the charge on each sphere is 52 nC.

0 4 . 1 Calculate the potential of one of the spheres.

[3 marks]

potential = _____ V

0 4 . 2 The charged spheres in **Figure 3** are at equilibrium.

Draw labelled arrows on **Figure 3** to show the forces on sphere **B**.

[2 marks]

0 4 . 3 Suggest a solution to **one** problem involved in the measurement of d in **Figure 3**.

[2 marks]

_____

_____

_____

_____

_____

_____

Question 4 continues on the next page

0 4 . 4 Show that the magnitude of the electrostatic force on each sphere is about 4×10^{-3} N.

[3 marks]

0 4 . 5 A student measures the angle θ when the apparatus in **Figure 3** is at equilibrium. The student records θ as $7°$.

Discuss whether this measurement is consistent with the other data in this investigation.

[2 marks]

0 4 . 6 The student says that the gravitational force between the two spheres has no **significant** effect on the angle at which the spheres are in equilibrium.

Deduce with a calculation whether this statement is valid.

[2 marks]

SUB-TOPIC 3.7.4

CAPACITANCE

Sub-topic 3.7.4 · 30 questions · 84 marks · lowest tariff first

1 8 A parallel-plate capacitor is fully charged and then disconnected from the power supply. A dielectric is then inserted between the plates.

Which row correctly identifies the charge on the plates and the electric field strength between the plates?

[1 mark]

	Charge	Electric field strength	
A	Stays the same	Increases	⬭
B	Increases	Decreases	⬭
C	Increases	Increases	⬭
D	Stays the same	Decreases	⬭

1 9 A capacitor of capacitance C has a charge of Q stored on the plates. The potential difference between the plates is doubled.

What is the change in the energy stored by the capacitor?

[1 mark]

A $\frac{Q^2}{2C}$ ⬭

B $\frac{Q^2}{C}$ ⬭

C $\frac{3Q^2}{2C}$ ⬭

D $\frac{2Q^2}{C}$ ⬭

2 0 A capacitor consists of two parallel square plates of side l separated by distance d. The capacitance of the arrangement is C.

What is the capacitance of a capacitor with square plates of side $2l$ separated by a distance $\frac{d}{2}$?

[1 mark]

A C ⬭

B $2C$ ⬭

C $4C$ ⬭

D $8C$ ⬭

2 1 A capacitor of capacitance $120\ \mu F$ is charged and then discharged through a $20\ k\Omega$ resistor.

What fraction of the original charge remains on the capacitor $4.8\ s$ after the discharge begins?

[1 mark]

A 0.14 ⬭

B 0.37 ⬭

C 0.63 ⬭

D 0.86 ⬭

2 3 An air-filled parallel-plate capacitor is charged from a source of emf. The electric field has a strength E between the plates. The capacitor is disconnected from the source of emf and the separation between the isolated plates is doubled.

What is the final electric field between the plates?

[1 mark]

A $2E$ ⬭

B E ⬭

C $\frac{E}{2}$ ⬭

D $\frac{E}{4}$ ⬭

2 4 A parallel-plate capacitor has square plates of length l separated by distance d and is filled with a dielectric.

A second capacitor has square plates of length $2l$ separated by distance $2d$ and has air as its dielectric.

Both capacitors have the same capacitance.

What is the relative permittivity of the dielectric in the first capacitor?

[1 mark]

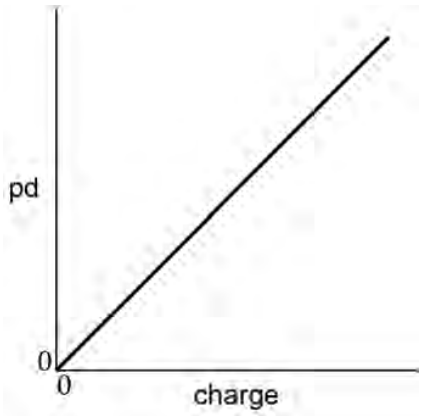
A $\frac{1}{2}$ ⬭

B 1 ⬭

C 2 ⬭

D 8 ⬭

2 5 The graph shows the variation of potential difference (pd) with charge for a capacitor while it is charging.



Which statement can be deduced from the graph?

[1 mark]

A The charging current is constant. ⬭

B The energy stored in the capacitor increases uniformly with time. ⬭

C The capacitance of the capacitor is constant. ⬭

D The power supply used to charge the capacitor had a constant terminal pd. ⬭

1 9 A parallel-plate capacitor is made by inserting a sheet of dielectric material between two plates. Both plates are in contact with the sheet.

Which relative permittivity and sheet thickness give the greatest capacitance?

[1 mark]

	Relative permittivity	Thickness / mm	
A	2	0.40	⬭
B	3	0.90	⬭
C	4	1.0	⬭
D	6	1.6	⬭

2 0 A $1.0\ \mu F$ capacitor is charged for $20\ s$ using a constant current of $10\ \mu A$.

What is the energy transferred to the capacitor?

[1 mark]

A $5.0 \times 10^{-3}\ J$ ⬭

B $1.0 \times 10^{-2}\ J$ ⬭

C $2.0 \times 10^{-2}\ J$ ⬭

D $4.0 \times 10^{-2}\ J$ ⬭

2 1 A $1.0\ \mu F$ capacitor initially stores $15\ \mu C$ of charge. It then discharges through a $25\ \Omega$ resistor.

What is the maximum current during the discharge of the capacitor?

[1 mark]

A $0.60\ mA$ ⬭

B $1.2\ mA$ ⬭

C $0.60\ A$ ⬭

D $1.2\ A$ ⬭

2 2 The initial potential difference across a capacitor is V_0. The capacitor discharges through a circuit of time constant T. The base of natural logarithms is e.

What is the potential difference across the capacitor after time T?

[1 mark]

A $\frac{V_0}{2}$ ⬭

B $\frac{V_0}{\mathrm{e}}$ ⬭

C $V_0\,\mathrm{e}$ ⬭

D $V_0 \ln 2$ ⬭

1 9 An uncharged capacitor is connected to a power supply which supplies a constant current of $10\ \mu A$.

After $100\ ms$, the potential difference across the capacitor is $5.0\ kV$.

What is the capacitance of the capacitor?

[1 mark]

A $2.0 \times 10^{-10}\ F$ ⬭

B $4.0 \times 10^{-10}\ F$ ⬭

C $2.5 \times 10^{9}\ F$ ⬭

D $5.0 \times 10^{9}\ F$ ⬭

2 0 When a parallel-plate capacitor is connected across a battery, the energy stored in the capacitor is W.

The battery remains connected as the distance between the capacitor plates is halved.

What is the energy now stored in the capacitor?

[1 mark]

A $0.5W$ ⬭

B W ⬭

C $2W$ ⬭

D $4W$ ⬭

2 1 A parallel-plate capacitor is made using a sheet of dielectric material between, and in contact with, two plates.
The properties of four sheets of dielectric material are shown.

Which sheet will produce the maximum capacitance?

[1 mark]

Sheet	Relative permittivity	Thickness / mm	
A	2	0.40	⬭
B	3	0.90	⬭
C	4	1.0	⬭
D	6	1.6	⬭

2 2 A 10 μF capacitor stores 4.5 mJ of energy.
It then discharges through a 25 Ω resistor.

What is the maximum current during the discharge of the capacitor?

[1 mark]

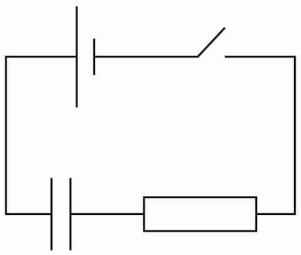
A 1.2 A ⬭

B 18 A ⬭

C 30 A ⬭

D 36 A ⬭

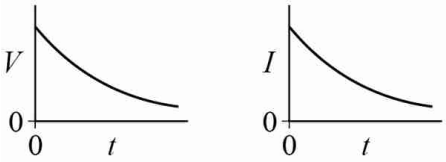
2 0 The capacitor in the circuit is initially uncharged.
The switch is closed at time $t = 0$



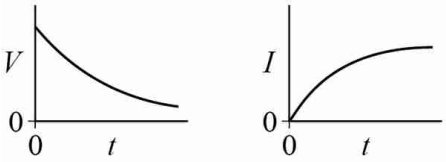
Which pair of graphs shows how the potential difference V across the capacitor and the current I in the circuit change with time t?

[1 mark]

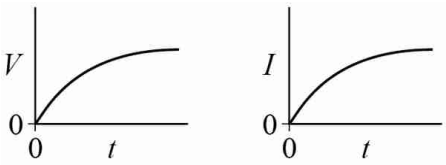
A



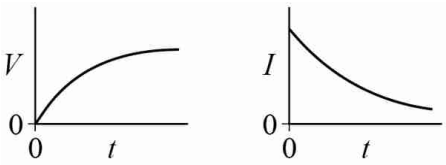
B



C



D



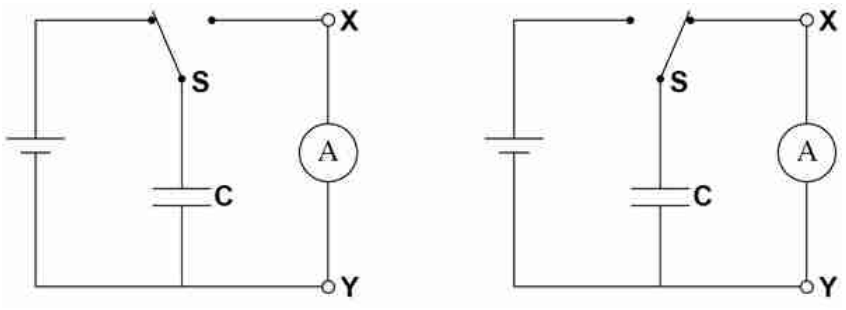
A ⬭

B ⬭

C ⬭

D ⬭

1 7 A switch **S** allows capacitor **C** to be completely charged by a cell and then completely discharged through an ammeter.
The emf of the cell is $4.0\ \text{V}$ and it has negligible internal resistance.
The capacitance of **C** is $0.40\ \mu\text{F}$ and there are 8000 charge–discharge cycles every second.



charging discharging

What are the magnitude and direction of the average conventional current in the ammeter?
[1 mark]

	Magnitude of current / A	Direction of current	
A	1.3×10^{-2}	**X** to **Y**	⬭
B	1.3×10^{-2}	**Y** to **X**	⬭
C	2.0×10^{-10}	**X** to **Y**	⬭
D	2.0×10^{-10}	**Y** to **X**	⬭

1 8 A $30\ \mu\text{F}$ capacitor is charged by connecting it to a battery of emf $4.0\ \text{V}$.
The initial charge on the capacitor is Q_0.

The capacitor is then discharged through a $500\ \text{k}\Omega$ resistor.
The time constant for the circuit is T.

Which is correct?

[1 mark]

A T is $15\ \text{ms}$. ⬭

B Q_0 is $12\ \mu\text{C}$. ⬭

C After a time T the pd across the capacitor is $1.5\ \text{V}$. ⬭

D After a time $2T$ the charge on the capacitor is $Q_0 e^2$. ⬭

1 9 Capacitor **X** of capacitance C has square plates of side length l and separation d and is made with a dielectric of relative permittivity ε.

Capacitor **Y** has square plates of side length $3l$ and separation $\frac{d}{3}$ and is made with a dielectric of relative permittivity $\frac{\varepsilon}{3}$.

What is the capacitance of **Y**?

[1 mark]

A $\frac{C}{27}$ ⬭

B $\frac{C}{9}$ ⬭

C $9C$ ⬭

D $27C$ ⬭

2 0 A parallel plate capacitor is connected across a battery and the energy stored in the capacitor is E.
Without disconnecting the battery, the separation of the plates is halved.

What is the energy now stored in the capacitor?

[1 mark]

A $0.5E$ ⬭

B E ⬭

C $2E$ ⬭

D $4E$ ⬭

2 1 A fully charged capacitor of capacitance $2.0\ \text{mF}$ discharges through a $15\ \text{k}\Omega$ resistor.

What fraction of the stored energy remains after 1.0 minute?

[1 mark]

A $\frac{1}{4}$ ⬭

B $\frac{1}{e^2}$ ⬭

C $\frac{1}{16}$ ⬭

D $\frac{1}{e^4}$ ⬭

1 1 An air-filled parallel-plate capacitor and a resistor are connected in series across the terminals of a battery.
The plates of the capacitor are then moved further apart.

This change results in

[1 mark]

A a decrease in the potential difference across the capacitor plates. ⬭

B a decrease in the charge held on the capacitor plates. ⬭

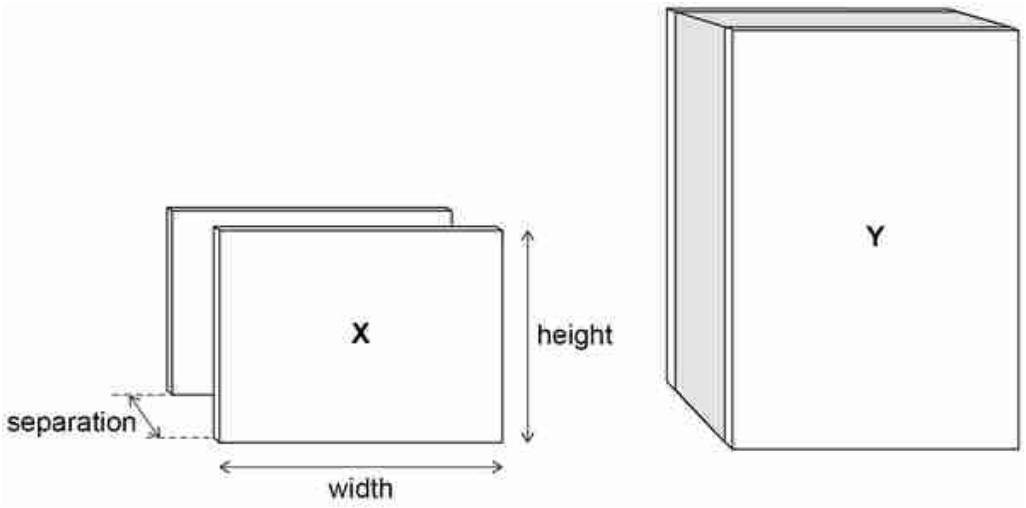
C an increase in the energy stored on the capacitor. ⬭

D an increase in the capacitance of the capacitor. ⬭

1 7 A parallel-plate capacitor **X** with the plates separated by air has a capacitance of $100\ \mu F$.

Another parallel-plate capacitor **Y** has plates that are double the height of the plates of **X**.

The plates of **Y** have the same separation and the same width as the plates of **X**.
The space between the plates of **Y** is filled with a material of dielectric constant 3.0



What is the capacitance of **Y**?

[1 mark]

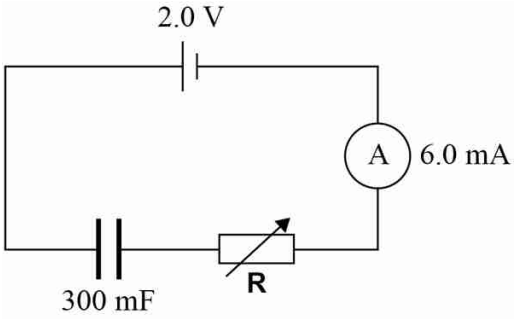
A $67\ \mu F$ ⬭

B $150\ \mu F$ ⬭

C $600\ \mu F$ ⬭

D $1200\ \mu F$ ⬭

1 8 A capacitor is initially uncharged and is then charged using a constant current. This is achieved by reducing the resistance of a variable resistor **R** as the charge on the capacitor increases.



The capacitor has a capacitance of 300 mF and is fully charged in a time $t = 100$ s.
The cell has an emf of 2.0 V and negligible internal resistance.
The charging current is 6.0 mA.

What is the resistance of **R** at $t = 30$ s?

[1 mark]

A 58 Ω ⬭

B 100 Ω ⬭

C 233 Ω ⬭

D 333 Ω ⬭

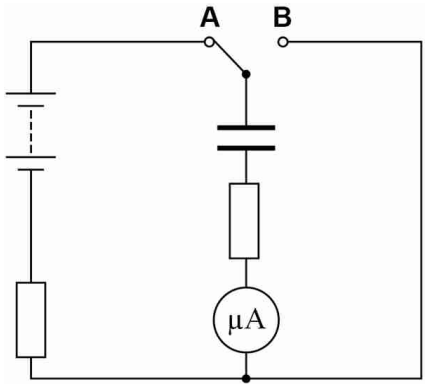
0 5 . 1 A material used between the plates of a capacitor has a dielectric constant of 7.0

State what is meant by a dielectric constant of 7.0

[1 mark]

Figure 3 shows a circuit that is used to charge and discharge a capacitor.

Figure 3



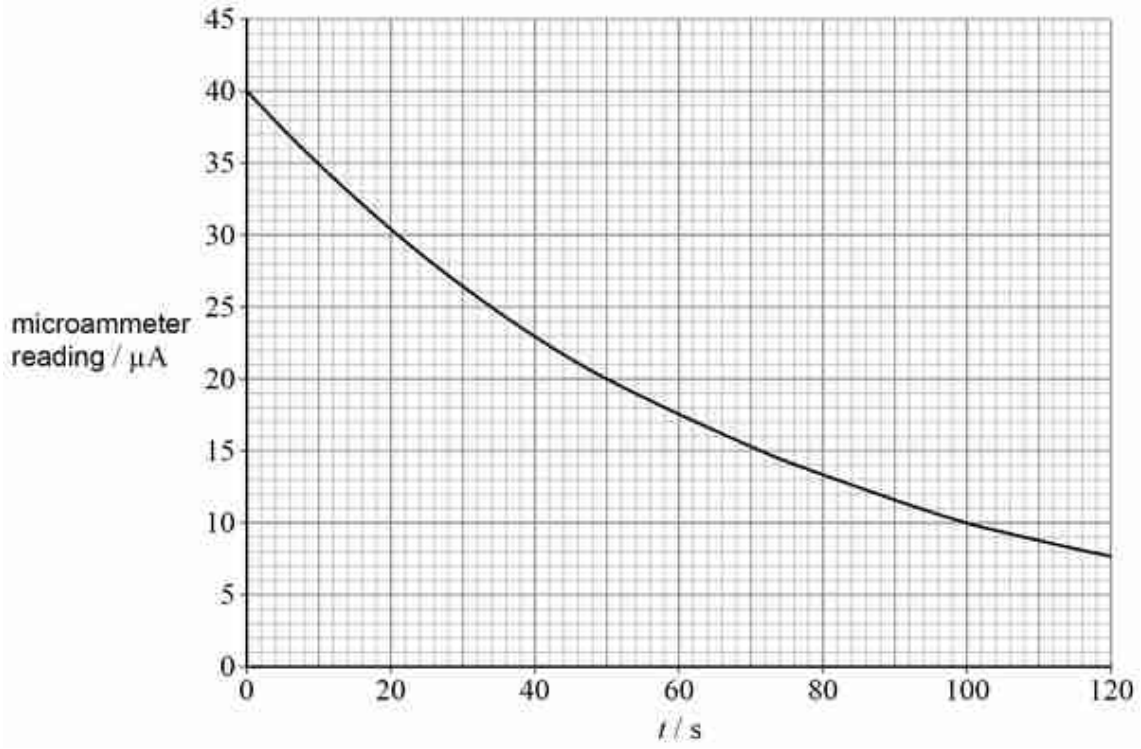
The battery has negligible internal resistance.

The two resistors in the circuit are identical.

The capacitor is fully charged and the switch is then moved from position **A** to position **B** at time $t = 0$

Figure 4 shows the variation of the microammeter reading with t until $t = 120$ s.

Figure 4



The time constant of the discharging circuit is T.

0 5 . 2 Determine T using **Figure 4**.

[2 marks]

$T =$ _____ s

0 5 . 3 Electronic engineers consider a capacitor to be fully discharged when $t = 5T$.

Calculate $\frac{\text{current when } t = 5T}{\text{current when } t = 0}$ as a percentage.

[2 marks]

$\frac{\text{current when } t = 5T}{\text{current when } t = 0} =$ _____ %

0 5 . 4 The capacitor is fully discharged and then the switch is moved from position **B** to position **A** as shown in **Figure 3**.

Draw, on **Figure 5**, the variation of the microammeter reading with time after the switch is moved to position **A**.
In **Figure 5**, the time is 0 at the instant when the switch is moved to position **A**.

[3 marks]

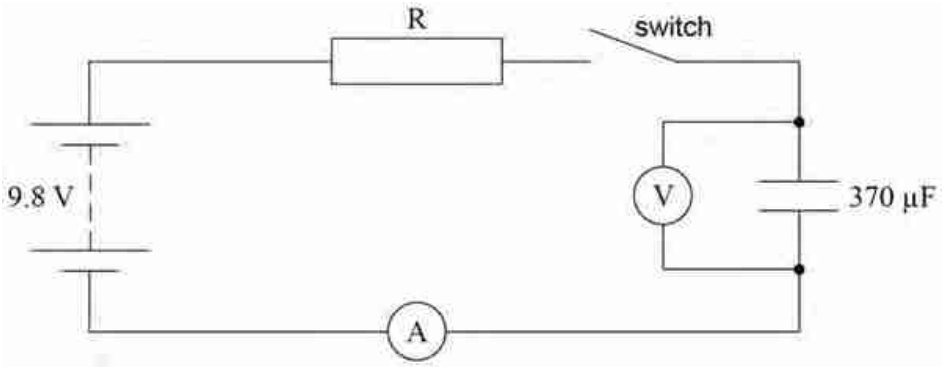
Figure 5

0 3 . 1 State what is meant by a capacitance of $370\ \mu F$

[2 marks]

0 3 . 2 The charging of a $370\ \mu F$ capacitor is investigated using the circuit shown in **Figure 4**. Both meters in the circuit are ideal.

Figure 4



The power supply of emf $9.8\ V$ has a negligible internal resistance. The capacitor is initially uncharged. When the switch is closed at time $t = 0$ charge begins to flow through resistor R. The time constant of the charging circuit is $1.0\ s$

Calculate the resistance of R.

[1 mark]

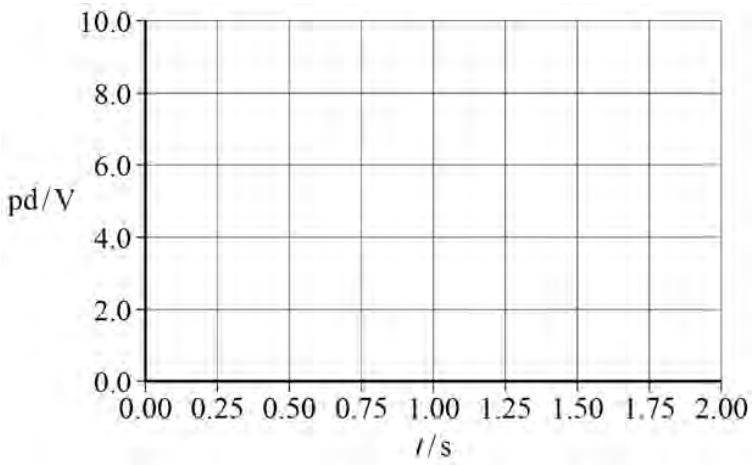
resistance of R = _____ Ω

Question 3 continues on the next page

0 3 . 3 Identify, with the symbol X on **Figure 5**, the potential difference (pd) across the capacitor when the switch has been closed for 2.0 s
Sketch the graph that shows how the pd varies from $t = 0$ to $t = 2.0$ s

[2 marks]

Figure 5



0 3 . 4 Calculate the time taken for the charging current to fall to half its initial value.

[1 mark]

time = _____ s

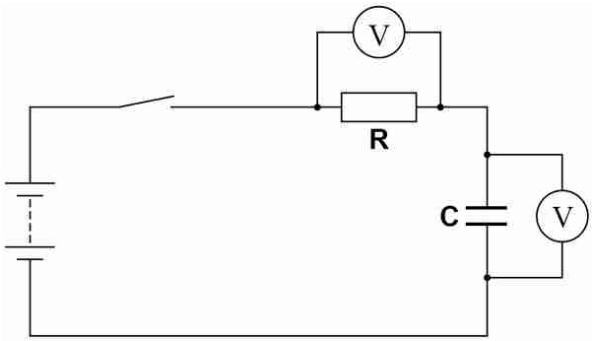
0 3 . 5 Calculate the time taken for the charge on the capacitor to reach $3.0\ \text{mC}$

[3 marks]

time = _____ s

0 2 **Figure 1** shows a circuit used to charge capacitor **C**.
The battery has negligible internal resistance.

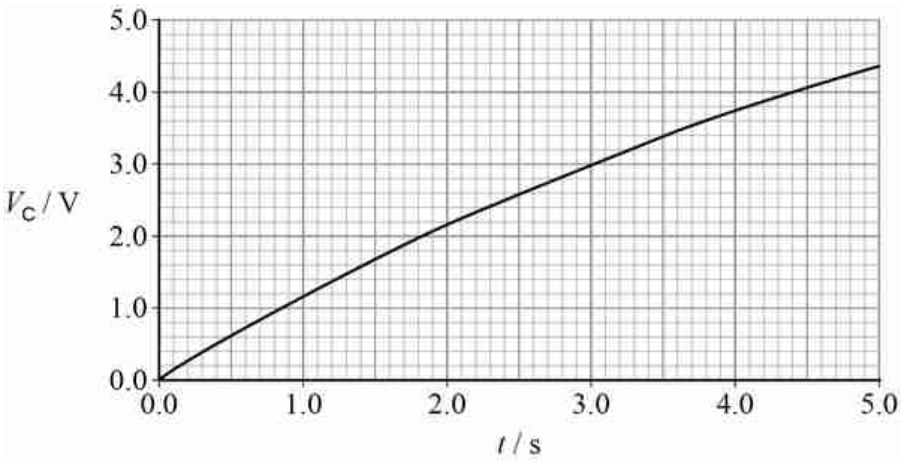
Figure 1



The capacitance of **C** is known.

0 2 . 1 The switch is closed at time $t = 0$ and the potential difference V_C across **C** is recorded at different times t.
Figure 2 shows the variation of V_C with t.

Figure 2

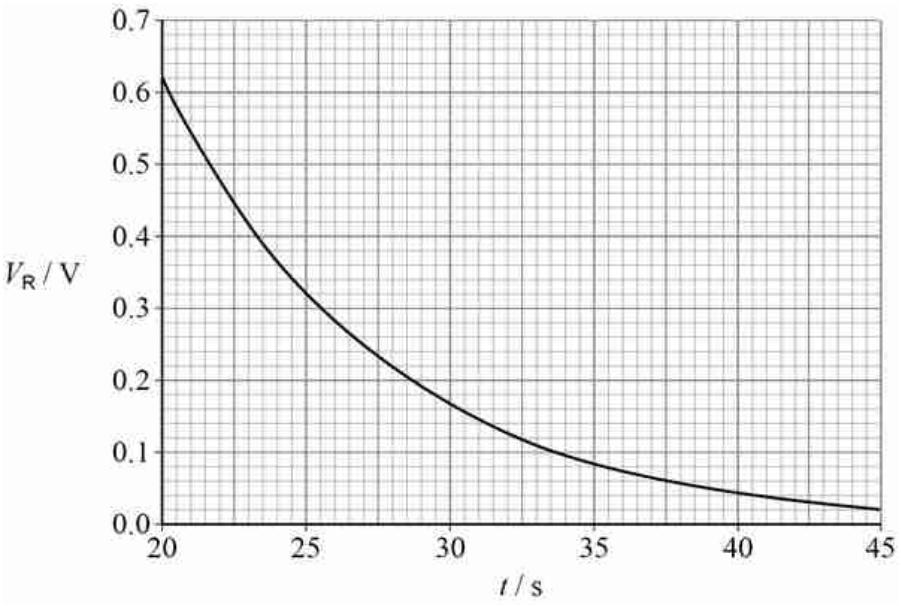


Explain how a gradient of the graph in **Figure 2** can be used to determine the initial current I_0 in the circuit.

[2 marks]

0 2 . 2 The potential difference V_R across **R** is also recorded.
Figure 3 shows the variation of V_R with t between $t = 20$ s and $t = 45$ s.

Figure 3



The capacitance of **C** is $31.0\ \mu F$.

Determine, using **Figure 3**, the time constant of the circuit.
Go on to show that the resistance of **R** is about $2.4 \times 10^5\ \Omega$.

[2 marks]

time constant = _____ s

resistance = _____ Ω

Question 2 continues on the next page

0 2 . 3 The current I_0 at time $t = 0$ is 3.6×10^{-5} A.

Determine the time at which V_C is 6.0 V.

[3 marks]

time = _____ s

0 2 . 4 **Figure 4** shows two fully charged parallel-plate capacitors **C**$_1$ and **C**$_2$ in a circuit.
A dielectric fills the space between the plates of **C**$_1$ and air fills the space between the plates of **C**$_2$.

Figure 4

Table 2 gives information about $\mathbf{C_1}$ and $\mathbf{C_2}$.

Table 2

	$\mathbf{C_1}$	$\mathbf{C_2}$
charge	Q	Q
surface area	S	S
potential difference	V_1	V_2
plate separation	d	$2d$
dielectric constant	4.0	1.0

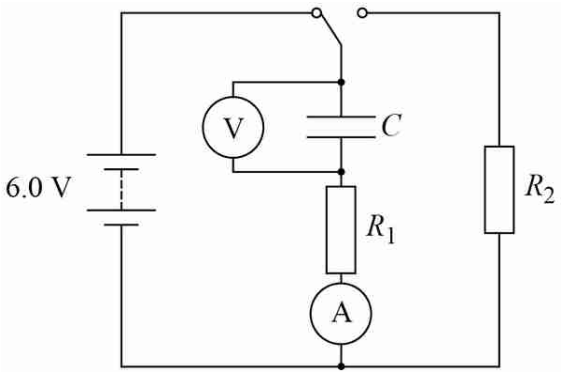
Determine $\frac{V_1}{V_2}$.

[2 marks]

$\frac{V_1}{V_2} =$ _____

0 5 **Figure 8** shows a circuit used to investigate the charge and discharge of a capacitor of capacitance C using resistors of resistances R_1 and R_2.

Figure 8



The battery has an emf of 6.0 V and negligible internal resistance.

0 5 . 1 Show that the time taken for the capacitor to charge from 2.0 V to 4.0 V is approximately $0.7R_1C$.

[3 marks]

Question 5 continues on the next page

The capacitor is fully discharged.
The capacitor is then charged until the potential difference (pd) across it is $4.0\ \text{V}$.
Figure 9 shows the variation with time of the ammeter reading as the capacitor is charged.

Figure 9

0 5 . 2 Show that the capacitance of the capacitor is about 1×10^{-4} F.

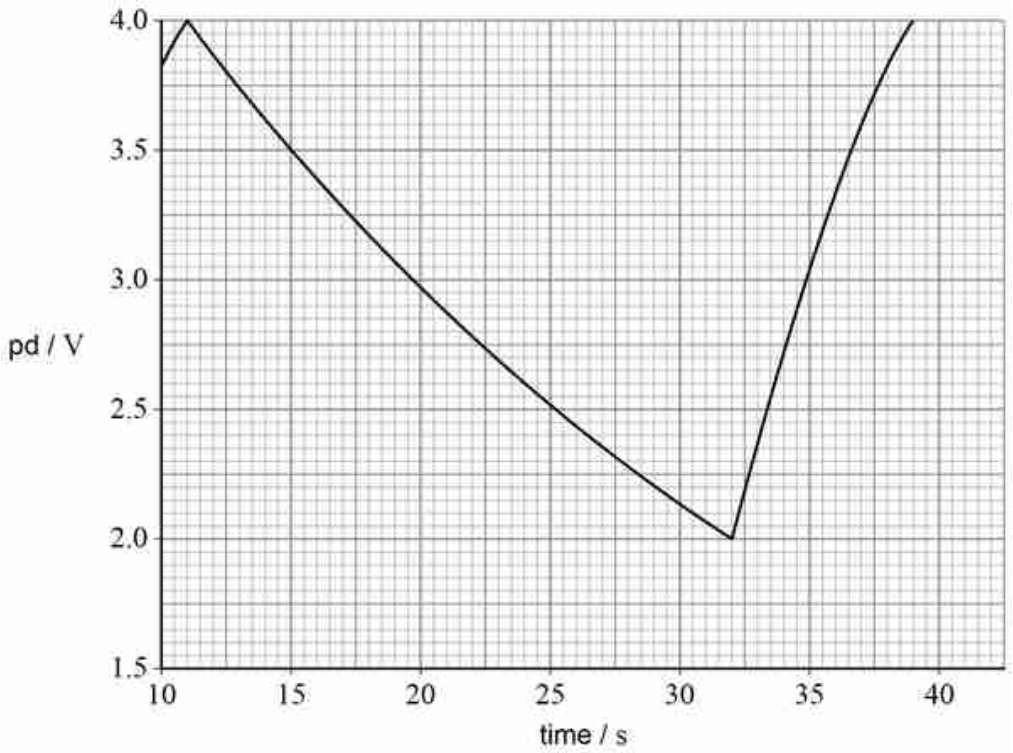
[4 marks]

Question 5 continues on the next page

0 5 . 3 When the pd reaches $4.0\ \text{V}$ the switch is immediately set to discharge the capacitor. When the pd reaches $2.0\ \text{V}$ the switch is immediately set to charge the capacitor.

Figure 10 shows how the pd across the capacitor varies with time.

Figure 10



Determine the value of R_2.

[3 marks]

$R_2 =$ _____ Ω

0 1 A capacitor of capacitance $63\ \text{pF}$ is made from two parallel metal plates separated by an air gap.
The capacitor is charged so that it stores a charge of $7.6 \times 10^{-10}\ \text{C}$; it is then isolated.

A sheet of mica of dielectric constant 6.0 is inserted between the plates so that it completely fills the space between them. The mica does not discharge the capacitor and does not change the separation of the plates.

0 1 . 1 Explain what is meant by a dielectric constant of 6.0

[1 mark]

0 1 . 2 Mica is made up of polar molecules. As the mica is inserted, the capacitance of the capacitor changes.

Explain how the polar molecules cause this change in capacitance.

[3 marks]

0 1 . 3 Calculate the difference between the initial energy stored by the capacitor and the energy stored when the mica has been fully inserted.

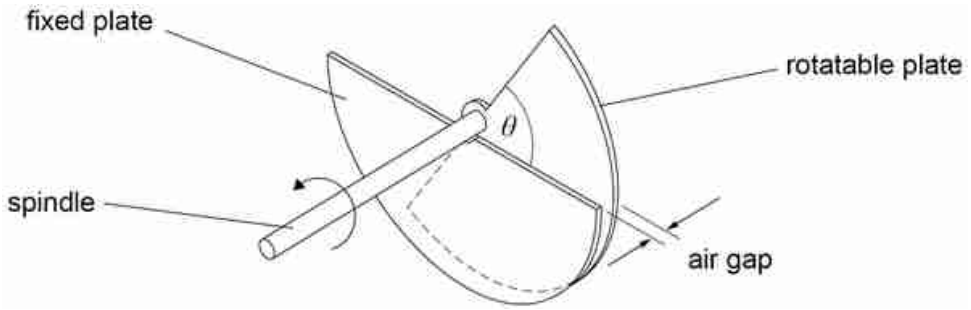
[3 marks]

energy difference = _____ J

Question 1 continues on the next page

Figure 1 shows the structure of a variable capacitor used for measuring angular movement. The capacitor consists of two semicircular metal plates. These plates are parallel and are separated by an air gap.

Figure 1



To vary the capacitance, one of the plates is rotated through an angle θ using the spindle. The other plate remains fixed.

0 1 . 4 Sketch a graph on **Figure 2** to show how the capacitance C varies with θ as the spindle is turned through $360°$.
When θ is $0°$, the plates completely overlap.

[2 marks]

Figure 2

0 1 . 5 In one situation, the variable capacitor is too large for the available space.

The same maximum capacitance is required using plates that have half the diameter of the original capacitor.

Explain, with numerical detail, **two** ways in which this can be achieved.

[3 marks]

1 _____

_____

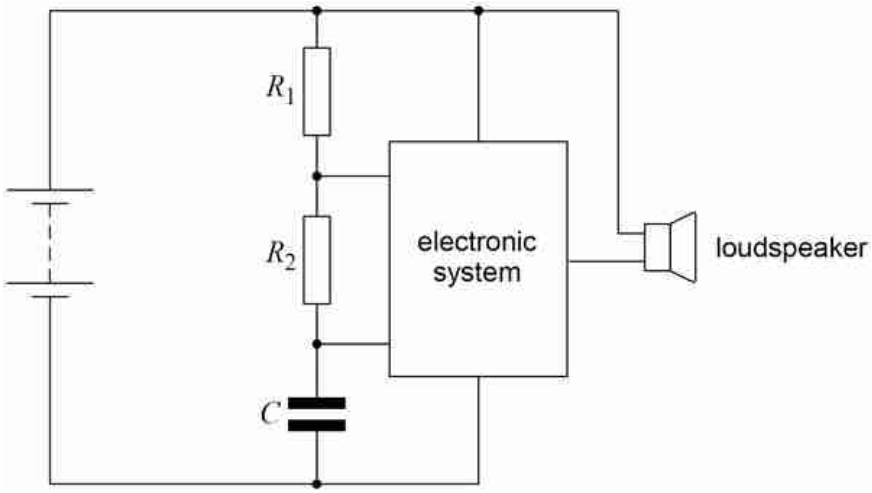
_____

_____

2 _____

0 2 **Figure 3** shows a circuit that causes a loudspeaker to emit 'clicks' at a constant rate. The time T between successive clicks depends on the resistances R_1 and R_2 and the capacitance C.
You do not need to know any details about the electronic system.

Figure 3



A student uses a stopwatch to determine T.
Table 1 shows the student's repeated measurements of $20T$.

Table 1

$20T$ / s	$20T$ / s	$20T$ / s	$20T$ / s	$20T$ / s
19.22	18.91	19.36	19.04	19.45

0 2 . 1 Suggest why the student measures $20T$.

[1 mark]

0 2 . 2 Suggest why the student repeats their measurements of $20T$.

[1 mark]

0 2 . 3 Determine the percentage uncertainty in the student's result for T.
Assume that all the data in **Table 1** are valid.

[2 marks]

percentage uncertainty in $T =$ _____ %

Question 2 continues on the next page

The student determines T for different values of R_2.
The values of R_1 and C are not changed.

The student produces the graph in **Figure 4**.

Figure 4

0 2 . 4 It can be shown that

$$T = (R_1 + 2R_2)C \ln 2$$

Determine C and R_1.

[5 marks]

$C =$ _____ F

$R_1 =$ _____ Ω

Question 2 continues on the next page

0 2 . 5 The student has access to a range of fixed and variable resistors.
The student wants to modify the circuit in **Figure 3** so that T can be varied continuously from a minimum of 0.70 s to a maximum of 1.25 s.

Show how the student can achieve this by combining two resistors to make R_2.
You should use information from **Figure 4**.

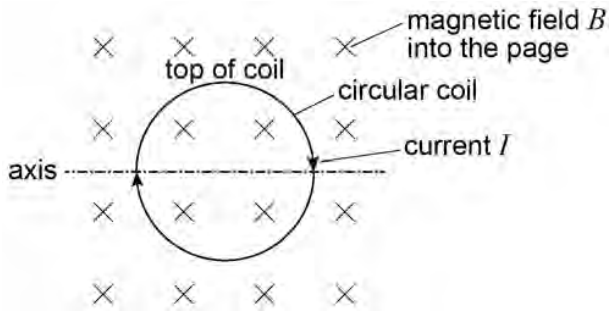
[3 marks]

SUB-TOPIC 3.7.5a

MAGNETIC FIELDS: FORCES ON WIRES AND CHARGED PARTICLES

Sub-topic 3.7.5a · 20 questions · 95 marks · lowest tariff first

2 7 The diagram shows a clockwise current I in a circular coil placed in a uniform magnetic field B with the plane of the coil perpendicular to the magnetic field.



What is the effect on the coil of the interaction between the current and the magnetic field?

[1 mark]

A It rotates about the axis with the top moving out of the page. ⬭

B It rotates about the axis with the top moving into the page. ⬭

C It causes an increase in the diameter of the coil. ⬭

D It causes a decrease in the diameter of the coil. ⬭

1 3 When an electron is moving at a speed v perpendicular to a uniform magnetic field of flux density B, it follows a path of radius R.

A second electron moves at a speed $\frac{v}{2}$ perpendicular to a uniform magnetic field of flux density $4B$.

What is the radius of the path of the second electron?

[1 mark]

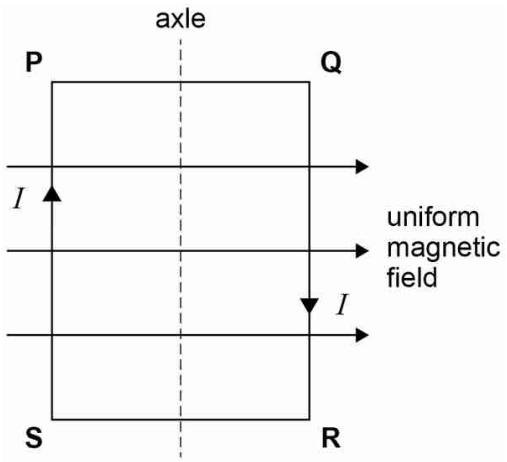
A $\frac{R}{8}$ ⬭

B $\frac{R}{4}$ ⬭

C $2R$ ⬭

D $8R$ ⬭

2 3 The plane of coil **PQRS** is parallel to a uniform magnetic field.



When a current I is in the coil

[1 mark]

A there are no magnetic forces acting on **SP** and **QR**. ⬭

B there are no magnetic forces acting on **PQ** and **RS**. ⬭

C an attractive magnetic force acts between **SP** and **QR**. ⬭

D an attractive magnetic force acts between **PQ** and **RS**. ⬭

2 4 A horizontal wire of length $0.50\ \text{m}$ and weight $1.0\ \text{N}$ is placed in a uniform horizontal magnetic field of flux density $1.5\ \text{T}$ directed at $90°$ to the wire.

What is the current that just supports the wire?

[1 mark]

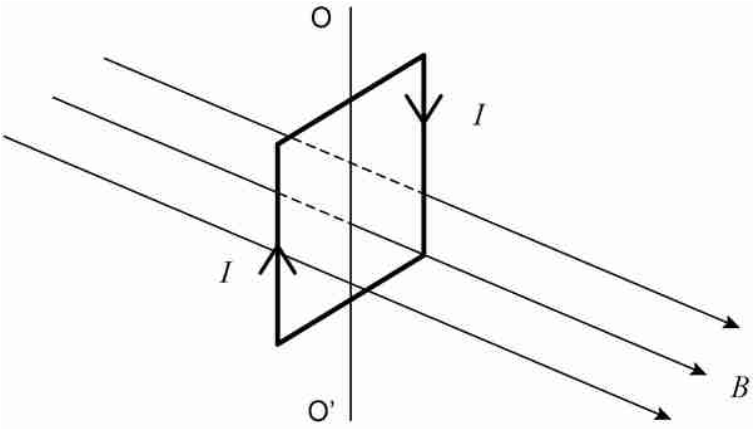
A $0.33\ \text{A}$ ⬭

B $0.75\ \text{A}$ ⬭

C $1.3\ \text{A}$ ⬭

D $3.0\ \text{A}$ ⬭

2 3 The diagram shows a current I in a vertical square coil.
The coil can rotate about an axis OO'.
The plane of the coil is at right angles to a uniform horizontal magnetic field of flux density B.



Which statement is correct?

[1 mark]

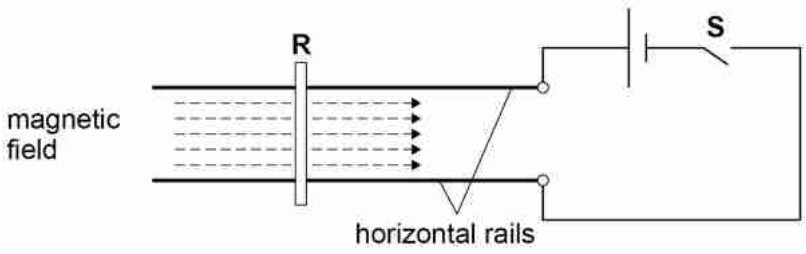
A The forces on the vertical sides of the coil are equal in magnitude and opposite in direction. ⬭

B A non-zero couple acts on the coil. ⬭

C No forces act on the horizontal sides of the coil. ⬭

D The forces on all sides of the coil act toward the centre of the coil. ⬭

2 1 A short copper rod **R** is placed on a pair of thick horizontal parallel copper rails. A horizontal magnetic field exists in the direction shown by the dashed arrows. The diagram shows the apparatus when viewed from directly above.



When switch **S** is closed, **R** will tend to

[1 mark]

A lift upwards away from the rails. ⬭

B move to the left. ⬭

C move to the right. ⬭

D be pressed downwards onto the rails. ⬭

1 4 When an electron moves at a speed v perpendicular to a uniform magnetic field of flux density B, the radius of its path is R.

A second electron moves at a speed $\frac{v}{2}$ perpendicular to a uniform magnetic field of flux density $4B$.

What is the radius of the path of the second electron?

[1 mark]

A $\frac{R}{8}$ ⬭

B $\frac{R}{4}$ ⬭

C $2R$ ⬭

D $8R$ ⬭

2 2 A horizontal wire of length $0.25\ \text{m}$ carrying a current of $3.0\ \text{A}$ is perpendicular to a magnetic field. The mass of the wire is $3.0 \times 10^{-3}\ \text{kg}$ and the weight of the wire is supported in equilibrium by the magnetic field.

What is the flux density of the magnetic field?

[1 mark]

A $2.6\ \text{T}$ ⬭

B $3.9 \times 10^{-2}\ \text{T}$ ⬭

C $2.2 \times 10^{-2}\ \text{T}$ ⬭

D $4.0 \times 10^{-3}\ \text{T}$ ⬭

2 6 Which row is correct for α, β and γ radiation?

[1 mark]

		α	β	γ	
A	Is it deflected by a magnetic field?	yes	yes	no	⬭
B	Is it deflected by an electric field?	yes	yes	yes	⬭
C	Does it have a positive charge?	yes	no	yes	⬭
D	Does it come from outside the nucleus?	no	yes	no	⬭

2 0 A wire is at right angles to a uniform magnetic field and carries an electric current. The wire is 150 mm in length.

When the current in the wire is increased by 4.0 A, the force acting on the wire increases by 3.6×10^{-3} N.

What is the magnetic flux density of the field?

[1 mark]

A 6.0×10^{-6} T ⬭

B 6.0×10^{-3} T ⬭

C 1.7×10^{2} T ⬭

D 1.7×10^{5} T ⬭

2 1 A beam consists of ionised atoms of two isotopes of an element.
When the beam enters a uniform magnetic field, the ions move in circular paths.
The ions have the same charge and travel at the same speed when they enter the magnetic field.

Which statement is true?

[1 mark]

A The force acting on an ion is different for each isotope. ⬭

B The radius of the path followed by an ion is different for each isotope. ⬭

C The kinetic energy of an ion increases for both isotopes. ⬭

D The acceleration of an ion is the same for both isotopes. ⬭

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 $\frac{2\pi m_e}{Be}$ ⬭

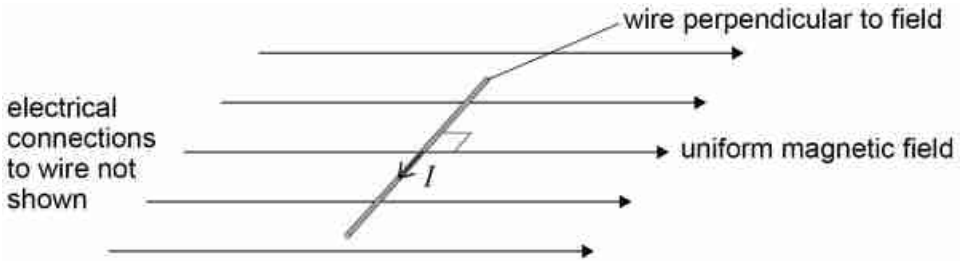
B $\frac{2\pi r}{v}$ ⬭

C $\frac{v}{\pi r}$ ⬭

D $\frac{Be}{2\pi m_e}$ ⬭

2 0 A horizontal wire is perpendicular to a horizontal uniform magnetic field of flux density B. The wire has length L and diameter d. The current in the wire is I.

The magnetic force acting on the wire is equal in magnitude and opposite in direction to the weight of the wire so that the wire is supported.



The wire is replaced with a second wire in the same orientation and position.

The second wire is made of the same material and has length $\frac{L}{2}$ and diameter $2d$.

What current is required to support the second wire?

[1 mark]

A $\frac{I}{2}$ ⬭

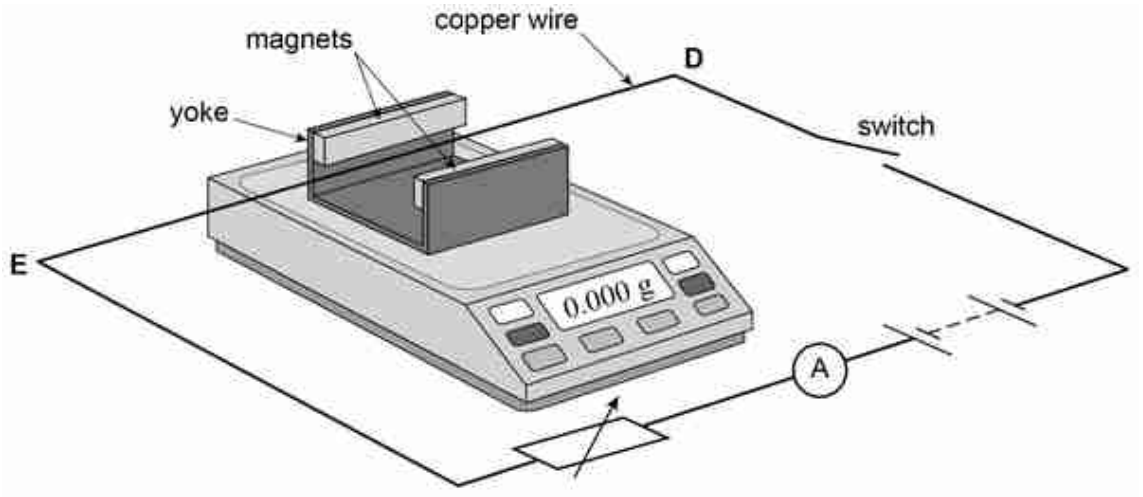
B I ⬭

C $2I$ ⬭

D $4I$ ⬭

0 2 **Figure 2** shows two magnets, supported on a yoke, placed on an electronic balance.

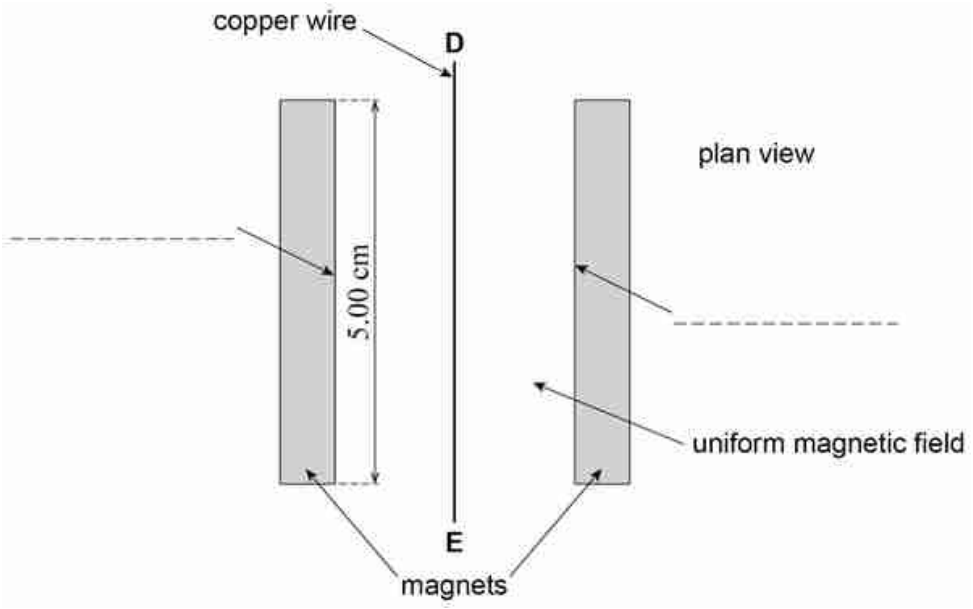
Figure 2



The magnets produce a uniform horizontal magnetic field in the region between them. A copper wire **DE** is connected in the circuit shown in **Figure 2** and is clamped horizontally at right angles to the magnetic field.

Figure 3 shows a simplified plan view of the copper wire and magnets.

Figure 3



When the apparatus is assembled with the switch open, the reading on the electronic balance is set to 0.000 g. This reading changes to a positive value when the switch is closed.

0 2 . 1 Which of the following correctly describes the direction of the force acting on the wire **DE** due to the magnetic field when the switch is closed?

Tick (✓) the correct box.

[1 mark]

towards the left magnet in **Figure 3** ☐

towards the right magnet in **Figure 3** ☐

vertically up ☐

vertically down ☐

0 2 . 2 Label the poles of the magnets by putting **N** or **S** on each of the two dashed lines in **Figure 3**.

[1 mark]

0 2 . 3 Define the tesla.

[1 mark]

_____

_____

_____

0 2 . 4 The magnets are $5.00\ \text{cm}$ long. When the current in the wire is $3.43\ \text{A}$ the reading on the electronic balance is $0.620\ \text{g}$.

Assume the field is uniform and is zero beyond the length of the magnets.

Calculate the magnetic flux density between the magnets.

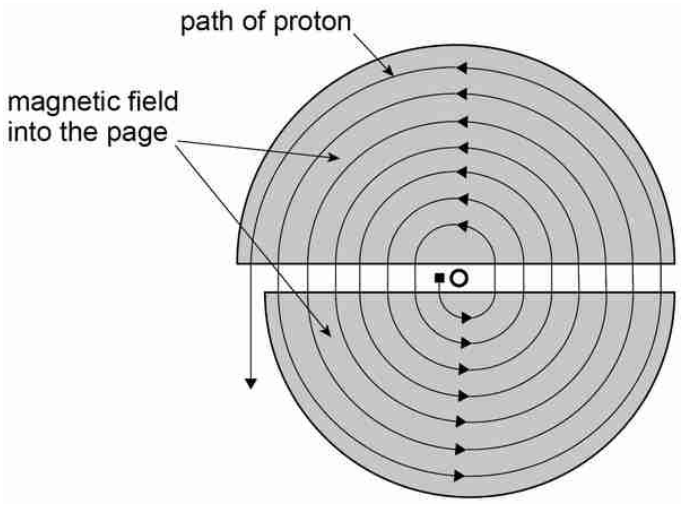
[2 marks]

magnetic flux density = _____ T

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 m and the magnetic flux density of the uniform field is 0.44 T.

Ignore any relativistic effects.

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

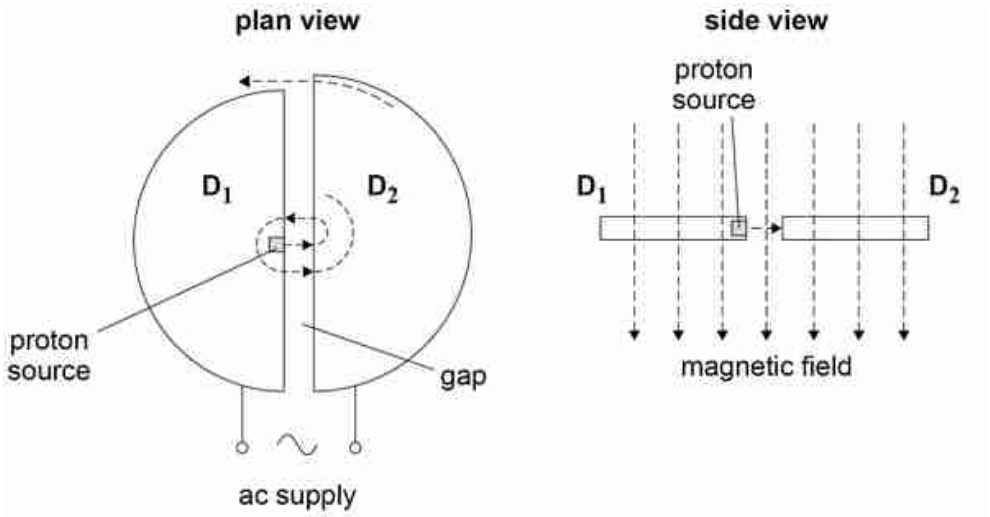
[2 marks]

maximum speed = _____ m s^{-1}

0 5 **Figure 9** shows a cyclotron. A proton is released from rest and is accelerated each time it reaches the gap between two horizontal 'dees' **D_1** and **D_2**. Between these accelerations the proton moves at constant speed. A vertical magnetic field of flux density B acts over the dees so that the proton follows a semicircular path in each dee.

The dees are connected to an alternating potential difference (pd).
This pd is adjusted so that the proton is always accelerated by the peak electric field as it crosses the gap between the dees.

Figure 9



0 5 . 1 Explain why the proton travels in a semicircular path in a dee.

[2 marks]

Question 5 continues on the next page

0 5 . 2 The peak pd of the alternating supply is $10.0\ \text{kV}$. The proton leaves the cyclotron with kinetic energy of $14\ \text{MeV}$.

Determine the number of times the proton moves across the gap before it leaves the cyclotron.

[1 mark]

number of times = _____

The radius of the outermost semicircular path of the proton is R and the proton leaves with a maximum kinetic energy E_k.

0 5 . 3 Show that E_k is given by

$$E_\text{k} = \frac{e^2 B^2 R^2}{2m_\text{p}}$$

[3 marks]

0 5 . 4 A hospital decides to purchase a cyclotron in order to manufacture its own radioactive isotopes using high-speed protons.
The required minimum kinetic energy of the emerging protons is $11\ \text{MeV}$.
The cost of a cyclotron is approximately proportional to $E_k^{1,5}$.
The cost of a $10\ \text{MeV}$ cyclotron is about £2.3 million.
Table 1 gives information for three cyclotrons **X**, **Y** and **Z**.

Table 1

Cyclotron	B / T	R / m
X	1.3	0.38
Y	1.1	0.50
Z	0.5	0.60

Deduce which cyclotron **X**, **Y** or **Z** will satisfy the energy requirement for the lowest cost.
Go on to determine the approximate cost of this cyclotron.

[4 marks]

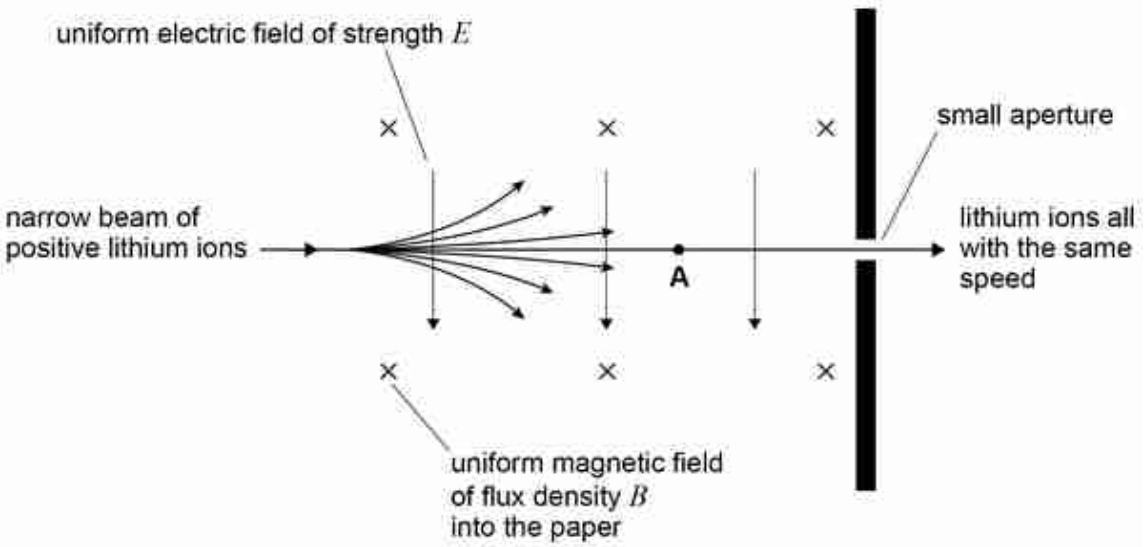
cyclotron = _____

cost = _____

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 $1.5 \times 10^5\ \text{m s}^{-1}$ pass through the small aperture.

Calculate E.

$B = 0.12\ \text{T}$

[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 $= 1.0 \times 10^{-26}\ \mathrm{kg}$

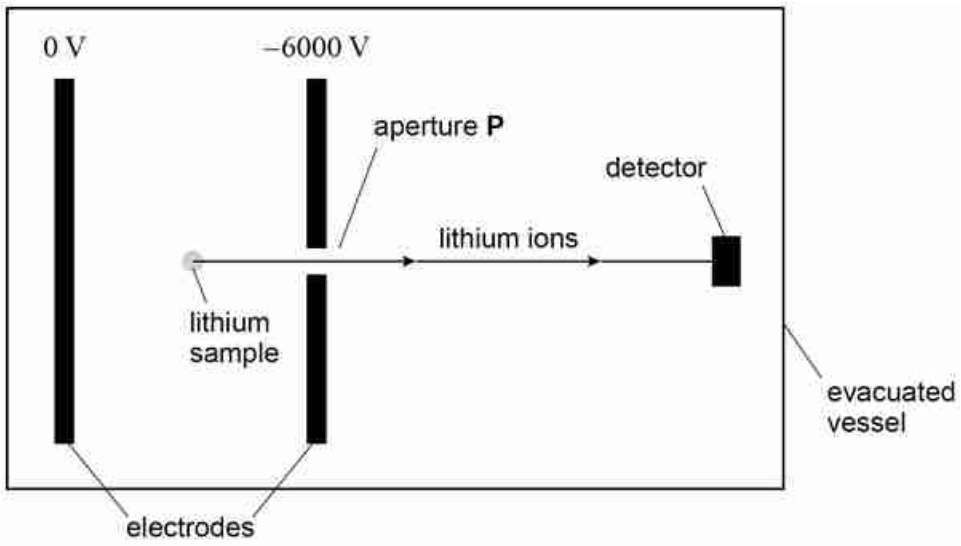
[2 marks]

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 This question is about a method to investigate how the force on a conductor varies with flux density and current (required practical activity 10).

Figure 10 shows a copper rod clamped above a horizontal bench.

Figure 10

0 3 . 1 Describe a method to show that the copper rod is horizontal.
Your method must include the use of a metre ruler.
You may annotate **Figure 10**.

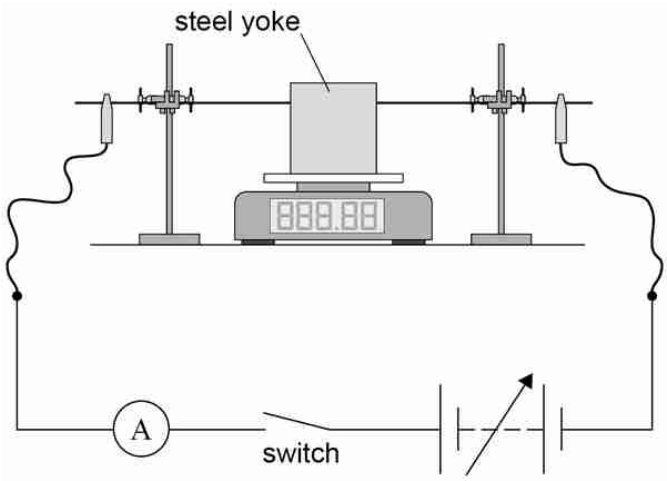
[3 marks]

Question 3 continues on the next page

Figure 11 shows the copper rod positioned above a digital balance.

Two identical magnets are mounted on a steel yoke with their opposite poles facing each other.
The balance is zeroed.
The yoke is then placed on the balance so that a horizontal uniform magnetic field is applied perpendicular to the copper rod.
The ends of the rod are connected as shown.

Figure 11



0 3 . 2 When the switch is open, the reading on the balance shows the mass of the yoke and the two magnets.
When the switch is closed, the reading on the balance decreases.

Explain, with reference to **Figure 11**, the direction of the horizontal magnetic field.

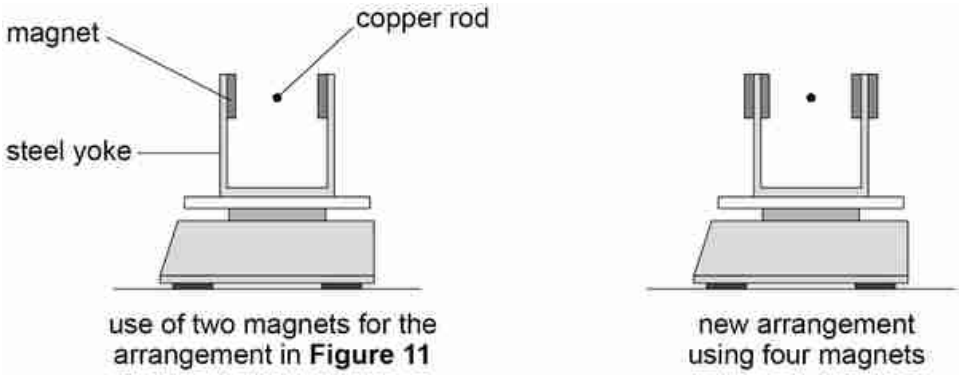
[3 marks]

The current I in the rod is varied.
The balance reading M_1 is recorded for different values of I.

The switch is now opened.
Two additional magnets, identical to those used before, are attached to the yoke.

Figure 12 shows how this new arrangement compares with the arrangement in **Figure 11**.

Figure 12



The balance reading with four magnets attached to the yoke is M_2.
With the switch open, M_2 is the mass of the yoke and the four magnets.

The switch is now closed.
M_2 is recorded for different values of I.

Question 3 continues on the next page

Figure 13 shows data from both experiments.
Values of M_1 and M_2 are plotted using different vertical axes.

Figure 13

It can be shown that

$$M = kBI + nZ + Y$$

where

M = balance reading when the current is I
B = magnetic flux density of the horizontal uniform magnetic field
n = number of magnets attached to the yoke
Z = mass, in g, of each magnet
Y = mass, in g, of the yoke
k is a constant.

0 3 . 3 Deduce the fundamental base units for k.

[3 marks]

fundamental base units = _____

0 3 . 4 Determine Y.

[3 marks]

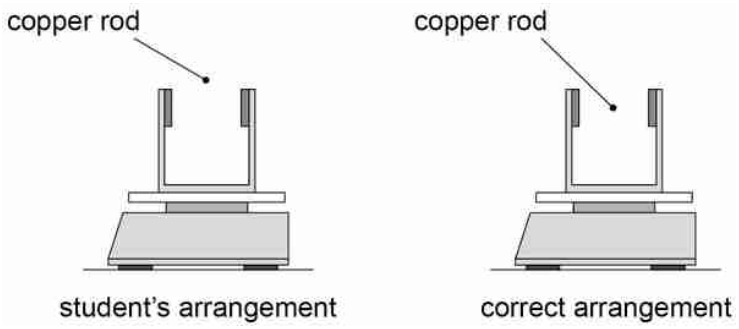
Y = _____ g

Question 3 continues on the next page

0 3 . 5 A student sets up the apparatus with the copper rod positioned incorrectly.

Figure 14 shows how the student's arrangement compares with the correct arrangement.

Figure 14



The student produces a graph of M_1 against I.

Compare the student's graph with the graph of M_1 against I (the solid line) in **Figure 13**.
Explain your answer.

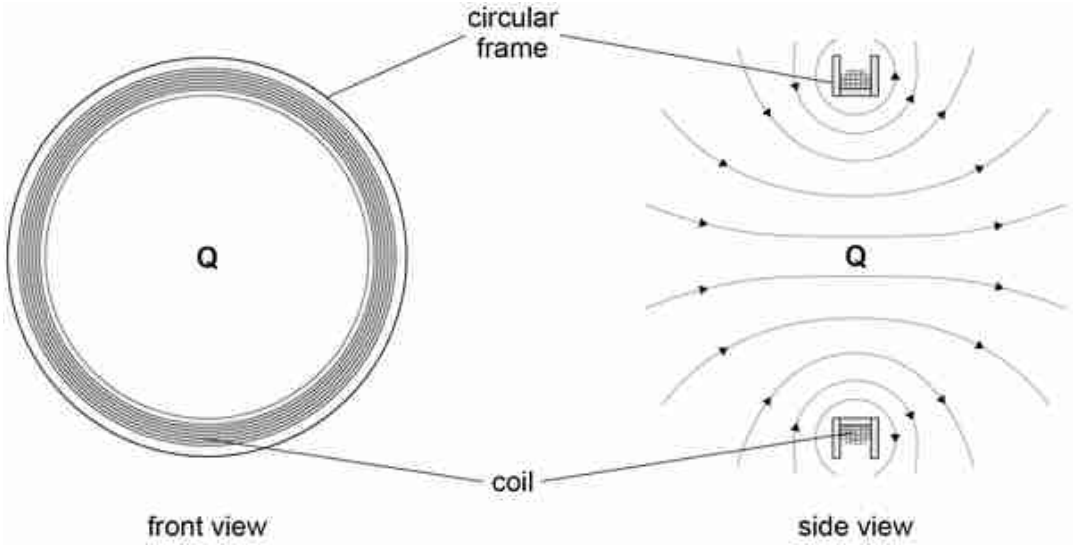
[3 marks]

END OF QUESTIONS

0 3 **Figure 7a** shows the front view of a vertical coil mounted on a circular frame.

Figure 7b is a side view showing a section through the frame and coil.
A constant direct current in the coil produces magnetic flux represented by the magnetic field lines on this diagram.

Figure 7a **Figure 7b**



Point **Q** is at the centre of the coil.
A sensor placed at **Q** detects B_H, the horizontal component of the magnetic flux density.
The effect of the Earth's magnetic field at **Q** is negligible.

0 3 . 1 Discuss whether a search coil is a suitable sensor to detect B_H.

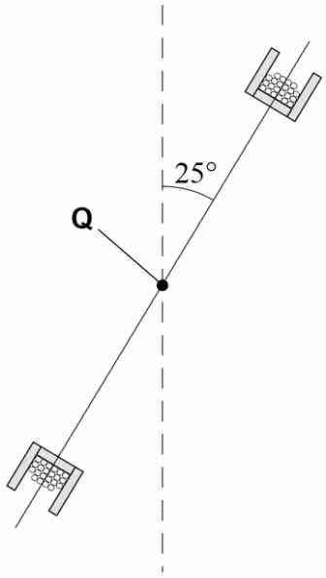
[2 marks]

Question 3 continues on the next page

B_H is measured at **Q** with the coil vertical.

The coil is now rotated about **Q** through $25°$ as shown in **Figure 8**.
The current in the coil does not change.

Figure 8



A new measurement of B_H is made with the coil fixed in this new position.

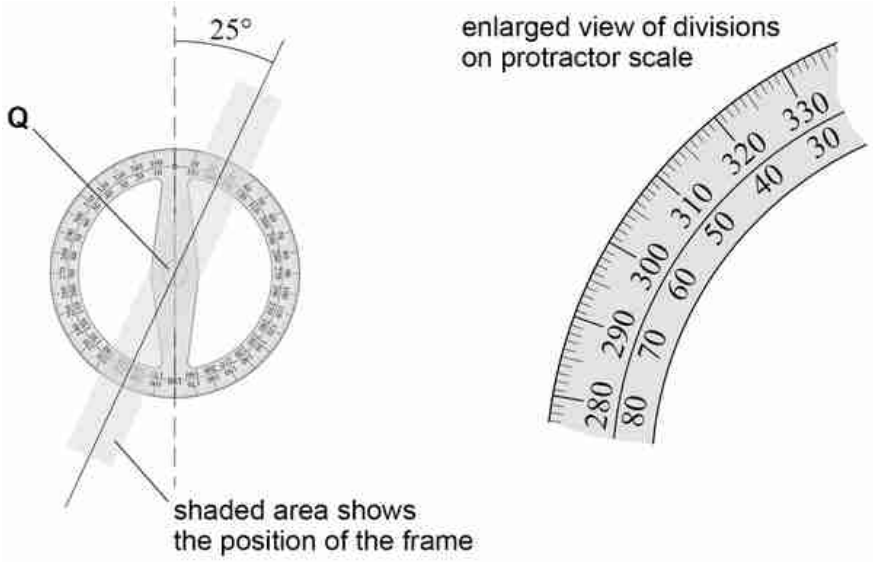
0 3 . 2 Determine the percentage change in B_H produced by this rotation of the coil.
Show your working.

[2 marks]

percentage change = _____ %

0 3 . 3 **Figure 9** shows a protractor being used to measure the angle through which the coil is rotated.

Figure 9



Estimate the percentage uncertainty in this result.
Justify your answer.

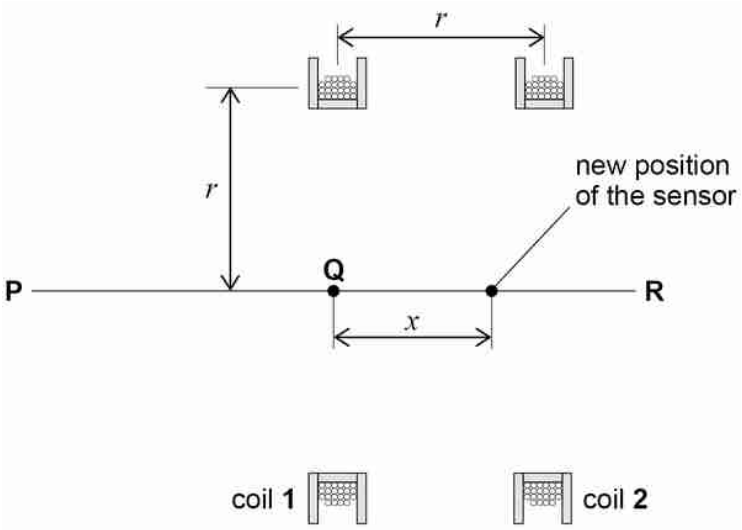
[3 marks]

percentage uncertainty = _____ %

Question 3 continues on the next page

Figure 10 shows an arrangement of two vertical coils.
Four experiments are done using this arrangement.

Figure 10



Coil **1** and coil **2** are identical and have a radius r.
The coils are separated by a distance r and have a common axis **PR**.
Q is at the centre of coil **1**.

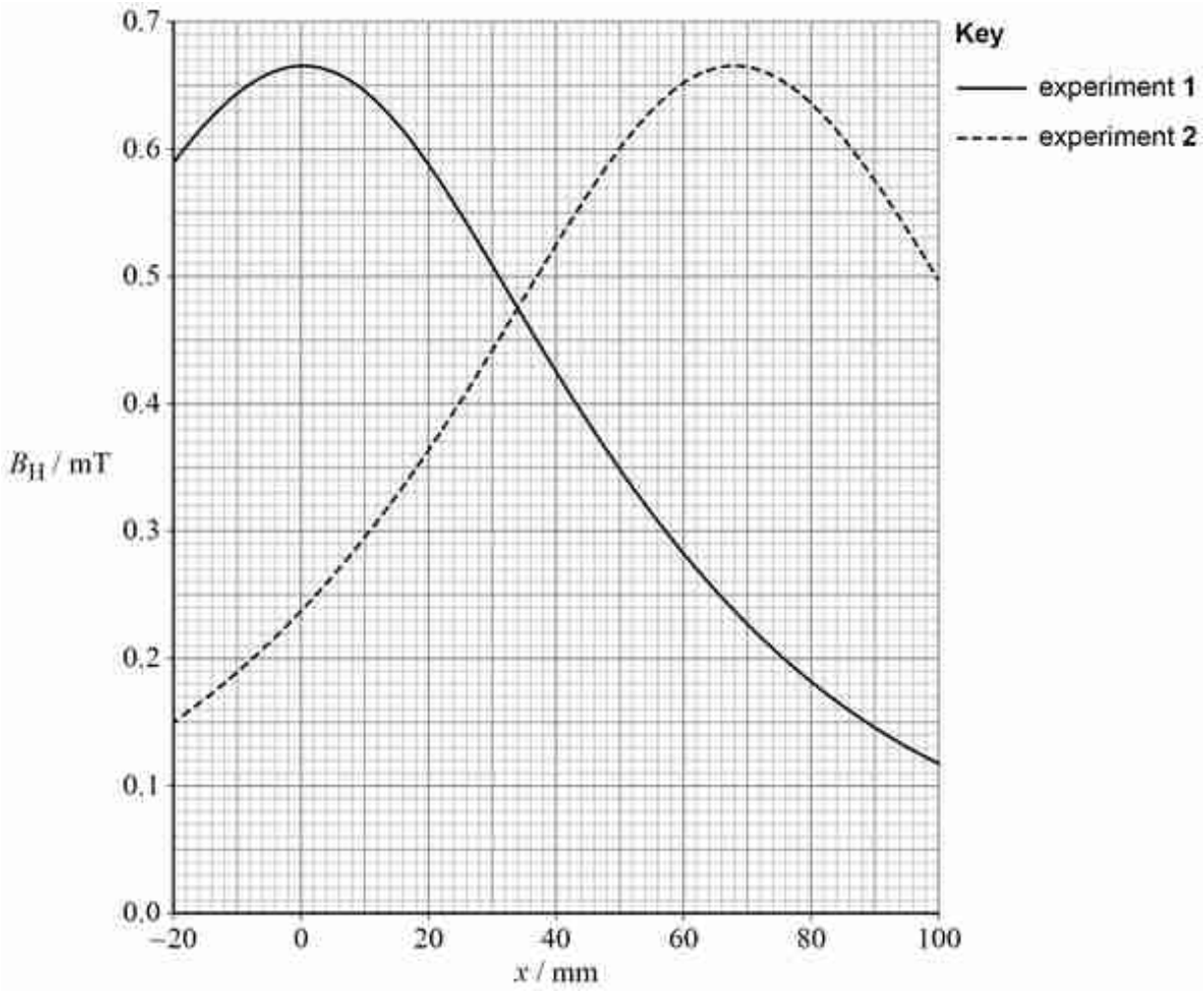
The four different experiments investigate how B_H varies with x, the displacement of the sensor from **Q** along **PR**.

In experiment **1**, the current in coil **1** is $225\ \text{mA}$ and the current in coil **2** is zero.

In experiment **2**, the current in coil **1** is zero and the current in coil **2** is $225\ \text{mA}$.

Figure 11 shows the results of experiment **1** and experiment **2**.

Figure 11



0 3 . 4 During experiment **1**, B_H is measured with the sensor at **Q**.
The sensor is then moved along **PR** until the value of B_H is halved.
The distance from **Q** to the sensor is $x_{0.5}$

Determine $\frac{x_{0.5}}{r}$

[2 marks]

$\frac{x_{0.5}}{r} =$ _____

In experiment **3**, the current in both coils is $225\ \text{mA}$ so that the magnetic fields produced by coil **1** and coil **2** are combined.

The resultant B_H has a constant maximum value in the region between $x = \frac{r}{4}$ and $x = \frac{3r}{4}$

0 3 . 5 Deduce, in mT, the value of B_H in this region.

[2 marks]

$B_H =$ _____ mT

0 3 . 6 State **two** characteristics of the magnetic field lines in this region.

[2 marks]

1 _____

_____

_____

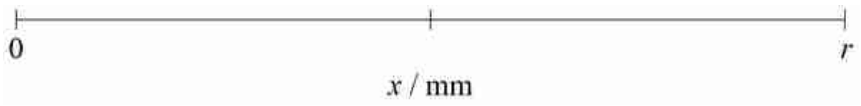
2 _____

0 3 . 7 In experiment **4**, the current in coil **2** is reversed so that the direction of the magnetic field produced by coil **2** is also reversed.
The magnitudes of the currents in coil **1** and coil **2** are still $225\ \text{mA}$.

Sketch a graph to show how B_H varies between $x = 0$ and $x = r$.
The x-axis has been provided for you.

Your graph should include numerical values on your B_H axis that correspond to $x = 0$ and $x = r$.

[3 marks]

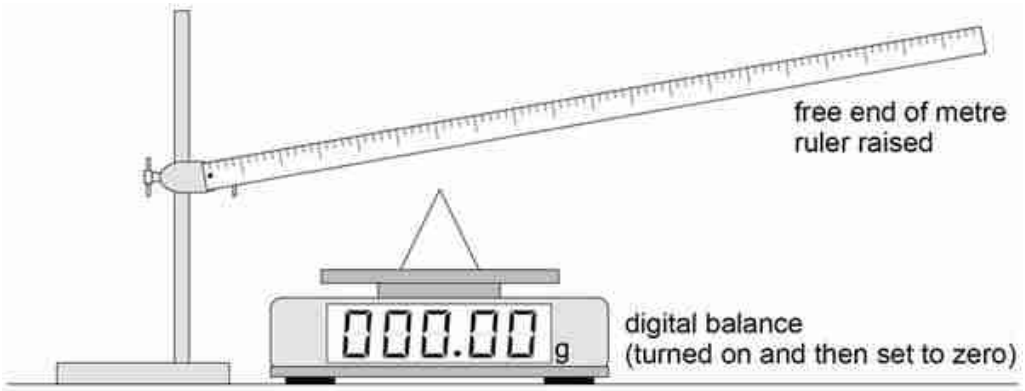


END OF QUESTIONS

0 1 This question is about using a digital balance to investigate the force on a wire placed in a magnetic field when there is an electric current in the wire.

A student carries out the procedure shown in **Figure 1** and **Figure 2**.
A metre ruler is pivoted at the 1.0 cm mark and a prism is placed on a digital balance.
The free end of the ruler is raised and the balance is turned on and then set to zero, as shown in **Figure 1**.

Figure 1



The ruler is then supported by the prism with the apex of the prism at the 30.0 cm mark as shown in **Figure 2**. The height of the pivot is adjusted so that the ruler is horizontal.

Figure 2

0 1 . 1 Deduce the mass of the ruler.
State **one** assumption you make.

[3 marks]

mass of ruler = _____ g

assumption _____

_____

Question 1 continues on the next page

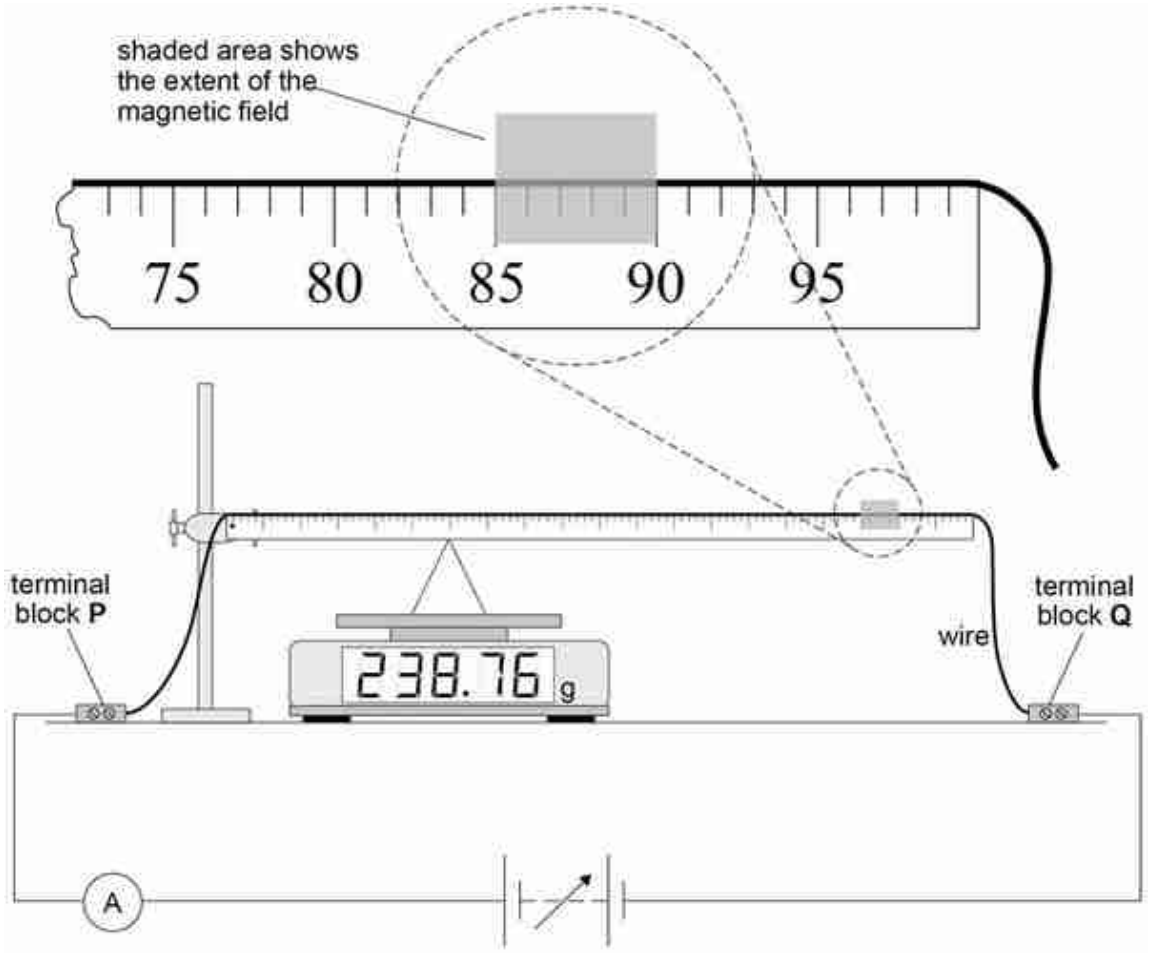
0 1 . 2 The student attaches a uniform wire to the upper edge of the ruler, as shown in **Figure 3**.

The ends of the wire are connected to terminal blocks **P** and **Q** which are fixed firmly to the bench. A power supply and an ammeter are connected between **P** and **Q**.

These modifications cause the balance reading to increase slightly.

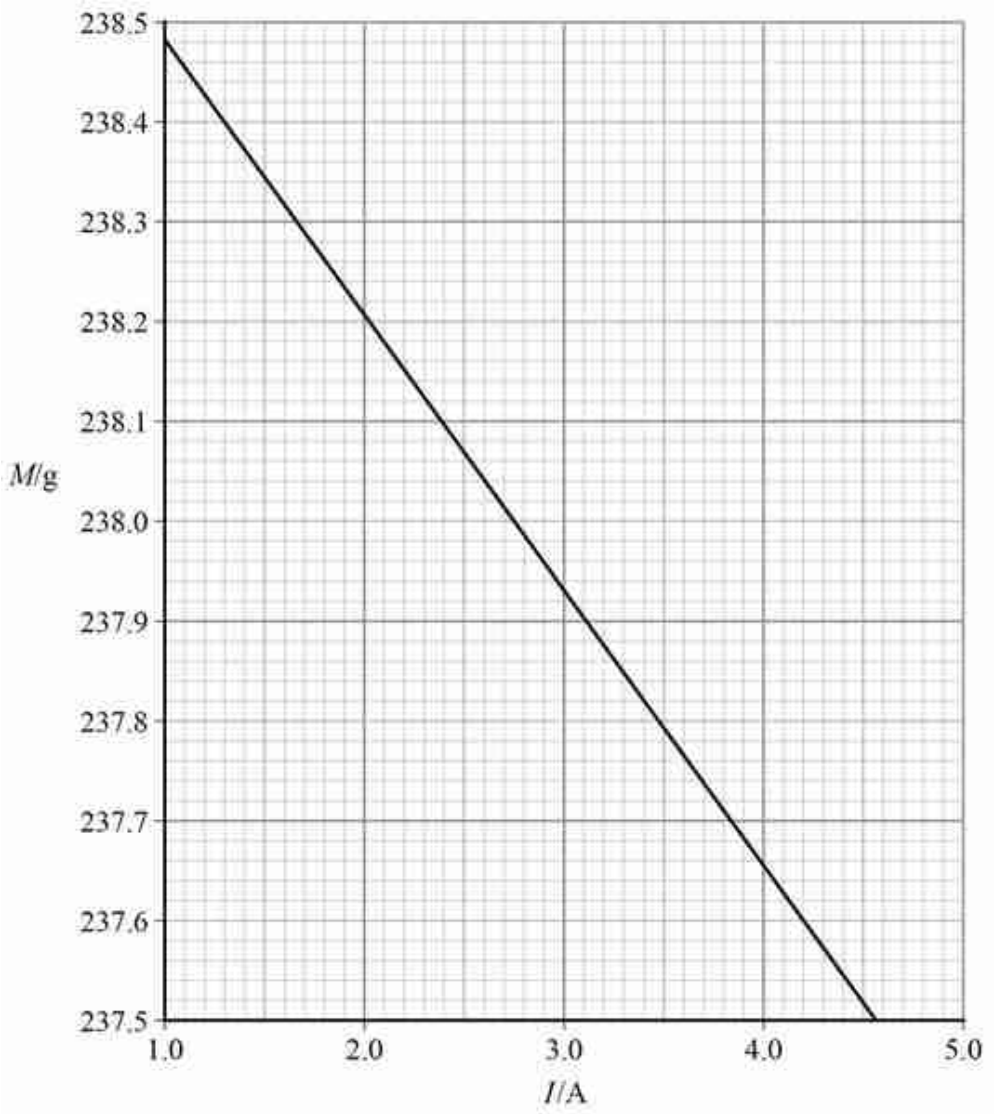
A horizontal uniform magnetic field is applied, perpendicular to the wire, between the 85 cm and 90 cm marks, as shown in the close-up diagram in **Figure 3**.

Figure 3



The balance reading M is recorded for increasing values of current I.
A graph of these data is shown in **Figure 4**.

Figure 4



State and explain the direction of the horizontal uniform magnetic field.

[3 marks]

Question 1 continues on the next page

0 1 . 3 It can be shown that B, the magnitude of the magnetic flux density of the horizontal uniform magnetic field, is given by

$$B = \frac{\sigma}{3L}$$

where σ = change in force acting on the prism per unit current in the wire
L = length of the region where the magnetic field cuts through the wire.

Determine B.

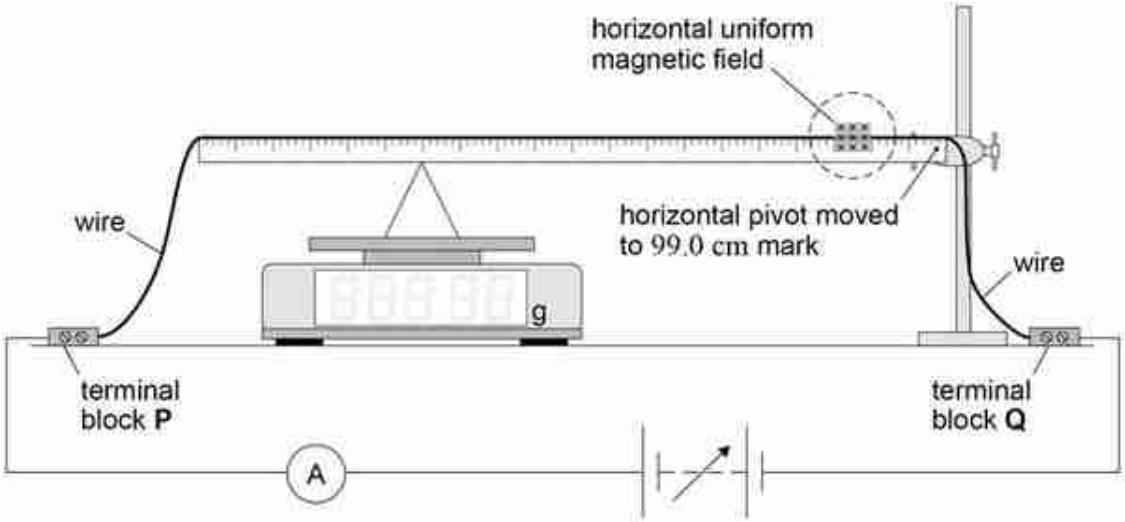
[3 marks]

$B =$ _____ T

0 1 . 4 The experiment is repeated with the ruler pivoted at the 99.0 cm mark. Nothing else is changed from **Figure 3**.

This arrangement is shown in **Figure 5**.

Figure 5



Tick (✓) **one** box in row 1 and **one** box in row 2 of **Table 1** to identify the effect, if any, on the magnitude of the forces acting on the apparatus as a certain current is passed through the wire.

Tick (✓) **one** box in row 3 and **one** box in row 4 of **Table 1** to identify the effect, if any, on the graph produced for this modified experiment compared with the graph in **Figure 4**.

[3 marks]

Table 1

		Reduced	No effect	Increased
1	Force acting on the current-carrying wire due to the horizontal uniform magnetic field			
2	Force acting on the prism due to the pivoted ruler			
3	Gradient of the graph			
4	Vertical intercept of the graph			

Question 1 continues on the next page

0 1 . 5 **Figure 6** shows the balance being used to measure the forces between two wires. The connections joining these wires to the power supply are not shown.

The pan of the balance moves a negligible amount during use and it supports a straight conducting wire **X** of horizontal length L.
Terminal blocks are used to connect **X** into the circuit. The weight of these does not affect the balance reading.
A second conducting wire **Y** is firmly supported a distance d above **X**.

Show, by adding detail to **Figure 6**, the wire connections that complete the circuit. The currents in **X** and **Y** must have the same magnitude and be in the directions indicated.

[2 marks]

Figure 6

0 1 . 6 The vertical force F on wire **X** due to the magnetic field produced by wire **Y** is given by

$$F = \frac{kI^2L}{d}$$

where k is a constant
d is the perpendicular distance between **X** and **Y**
I is the current in the wires
and L is the horizontal length of wire **X**.

A student wants to measure k using the arrangement in **Figure 6**.

The student is told that the following restrictions must apply:

- L is fixed
- I must not exceed $5.0\ \text{A}$
- the result for k must be obtained using a **graphical method**
- the experimental procedure must involve **only one** independent variable.

Explain what the student could do to find k.

[5 marks]

SUB-TOPIC 3.7.5b

ELECTROMAGNETIC INDUCTION, AC AND TRANSFORMERS

Sub-topic 3.7.5b · 29 questions · 85 marks · lowest tariff first

2 2 A coil with 20 circular turns each of diameter 60 mm is placed in a uniform magnetic field of flux density 90 mT.

Initially the plane of the coil is perpendicular to the magnetic field lines as shown in **Figure X**.

Figure X

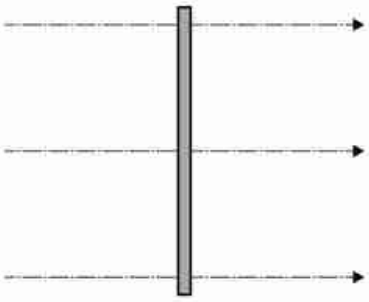
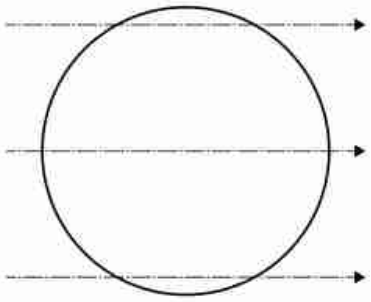


Figure Y



The coil is rotated about a vertical axis by 90° in a time of 0.20 s so that its plane becomes parallel to the field lines as shown in **Figure Y**.
Assume that the rate of change of flux linkage remains constant.

What is the emf induced in the coil?

[1 mark]

A zero ⬭

B 1.3 mV ⬭

C 25 mV ⬭

D 100 mV ⬭

2 5 A mains transformer has a primary coil of 2500 turns and a secondary coil of 130 turns.
The primary coil is connected to a mains supply where V_{rms} is 230 V.
The secondary coil is connected to a lamp of resistance $6.0\ \Omega$.
The transformer is 100% efficient.

What is the peak power dissipated in the lamp?

[1 mark]

A 12 W ⬭

B 24 W ⬭

C 48 W ⬭

D 96 W ⬭

2 8 A transformer has an efficiency of 80%
It has 7000 turns on its primary coil and 175 turns on its secondary coil. When the primary of the transformer is connected to a 240 V ac supply, the secondary current is 8.0 A

What are the primary current and secondary voltage?

[1 mark]

	Primary current / mA	Secondary voltage / V	
A	250	6.0	⬭
B	160	6.0	⬭
C	250	9600	⬭
D	160	9600	⬭

2 8 A steady current I dissipates power P in a resistor of resistance R.
An alternating current through a resistor of resistance $2R$ has a peak value of I.

What is the power dissipated in the second resistor?

[1 mark]

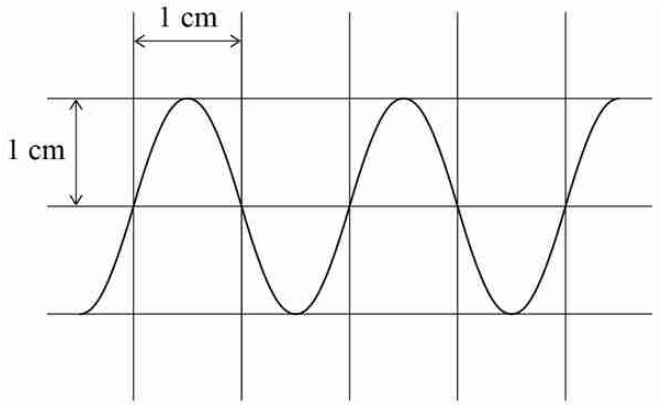
A $\frac{P}{\sqrt{2}}$ ⬭

B P ⬭

C $\sqrt{2}\,P$ ⬭

D $2P$ ⬭

2 9 The figure shows an oscilloscope trace of a sinusoidal ac voltage.



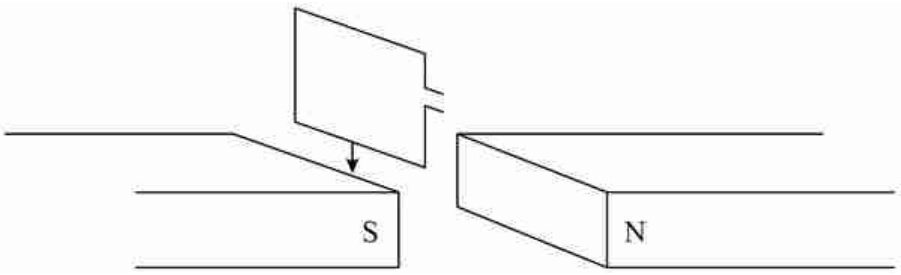
The time base setting is $5\ \text{ms cm}^{-1}$ and the Y-voltage gain is $10\ \text{V cm}^{-1}$.

Which row describes the ac voltage?

[1 mark]

	rms voltage / V	Frequency / Hz	
A	14	50	⬭
B	14	100	⬭
C	7	50	⬭
D	7	100	⬭

2 4 The diagram shows a small rectangular coil falling between two magnetic poles.

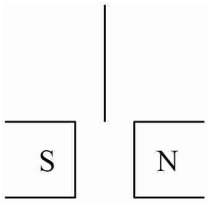


The coil is shown at four instants as it passes through the magnetic field.

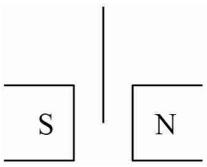
At which instant will the induced emf be a maximum?

[1 mark]

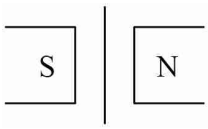
A



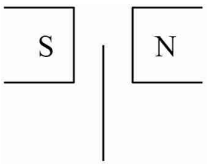
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

2 5 An alternating emf is induced in a coil rotating in a magnetic field.

What is the phase difference between the magnetic flux linkage through the coil and the emf?

[1 mark]

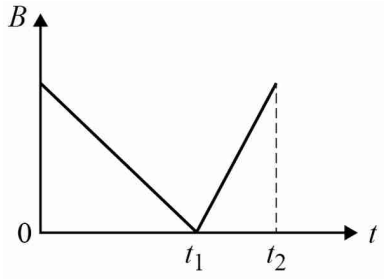
A 0 ⬭

B $\frac{\pi}{3}$ rad ⬭

C $\frac{\pi}{2}$ rad ⬭

D π rad ⬭

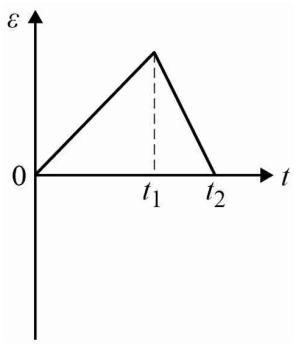
2 6 The diagram shows the variation with time t of the magnetic flux density B of the field linking a coil.



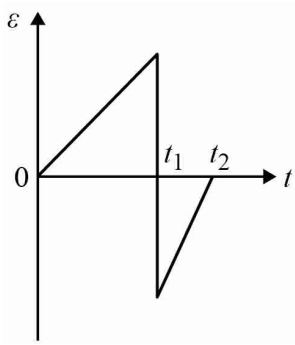
Which graph shows the variation of induced emf ε in the coil during this time interval?

[1 mark]

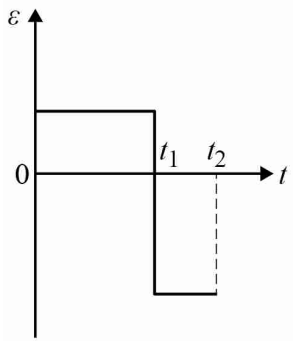
A



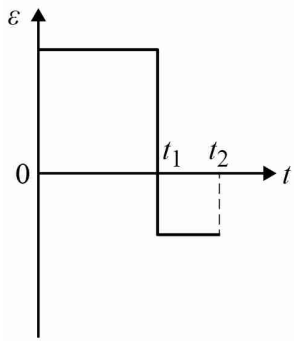
B



C



D



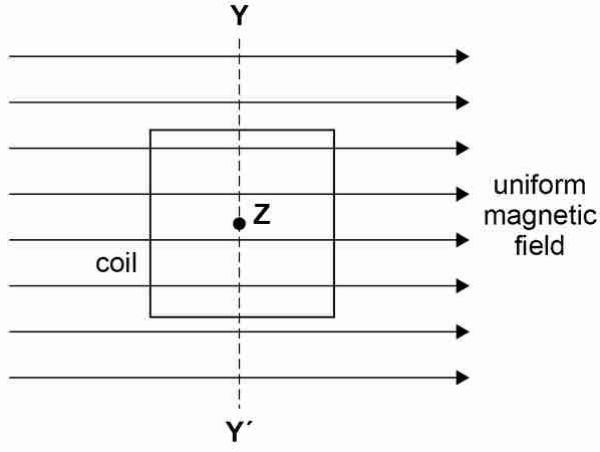
A ⬭

B ⬭

C ⬭

D ⬭

2 2 The diagram shows a square coil with its plane parallel to a uniform magnetic field.



The coil always remains within the magnetic field.
There are four possible changes to the position of the coil:

- moving it to the left
- moving it towards **Y**
- rotating it about the axis **YY´**
- rotating it about an axis **Z** that is at its centre and perpendicular to the plane of the coil.

How many of these changes will result in an induced emf in the coil while the change occurs?

[1 mark]

A one ⬭

B two ⬭

C three ⬭

D four ⬭

2 3 Mains electricity is rated 230 V in the UK.

Which is correct?

[1 mark]

A The mean voltage is 163 V. ⬭

B The peak voltage is 230 V. ⬭

C The root mean square voltage is 325 V. ⬭

D The peak-to-peak voltage is 650 V. ⬭

2 4 In a resistor of resistance R, a steady current I dissipates a power P.

In a resistor of resistance $\frac{R}{2}$ there is an alternating current of root mean square value $3I$.

What is the mean power dissipated in the resistor of resistance $\frac{R}{2}$?

[1 mark]

A $9P$ ⬭

B $\frac{9}{2}P$ ⬭

C $\frac{9}{4}P$ ⬭

D $\frac{3}{2}P$ ⬭

2 5 The primary winding of a transformer has 200 turns and the secondary winding has 1600 turns.
A root mean square (rms) alternating voltage of 25 V is applied to the primary winding causing a primary rms current of 4.0 A. The transformer is 90% efficient.

What are the rms values of the secondary voltage and the secondary current?

[1 mark]

	Secondary voltage / V	Secondary current / A	
A	200	0.50	⬭
B	200	0.45	⬭
C	180	0.50	⬭
D	3.1	29.0	⬭

2 3 A coil is rotated at frequency f in a uniform magnetic field.
The magnetic flux linking the coil is a maximum at time t_1 and the emf induced in the coil is a maximum at time t_2.

What is the smallest value of $t_1 - t_2$?

[1 mark]

A 0 ⬭

B $\frac{1}{4f}$ ⬭

C $\frac{1}{2f}$ ⬭

D $\frac{3}{4f}$ ⬭

2 4 Power P is dissipated in a resistor of resistance R carrying a direct current I.

A second resistor of resistance $2R$ carries an alternating current with peak value I.

What is the power dissipated in the second resistor?

[1 mark]

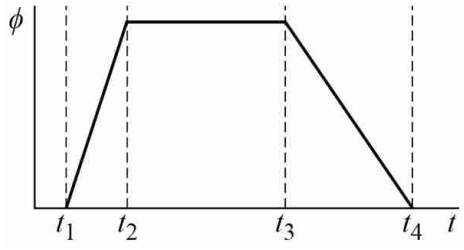
A $\sqrt{2}P$ ⬭

B P ⬭

C $2P$ ⬭

D $4P$ ⬭

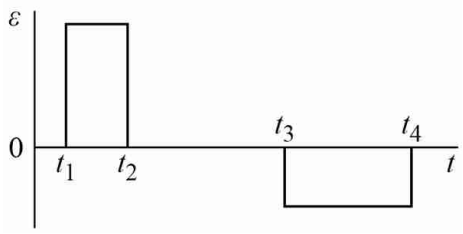
2 2 The magnetic flux ϕ in a coil varies with time t as shown.



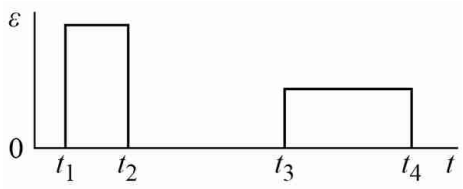
Which graph shows how the emf ε induced in the coil varies with t?

[1 mark]

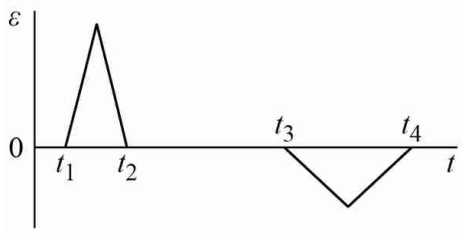
A



B



C



D



2 3 The distance between the wing tips of a metal aircraft is $30\ \text{m}$.
The aircraft flies horizontally at a steady speed of $100\ \text{m s}^{-1}$.
The aircraft passes through a vertical magnetic field of flux density $2.0 \times 10^{-7}\ \text{T}$.

What is the emf induced between its wing tips?

[1 mark]

A $0.2\ \mu\text{V}$ ⬭

B $20\ \mu\text{V}$ ⬭

C $300\ \mu\text{V}$ ⬭

D $600\ \mu\text{V}$ ⬭

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 ⬭

2 7 A transformer for use in a 230 V ac supply is 90% efficient.
The transformer provides a current of 3.00 A at 12.0 V.

What is the current in the primary coil?

[1 mark]

A 0.141 A ⬭

B 0.156 A ⬭

C 0.174 A ⬭

D 5.75 A ⬭

1 2 Which change will increase the efficiency of a transformer?

[1 mark]

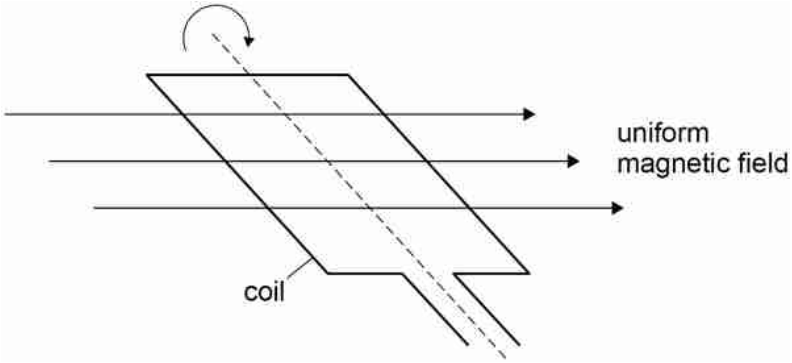
A increasing the thickness of the iron layers in the laminated core ⬭

B decreasing the frequency of the ac input voltage ⬭

C decreasing the diameter of the copper wire in the primary coil ⬭

D increasing the distance between the primary coil and the secondary coil ⬭

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]

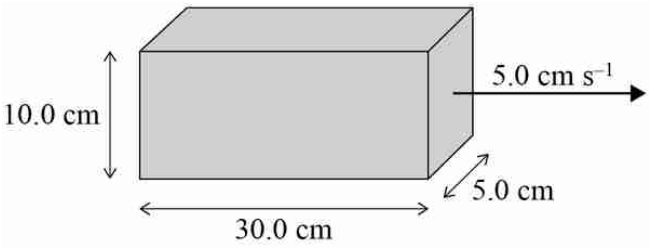
A 0 ⬭

B 0.50 ⬭

C 100 ⬭

D 157 ⬭

2 2 A metal block has dimensions $30.0\ \text{cm} \times 10.0\ \text{cm} \times 5.0\ \text{cm}$ as shown.



The block is moved at a constant horizontal velocity of $5.0\ \text{cm s}^{-1}$ through a uniform vertical magnetic field so that an emf is induced across the block.

The magnetic field has a magnetic flux density of $2.5\ \text{mT}$.

What is the induced emf?

[1 mark]

A $150\ \mu\text{V}$ ⬭

B $37.5\ \mu\text{V}$ ⬭

C $12.5\ \mu\text{V}$ ⬭

D $6.25\ \mu\text{V}$ ⬭

2 3 A transformer is used to connect an ac power supply to a 100 W filament lamp.

When the lamp is operating at its rated power, the power supply has a peak potential difference of 50 V and supplies a peak current of 5.0 A.

What is the efficiency of the transformer?

[1 mark]

A 80% ⬭

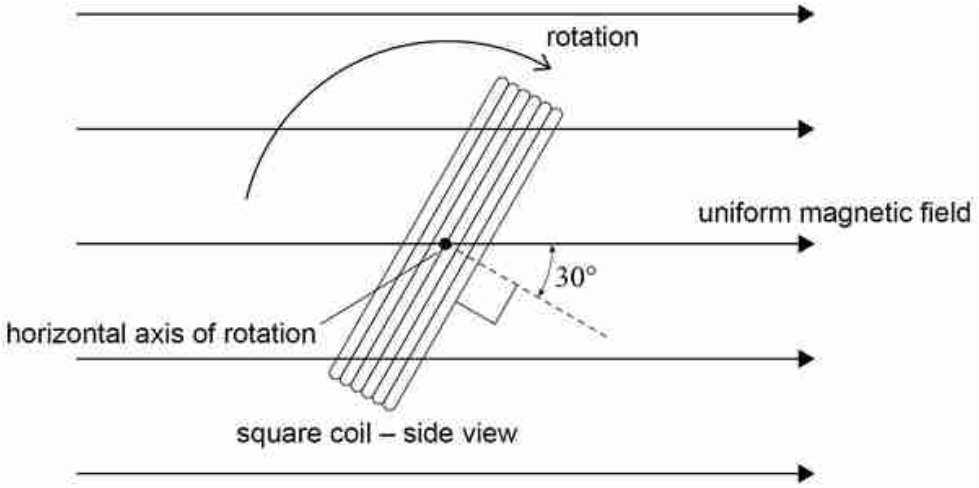
B 57% ⬭

C 40% ⬭

D 28% ⬭

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**.

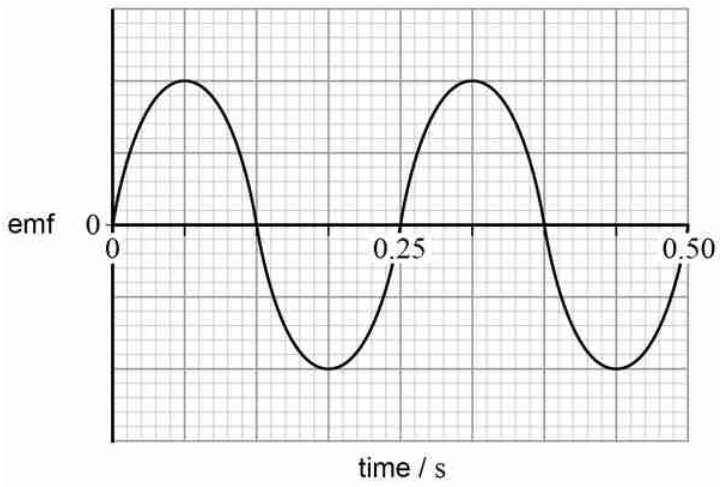
[1 mark]

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**.

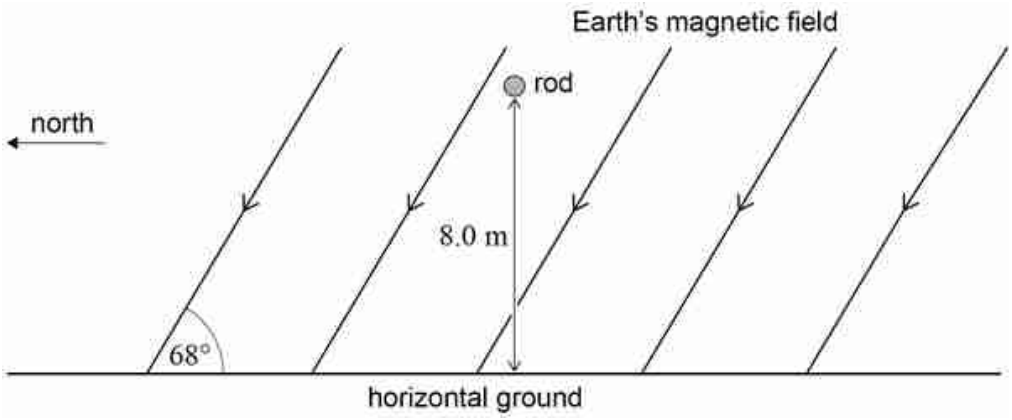
[1 mark]

Figure 6

0 3 A conducting rod is held horizontally in an east–west direction.
The magnetic flux density of the Earth's magnetic field is 4.9×10^{-5} T and is directed at an angle of $68°$ to the ground.

0 3 . 1 **Figure 5** shows the arrangement. The rod has a length of 2.0 m.

Figure 5



The rod is released and falls 8.0 m to the ground. It remains in a horizontal east–west direction as it falls.

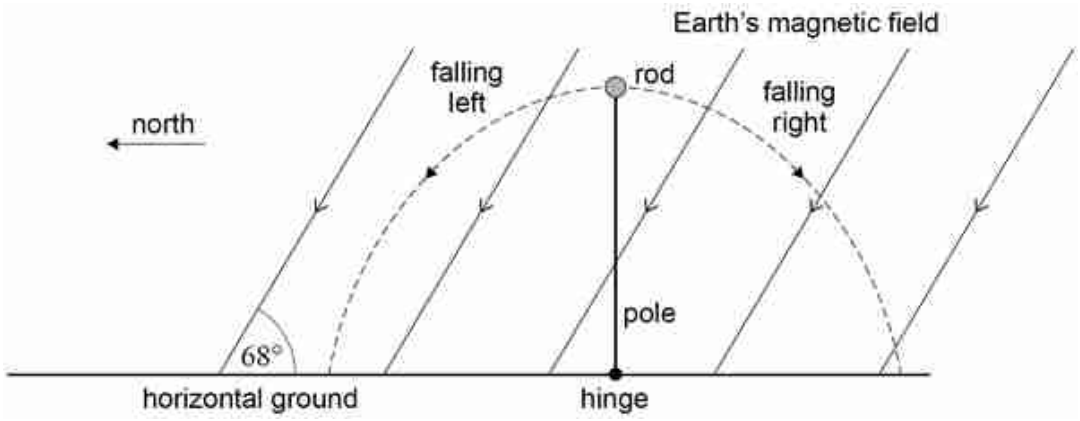
Determine the average emf across the rod during its fall to the ground.
Assume that air resistance is negligible.

[3 marks]

average emf = _____ V

0 3 . 2 The rod is returned to its original position. It is now supported by a non-conducting pole that is hinged on the ground as shown in **Figure 6**.
The pole is initially vertical and is then released.
The rod and pole can fall to the ground to the left or to the right.

Figure 6



During each fall there are changes in the magnitude and direction of the induced emf.
These changes differ depending on whether the rod falls to the left or to the right.

Explain any changes in the magnitude and direction of the induced emf as the rod falls:
- to the left
- to the right.

[4 marks]

left _____

_____

_____

_____

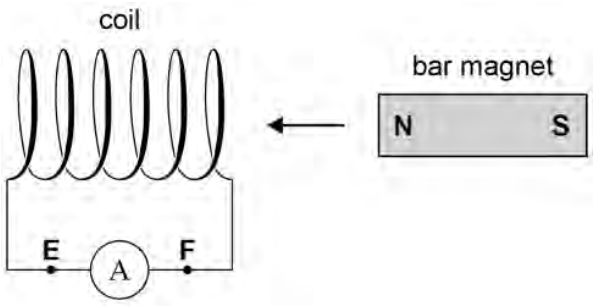
right _____

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]

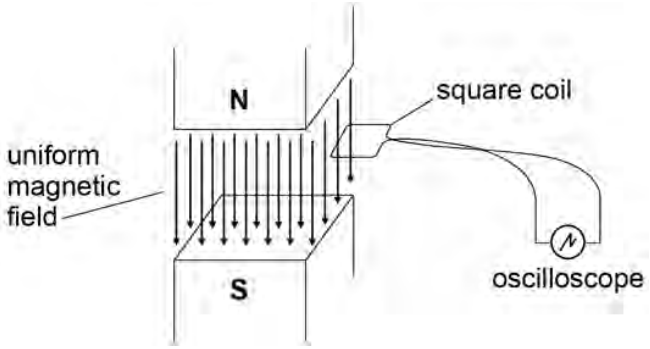
0 4 . 3 During the demonstration an induced current is detected by the ammeter. The induced current is in the direction **E** to **F**.

Explain how this demonstrates Lenz's law.

[2 marks]

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

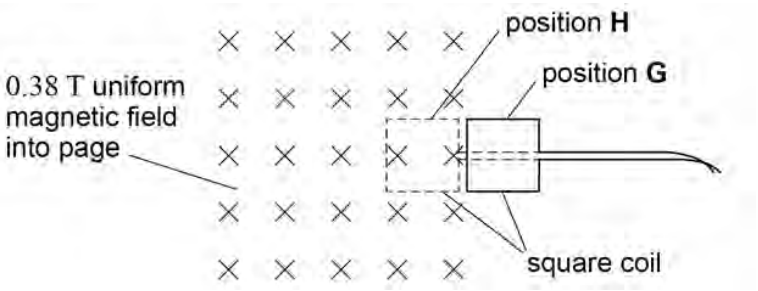
Figure 7



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**.

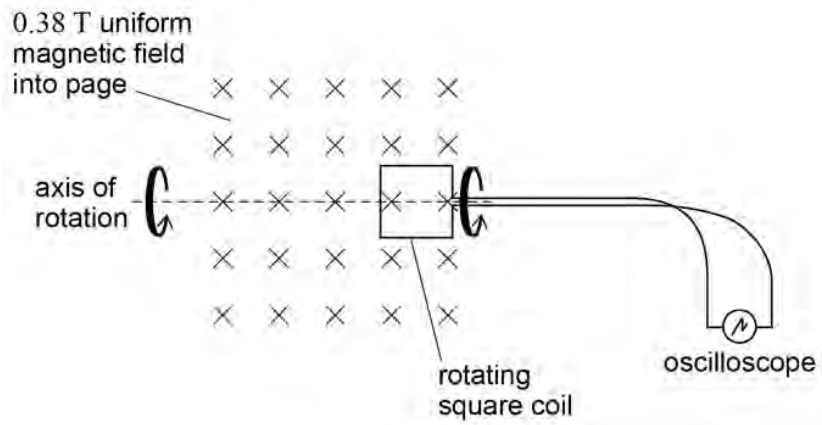
[2 marks]

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



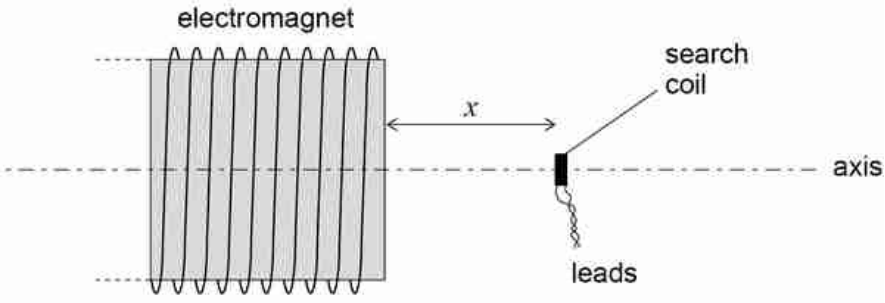
Calculate the angular speed of the coil when the maximum reading on the oscilloscope is 5.1 mV

[2 marks]

angular speed = _____ rad s^{-1}

0 4 **Figure 7** shows a search coil positioned on the axis of an electromagnet, with the plane of the search coil perpendicular to the axis. A magnetic field is produced by a constant current in the electromagnet.
Assume that the magnetic flux density inside the search coil is uniform.

Figure 7



The distance between the search coil and the end of the electromagnet is x.
Figure 8 shows how the magnetic flux density B of the field varies with x.

Figure 8

The search coil has 200 turns and a cross-sectional area of 3.5×10^{-5} m^2.

0 4 . 1 The search coil is placed at $x = 0.070$ m.

Show that the magnetic flux linkage through the search coil is about 5×10^{-4} Wb.

[2 marks]

Question 4 continues on the next page

The search coil is now moved at a constant speed of $0.80\ \text{m s}^{-1}$ along the axis so that x is increasing. An emf is induced across the terminals of the search coil.

0 4 . 2 Explain what happens to the value of the emf as the search coil moves.

[2 marks]

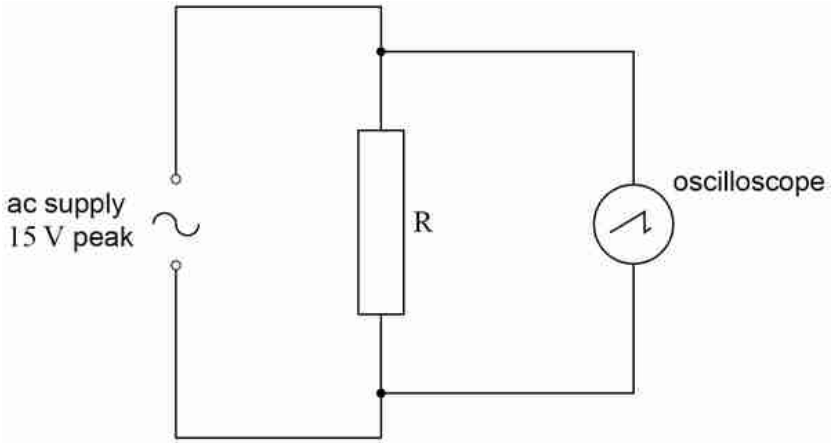
0 4 . 3 The search coil passes through the position where $x = 0.10\ \text{m}$.

Deduce whether the emf can exceed $5\ \text{mV}$ for values of x greater than $0.10\ \text{m}$.

[4 marks]

0 4 **Figure 6** shows an oscilloscope connected across resistor R which is in series with an ac supply. The supply provides a sinusoidal output of peak voltage 15 V.

Figure 6



0 4 . 1 Calculate the rms voltage of the supply.

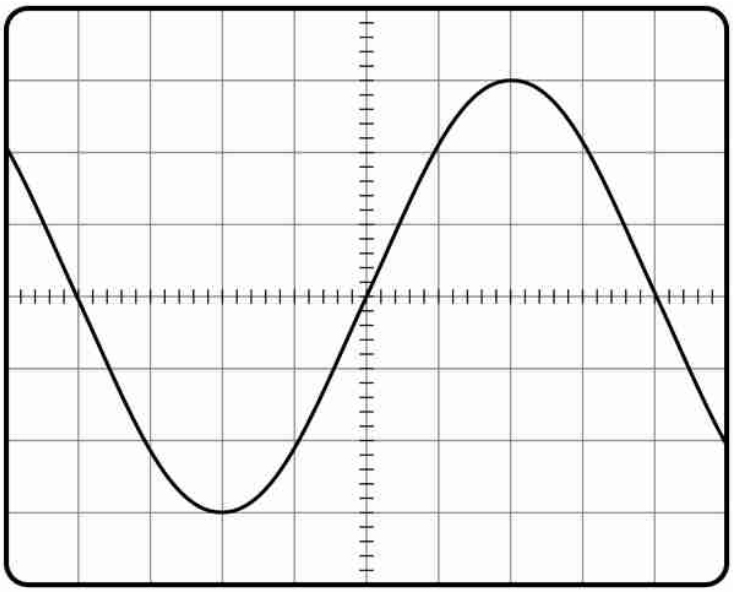
[1 mark]

rms voltage = _____ V

Question 4 continues on the next page

Figure 7 shows the trace of the waveform displayed on the oscilloscope.

Figure 7



0 4 . 2 Determine the y-voltage gain of the oscilloscope used for **Figure 7**.

[1 mark]

y-voltage gain = _____ V div^{-1}

0 4 . 3 A dc supply gives the same rate of energy dissipation in R as the ac supply in **Figure 6**.

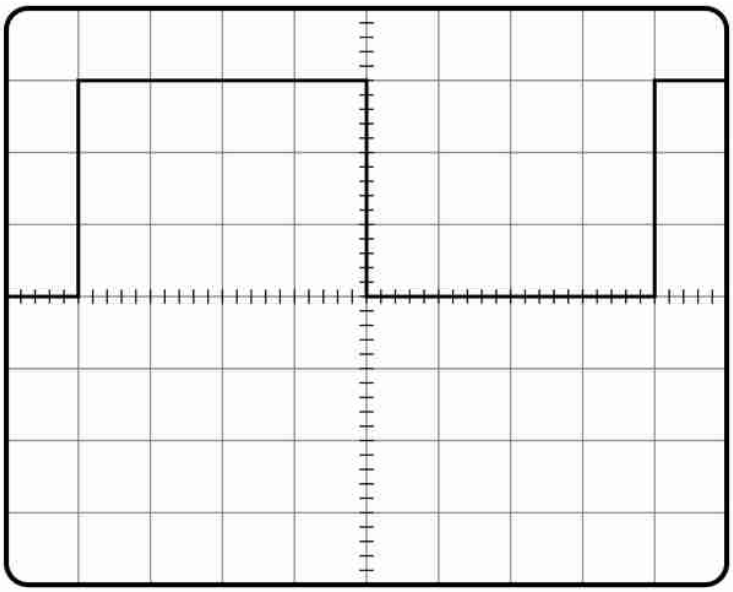
Draw the trace of the output of the dc supply on **Figure 7**.
The oscilloscope settings remain the same.

[1 mark]

0 4 . 4 The ac supply shown in **Figure 6** is replaced with a square-wave generator operating between 0 and +15 V.

Figure 8 shows the trace of the new waveform displayed on the oscilloscope.
The time-base is set to 5.0×10^{-4} s div^{-1}.

Figure 8



Calculate the frequency of the square waves.

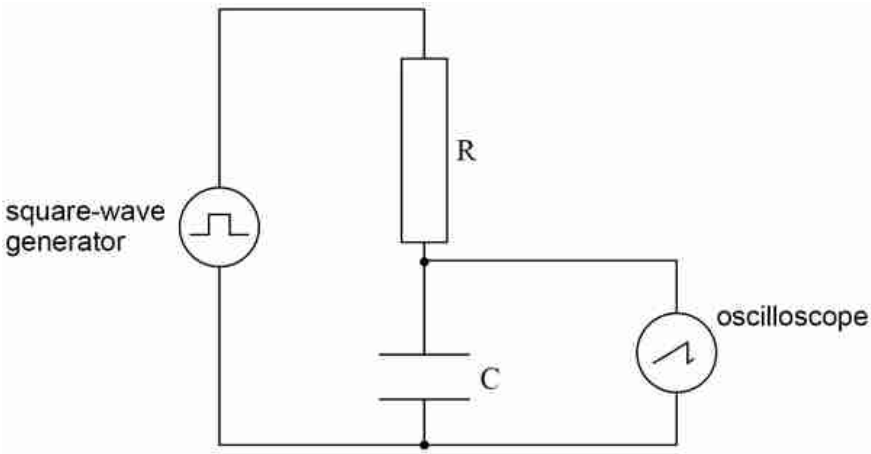
[1 mark]

frequency = _____ Hz

Question 4 continues on the next page

0 4 . 5 **Figure 9** shows the arrangement with the square-wave generator connected to an RC circuit.
A capacitor C is placed in series with the resistor R.
The oscilloscope is connected across the capacitor C.

Figure 9



The capacitor charges and discharges.

Figure 10 shows the trace of the waveform displayed on the oscilloscope.
The settings of the oscilloscope remain the same as in Question **04.4**.

Figure 10

Deduce the time constant for the RC circuit, explaining each step of your method.

[3 marks]

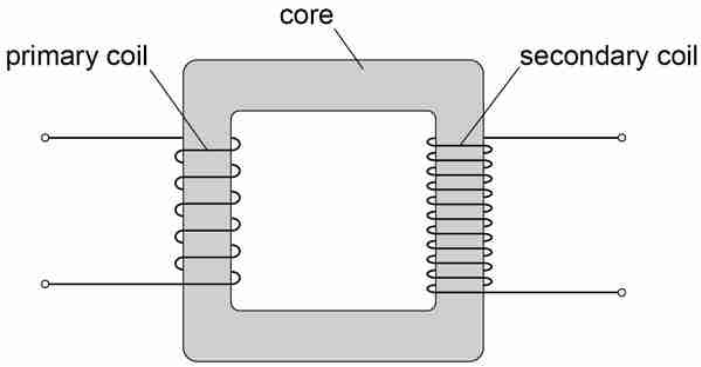
time constant = _____ s

0 4 . 6 State and explain a change to **one** control setting on the oscilloscope that would reduce the uncertainty in the value of the time constant.

[2 marks]

0 5 **Figure 7** shows a transformer.

Figure 7



0 5 . 1 Explain the functions of the core and the secondary coil.

[3 marks]

core _____

_____

_____

_____

secondary coil _____

0 5 . 2 **Figure 8** shows a cross-section through the transformer core. Thin iron sheets are separated by material **M**.

Explain how the efficiency of the transformer is increased by constructing the core in this way.

[3 marks]

Figure 8

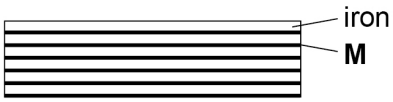
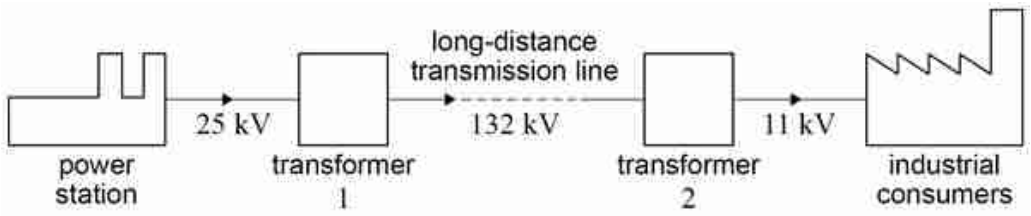


Figure 9 shows a schematic diagram of a power transmission system.

Figure 9



0 5 . 3 Voltages between 33 kV and 400 kV are used for long-distance transmission.

Suggest why engineers have chosen 132 kV for this system.

[2 marks]

Question 5 continues on the next page

0 5 . 4 The industrial consumers use 72 MW of power.
Transformers 1 and 2 each have an efficiency of 98% and the transmission line has an efficiency of 94%.

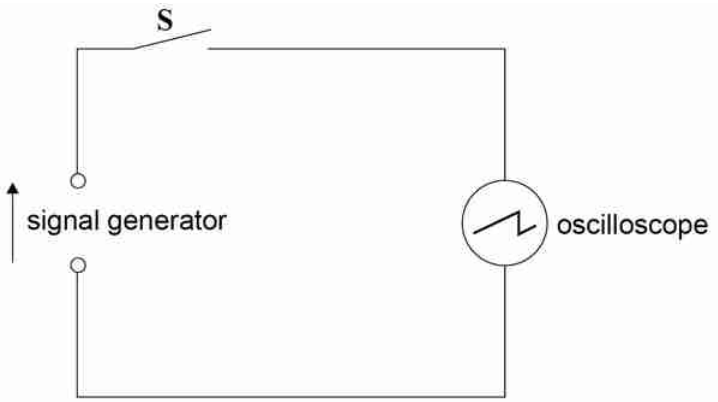
Calculate the current in the 25 kV line from the power station.

[3 marks]

current = _____ A

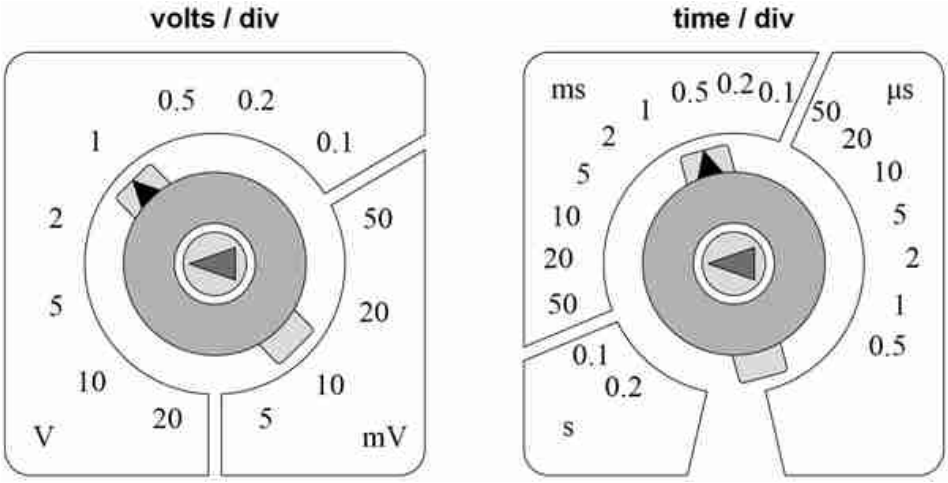
0 2 A signal generator is connected to an oscilloscope, as shown in **Figure 5**.

Figure 5



The Y-voltage gain and time-base settings of the oscilloscope are shown in **Figure 6**.

Figure 6



Question 2 continues on the next page

When switch **S** is open (off) the oscilloscope displays the waveform shown in **Figure 7**.

When **S** is closed (on) the oscilloscope displays the waveform shown in **Figure 8**.

0 2 . 1 Determine the peak-to-peak voltage V of the waveform shown in **Figure 8**.

[1 mark]

V = _____ V

0 2 . 2 Determine the frequency f of the waveform shown in **Figure 8**.

[2 marks]

f = _____ Hz

Figure 7

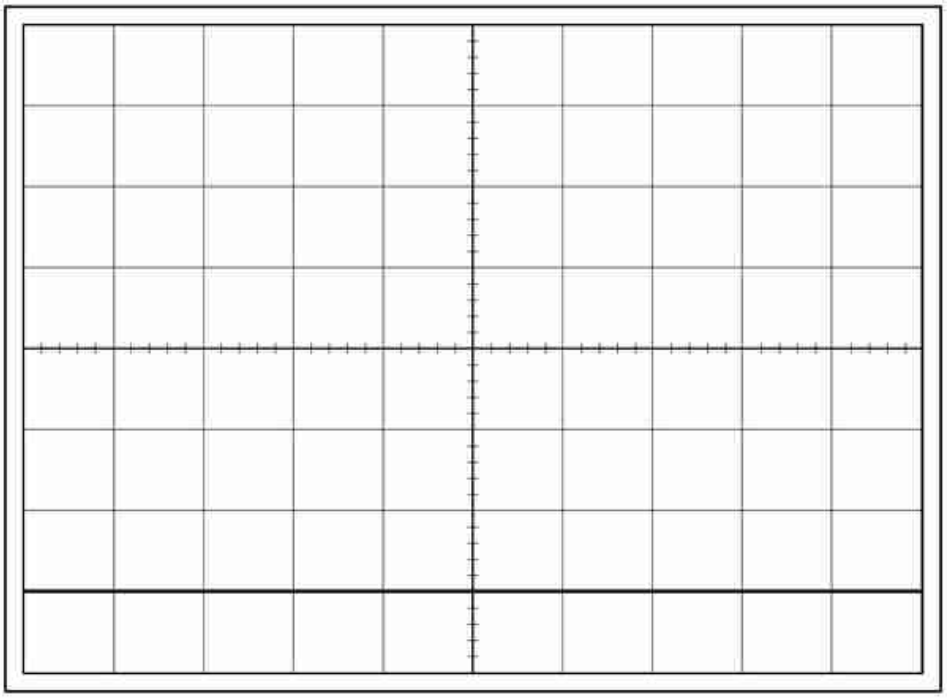
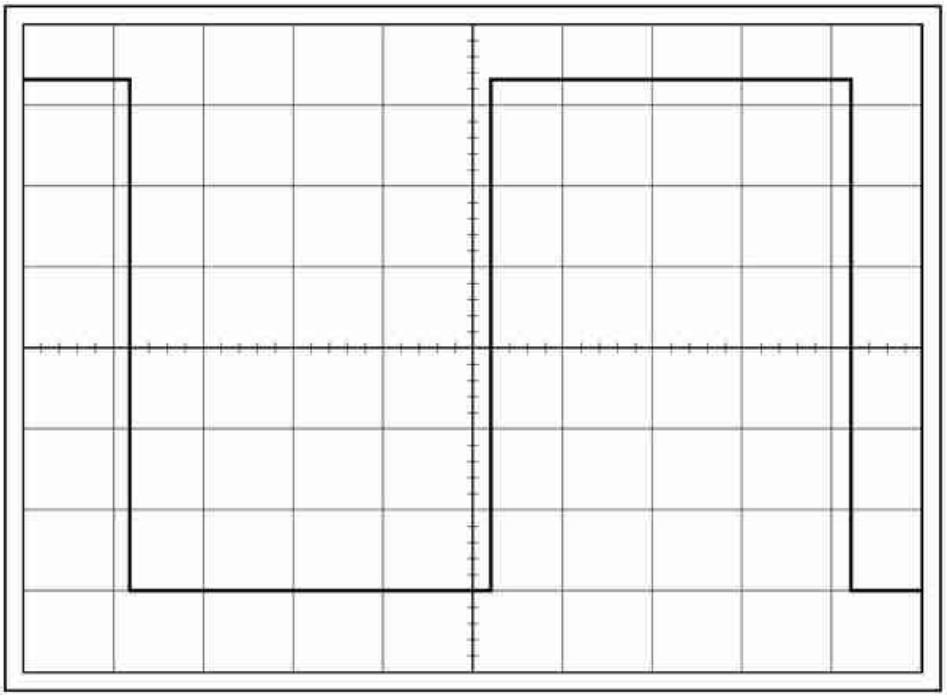


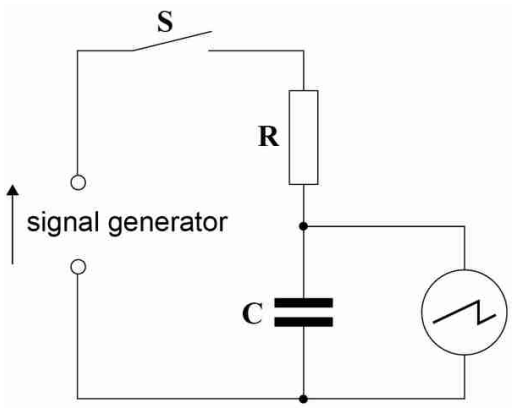
Figure 8



Question 2 continues on the next page

0 2 . 3 **Figure 9** shows the signal generator connected in series with a resistor **R** and a capacitor **C**.

Figure 9



The oscilloscope is connected across the capacitor.
The Y-voltage gain and time-base settings are still the same as shown in **Figure 6**.

When **S** is closed (on) the oscilloscope displays the waveform shown in **Figure 10**.

Figure 10

Determine the time constant of the circuit in **Figure 9**.

[2 marks]

time constant = _____ s

0 2 . 4 A student suggests that setting the time-base to $0.2\ \text{ms division}^{-1}$ might reduce uncertainty in the determination of the time constant.

State and explain any possible advantage or disadvantage in making this suggested adjustment.

[3 marks]

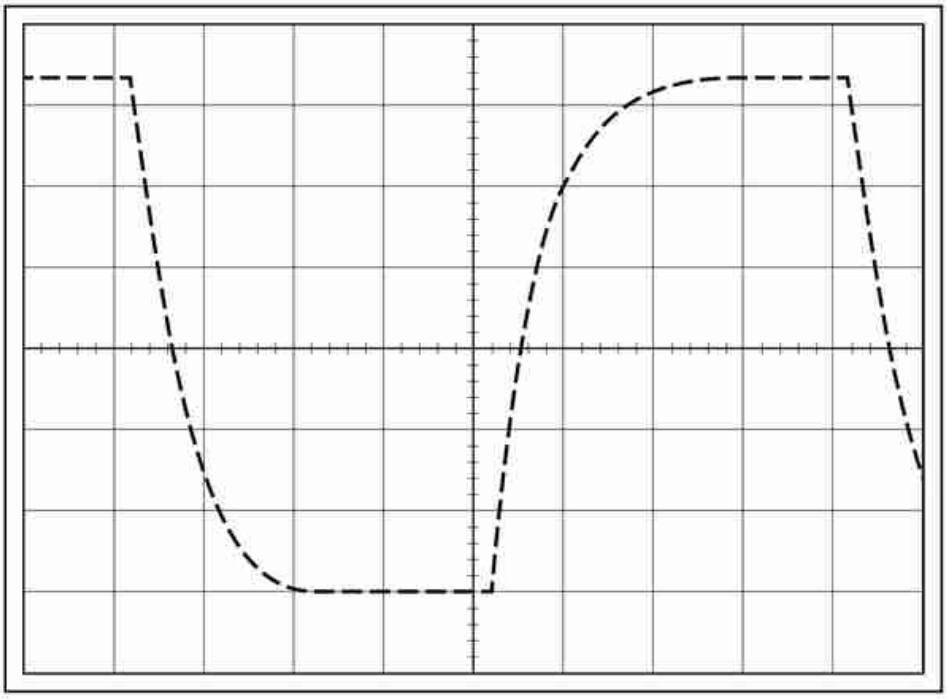
Question 2 continues on the next page

0 2 . 5 The student connects an identical resistor in parallel with **R** and uses the oscilloscope to display the waveform across **C**.

Draw on **Figure 11** the waveform you expect the student to see.

The waveform of **Figure 10** is shown as a dashed line to help you show how the waveform changes.

Figure 11



Explain the change in the waveform.

[2 marks]

0 2 . 6 **Figure 12a** is a graph of voltage against time showing the output of the signal generator. **Figure 12b** shows the voltage across **C** during the same time interval.

The student interchanges the positions of **R** and **C** and connects the oscilloscope across **R**.

Complete **Figure 12c** to draw the voltage across **R** during the time interval.

[2 marks]

Figure 12a

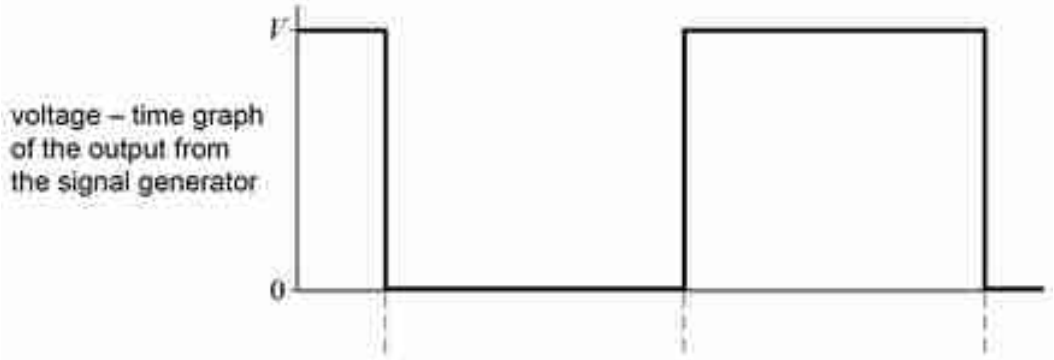


Figure 12b

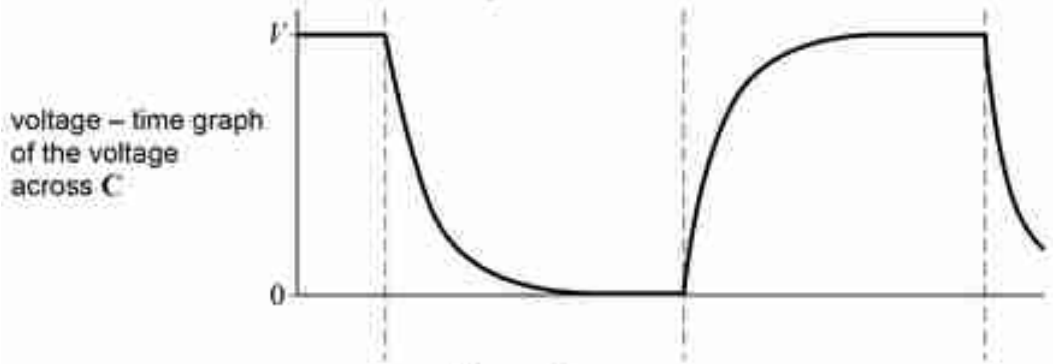
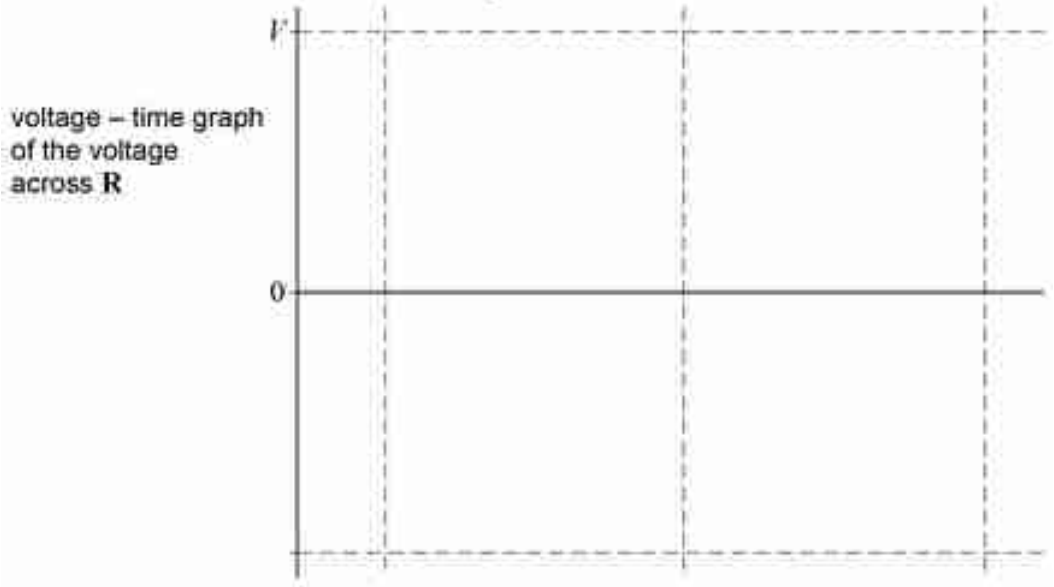


Figure 12c



Question 2 continues on the next page

0 2 . 7 State and explain what changes, if any, the student needs to make to the settings of the oscilloscope so the waveform across **R** is fully displayed.

[2 marks]

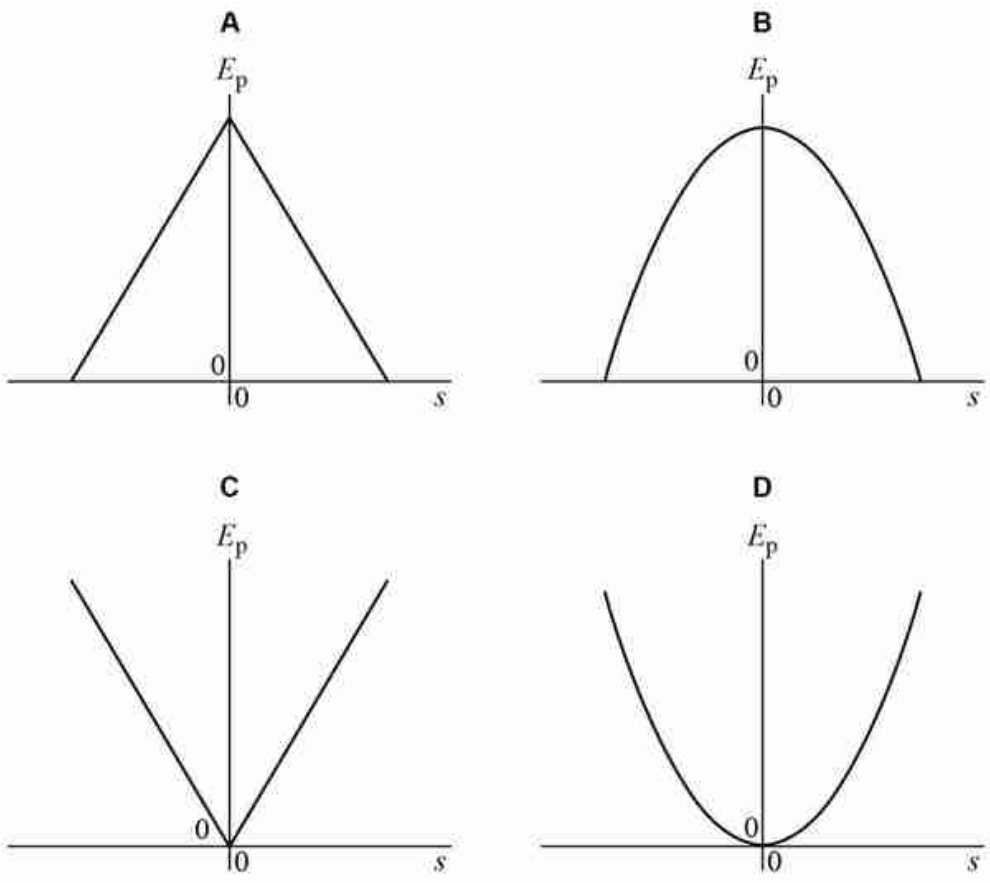
SUB-TOPIC 3.7.S

SYNOPTIC AND CROSS-TOPIC QUESTIONS

Sub-topic 3.7.S · 7 questions · 49 marks · lowest tariff first

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.

1 6 A body of constant mass falls freely due to gravity.

The rate of change of momentum of the body is equal to its

[1 mark]

A kinetic energy. ⬭

B mass. ⬭

C gravitational potential energy. ⬭

D weight. ⬭

2 5 A parachutist descends to the ground at a constant speed with the parachute open.



Which force, together with the parachutist's weight, makes a pair according to Newton's third law of motion?

[1 mark]

A the drag force on the parachutist from the air ⬭

B the tension in the strings of the parachute ⬭

C the gravitational force of the parachutist on the Earth ⬭

D the lift force on the parachute from the air ⬭

2 5 A pendulum is oscillating with simple harmonic motion.

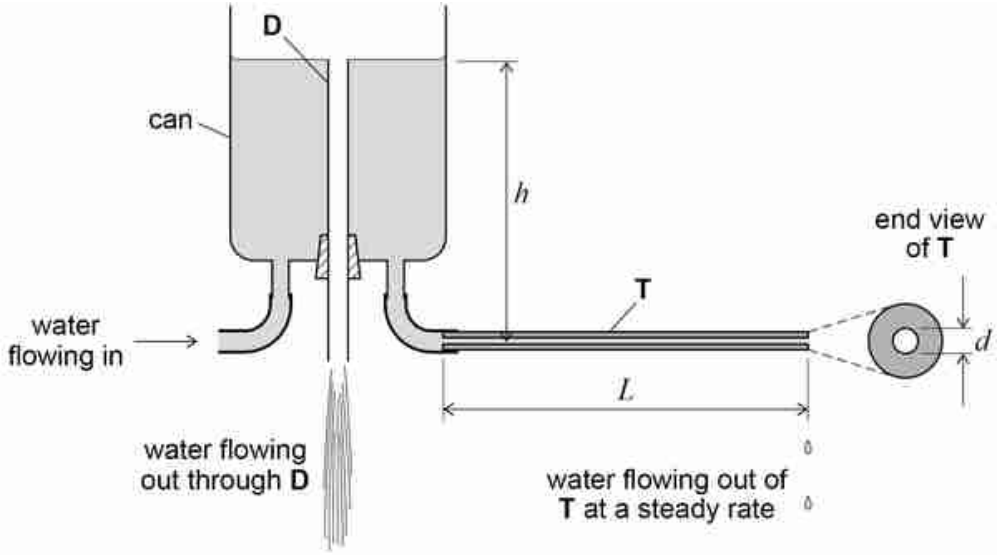
Which row gives the momentum of the pendulum bob and its gravitational potential energy (GPE) when the acceleration of the pendulum bob is zero?

[1 mark]

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

0 2 **Figure 7** shows apparatus used to investigate the rate at which water flows through a horizontal cylindrical tube **T** of internal diameter d and length L.

Figure 7



The apparatus ensures that the water level in the can is at a constant height h above the centre of **T**.

Water flows out of **T** at a steady rate.

0 2 . 1 The volume flow rate through **T** is Q, where Q is in $\mathrm{m^3\,s^{-1}}$.
A student wants to measure Q as water flows through **T**.

Outline a procedure the student should follow to measure Q.
Include in your answer

- the measuring instruments used
- how uncertainty in the measurements can be reduced.

[4 marks]

0 2 . 2 It can be shown that

$$Q = \frac{\pi \rho g h d^4}{128 L \eta}$$

where ρ is the density of water
g is the gravitational field strength
η is a property of the water called the coefficient of viscosity.

What is the SI unit for η?
Tick (✓) **one** box.

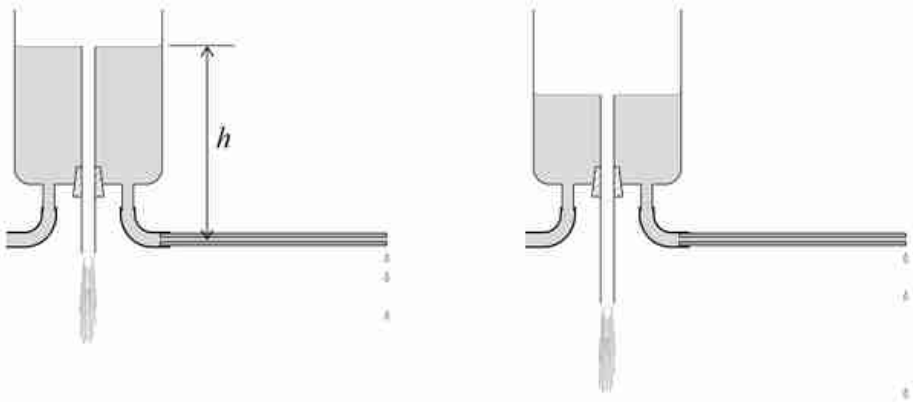
[1 mark]

- $\text{N m}^{-1}\text{ s}$ ☐
- $\text{N m}^{-2}\text{ s}$ ☐
- $\text{N m}^{-1}\text{ s}^{-1}$ ☐
- $\text{N m}^{-2}\text{ s}^{-1}$ ☐

Question 2 continues on the next page

0 2 . 3 An experiment is carried out to determine η by a graphical method.
The rate at which water flows out of **T** is varied by adjusting the height of the drain tube as shown in **Figure 8**.

Figure 8



During the experiment the temperature is kept constant.
Q is found for different values of h and a graph of these data is plotted, with Q on the vertical axis.
The percentage uncertainty in the gradient of the graph is 6.4%.

The dimensions of tube **T** are measured and the uncertainties in these data are calculated.

The percentage uncertainty
- in d is 2.9%
- in L is 1.8%.

The percentage uncertainties in ρ and g are negligible.

Deduce the percentage uncertainty in the result for η.

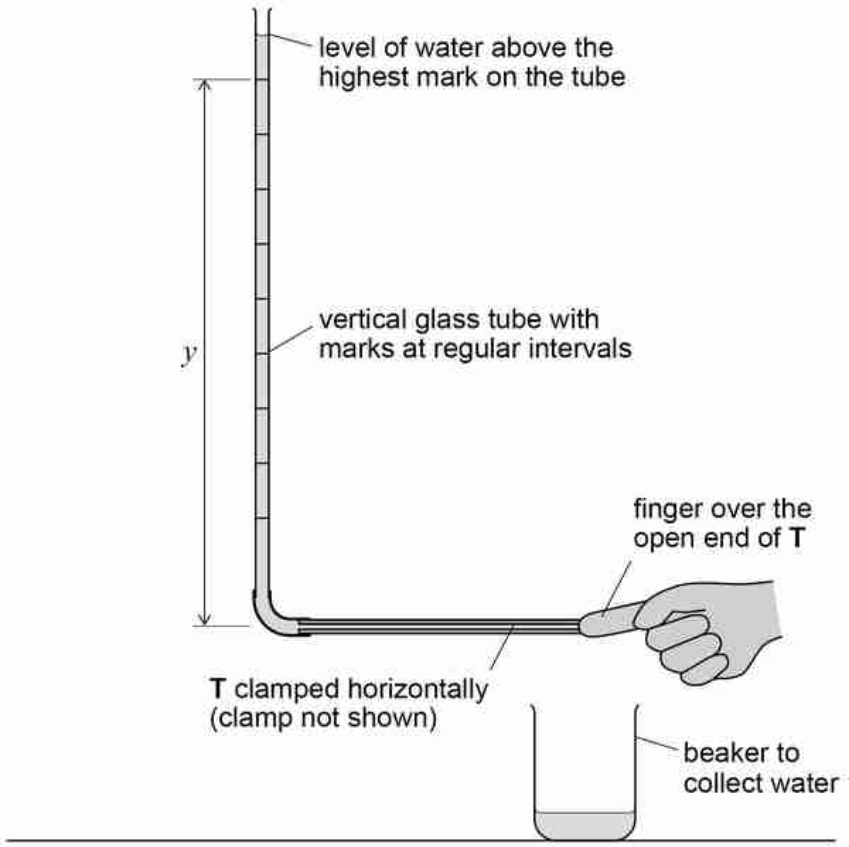
[2 marks]

percentage uncertainty in η = _____

0 2 . 4 In a different experiment, the horizontal tube **T** is connected to a vertical glass tube.
Marks have been made at regular intervals on the glass tube.
The student measures and records the vertical distance y between each of the marks and the centre of **T**.

She seals the open end of **T** and fills the glass tube with water, as shown in **Figure 9**.

Figure 9



T is opened and water flows into a beaker.
When the water level falls to the highest mark on the tube, she starts a stopwatch.
She records the time t for the water to reach each of the other marks.

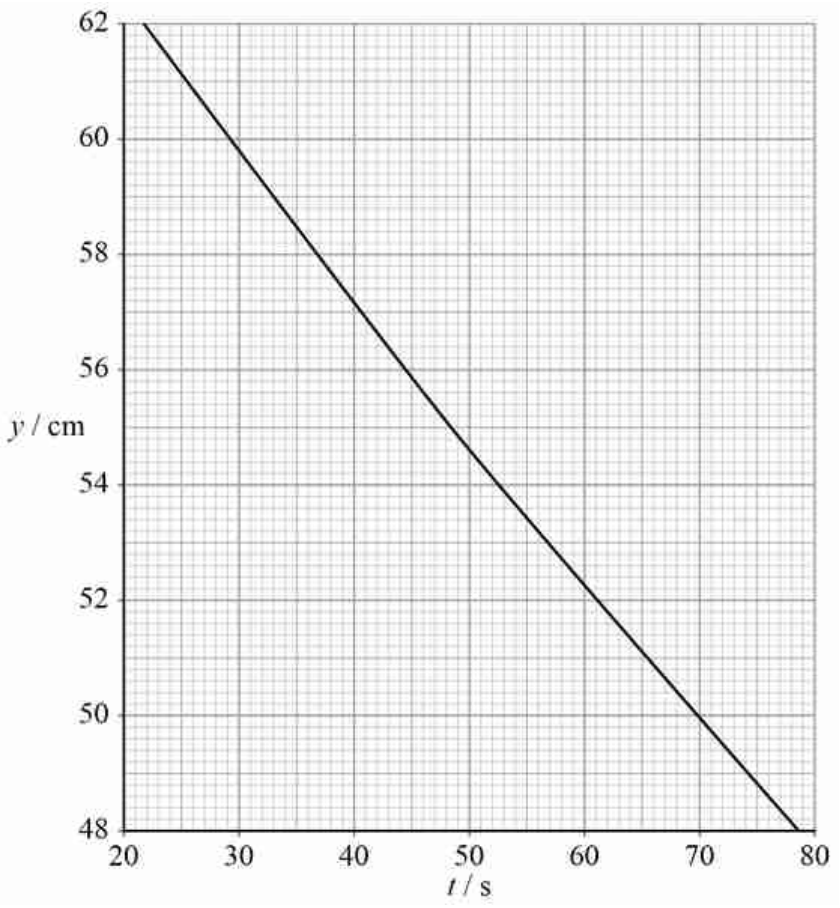
Explain how the student could check that the glass tube was vertical.
You may wish to add detail to **Figure 9** to illustrate your answer.

[1 mark]

Question 2 continues on the next page

0 2 . 5 **Figure 10** shows part of the graph drawn from the student's data.

Figure 10



It can be shown that y decreases exponentially with t.

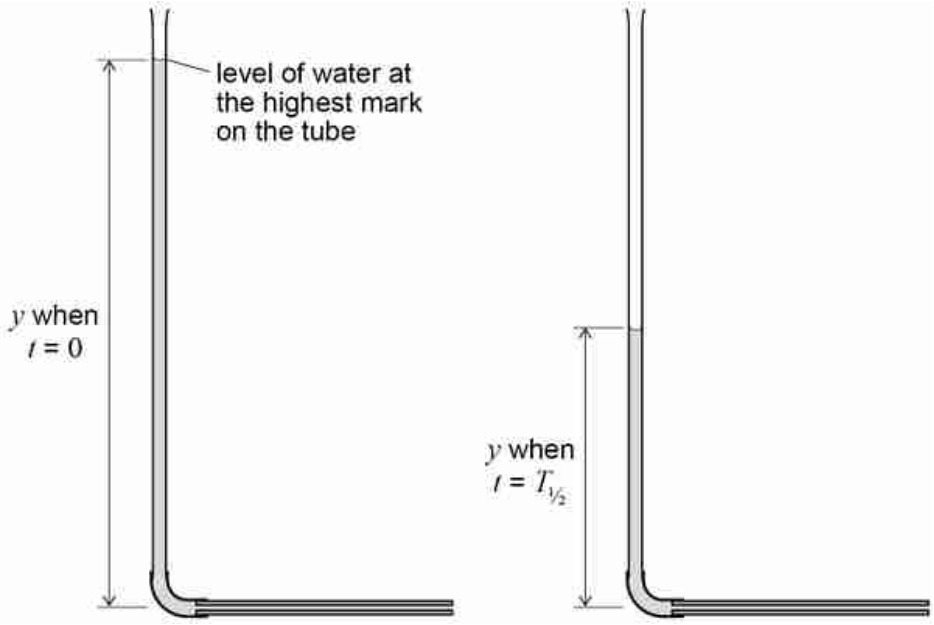
Show that λ, the decay constant for this process, is about 4.5×10^{-3} s^{-1}.

[2 marks]

λ = _____ s^{-1}

0 2 . 6 $T_{1/2}$ is the time for y to decrease by 50%, as shown in **Figure 11**.

Figure 11



Determine $T_{1/2}$.

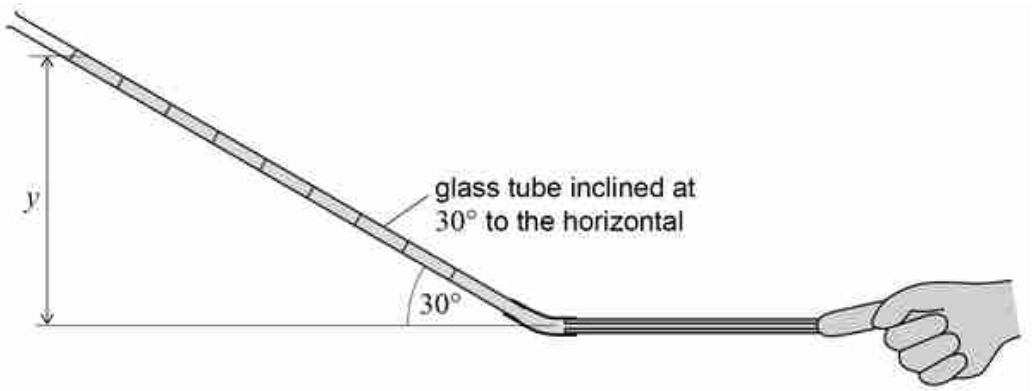
[1 mark]

$T_{1/2}$ = _____ s

Question 2 continues on the next page

0 2 . 7 The apparatus is adjusted so that the glass tube is inclined at $30°$ to the horizontal tube **T**, as shown in **Figure 12**.

Figure 12



The student measures and records the new values of y, the mean vertical distance between each of the marks and the centre of **T**.
She then carries out the experiment as before, recording new values of t corresponding to each new value of y.

Draw a line on **Figure 13** to show the graph produced using the modified apparatus. The dashed line is the original graph when the glass tube was vertical as shown in **Figure 9**.

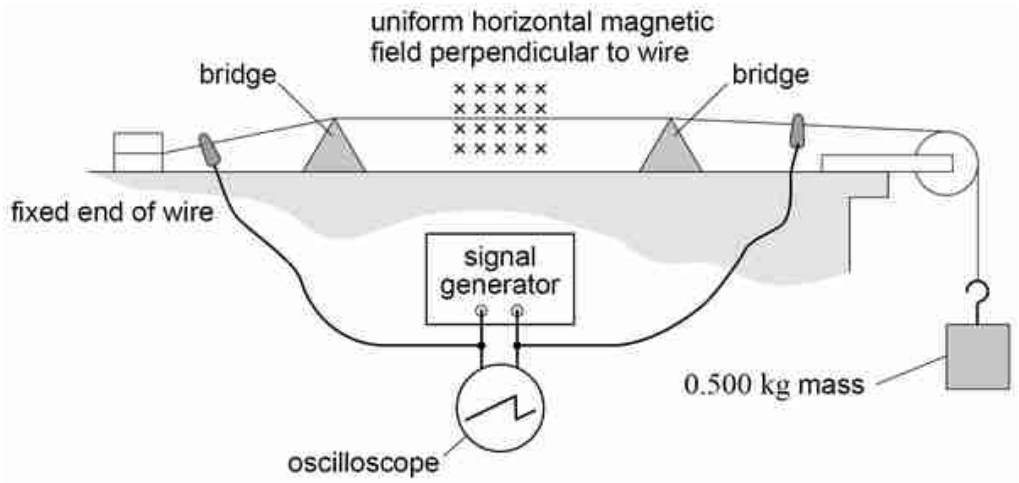
[2 marks]

Figure 13

0 3 A stationary wave is formed on a stretched wire.

Figure 14 shows the wire, fixed at one end, supported by two bridges and passing over a pulley.

Figure 14



A 0.500 kg mass is attached to the free end of the wire.
A uniform horizontal magnetic field is applied perpendicular to the wire between the bridges.
A signal generator is connected to each end of the wire.

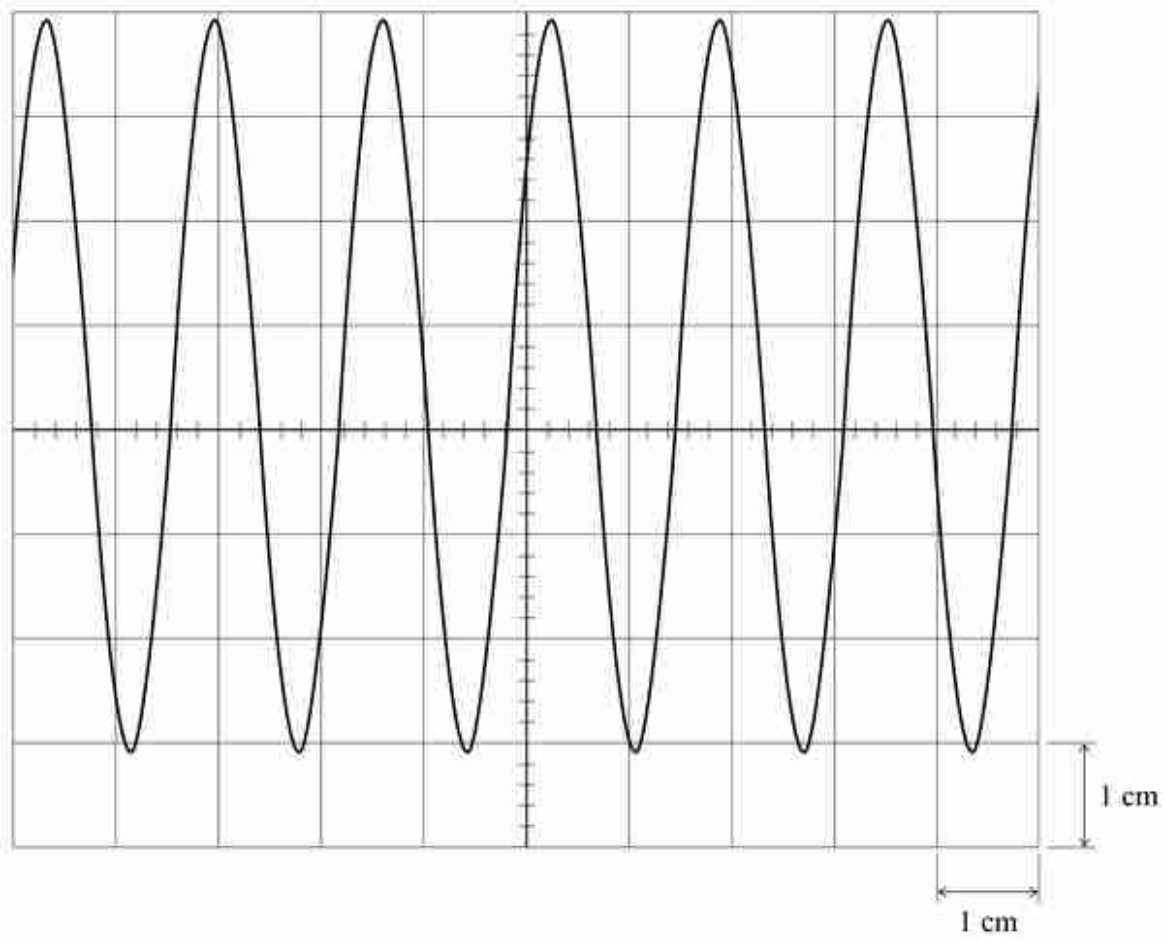
The oscilloscope shown is used to determine the frequency of the output of the signal generator. The wire oscillates because the alternating current in the wire interacts with the magnetic field.

Figure 15 shows the first harmonic stationary wave produced when the distance x between the bridges is adjusted.

Figure 15

0 3 . 1 The output potential difference (pd) of the signal generator is displayed on the oscilloscope, as shown in **Figure 16**.

Figure 16



The time-base setting of the oscilloscope is $10\ \text{ms cm}^{-1}$.

Determine f, the frequency of the alternating pd.

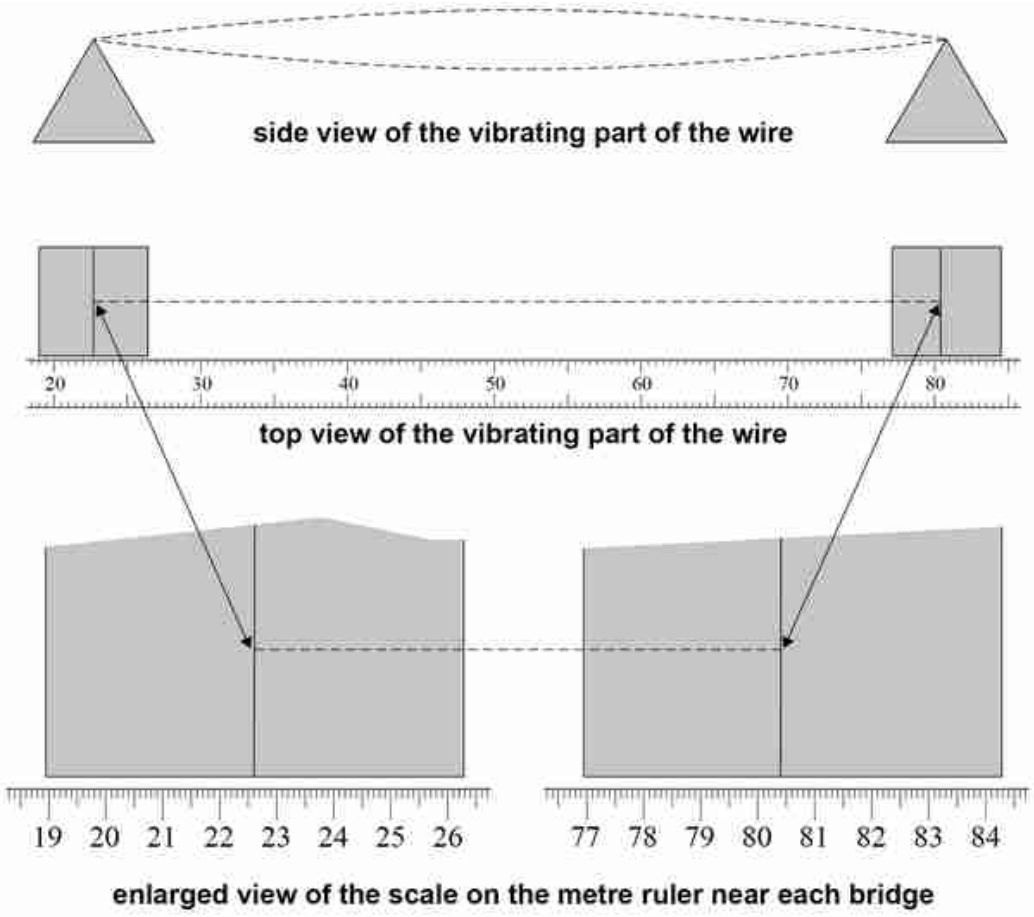
[2 marks]

f = _____ Hz

Question 3 continues on the next page

0 3 . 2 A metre ruler is placed next to the bridges supporting the wire, as shown in **Figure 17**.

Figure 17



Determine the wavelength λ of the stationary wave shown in **Figure 17**.

[2 marks]

λ = _____ m

0 3 . 3 The stationary wave is formed by two waves of frequency f and wavelength λ travelling with speed c in opposite directions.

Determine c.

[1 mark]

c = _____ m s^{-1}

0 3 . 4 Determine, in kg m^{-1}, the mass per unit length of the wire.

[2 marks]

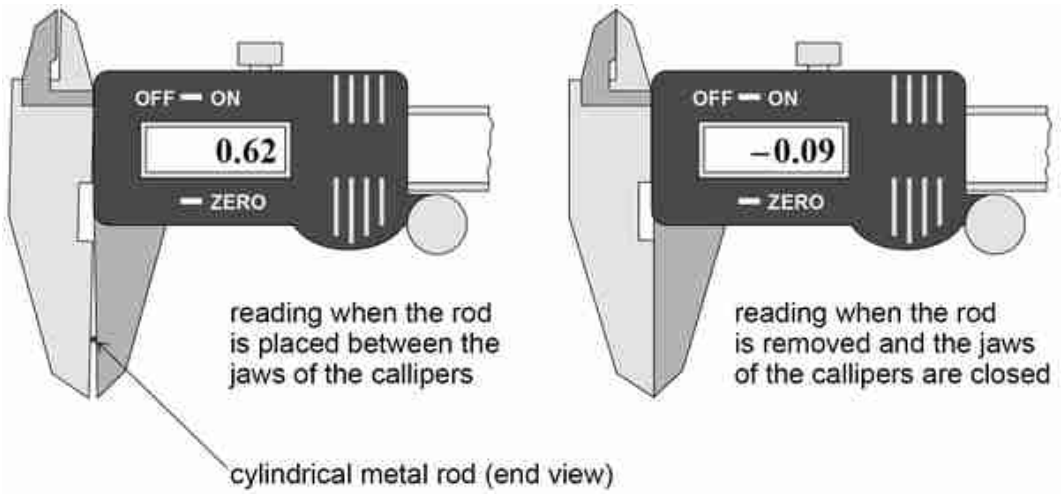
mass per unit length = _____ kg m^{-1}

Question 3 continues on the next page

0 3 . 5 A student uses digital vernier callipers to measure the diameter of a cylindrical metal rod. The student places the rod between the jaws of the callipers and records the reading indicated. Without pressing the zero button, the student removes the rod and closes the jaws.

Figure 18 shows the calliper readings in millimetres, before and after the jaws are closed.

Figure 18



Calculate the diameter d of the rod.

[1 mark]

d = _____ mm

0 3 . 6 Describe relevant procedures to limit the effect of random error in the result for d.

[2 marks]

0 3 . 7 Determine the density of the rod.
The mass per unit length of the rod is 3.54×10^{-3} kg m^{-1}.

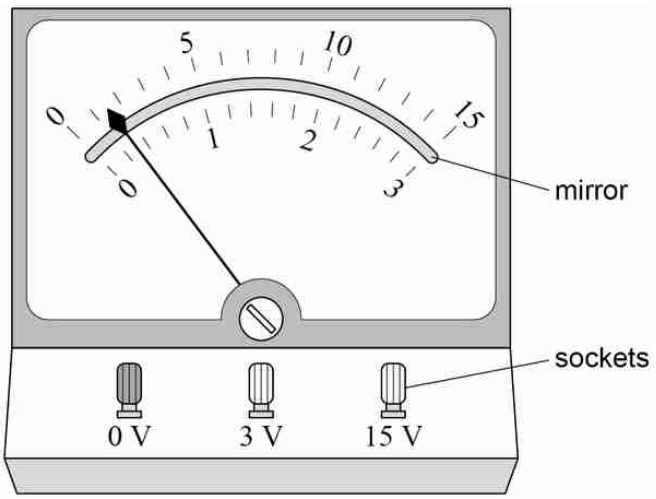
[3 marks]

density = _____ kg m^{-3}

END OF QUESTIONS

0 3 An analogue voltmeter has a resistance that is much less than that of a modern digital voltmeter.
Analogue meters can be damaged if the full-scale reading is exceeded.
Figure 6 shows a dual-range analogue voltmeter with a zero error.

Figure 6



0 3 . 1 The voltmeter is set to the **more sensitive** range and then used in a circuit.

What is the potential difference (pd) between the terminals of the voltmeter when a full-scale reading is indicated?

Tick (✓) **one** box.

[1 mark]

2.7 V ☐

3.3 V ☐

13.5 V ☐

16.5 V ☐

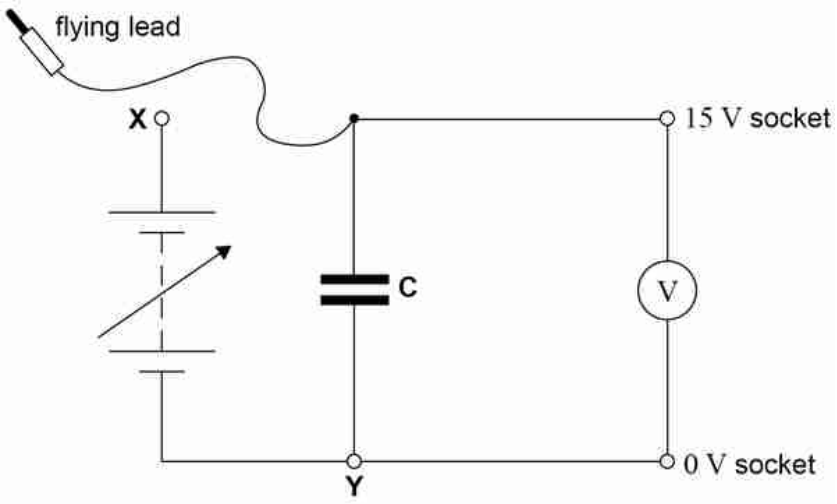
0 3 . 2 Explain the use of the mirror when reading the meter.

[2 marks]

Question 3 continues on the next page

A student corrects the zero error on the meter and then assembles the circuit shown in **Figure 7**.
The capacitance of the capacitor **C** is not known.

Figure 7



The output pd of the power supply is set to zero.
The student connects the flying lead to socket **X** and adjusts the output pd until the voltmeter reading is full scale (15 V).
She disconnects the flying lead from socket **X** so that **C** discharges through the voltmeter.

She measures the time $T_{½}$ for the voltmeter reading V to fall from 10 V to 5 V.

She repeats this process several times.

Table 1 shows the student's results, **none** of which is anomalous.

Table 1

$T_{½}$ / s	12.00	11.94	12.06	12.04	12.16

0 3 . 3 Determine the percentage uncertainty in $T_{½}$.

[2 marks]

percentage uncertainty = _____ %

0 3 . 4 Show that the time constant for the discharge circuit is about 17 s.

[1 mark]

Question 3 continues on the next page

0 3 . 5 The student thinks that the time constant of the circuit in **Figure 7** is directly proportional to the range of the meter.
To test her theory, she repeats the experiment with the voltmeter set to the $3\ \text{V}$ range.
She expects $T_{½}$ to be about $2.5\ \text{s}$.

Explain:

- what the student should do, before connecting capacitor **C** to the $0\ \text{V}$ and $3\ \text{V}$ sockets, to avoid exceeding the full-scale reading on the voltmeter
- how she should develop her procedure to get an accurate result for the time constant
- how she should use her result to check whether her theory is correct.

[4 marks]

The student wants to find the resistance of the voltmeter when it is set to the 15 V range.
She replaces **C** with an 820 μF capacitor and charges it to 15 V.
She discharges the capacitor through the voltmeter, starting a stopwatch when V is 14 V.
She records the stopwatch reading t at other values of V as the capacitor discharges.

Table 2 shows her results.

Table 2

V / V	14	11	8	6	4	3	2
t / s	0.0	3.1	7.2	11.0	16.2	19.9	25.2

0 3 . 6 Suggest **two** reasons why the student selected the values of V shown in **Table 2**.
Explain each of your answers.

[4 marks]

1

2

Question 3 continues on the next page

Figure 8 shows a graph of the experimental data.

Figure 8

0 3 . 7 Show, using **Figure 8**, that the resistance of the voltmeter is about 16 kΩ.

[3 marks]

0 3 . 8 Determine the current in the voltmeter at $t = 10$ s.

[2 marks]

current = _____ A

END OF QUESTIONS

MARK SCHEMES

official mark schemes

C

A

A

D

C

B

D

C

B

B

D

C

D

B

09	A	**A**	μ^+	✓	✓	

11	B	

12	B	$4g$

13	A	7.2 J

09	D (AO2)	R	

10	B (AO1)	2.7×10^{-6} rad s^{-1}	

11	B (AO2)	$\sqrt{2gR}$	

13	D (AO2)	the orbital period of the satellite

11	B	$\left(\frac{M}{R}\right)^{\frac{1}{2}}$

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

21	C	$\frac{R}{2}$

22	B	10^4 m	

23	D	The work done moving from **Q** to **R** and moving from **Q** to **S** is the same.
		the charge stored on a capacitor consisting of two parallel plates of area $1\ \mathrm{m}^2$

7	B	$\frac{\sqrt{2}}{3}v$	AO2

03.1	the work done/energy required in bringing 1 kg/unit mass from infinity to the point ✓	mass. Ignore extra comments eg about charge.	1	AO1-1a-1
03.2	The potential difference between the lines is constant but the distances are not Or $\frac{\Delta V}{\Delta r}$ is changing ✓ (potentials $\frac{\Delta V}{\Delta r}$, inner 0.857, outer = 0.625) Or The equipotential surfaces are not straight / not parallel / are curved ✓	The mark is given for the idea that the separation should be uniform or that equipotential lines should not be curved. Owtte Discussions should not imply there is a correct curvature. Errors can come from references to the moon to first equipotential distance. Or by saying the potential gaps are not uniform or by saying the distance from the centre of the Moon is not proportional to the potential.	1	AO3-1a-1
03.3	M = mass of Moon $= \frac{-V \times r}{G} = \frac{(-1) \times -1.60 \times 10^{6} \times 3.06 \times 10^{6}}{6.67 \times 10^{-11}}$ ✓$_1$ $M = 7.3$ or 7.4×10^{22} (kg) ✓$_2$ (Use of $\frac{GMm}{r} = \frac{1}{2}mv^2$) $v = \sqrt{\frac{2GM}{r}}$ ✓$_3$	✓$_1$ The mark is given for use and rearranging the equation so errors may be seen in the data and any equipotential may be used. Condone the misuse of a negative sign ✓$_2$ Note All equipotential lines produce the same mass. The answer my be seen in the equations that follow. ✓$_2$ An attempt to use this re-arranged formula gains this 3rd mark.	4	AO3-1b-1 AO2-1f-3 Math2-2

	$v = 2.3$ or 2.4×10^3 (m s^{-1}) ✓$_4$ (2370 m s^{-1})			

	Alternative (Use of $V = \frac{-GM}{r}$) $Vr = -MG$ = constant $Vr = -1.60 \times 10^6 \times 3.06 \times 10^6$ $= -4.9 \times 10^{12}$ (J Kg^{-1} m) ✓$_{1Alt}$ (at the surface of the Moon) $V_{surface} = \frac{-4.9 \times 10^{12}}{1.74 \times 10^6}$ $V_{surface} = -2.8(2) \times 10^6$ (J kg^{-1}) ✓$_{2Alt}$ (Use of $mV = \frac{1}{2}mv^2$) $v = \sqrt{2V_{surface}} = \sqrt{2 \times 2.82 \times 10^6}$ ✓$_{3Alt}$ $v = 2.4 \times 10^3$ (m s^{-1}) ✓	✓$_{1Alt}$ Any attempt to calculate Vr OR to indicate that it is constant gains this mark. ✓$_{3Alt}$ An attempt to use this re-arranged formula gains this 3rd mark. ✓$_{4Alt}$ A correct answer shows the previous work has been done correctly and gains all 4 marks.		

Total			**6**

Question	Answers	Additional Comments/Guidance	Mark	ID details
	C (= $4\pi\varepsilon_o r = 4\pi \times 8.85 \times 10^{-12} \times 0.020$) $= 2.2(2) \times 10^{-12}$ (F) ✓1	✓1 Mark for substitution or answer. Also it may be seen incorporated into the second mark. Substitution of ✓2 Use of r = 0.04 m in the previous mark is treated as an arithmetic error and the substitution $52 \times 10^{-9}/4.44 \times 10^{-12}$ is given a CE mark. ✓3 A continuation of the CE gives a mark to the		AO1-1a-1

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

04.1	Calculation of either radius by adding radius of Saturn to height ✓ Use of $\frac{T_1}{r_1^{\frac{3}{2}}} = \frac{T_2}{r_2^{\frac{3}{2}}}$ **OR** use of $T^2 = \frac{4\pi^2 r^3}{GM}$ **OR** Calculation of constant of proportionality (k) ✓ 1.36 (Earth days) ✓	Ignore PoT for first 2 marks $r_{\text{Mimas}} = 1.86 \times 10^8$ m $r_{\text{Enceladus}} = 2.38 \times 10^8$ m $k = \frac{T}{r^{1.5}}$ or $\frac{T^2}{r^3}$ or $\frac{T^{\frac{2}{3}}}{r}$ Allow ecf for MP2 and MP3 for ignoring radius of Saturn to give 1.57 (Earth days)	3	AO1

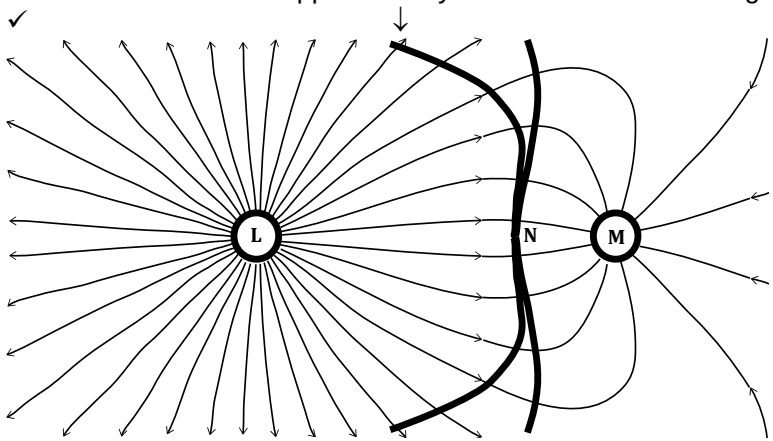
Question	Answers	Additional comments/Guidance	Mark	AO
04.2	Variation of potential with distance is (approximately) a straight / linear line / constant gradient **AND** the field strength is equal to the (potential) gradient ✓	Do **NOT** allow (directly) proportional Allow range shown on graph is much smaller than the distance from Saturn with support from a suitable equation.	1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
04.3	12.025×10^8 to 12.045×10^8 (m) ✓ (field = potential gradient, distance at which gradient = 0)	≥ 4 SF required Do **not** allow 12.02 or 12.05. **For non-standard papers:** MLP18A4 as main mark scheme MLP18A3 12.015×10^8 to 12.050×10^8 (m)	1	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
04.4	Gravitational potential from Titan = value from dashed line − value from solid line at consistent distance $= -3.2(00) \times 10^7 - -3.135 \times 10^7 = -6.5 \times 10^5$ (J kg^{-1}) ✓	ignore PoT for MP1 and MP2 Allow $-3.2(00) \times 10^7$ to -3.203×10^7 Allow -3.135×10^7 to -3.138×10^7 Allow -6.2×10^5 to -6.8×10^5 **For non-standard papers:** MLP18A4 as main mark scheme MLP18A3 allow variation in read offs but answer in same range.	3	AO2
	Any **one** from: ✓ • distance from Titan = $12.22 \times 10^8 - 12.08 \times 10^8$ $(= 1.4 \times 10^7)$ • use of $V = -\frac{GM}{r}$ (including with data taken directly from either line or their distance from Titan)			
	Correct answer for their V ✓	their V due to Titan (or -7×10^5) $\times 2.1 \times 10^{17}$ 1.36×10^{23} (kg) from -6.5×10^5 1.47×10^{23} (kg) from -7×10^5		
Total			**8**	

Question	Answers	Additional comments/Guidance	Mark	AO
		Allow material for dielectric		

06.1	Gravitational field lines show the direction (and relative magnitude) of force on a mass (placed in the force field) ✓ Or The direction a stationary/placed mass would (initially) move.		1
06.2	(Lines are closer together so) the field is stronger ✓ (Material forming the Earth) at **K** has a high(er) density (than the surrounding material) ✓	For second mark allow more mass at **K**. 'Force is stronger' does not gain first mark.	2
06.3	The ball will speed up/accelerate (when moving towards **K**) ✓ (because) the potential is lower at **K** ✓ Or the angled field lines between **J** and **K** have a component towards the right ie towards **K**) ✓		2
06.4	A gravitational field should only show attraction to a body / lines of force should only be going to an object / arrow heads (on the left) should point towards **L**. ✓ (owtte)	Reference to positive or negative almost always will lose the mark.	1
06.5	object = L object = L ✓		1

Question	Answers	Additional Comments/Guidelines	Mark
06.6	The drawn line should approximately cross the field lines at right angles ✓  A mark is given if the line is symmetrical top to bottom and it bend to the left. ✓	First mark: Only look at the <u>4 lines</u> of force close to N. Essentially the range is from a vertical line to one that curves only slightly in order to cross the 4 field lines close to N at right angles. This mark can also be given if a right angle symbol appears on the diagram at any field crossing of the drawn line. Second mark: There must be some bending of the line to the left (beyond the 4 lines close to N) but no more than that indicated by the arrow above the diagram (For reference the range extends to the position of the second field line that is truncated) So a very large circle centred on L and leaving the diagram might get 2nd mark but not the 1st. A vertical line might get the 1st but not the 2nd. A small circle around M will not score. If multiple lines are drawn only mark the line that passes through N.	2
Total			**9**

Question	Answers	Additional Comments/Guidelines	Mark

07.1	(centripetal) force = $m\,r\,(2\,\pi / T)^2$ Or $m\,r\,(\omega)^2$ (is given by the gravitational) force = $G\,m\,M / r^2$ ✓ (mark for both equations) (equating both expressions and substituting for ω if required) $T^2 = (4\pi^2 / GM)\,r^3$ ✓ ($4\pi^2 / GM$ is constant, the constants may be on either side of equation but T and r must be numerators)	First mark is for two equations (gravitational and centripetal) The second mark is for combining.	2
07.2	(use of $T^2 \propto r^3$ so $(T_P / T_E)^2 = (r_P / r_E)^3$) $(T_P /1.00)^2 = (5.91 \times 10^9 /1.50 \times 10^8)^3$ ✓ (mark is for substitution of given data into any equation that corresponds to the proportional equation given above) (T_P^2 = 61163) T_P = 250 (yr) ✓ (247 yr)	Answer only gains both marks The calculation may be performed using data for the Sun in $T^2 = (4\pi^2 / GM)\,r^3$ easily spotted from M_s = 1.99 x 10^{30} kg giving a similar answer 247 – 252 yr.	2
07.3	using M (= $g\,r^2 / G$) = $0.617 \times (1.19 \times 10^6)^2 / 6.67 \times 10^{-11}$ ✓ $M = 1.31 \times 10^{22}$ kg ✓ answer to 3 sig fig ✓ (this mark stands alone)	The last mark may be given from an incorrect calculation but not lone wrong answer.	3

07.4	Initial KE = ½ (m) 1400^2 = 9.8 x 10^5 (m) J✓ Energy needed to escape = 7.4 x 10^5 (m) J✓ So sufficient energy to escape. ✓ ***OR*** For object on surface escape speed given by 7.4 x10^5 = ½ v^2✓ escape speed = 1200 m s^{-1}✓(if correct equation is shown the previous mark is awarded without substitution) So sufficient (initial) speed to escape. ✓ ***OR*** escape velocity = $\sqrt{\frac{2GM}{R}}$ substituting *M* from 07.3 ✓ escape speed = 1200 m s^{-1}✓ (1210 m s^{-1}) So sufficient (initial) speed to escape. ✓ ***OR*** escape velocity = $\sqrt{2Rg}$ substituting from data in 07.3 ✓	Third alternative may come from a CE from 07.3 (1.06 x 10^{-8} x $\sqrt{\text{answer } 0.73}$) Conclusion must be explicit for third mark and cannot be awarded from a CE	3
Total			**10**

	Keys to Objective Test Questions (each correct answer is worth 1 mark)												
Q	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
A	B	A	C	D	C	A	A	A	A	C	D	C	D
Q	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	

A	A	C	B	B	C	C	D	B	B	A	D	C

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		

03.1	Any **one** from: ✓1 • region in which a mass experiences force due to another mass • (the field is conservative so) any change in potential energy only depends on the initial and final positions and not on path taken OWTTE • the force is always attractive **OR** field lines point to the (centre of) mass **OR** the equipotential surfaces are spherical about the (centre of) mass • gravitational force is a non-contact force The field strength/force has an inverse-square variation (with distance). ✓2	✓1 is a general point about gravitational fields ✓2 is specific to a radial gravitational field The 'force is attractive' is insufficient When required the term "force" must be used rather than words like "effect", "gravity" etc. When required the word 'mass' must be used rather than object or similar.terms Condone reference to "circular" for "spherical" in describing an equipotential surface	2	AO1 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	The shaded area corresponds to: the (minimum) energy needed/work done to launch the space probe to a height of 8×10^6 m **OR** the change in GPE of the probe when moved from Earth's surface to a height of 8×10^6 m ✓		1	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	Evaluates the gravitational field strength due to the Sun = 5.90×10^{-3} (N kg^{-1}) OR shows substitution into a valid equation ✓1 Evaluates $\frac{g_S}{g_E}$ ($= \frac{5.90 \times 10^{-3}}{9.81}$) 6.0×10^{-4} or 0.060% ✓2	✓1 $g_S = \frac{GM_S}{r^2} = \frac{6.67 \times 10^{-11} \times 1.99 \times 10^{30}}{(1.50 \times 10^{11})^2}$ ✓1 ALTERNATIVE The Universal gravitational equation for both bodies may be used: $\frac{g_{Sun}}{g_{Earth}} = \frac{M_{Sun}}{M_{Earth}} \times \left(\frac{r_{Earth}}{r_{Sun}}\right)^2$ ✓2 Answer needed to at least 2 sf. If 3+ sf are seen, the answer must round to (6.01 or 6.02)$\times 10^{-4}$.	2	AO2 ×2

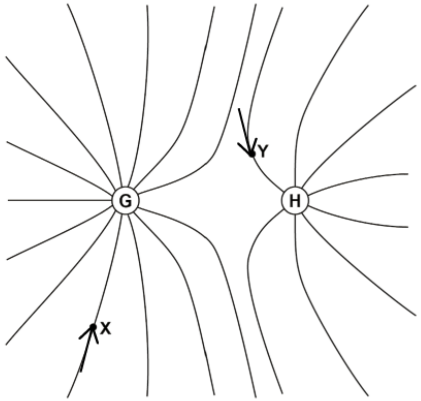
Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	The force from Earth because of its smaller mass, is less than the force from the Sun at a similar distance. **OR** The total work done in moving a long way from the Sun is much greater than that in moving a long way from the Earth because $m_E \ll m_S$.	Condone reference to “edge of Solar System” as “a similar distance”.	1	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
03.5	change in kinetic energy or kinetic energy per unit mass formulated ✓1 allow 2 sf	✓1 $\frac{1}{2}m\left(v^2_B - v^2_A\right)$ **OR** 1.18×10^{10} (J) **OR** $\frac{\Delta E_k}{m} = \frac{1}{2}\left(v^2_B - v^2_A\right)$ **OR** $m \times 2.40 \times 10^5$ J	4	AO1 AO1 AO2 ×2
	change in gravitational potential energy / potential formulated ✓2	✓2 $\Delta E_p = GMm\left(\frac{1}{1.7\times10^5} - \frac{1}{6.0\times10^6}\right)$ = $GMm \times 5.72 \times 10^{-6}$ OR $\frac{\Delta E_p}{m} = GM\left(\frac{1}{1.7\times10^5} - \frac{1}{6.0\times10^6}\right)$		
	evidence of intention to equate their ΔE_k and ΔE_p (even if not carried through; allow ecf) ✓3	Loss and gain may be replaced with change or Δ's for this mark. ✓3 $\frac{1}{2}\left(v^2_B - v^2_A\right) = \frac{-GM}{r_A} - \frac{-GM}{r_B}$ and substitution of data into working equation. This can be seen anywhere in the solution.		
	mass of **X** = 6.3×10^{20} kg ✓4			

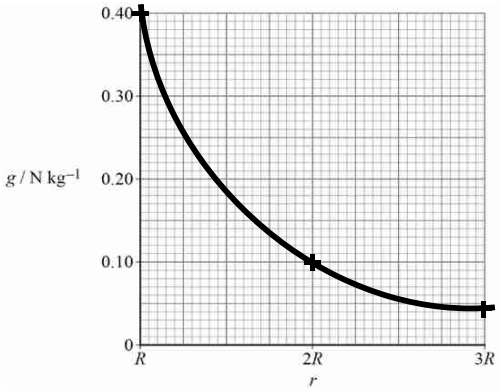
Total			10

Question	Answers	Additional comments/Guidelines	Mark	AO

04.1	G has greater mass with evidence from diagram ✓1 Explanation based on gravitational field strength or gravitational potential ✓2	E.g. ALTERNATIVE A G has greater mass because null point is closer to H ✓1 G field equals that of H at a greater distance from null than H ✓2 ATERNATIVE B G has greater mass because the density of field lines is greater ✓1 Density of field lines depends on mass ✓2 Allow arguments based on potential maximum at null point.	2	2 x AO3 3.7.2.2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	The lines given tangential arrows at X and Y that flow towards **G** and **H** respectively. ✓  	Condone arrow heads only but if arrows are drawn in full they must not follow a curved line. Arrows are acceptable if drawn alongside X and Y but must not be further away than the **X** or **Y** label.	1	AO1 3.7.2.2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.3	$R = \left(\left\{ \frac{GM}{g} \right\}^{1/2} = \left\{ \frac{6.67\times10^{-11}\times2.0\times10^{20}}{0.40} \right\}^{1/2} \right) = 1.8 \times 10^{5}$ (m) ✓		1	AO2 3.7.2.2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.4	Sketch must pass through coordinates (R, 0.40), ($2R$, 0.10) and ($3R$, 0.044) ✓	Must be within one ½ small division of coordinates requested. If plotted points differ a little from the line drawn then plotted points take priority. 	1	AO2 3.7.2.3

Question	Answers	Additional comments/Guidelines	Mark	AO
04.5	ALTERNATIVE A (The area underneath) represents the energy transferred/work done (for an object) of 1 kg / unit mass ✓1a OR (area is) energy transferred to/work done on the object per unit mass when it is moving from *R* to 2*R* ✓1a✓2a ALTERNATIVE B change in gravitational potential ✓1b OR increase in gravitational potential when moving from *R* to 2*R* ✓1b✓2b	Accept reverse direction 2*R* to *R* with appropriate direction of energy transfer/gravitational potential. In each alternative, the first answer is only awarded MP1. The second, fuller answer scores MP1 and MP2. *R* may be given as 1.8×10^5	2	2 x AO2 3.7.2.3

Question	Answers	Additional comments/Guidelines	Mark	AO
04.6	Use of $F = \frac{GMm}{r^2}$ to find the force between **P** and **H** ✓1 ($F_{(PH)} = 1.8 \times 10^{13}$ N) (Calculation of the resultant force Use of $F_{total} = (F_{(PH)}{}^2 + F_{(PG)}{}^2)^{1/2}$) ✓2 $\left(F_{total} = \left[\left(1.8 \times 10^{13}\right)^2 + \left(6.4 \times 10^{12}\right)^2\right]^{1/2}\right)$ $F_{total} = 1.9 \times 10^{13}$ ✓3 Use of $a = \frac{F}{m} = \frac{1.9\times10^{13}}{2.0\times10^{20}} = 9.4$ to 9.5×10^{-8} (m s^{-2}) ✓4	✓1 $F_{(PH)} = \frac{6.67\times10^{-11}\times3.0\times10^{25}\times2.0\times10^{20}}{\left(1.5\times10^{11}\right)^2}$ ✓2 Mark is for the use of the equation allowing for ecf from candidate's force calculation. ✓3 Correct answer only, no ecf this interim calculation may be subsumed in the next mark. ✓4 Allow ecf from F_{total} Condone the vector addition of the acceleration to obtain the answer acc^n due to G = 3.91x10^{-8} m s^{-2} acc^n due to H = 8.9 x10^{-8} m s^{-2}	4	2 x AO1 2 x AO2 3.7.2.1 (synop)

Question	Answers	Additional comments/Guidelines	Mark	AO
04.7	The resultant force is not (centripetal and continually) directed towards the centre of **H**. OR A circular orbit does not follow a gravitational equipotential (owtte) ✓	Condone lack of “resultant” The answer can focus on the conditions necessary for circular motion eg the need for a centripetal force. Or At different locations on a circular path the total gravitational potential energy is different which requires energy which is not provided. NB stating that the force is not perpendicular to the motion does not count as a full explanation as the motion has not been established.	1	AO3 3.7.2.3 (synop)
Total			**12**	

Question	Answers	Additional comments/Guidelines	Mark	AO

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

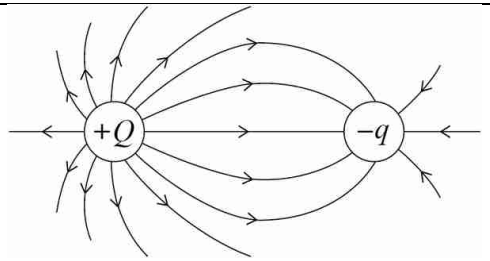
Question	Answers	Additional comments/Guidance	Mark	AO
06.2	Arrow starting at dot, pointing vertically down the page ✓	Condone a downwards vertical arrow where the line of action passes through the point. The line of action of the arrow must travel through the plasma torus near to the ion. Ignore arrows 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

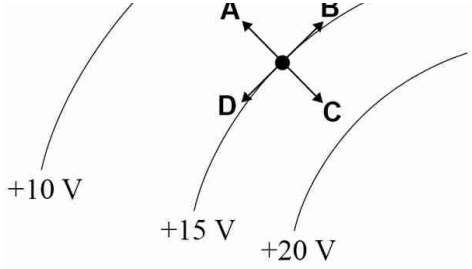
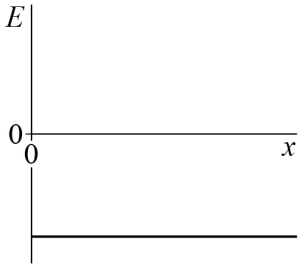
Question	Answers	Additional comments/Guidance	Mark	AO
06.3	$BQv = \frac{mv^2}{r}$ ✓	Evidence for MP1 can come from substitution of candidates centripetal force as their magnetic force in second equation. Do **not** accept e for Q in MP1 when correct answer not seen. Allow ecf for use of their centripetal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

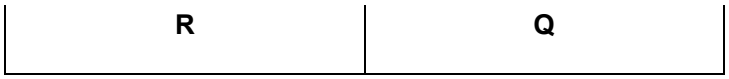
Question	Answers	Additional comments/Guidance	Mark	AO
06.4	Use of $F = ma$ / $a = \frac{v^2}{r}$ **OR** use of $F = QE$ ✓ $a\left(=\frac{QE}{m}\right)=\frac{3.2\times10^{-19}\times371\times10^{-6}}{5.31\times10^{-26}}$ ✓ 2.24×10^3 (m s^{-2}) ✓	Ignore PoT in MP1 and MP2 Condone in MP1 **and** MP2 the 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

02.1	$\frac{GmM}{r^2}(=ma)=mr\omega^2$ OR $\frac{GMm}{r^2}=\frac{mv^2}{r}$ ✓ $\omega^2=\left(\frac{2\pi}{T}\right)^2$ OR $v=\frac{s}{t}=\frac{2\pi r}{T}$ ✓ $\frac{GM}{r^2}=r\frac{4\pi^2}{T^2}$ results in $T^2=\left(\frac{4\pi^2}{GM}\right)r^3$ ✓	The starting point must be from relating forces or accelerations – not a remembered equation produced at a later stage in the manipulation of the equation. Middle mark may be given when seen as a substitution and can be a stand-alone mark. Last mark is only given if accompanied with the working and must eventually be in the form with T^2 and r^3 .	3	AO1.1b AO1.1a ×2 MS 2.1 ×2
02.2	$\left(\frac{T_U^2}{T_M^2}=\frac{r_U^3}{r_M^3}\right)$ $r_U=r_M\left(\frac{T_U}{T_M}\right)^{2/3}$ OR Substitution of data in equation in any of its forms ✓ $(r_U=)$ radius $=2.6(5)\times10^8$ (m) ✓	The first mark is for converting the equation into a proportion with or without substitution of data. Eg $r_U=1.29\times10^8\left(\frac{4.14}{1.41}\right)^{2/3}$ Last mark is for evaluating the correct answer Answer only gains both marks	2	AO1.1b AO2.1d M2 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	Rearranging $T^2 = \frac{4\pi^2}{GM} r^3$ To give $M = \frac{4\pi^2}{T^2 G} r^3$ or $M = \frac{4\pi^2}{Gk}$ Or substitution of data ✓(allow use of their calculated *k* from **02.2**) Conversion of T to seconds for Miranda $T = 1.41 \times 24 \times 3600 = 1.22 \times 10^5$ s ✓ (or $T^2 = 2.48 \times 10^{10}$) Substitution into equation and determination of *M* $M = 8.5(6) \times 10^{25}$ kg ✓	Give full credit for use of Umbriel period and their answer to 02.2 Alternative: Conversion of T to seconds for Umbriel $T = 4.14 \times 24 \times 3600 = 3.58 \times 10^5$ s ✓ Determine k from $T^2 = kr^3$ for Miranda (or Umbriel) ✓ $k = 6.9 \times 10^{-15}$ Converting to seconds mark stands alone use of $k = \frac{4\pi^2}{GM}$ to find $M = 8.56 \times 10^{25}$ kg✓ No ecf for final answer mark.	3	AO2.1b ×3

02.4	$\frac{GM\cancel{m}}{(d/2)} = \frac{1}{2}\cancel{m}v^2$ OR $v = \left(\frac{4GM}{d}\right)^{1/2}$ OR stating the escape velocity depends on M/d ✓ Any correct calculation of an escape velocity or ratio M/d or $\left(M/d\right)^{1/2}$ ✓ Last mark only given with three correct relevant calculations Correct conclusion = Titania ✓	Full credit may be given for answers that use *r* rather than *d*. Table to help identify 2nd mark **Name** / **m/d** / **(m/d)½** / ***v*** Ariel / 1.09×10^{15} / 3.31×10^{7} / 540 Oberon / 1.99×10^{15} / 4.46×10^{7} / 729 Titania / 2.21×10^{15} / 4.70×10^{7} / 768	3	~~AO2.1a~~ AO3.1a ×2 M2 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
02.5	(On Ariel surface $g = \frac{GM}{r^2} = \frac{6.67\times10^{-11}\times1.27\times10^{21}}{(1.16\times10^{6}/2)^2}$) g = 0.25 (m s^{-2}) ✓ (spring supplies the same potential energy so ($\cancel{m}gh$)$_{\text{Earth}}$ = ($\cancel{m}gh$)$_{\text{Ariel}}$) $9.8 \times 1.0 = 0.25 \times h$ OR (comparing $s = \frac{v^2-u^2}{2a}$) $h = \frac{0-20}{-2\times0.25}$ ✓ h = 39 or 40 m , so it could not ✓ {allow ecf for arithmetic errors only}	The second mark can be given for the idea that the gravitational potential energy gained on the Earth is the same as that on Ariel with or without data. Or that the initial kinetic energy is the same in both cases. Last mark allow ecf for arithmetic errors only. Condone incorrect use of signs.	3	AO2.1f ×3 M2 ×2
Total			***14***	

12

Question	Answers	Additional comments/Guidelines	Mark	AO

A

C

C

D

D

D

D

C

D

A

B

15	C	10^{36}

16	C	OV

17	D	72 mm

18	D	$\frac{E}{9}$ $\frac{V}{3}$

19	C	No work is done moving an electron from **M** to **N**.

22

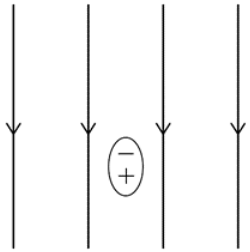
16	A (AO1)	135 μJ	

10	C	10^{36}

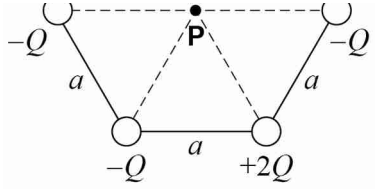
16	A	vertically down the plane.	

17	C	the electric potential of the sphere.

30

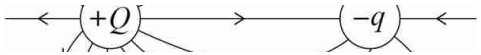
18	A	

24	B	the charge stored on a capacitor consisting of two parallel plates of area $1\ \mathrm{m}^2$ separated by $1\ \mathrm{m}$ when the potential difference between the plates is $1\ \mathrm{V}$

26	D	

27	B	1.38×10^{-7} V m^{-1} downwards

28	A	an electron and a positive pion

11	B		AO2

13	A	qV	AO1

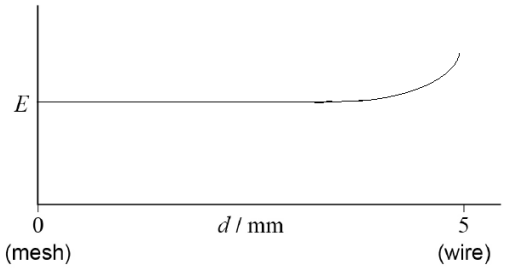
28

			AO1

14	C	

15	D	$\frac{Q}{q}$	AO2

16	D		AO1

04.1	Horizontal line above zero for > half the distance ✓ (then) curves upwards ✓	 Marks are independent.	2	AO2 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	statement that (kinetic) energy is the same **OR** correct substitution of data into equation/ratio ✓ ratio $\left(=\sqrt{\frac{6.64\times10^{-26}}{9.11\times10^{-31}}}\right)=270$ ✓	Some factors (e.g. ½) that cancel may be absent.	2	AO3 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.3	Due to collisions argon loses more energy / speed / momentum (than electron) **OR** Electron is less ionising (than argon) / Argon is more ionising (than electron) so ratio is larger. ✓	Mark is for the explanation Do not allow explanations that suggests the particles have different distances to travel. Do not allow references to air resistance. Accept idea that “argon has higher probability of collision (than electron)” Accept reverse arguments	1	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
04.4	Evidence of suitable test for student A suggestion involving 2+ data points ✓1 Evidence of suitable test for student B suggestion involving 2+ sets of data ✓2 Both tests performed **AND** rejects both suggestions ✓3	✓1 test inverse square: e.g. $Nh^2 =$ constant ✓2 test exponential: e.g. N should decrease by half in equal intervals of h **OR** test $N = k\,e^{-h}$: show that $N\,e^{h}$ is not constant Accept log/ln interpretations of the test. ✓3 Expect to see for student A $10 \times 1.0^2 = 10$ and $4 \times 1.34^2 = 7.18$ or similar Expect to see for student B $N = 10$ to $N = 5$ changes h by 0.25 and $N = 5$ to $N = 2.5$ changes h by 0.31 or similar reject both students' suggestions with reasons eg Nh^2 is not constant and N does not fall by the same fraction in equal intervals of h Allow answer accepting B if a reference to experimental error is made and the difference is small.	3	AO3 ×3
Total			**8**	

Question	Answers	Additional comments/Guidelines	Mark	AO

02.1	charge ✓ On a (small) <u>positive</u> charge (at that point) ✓(only given if an attempt is made at the first mark)	the question but a reference to moving between points or other points can cancel a mark.) If “mass” appears in the answer, it must be a synonym for “object”.	2	AO1

02.2	(At B) the (magnitude) of the electric field strength due to Q = the magnitude of the electric field strength due to the 46 μC charge ✓ $\frac{46 \times 10^{-6}}{4\pi\varepsilon_o(0.054)^2} = \frac{Q}{4\pi\varepsilon_o(0.066)^2}$ ✓ $(Q = 46 \times 10^{-6}\left(\frac{0.066}{0.054}\right)^2)$ $Q = 6.9 \times 10^{-5}$ (C) ✓ (68.7 μC rounding must be correct)	This first mark may be inferred from the equation but must refer to an electric field. (Note: the answer 5.6×10^{-5} shows that an inverse square has not been used) A correct answer gains full marks. Allow first and second marks even with arithmetic errors ie 10^{-6} missing, distances in mm and the constant $4\pi\varepsilon_o$ not present Award one mark if they use the inverse square coulomb law equation to correctly calculate one side of the equation ($\frac{46 \times 10^{-6}}{4\pi\varepsilon_o(0.054)^2}$ =) 1.4 × 10^8.	3	AO2
02.3	Work must be done on the positive proton because P is at a positive potential **OR** Work must be done (on the positive proton) due to the repulsive forces / because like charges repel.OWTTE ✓ The potential at infinity is zero. ✓		2	AO3 AO1

02.4	(As the ball falls) it experiences both vertical and horizontal <u>forces/accelerations</u> ✓ The ball is given a constant acceleration **OR** The motion is in a straight line **OR** The motion is at 30° to the vertical (away from the wall) ✓ In this 2nd mark a wrong answer will gain zero marks even if accompanied by a correct answer.	‘Horizontal’ needs to be accompanied by some implication that it is away from the wall. This may be by some reference to repulsion from the wall. Moves diagonally can imply straight “Moving away and downwards” does not imply straight. Do not credit “horizontal straight line” or “vertical straight line” ‘gravity ‘ on its own is not a force whereas weight is.	2	2 AO3

Total			**9**

Question	Answers	Additional Comments/Guidance	Mark	ID details
	(refers to a capacitor that) stores/holds/changes by 370 μC of charge ✓ for every (1) volt/volt change (of pd across its plates) ✓	"Unit of pd" is no substitute for using volt and "unit of charge" is no substitute for coulomb. However the alternative marking could give a single mark for 370 × 10^{-6} units of charge per unit of pd.		

03.1	MAX 2 from: ✓✓ the (excess) electrons move onto/are located on the (outer) surface the (excess) electrons are equally spaced (conditional on the first point being awarded) (because) the electrons mutually repel	Condone “like charges repel” in the context of electrons.	2	2 x AO3 3.7.3.1

Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	The triangle used to find the gradient covers more than 50% of the horizontal scale. ✓1 Finding the gradient from their tangent ✓2 $2.0 \pm 0.3 \times 10^{6}$ ✓3 (correct answer within limits only and to better than 1 sf) Unit $N\ C^{-1}$ **or** $V\ m^{-1}$ ✓4	✓2 eg gradient at 0.30 m $E = -\left(\frac{0 - -1.2 \times 10^{6}}{0.6 - 0}\right)$ (Ignore minus sign and PoT errors but numerical substitutions must be accurate Condone answer to more than 3 sf. Condone 'kg m s^{-3} A^{-1}' for unit. (Any alternative method that does not use the relationship violates the rubric e.g. $V = kQ/r$ $E = kQ/r^2$ so $E = V/r$ $E = 060 \times 10^{6} \div 0.30$ However, MP3 and MP4 can be awarded)	4	2 x AO1 2 x AO2 MS 3.4 3.1.1

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	(Alternative A finding the charge held by the sphere) Use of $V = \frac{Q}{4\pi\varepsilon_o r}$ for any data point Or using *E* from part 03.2 Use of $E = \frac{Q}{4\pi\varepsilon_o r^2}$ with *E* at 0.3 m ✓1,a $Q = 2.0 \times 10^{-5}$ (C) ✓2,a $C\ (= Q/V = 2.0 \times 10^{-5} / 1.8 \times 10^{6}) = 1.1 \times 10^{-11}$ (F) ✓3.a (2 sf at least) OR (Alternative B without need to evaluate *Q*) Using or referring to both equations $C = Q/V$ and $V = \frac{Q}{4\pi\varepsilon_o r}$ ✓1,b $C(= 4\pi\varepsilon_0 r) = 4\pi \times 8.85 \times 10^{-12} \times 0.100$ ✓2,b $C = 1.1 \times 10^{-11}$ (F) ✓3.b (at least 2 sf needed)	The marks must come from one alternative not a mixed route. Do not award credit for solutions based on parallel-plate capacitor equation. ✓1,a $Q = 4\pi\varepsilon_o r V =$ $4\pi \times 8.85 \times 10^{-12} \times 0.100 \times 1.8 \times 10^{6}$ OR $Q = 4\pi\varepsilon_o r^2 E =$ $4\pi \times 8.85 \times 10^{-12} \times 0.30^2 \times 2.0 \times 10^{6}$ OR ✓1b Combining equations to give $C = 4\pi\varepsilon_0 r$ For MP1 condone a starting point of $C = 4\pi\varepsilon_0 r$	3	2 x AO2 1 x AO3 3.7.3.3

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	($E = \frac{CV^2}{2}$) Calculate the energy stored at 1.0×10^6 V ✓1 Making use of any one of the energy stored equations $E = \frac{QV}{2} = \frac{CV^2}{2} = \frac{Q^2}{2C}$ to calculate the energy stored when fully charged. = 18 (J) ✓2 change in electrical energy = 18 – 5.5 = 12.5 (J) ✓3	✓1 The calculation can use C as an ecf from **03.3** or taken as 1×10^{-11}. $E = \frac{1.1\times10^{-11}\times(1.0\times10^6)^2}{2}$ = 5.5 J OR 5.0 J when using 1×10^{-11} F ✓2 Allow ecf from **03.3** for example $E = \frac{1\times10^{-11}\times(1.8\times10^6)^2}{2}$ = 16.2 J $E = \frac{(2.0\times10^{-5})^2}{2\times1\times10^{-11}}$ = 20 J note different values from different forms of the E equation because of rounding and data choice ✓3 Allow ecf from the previous two answers and may be positive or negative Accept alternative routes based on calculation of two separate energies and a difference When no other marks awarded, credit one mark for an attempt to calculate an energy difference provided one correct energy equation seen.	3	1 x AO2 2 x AO3 3.7.4.3
Total			**12**	

16

Question	Answers	Additional comments/Guidelines	Mark	AO

06.1	(-)4 J of work done per unit charge ✓ moving from infinity to the point / point to infinity✓ correctly linking direction of movement and sign of charge to gain or loss of energy / sign of energy✓	Do not allow 4V for 4J in mp1 only Condone answer in terms of eV and electron or proton. Do not consider the sign of the charge or work in mp1 and mp2 Allow ideas in terms of energy transfer from kinetic to potential (or vice versa). It is insufficient for mp1 to only refer to potential energy. Example 3 mark answers -4 J of work is done in moving (+) 1 C charge from infinity to the point. 4 J of work is done in moving a -1 C charge from infinity to the point. -4 J of work is done in moving a -1 C charge from the point to infinity. 4 J of work is done in moving (+)1 C charge from the point to infinity.	3	AO1a

Question	Answers	Additional comments/Guidelines	Mark	AO
06.2	Appreciation that the electric field is the potential gradient OR identify highest electric field occurs in the straight section ✓1 Tangent drawn along the straight section and used for gradient or straight section used with triangle of sufficient size ($\Delta V \geq 1.5V$) ✓2 Value between 1.8 and 2.2×10^7 (or 2.0×10^7) when rounded to 2 SF✓3 Unit V m^{-1} or N C^{-1} ✓4	Allow ✓1 for use of $E_{avg} = \frac{\Delta V}{\Delta d}$ not from a tangent (outside of straight section) Just stating $E = \frac{\Delta V}{\Delta r}$ (or $\frac{\Delta V}{\Delta d}$) is not sufficient for mp1. Straight section of line x =110 to 230, 350 to 480, 610 to 730, 850 to 980 No credit for ✓1, ✓2 or ✓3 attempt to find Q from a V, d pair then use of $E = \frac{Q}{4\pi\varepsilon_0 r}$ Expected value 2.01×10^7 V m^{-1} ✓4 is standalone mark with some working Do **not** accept a unit given in base units. Allow unit consistent with their value in mp3 and mp4.	4	2 × AO1b 1 × AO2b 1 × AO3-1a

Question	Answers	Additional comments/Guidelines	Mark	AO
06.3	(Loss in) kinetic energy = (Gain in) potential energy OR use of $W = QV$✓ E_k ($= e \times (V_{peak} - V_{trough}) = 1.60 \times 10^{-19}$ $(-0.20 - -3.40)) =$ 5.12×10^{-19} (J) ✓	mp1 can be from an attempt to calculate potential energy even with a mistake in data values.	2	AO2f

Question	Answers	Additional comments/Guidelines	Mark	AO
06.4	Initial direction of motion e.g. electron initially moves left/towards $x = 0$ / $x = 300$ / **P** ✓a Explanation for motion in terms of field e.g. electric field is to the right but electron charge is negative ✓b Linking the gradient of the electrical potential/graph to the magnitude of the acceleration of the electron ✓c Explanation for motion in terms of potential/energy eg electron moves towards higher potential (due to negative charge) / lower potential energy ✓d Electrical potential energy is converted into kinetic energy ✓e Recognition that the electron oscillates (about $x = 300$ nm) ✓f Explanation for oscillation in terms of potential / field ✓g	Max 3 Do not accept electron is repelled by negative electrode unless no other marks are awarded. Allow ✓f for oscillations about the wrong point or if it is unclear where it oscillates about. Accept acceleration is 0 at e.g. 300 nm for ✓c Condone reference to SHM for oscillate. Reject vibration for ✓f Condone Ep → Ek → Ep → Ek without reference to oscillation in ✓f	3	AO3-1b
Total			**12**	

20

Question	Answers	Additional comments/Guidelines	Mark	AO

04.1	V (= Q/C) = $52 \times 10^{-9}/2.22 \times 10^{-12}$ ✓2 V = 23 000 (V) ✓3 (23 400 V)	answer 12000 or 11700 (V) A correct answer gains all 3 marks. Commonly 23000 V gives 3 marks 11700 V gives 2 marks Also a power of 10 error in the final answer gives 2 marks. For any other final answer the only possibility is to get one mark for use of $V = Q/C$ when C is clearly given or $V = \frac{Q}{4\pi\varepsilon_o r}$ is uses with an incorrect value of r.	3	AO2-1d-1 Math2-1

04.2	Labelled arrows on **B** • Tension or T parallel to thread and upwards • weight or *mg* or W starting from sphere centre vertically down • electrostatic force or repulsion to right and starting from the inside or edge of the sphere ✓✓ 2 marks for all 3 arrows and labels 1 mark for 2 arrows and labels 1 mark for 3 arrows, no or incomplete labels	For the electrostatic force label also allow F_{elec} or 'force between charges. F_A etc. Ignore gravity between spheres. If a reaction force given – max 1 mark.	2	AO1-1c-2
04.3	One mark for stating the problem. ✓1 One mark for giving a corresponding solution. ✓2 For example Metallic or conducting instruments placed between the spheres will affect the separation (because of the movement of charge/electrons within the instrument) (Inside) calipers made from a non-conduction material in conjunction with a ruler could be used Or A travelling telescope on a vernier scale could be used (at a distance) Other examples of problems Physically touching the spheres may alter the reading. Difficulty of measuring distance between curved objects. A measuring instrument can have a dielectric constant/permittivity, which will affect the separation/disrupt the field. Reading a ruler behind the spheres will give rise to a parallax error.	✓1 The problem must be explicitly stated but not much detail is needed. EG Anything used between the spheres my disrupt the field. ✓2 The solution must be detailed enough to convey what must happen. Other examples of solutions. Ruler and set square set up parallel to the line joining the centres of the spheres. Measure (beforehand) the length of thread *y* and measure the angle with a protractor and calculate distance x using trig'.		AO2-1c-2

Question	Answers	Additional Comments/Guidance	Mark	ID details
04.4	Using distance = 80 mm (mark given even in a wrong formula) Or Stating that the charge can be considered to be in the centre of each sphere ✓1 $F\ (=\frac{Q_1Q_2}{4\pi\varepsilon_o r^2}) = \frac{\left(52\times10^{-9}\right)^2}{4\pi\varepsilon_o(0.080)^2}$ ✓2 $F = 3.8\times10^{-3}$ (N) ✓3 (Showing at least 2 sig figs)	✓2 Power of 10 errors are condoned and so is the use of the wrong separation (as this was penalized in the previous mark). ✓3 No ecf for this final mark.	3	AO1-1a-1 AO2-1f-1 Math2-2
04.5	(As each sphere is in equilibrium then $\tan\theta = \frac{F_{\text{electrostatic}}}{mg}$ a mark is given for a reference and substitution into this equation in any configuration. The second mark is for an evaluation that is said to be consistent. Use of 4×10^{-3} N given in **04.4** gains full credit.) $\theta = \tan^{-1}\left\{\frac{3.8\times10^{-3}}{3.2\times10^{-3}\times9.8}\right\}$ ✓= 6.9° which is consistent ✓ or $F_{\text{electrostatic}} = \left\{3.2\times10^{-3}\times 9.8\times\tan 7^o\right\}$ ✓ = 3.8(5) × 10^{-3} (N) which is consistent ✓ or $m = \left\{\frac{3.8\times10^{-3}}{9.8\tan 7^o}\right\}$ ✓ = 3.1(6) × 10^{-3} (kg) which is consistent ✓ Alternatively $T = \frac{3.2\times10^{-3}\times9.8}{\cos 7^o} = 0.032$ ✓1Alt and $T = \frac{3.8\times10^{-3}}{\sin 7^o} = 0.031$, the same value so consistent ✓2Alt	using 4×10^{-3} N gives 7.3° More circular routes using Pythagoras are possible but they end in the same calculated results. using 4×10^{-3} N gives $3.3(2)\times10^{-3}$ kg ✓1Alt Any equation that results in the calculation	2	AO2-1f-2 Math2-2

		of the tension. ✓2Alt A second calculation of the tension which is stated to be consistent with the first.		

Question	Answers	Additional Comments/Guidance	Mark	ID details
04.6	(In the following calculations condone the use of 1 sig fig for all data) $F_{grav}(=\frac{GMm}{r^2}) = 6.67 \times 10^{-11} \times \frac{(3.2\times10^{-3})^2}{0.080^2}$ ✓1a $F_{grav} = 1.1 \times 10^{-13}$ (N) which is small/negligible compared to F_{elect} ($\approx 4 \times 10^{-3}$ N) so statement is valid ✓2a **Alternative** (find the ratio between the forces) $(\frac{F_{elec}}{F_{grav}} = \frac{\frac{Q_1Q_2}{4\pi\varepsilon_o r^2}}{\frac{GMm}{r^2}})$ $\frac{F_{elec}}{F_{grav}} = \left(\frac{Q_1Q_2}{Mm}\right)\frac{1}{G4\pi\varepsilon_o}$ (mark given for this ratio or the substitution below) $\frac{F_{elec}}{F_{grav}} = \left(\frac{(52\times10^{-9})^2}{(3.2\times10^{-3})^2}\right) \times \left(\frac{1}{6.67\times10^{-11}\times4\times\pi\times8.85\times10^{-12}}\right)$ ✓1b F_{elec} is 3.6×10^{10} times F_{grav} OR or F_{grav} is 2.8×10^{-11} times F_{elec} ✓2b	✓1a It is the use of the formula that is important for the mark. Giving the equation in symbols followed by an answer gains the mark. ✓2a No ecf for the second mark in order to keep the same level of difficulty as in the alternative.	2	AO3-1a-2 Math2-2

Total			14

Question	Answers	Additional Comments/Guidance	Mark	ID details
	$N = \frac{\Phi}{AB}$ Or $N = \frac{1.5 \times 10^{-3}}{2.5 \times 10^{-2} \times 5.0 \times 10^{-4}}$ ✓1	✓1 *N* must be the subject of the equation for the mark. ✓2 A correct answer gains both marks.		AO1-1a-1

D

C

D

A

B

C

C

A

C

C

B

A

C

A

A

20	D		

17	A (AO2)	1.3×10^{-2}	**X** to **Y**

18	C (AO2)	After a time T the pd across the capacitor is $1.5\ \text{V}$.

19	C (AO2)	$9C$

32

20	C (AO2)	$2E$	

21	D (AO2)	1	

11	B		a decrease in the charge held on the capacitor plates.

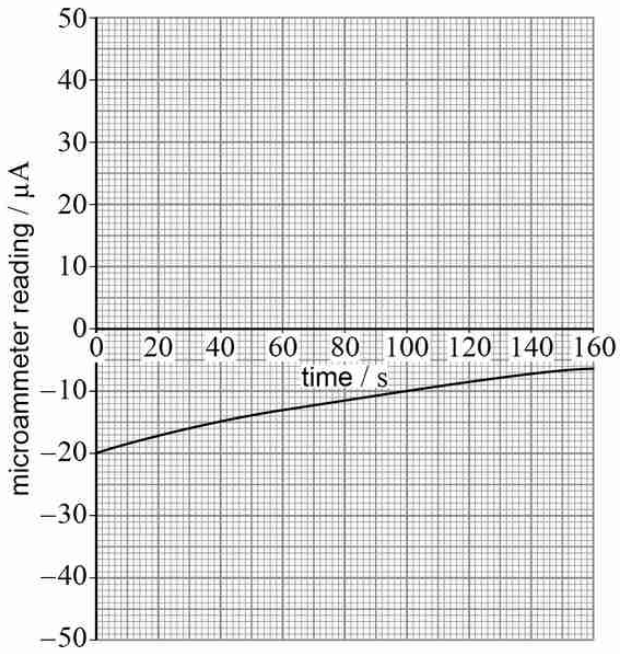
17	C	600 μF	AO2

18	C	233 Ω	AO2

05.1	Idea that capacitance / charge stored with dielectric is seven times greater than with vacuum / air / free space (for same geometry and pd) ✓	Allow material for dielectric. Allow $\frac{\text{permittivity of dielectric}}{\text{permittivity of free space}} = 7.0$ Allow ε or $\varepsilon_{\text{dielectric}}$ (but not ε_r) only if it is named as the permittivity of the dielectric. Allow the permittivity of the dielectric is seven times greater than the permittivity of free space/vacuum/air. Do **NOT** allow the **relative** permittivity of the dielectric is seven times greater than the permittivity of free space. Do **NOT** allow $\frac{\varepsilon_r}{\varepsilon_0} = 7.0$	1	AO1

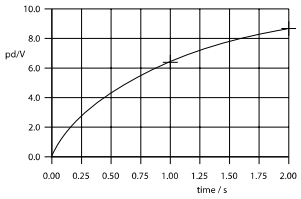
Question	Answers	Additional comments/Guidance	Mark	AO
05.2	Attempt at a valid method ✓ (allow minor read-off errors) 73 ± 2 (s) ✓	**Valid methods** Measuring time until $\frac{40}{e} = 14.7\ \mu A$ Condone 14-15 microammeter read off for MP1. Measuring one or two half-lives with $\frac{t_{0.5}}{\ln 2}$ Picking a point and substituting into $I = I_0 e^{-\frac{t}{T}}$ Some working must be seen for MP1 and may be seen on graph only for a direct read off of the time constant.	2	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
05.3	Use of e^{-5} **or** use of $I = I_0\, e^{-\frac{5T}{T}}$ with their I_0 and T ✓ (convert to a percentage) 0.67% ✓	Condone 0.37^5 for MP1… …leading to 0.69% for MP2.	2	1 × AO1 1 × AO2

Question	Answers	Additional comments/Guidance	Mark	AO
05.4	**Award MAX 3 for ✓✓✓** The magnitude of the current generally decreases with time, together with • Starts at (−)20 μA • Half-life of 100 ± 4 s $I_0 = \pm 20\ \mu A$: check $(100, \pm 10)$ $I_0 = \pm 40\ \mu A$: check $(100, \pm 20)$ • Line to at least 120 s with correct shape including: decreasing gradient **throughout** does **not** have a non-zero asymptote • Negative current shown for all times	When **increasing** magnitude of current seen, **MAX 1** for either: • correct half life: shown by passing through (0,0) **AND** either $(100, \pm 10)$ or $100, \pm 20)$ • negative current shown for all times. Award MAX 2 when two curves given and one is not clearly deleted/erased. 	3	AO3
Total			**8**	

22

Question	Answers	Additional comments/Guidance	Mark	AO

03.1	**OR** reference to charge to pd OR charge to voltage ratio✓ includes units C or coulomb and V or volt ✓	An equation may contribute towards the first mark but only if the symbols are identified. A second mark can be given if the units are identified. Ignore poor phrasing like 'per unit volt passing through'.	2	AO1
03.2	(Using time constant = RC) (R = $1.0 / 370 \times 10^{-6}$) R = 2.7×10^{3} (Ω) ✓	Check that the unit on answer line has not been altered	1	AO1
03.3	First mark for marking a cross at 2 s and 8.5 V (by eye) ✓ Second mark for graph starting at the origin and having a decreasing gradient ie not reaching horizontal ✓  	Cross must be in the bottom half but not on the 8.0 V major grid line or exactly half way up (9.0 V) If a series of plotting crosses are given only consider the one placed at 2 s for the first mark.	2	AO2

10

03.4	(Using $T_{½} = 0.69\,RC = 0.69 \times 1.0$) $T_{½} = 0.69$ (s) ✓	1 sig fig is not acceptable	1	AO1
03.5	(Use of $Q = Q_o(1 - e^{-\frac{t}{RC}}) = CV_o(1 - e^{-\frac{t}{RC}})$) mark for max charge = CV_o which may come from substitution or seeing 3.6(2) × 10^{-3} C ✓ $3.0 \times 10^{-3} = 370 \times 10^{-6} \times 9.8\,(1 - e^{-t})$ ✓ mark for substitution ($0.8274 = (1 - e^{-t})$ so $e^t = 1/0.173 = 5.79$) t = 1.7 s or 1.8 s ✓ **OR** voltage $V = Q/C = 3 \times 10^{-3} / 370 \times 10^{-6}$ = 8.1(1) V✓ (Substitute into $V = V_o(1 - e^{-\frac{t}{RC}})$) $8.1 = 9.8\,(1 - e^{-t})$ ✓ t = 1.7 s or 1.8 s ✓	Alternative mark scheme uses the voltage as proportional to the charge. Do not allow use of the graph for 2nd mark and 3rd mark. An answer only gains only the last mark. Evidence of working must be shown which shows substitution into a ($1\text{-}e^{-t}$) form of the equation.	3	AO2
Total			**9**	

Question	Answers	Additional Comments/Guidance	Mark	ID details
	The direction of the induced emf (when there is a change of	A reference to emf is needed rather than induced current as this is dependent on a		

02.1	Show attempted use of all three equations: gradient $= \frac{\Delta V}{\Delta t}$ AND $I = \frac{\Delta Q}{\Delta t}$ AND $Q = CV$ ✓ $I_0 = C \times$ **initial** gradient ✓	mp2 $V = \frac{Q}{C}$ so $\Delta V = \frac{\Delta Q}{C}$ so gradient $\frac{\Delta V}{\Delta t} = \frac{\Delta Q}{C\Delta t} = \frac{I}{C}$ hence $I_0 = C \times$ initial gradient $(\Delta)Q = I(\Delta)t$ can be seen via substitution if **both** (Δ)Q and $I(\Delta)t$ are seen in equivalent expressions e.g. $I(\Delta)t = CV$ is insufficient without $(\Delta)Q = CV$. Condone omission of Δ's in MP1. Condone C or initial gradient as subject for mp2. Condone a calculation and an **initial** gradient shown on Figure 2 mp1 and mp2 are independent. If no other marks award 1 for $I = C \times$ gradient or C or gradient as subject.	2	AO2c

Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	time constant = 7.5 ± 0.5 (s) ✓ evaluated $R = \frac{\text{their } T}{C}$ correctly ✓	Do NOT allow $T = RC$ for mp1. Value must come from Figure 3 using a valid method. 7.44 s is likely to come from RC and not from the graph. mp1 Time taken to fall to $1/e$ or 0.37 of its value = time constant eg 0.45 V to 0.166 V takes 7.5 s This may be calculated over a larger range or the time to halve the voltage found and this value divided by $\ln 2$ eg 0.45 V to 0.225 V takes 5.2 s giving = 7.5 s Half life 5.2 ± 0.5 (s) and $T = \frac{T_{\frac{1}{2}}}{\ln(2)} = \frac{T_{\frac{1}{2}}}{0.69}$ mp2 $T = RC$ so $R = \frac{T}{C} = \frac{7.5}{31.0\times10^{-6}} = 2.4(2) \times 10^5\ \Omega$ Condone 2SF for mp2 if working is shown.	2	1 × AO1b 1 × AO3-1a

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	Supply voltage $V_0 = I_0R$ (expect 8.6 V)✓$_1$ Use of $V = V_0\left(1 - e^{\frac{-t}{RC}}\right)$ ✓$_2$ **Alternative** Use of $V_0 = I_0R$ so $I = \frac{I_0R-6}{R}$ (expect 1.1×10^{-5} A)✓$_1$ Use of $I = I_0e^{-\frac{t}{RC}}$ ✓$_2$ Calculation of the time from correct physics (expect 8.8 to 9.0 s) ✓$_3$	Allow 9V for mp1 or mp2 but do not allow ecf for rounded value in mp3 mp2 allow substitutions OR rearrangements using ln or use of $V = \frac{Q}{C}$ and $Q = Q_0\left(1 - e^{\frac{-t}{RC}}\right)$ Allow ecf for ✓$_3$ R, T values but not from the wrong equation or mix up of V and I.	3	1 × AO2d 2 × AO3-1a

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	use of $C = Q/V$ and $C = \varepsilon_r\varepsilon_0 A/d$ ✓ $\frac{V_1}{V_2} = 0.125$ ✓	mp1 $V = \frac{Qd}{\varepsilon_r\varepsilon_0 A}$ may be seen anywhere in the working, possibly with subscripts or rearranged. mp2 $\frac{V_1}{V_2} = \frac{d}{4\times 2d} = 0.125$ Condone $\frac{1}{8}$ for mp2 Award 1 mark for 8 regardless of working mp2 implies mp1	2	AO2f
Total			9	

Question	Answers	Additional comments/Guidelines	Mark	AO
	Max 2 from one route ✓✓			

05.1	$V = V_0\left(1 - e^{-\frac{t}{RC}}\right)$ with substitution attempted with V_0 being larger than V ✓1 Time to charge to 4.0 V = $t_2 = -R_1 C \ln\left(1 - \frac{4}{6}\right)$ **OR** Time to charge to 2.0 V = $t_1 = -R_1 C \ln\left(1 - \frac{2}{6}\right)$ ✓2 $t = t_2 - t_1 = -R_1 C \ln\left(\frac{1}{3}\right) - \left\{-R_1 C \ln\left(\frac{2}{3}\right)\right\}$ $\left(= -R_1 C\left(\ln\frac{1}{3} - \ln\frac{2}{3}\right) = -R_1 C \ln\left(\frac{\frac{1}{3}}{\frac{2}{3}}\right)\right) = -R_1 C \ln\left(\frac{1}{2}\right) = 0.69 R_1 C$ **OR** $= R_1 C(1.10 - 0.41) = 0.69 R_1 C$ ✓3	NB The answer can be obtained incorrectly by finding the time to charge to 2V using a 4V supply. This approach may only gain the first mark for an attempted use of the equation. Award 0 for a solution using the discharge equation. Condone R for R_1 ✓2 If given in an equation then then time must be the subject or be in a form that is used to obtain mp3 can be awarded for $t_2 = 1.10 \times R_1 C$ **OR** $t_1 = 0.41 \times R_1 C$ ✓3 Must see $0.69\ R_1\ C$ for 3 marks. Only award MP3 for $0.69 R_1 C$ if the solution involves a time difference.	3	AO1 AO2 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	Attempt to find usable data from **Figure 9** ✓1 Determine scaling factor **OR** Determine R_1 ✓2 Calculate Q the charge stored at 4 V or the charging time constant **from a valid method** ✓3 Determine C to a value that rounds to 1×10^{-4} (F) to 2 or more sf (expect to see 1.0×10^{-4} F) ✓4 **Method 1 (from area)** ✓1a Attempt at finding area under I–t graph by counting boxes ✓2a 1 cm^2 box corresponds to charge 0.5×10^{-5} C ✓3a Number of 1 cm^2 boxes = 80 (78 to 82) $Q = (80 \times 0.5 \times 10^{-5}) = (3.9 \text{ to } 4.1) \times 10^{-4}$ (C) ✓4a $C = \frac{\text{their } Q}{4}$ = a value that rounds to 1×10^{-4} (F) (≥ 2 sf required) Award **MAX 1** for estimating the average current by sight and using $C = \frac{IT}{V}$.	**Method 2 (from individual data points)** Possible methods are shown but only final answers requested are needed to gain marks. ✓1b Use of a current and voltage across the resistor, e.g. $I = 2.0 \times 10^{-5}$ A and voltage across resistor = 2 V (when capacitor has 4 V) **OR** $I = 6.0 \times 10^{-5}$ A and voltage across resistor = 6 V (when capacitor has 0 V) ✓2b $R_1 = \frac{V}{I} = \frac{2.0}{2.0 \times 10^{-5}}$ **OR** $\left(\frac{V}{I} = \frac{6}{6 \times 10^{-5}}\right) = 1.0 \times 10^5$ (Ω) ✓3b Charging time constant = R_1C Eg using $I = I_0 e^{\frac{-t}{R_1 C}}$ then $R_1 C = \frac{t}{\ln\left(\frac{I_0}{I}\right)}$ Substituting $I = 2 \times 10^{-5}$ A and $I_0 = 6 \times 10^{-5}$ A and $t = 11$ s. OR Graphical method must include evidence from Figure 9 charging time constant $(R_1C) = 10.(0)$ (s) ✓4b $C = \frac{\text{time constant}}{R_1} = \frac{10.0}{1.0 \times 10^5}$ = a value that rounds to 1×10^{-4} (F) (≥ 2 sf required)	4	AO2 ×3 AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
05.3	Reading of relevant discharge data from **Figure 10** provided there is an attempt to use data ✓1 A valid substitution of their data into a relevant equation to find R_1 or R_{Total} ✓2 $R_2 = R_{Total} - \text{their } R_1 = 2.0 \times 10^5\ \Omega$ ✓3 allow **one** ecf from either their R_{Total} **or** their R_1 When R_1 is derived in an earlier question accept this value of R_1 and allow ecf for R_{total} When R_1 is derived in this question, allow one ecf from either their R_{total} or their R_1	✓1 From **Figure 10** this can be the time taken for the voltage to fall to half its value. ✓2 Finding R_{Total} from **Figure 10** 4.0 V to 2.0 V in $(32 - 11)$ s using $t_{\frac{1}{2}} = 0.69RC$ allow $= 0.7RC$ $R_{Total} = 3.0 \times 10^5\ \Omega$ Finding R_1 from **Figure 9** 6.0 A to 3.0 A in 6.8 s using $t_{\frac{1}{2}} = 0.69RC$ allow $= 0.7RC$ $R_1 = 1.0 \times 10^5\ \Omega$ **OR** Using $I = I_o e^{\frac{-t}{R_1 C}}$ for example, with $I = 2 \times 10^{-5}$ A and $I_o = 6 \times 10^{-5}$ A and $t = 11$ s Note R_1 may be taken from **05.2** and not use the graph information.	3	AO3 ×3

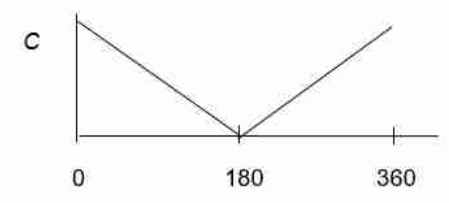
Total			10

Question	Answers	Additional comments/Guidelines	Mark	AO

01.1	(Dielectric constant is) $\frac{\text{permittivity of medium}}{\text{permittivity of free space}}$ and is equal to 6 ✓ OR The permittivity of the dielectric is 6 times the permittivity of free space	Allow: $\frac{C \text{ with dielectric (between plates)}}{C \text{ in a vacuum}} = 6$. Its not enough to quote relative permittivity = 6	1	AO1 1a

Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	(Electric field exists between plates) Polar molecules align with their positive side facing the negative plate (owtte) ✓1 producing a counter electric field/reducing the field between the plates ✓2 The pd V reduces between the capacitor plates but charge Q remains the same so capacitance Q/V increases. ✓3	✓1 or vice versa. ✓3 This mark may be approached from the idea that more charge would be required to maintain pd hence C increases by referencing $C = Q/V$	3	AO1 1a ×3

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	Q remains the same ✓$_1$ New C is 6 × previous C ✓$_2$ Energy difference = 3.8×10^{-9} J ✓$_3$	✓$_2$ May be seen in the substitution in the energy difference calculation ✓$_3$ Calculates change in energy using $E = ½Q^2\left(\frac{1}{c_2} - \frac{1}{c_1}\right)$ = 4.58x10^{-9} – 7.64x10^{-10} Where $Q = 7.6 \times 10^{-10}$ C : $c_1 = 63 \times 10^{-12}$ F and $c_2 = 6 \times 63 \times 10^{-12}$ $E = 378 \times 10^{-12}$ J Condone a negative final answer If no marks given award single mark for the initial energy stored = 4.58x10^{-9} J	3	AO2 1h ×3

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	showing a linear decrease and increase ✓ points correct at 0, 180 and 360 degrees ✓	 Ignore graph beyond 360 degrees	2	AO2 1h × 1 AO3 1b × 1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	Insert dielectric between plates/attach dielectric to one plate OR reduce air gap explained ✓ Dielectric has $\varepsilon_r = 4$ ✓ air gap reduced to ¼ ✓	1st mark for <u>quantitative</u> answer for air gap or dielectric or both. (Allow: more plates when explained) 2nd and 3rd marks for numerical analysis for air gap **and** dielectric change. Do not allow incorrect physics.	3	AO3 1a × 3

Total			**12**

8

Question	Answers	Additional comments/Guidelines	Mark	AO

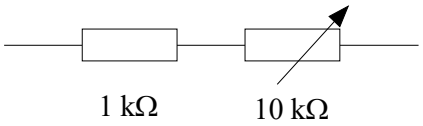
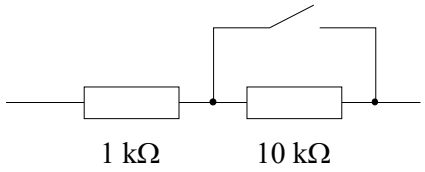
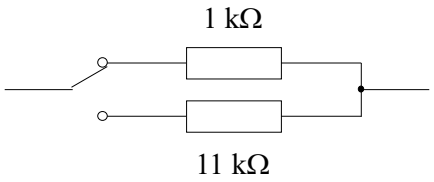
02.1	(measuring $20T$) (idea of) reduces the **effect of** random error (on T) OR reduces the **percentage** uncertainty ✓	allow (idea of) 'reducing **the effect** of uncertainty due to 'stop-start error' / 'human reactions' / 'human error'; accept 'to improve precision' / 'to reduce relative error' / reduces the **percentage** error; condone 'reduces the uncertainty in T ' 'to calculate an average' is neutral; to reduce 'uncertainty' / 'measurement error' / 'human error' / 'human reactions' / 'stop-start error' are neutral 'easier to measure' / 'improve accuracy' / comments about systematic error are neutral	1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
02.2	(repeating the ($20T$) measurements) (idea of) a check for / enables the detection of / elimination of anomalies (in $20T$) ✓	allow 'to avoid miscounting cycles'; accept 'to improve accuracy' / 'to reduce statistical error' / 'account for systematic error' 'to reduce the effect of anomalies' / 'to calculate an average' are neutral; 'to reduce (effect of) uncertainty' / 'measurement error' / 'human error' are neutral 'improve precision' / comments about random error are neutral	1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
02.3	average $(20)T$ OR uncertainty in $(20)T$ 1✓	for 1✓ average $20T = 19.2$ (s) (use evidence of calculator value 19.196 to confirm that all 5 sets were used) OR uncertainty in $20T = 0.27$ OR $\frac{19.45 - 18.91}{2}$; allow $19.45 - 19.2(0)$ OR $19.2(0) - 18.91$ average $T = 0.96$ (s) (calculator value 0.9598) OR uncertainty in $T = 0.0135 / 0.014$ (s) OR $\frac{0.973 - 0.946}{2}$; allow $0.973 - 0.96$ OR $0.96 - 0.946$	2	AO2
	percentage uncertainty **based on a correct method** $= 1.4\ \%$ 2✓	for 2✓ accept any $>$ 2 sf that rounds to 1.4%; condone max 4 sf; do **not** allow 0.014		

Question	Answers	Additional comments/Guidance	Mark	AO
02.4	gradient evaluated from ΔT divided by ΔR_2 with $\Delta R_2 \geq 6\ \text{k}\Omega$; OR evidence of valid simultaneous equations with full substitution using read-offs for T and R_2 with $\Delta R_2 \geq 6\ \text{k}\Omega$ $_1$✓ attempts to determine C by a valid method $_2$✓ C in range 3.8×10^{-5} to 4.1×10^{-5} (F) $_3$✓ attempts to determine R_1 by a valid method $_4$✓ R_1 in range 2.2 to 2.5×10^4 (Ω) $_5$✓	$_1$✓ is for the process, not the result allow **one** read off error; allow POT error in substituted data expect gradient $\approx 5.5 \times 10^{-5}$ (s Ω^{-1}); award $_2$✓$_3$✓ for C in range with correct POT; $_2$✓ is for the process, not the result: see page 12 for $_3$✓ allow ECF for use of their R_1 ; no ECF for POT OR a calculation error in gradient award $_4$✓$_5$✓ for R_1 in range with correct POT; $_4$✓ is for the process, not the result etc; do **not** allow working off grid to determine R_1 for $_5$✓ allow ECF for use of their C or their gradient min 2 sf for $_3$✓ and $_5$✓; allow ≥ 3 sf rounding to 2 sf in range; don't penalise twice for results based on simultaneous equations with R_2 values in $\text{k}\Omega$	5	AO2

Question	Additional comments/Guidelines for $_2$✓	Additional comments/Guidelines for $_4$✓
02.4	$C = \frac{\text{their gradient}}{2 \times \ln 2}$ OR $C = \frac{\text{their gradient}}{\ln 4}$ OR $C = \frac{\text{their } \Delta T}{2 \times \ln 2 \times \text{their } \Delta R_2}$ OR correct manipulation of valid simultaneous equations OR $C = \frac{\text{their } T}{\ln 2 \times (\text{their } R_1 + 2(\text{their } R_2))}$ (where their R_1 has been found by a method not involving C; their T and their R_2 are corresponding values read-off **Figure 4**)	$R_1 = \frac{2 \times \text{their vertical intercept}}{\text{their gradient}}$ OR $R_1 = \frac{\text{their vertical intercept}}{\ln 2 \times \text{their } C}$ OR $R_1 = \frac{\text{their } T}{\ln 2 \times \text{their } C} - 2 \times \text{their } R_2$ (where their T and their R_2 are corresponding values read-off **Figure 4**) OR correct manipulation of valid simultaneous equations OR $R_1 = \frac{T_P R_{2Q} - T_Q R_{2P}}{T_Q - T_P}$ (based on read-offs from **Figure** 4 where their R_{2Q} is their value of R_2 at time T_Q etc)

Question	Answers	Additional comments/Guidance	Mark	AO
02.5	marks can be awarded for suitable sketches up to $_{12}$✓✓ for identifying that their R_2 should • have minimum resistance $1\ \text{k}\Omega$ $_{A}$✓ • have maximum resistance $11\ \text{k}\Omega$ $_{B}$✓ • be a (fixed) resistor (or resistors) **in series** with a variable resistor $_{C}$✓ **one** $1\ \text{k}\Omega$ resistor **in series** with **one** $10\ \text{k}\Omega$ **variable** resistor or valid labelled sketch $_{3}$✓ eg  	allow $_{A}$✓$_{B}$✓ for a switched 2 fixed resistor circuit that can produce both limiting values, eg   allow $_{A}$✓$_{B}$✓ (R_2) from $1\ \text{k}\Omega$ to $11\ \text{k}\Omega$; allow $_{AB}$✓ for deducing range = $10\ \text{k}\Omega$; for $_{C}$✓ allow any arrangement that allows R_2 to be varied **continuously** between limiting values; do not allow fixed resistor in parallel with a variable resistor for $_{3}$✓ CAO	3	1 × AO1 2 × AO3
Total			**12**	

Question	Answers	Additional comments/Guidance	Mark	AO

C

A

B

C

A

21	A	lift upwards away from the wires.

14	A (AO2)	$\frac{R}{2}$	

22	B (AO2)	3.9×10^{-2} T	

26	A (AO1)		Is it deflected by a magnetic field?	yes	yes	no

20	B	6.0×10^{-3} T	

21	B	The radius of the path followed by an ion is different for each isotope.

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

20	D	$4I$	AO2

02.1	Vertically up (third row of table) ✓		1
02.2	(Using Flemings LHR) the configuration of the letters is S N ✓	Answer must be near/on the dashed lines.	1
02.3	The tesla is the (strength) of the magnetic field/flux density that produces a force of 1 newton in a wire of length 1m with 1 ampere (flowing perpendicular to the field). ✓ (owtte but must contain 1N, 1A and 1m)	For mark a reference to 1N, 1A and 1m must be seen. However the word 'unit' is equivalent to '1'. E.g. unit force = 1N. Do not allow definitions based on $F = Bqv$.	1
02.4	Use of ($B = F / I l$) = $m g / I l$ ✓ (mark may come from substitution as in next line) $B = 0.620 \times 10^{-3} \times 9.81 / (3.43 \times 0.0500) = 0.035$ or 0.036 (T) ✓	Treat power of 10 error as an AE so lose one mark only. Lack of use of 'g' is a PE and scores zero.	2
Total			**5**

Question	Answers	Additional Comments/Guidelines	Mark

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	$B Q v = m v^2 / r$ ✓ $t_{semi\text{-}circle}$ (= 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 ($t_{circle} = 2\pi m / B Q$ so) $t_{semi\text{-}circle} = \pi m / B Q$ (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	Force due to uniform magnetic field (is constant and always) at 90º to direction of travel ✓ Identifies this force as the centripetal force for circular/semicircular motion ✓	Reference to velocity will be taken as the velocity of the proton	2	AO1 1a ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	(1 electron through 10 kV = 10000 eV 14 MeV by 10000 eV) = 1400 (times) ✓		1	AO2 1f × 1

Question	Answers	Additional comments/Guidelines	Mark	AO
05.3	$F = Bev$ AND $F = m_p v^2/R$ ✓ Equates forces giving $v = eBR/m_p$ ✓ $E_k = ½m_p v^2 = ½m_p(eBR/m_p)^2$ ✓ $E_k = e^2B^2R^2 / 2m_p$	1st mark for either or both 2nd mark for expression for v 3rd mark for substituting in $½m_p v^2$ Condone use of *Q or q* for *e*	3	AO2 1d ×3

Question	Answers	Additional comments/Guidelines	Mark	AO
05.4	Uses = $\frac{e^2B^2R^2}{2m_p}$ to calculate E_k for any one cyclotron in J or eV ✓ Calculates E_k for 3 cyclotrons or argues that as **X** is just OK, **Y** will be greater and **Z** will be less than 11 MeV ✓ So reasoned choice of **X** ✓ cost/$11.7^{1.5}$ = £2.3 million/$10^{1.5}$ cost = £2.9 million ✓	For **X** $E_k = \frac{(1.6 \times 10^{-19})^2 \times 1.3^2 \times 0.38^2}{2 \times 1.67 \times 10^{-27}}$ $= 1.87 \times 10^{-12}$ J or 11.7 MeV For **Y** $E_k = 2.32 \times 10^{-12}$ J or 14.5 MeV **or Y** must have higher energy because BR and hence B^2R^2 must be greater For **Z** $E_k = 6.89 \times 10^{-13}$ J 4.3 MeV **or** by inspection B^2R^2 will be too low to give 11 MeV Or other appropriate method	4	AO2 1h ×1 AO3 1a ×3
Total			**10**	

Question	Answers	Additional comments/Guidelines	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	(use of a ruler to) **measure** height **from bench to rod** at (minimum of two) different points $_1$✓ explains how the **ruler** is made vertical $_2$✓ checks heights are the same $_3$✓ (contingent on $_1$✓) OR use of a metre ruler placed on the rod with a spirit level placed on the ruler; check no gap between ruler and rod $_{12}$✓ check bubble is at centre $_3$✓ (contingent on $_{12}$✓) OR use of metre ruler placed with no gap on top of nested set-squares so the metre ruler can be compared with rod $_{12}$✓ lower set-square in contact with the bench (no gaps) $_3$✓ (contingent on $_{12}$✓)	for $_1$✓ points may be **anywhere** along rod; allow 'measure height of rod at each end' / 'at both clamps'/ 'measure height from ground' do not allow 'find height' / 'measure on both sides of the rod / wire' for $_2$✓ expect to see a set-square in **contact with** the bench AND in **contact with** the upright ruler; allow use of a spirit level / T-square / plumb line / **large** protractor to make ruler vertical; use of set-square between the ruler and the rod OR between stand and rod is neutral; for $_1$✓ and $_2$✓ allow annotation to **Figure 10** allow $_{12}$✓ for use of a set-square in contact with the bench that reaches the rod (ie no ruler mentioned) as long as **measuring** is being done with it for $_3$✓ allow 'compare heights to check rod is parallel to bench / level' allow 'measurements match' / 'contingent' etc 'straight' for horizontal or for vertical / 'heights are constant' is neutral	3	AO1

20

Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	force on **rod** is down(wards) $_1$✓	‘force down’ & ‘current to right’ & ‘field out of page by left-hand rule’ earns ✓✓✓ = 3/3; for $_1$✓ allow use of F ↓ for force on rod down; may be indicated on **Figure 11** allow unqualified ‘force’; condone force = ‘motion’ / rod = ‘wire’ ‘force **on balance / yoke** is up’ is neutral	3	1 × AO1 2 × AO3
	the current (in rod) is from left / to right / rightwards $_2$✓	for $_2$✓ allow I → for current from left / to right; may be indicated on **Figure 11** condone ‘current clockwise’; ‘from positive to negative’ is neutral		
	predicts direction of field based on their force and their current using valid (left-hand) rule or WTTE $_3$✓	$_3$✓ is contingent on seeing $_1$✓ force up or down and on seeing $_2$✓current left or right etc; for $_3$✓ allow use of B for field and LHR for left-hand rule; allow B ⊙ by LHR; for reversed F OR for reversed I allow ⊗ by LHR, eg ‘force upwards’ / ‘current to right’ / ‘field into page’ etc earns ×✓✓ = 2/3		

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	MAX 2 from: • **any** valid expression to demonstrate homogeneity of terms A✓ • $B = \frac{F}{IL}$ OR $BI = \frac{F}{L}$ B✓ • identifies the base units of F as kg m s^{-2} C✓ the units for k are s^2 3✓	correct units for k earns 3 marks unless evidence of incorrect working seen for A✓ and B✓ allow any valid expression or statement that contains both units AND quantities for A✓ idea that $k\ B\ I$ has units of **mass** any subject eg $k \equiv \text{kg T}^{-1}\ \text{A}^{-1}$ allow 'M OR mass OR g = $k\ B\ I$' condone words for **units**, eg 'amps' / 'tesla'; accept use of dimensional analysis, M (mass), L (length) and T (time) for B✓ allow T (OR B) $\equiv \frac{\text{N}}{\text{A m}} \equiv \frac{\text{N s}}{\text{C m}}$ for B✓ allow TA (OR $B\ I$) $\equiv \frac{\text{N}}{\text{m}}$ for AB✓✓ allow $k \equiv \text{kg}\ \frac{(\text{A})\text{m}}{\text{N}} (\text{A}^{-1})$ for BC✓✓ allow T (OR B) $\equiv \frac{\text{kg (m) s}^{-2}}{\text{A (m)}} \equiv \frac{\text{kg}}{\text{C s}}$ for BC✓✓ allow TA (OR $B\ I$) $\equiv \frac{\text{kg (m) s}^{-2}}{\text{(m)}}$	3	1 × AO1 2 × AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	records **two** vertical intercepts to 2 dp with at least one intercept correct to ± 0.05 (g) OR M_1 and M_2 read off to 2 dp for the same value of I with at least one read off correct to ± 0.05 (g) $_1$✓ derives **two** valid equations using their M_1 and M_2 that can be solved to determine Y OR their Y min 1 dp, consistent with their intercepts to $\pm 0.1(0)$ (g) $_2$✓ $Y = 87.85 \pm 0.1(0)$ (g) CAO $_3$✓	M_1 intercept $= 134.85 \pm 0.05$ (g) M_2 intercept $= 181.85 \pm 0.05$ (g) allow either value seen in working for $_2$✓ mark is for method OR for their Y equations **[A]** and **[B]** seen: $134.85 = (0+)\ 2Z + Y$ ……**[A]** $181.85 = (0+)\ 4Z + Y$ ……**[B]** OR $Y = 2 \times M_1$ intercept $- M_2$ intercept; $_2$✓ not contingent on $_1$✓ so allow their Y correctly deduced using two incorrect intercepts including intercepts rounded to 1 dp $_3$✓ is contingent on $_1$✓ for $_3$✓ min 1 dp; only allow 1 dp 87.8 OR 87.9	3	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
03.5	identifies that B is less $_1$✓	for $_1$✓ allow 'field' / '(magnetic) **flux density**' for B; allow 'B weaker' / 'less field lines through the rod' / '(rod) not affected by field as much'; 'B is not uniform' / '(rod) cuts less flux' / 'cutting less field lines' are neutral $_1$✓	3	1 × AO2 2 × AO3
	states and explains why the intercept is the same $_2$✓	for $_2$✓ allow intercept is the same **because** 'intercept is the mass of yoke **and** magnets' / 'intercept $= 2Z$ AND Y' / 'Z AND Y don't change' / 'there is the same initial mass'		
	states and explains why the line is less steep $_3$✓	for $_3$✓ allow 'gradient is smaller' / 'gradient is **less** negative' / 'line is flatter' **because**		
	allow $_{23}$✓ for **stating** that the line is less steep **AND** that the intercept is the same without a valid explanation for either statement	'**change in** M_1 / balance reading / force is less for each (**change in**) I ' OR 'force won't **change as much** with current' OR 'less force per unit current' OR gradient is kB / gradient $\propto B$		
	allow $_{13}$✓ for $B = 0$ or WTTE (reject 'rod not in field'); intercept same as in **Figure 13** AND gradient $= 0$ or WTTE; then mark $_2$✓ as above	'less force for same current' is neutral take account any sketch graph that correctly compares the new graph of M_1 against I with **Figure 13**		
Total			**15**	

03.1	search coil is not suitable or wtte: no <u>emf</u> (would be induced in a search coil) $_1$✓	$_1$✓and $_2$✓ can be earned independently but are contingent on a statement that the search coil is not suitable; insist on suitable use of the appropriate underlined term for $_1$✓condone 'potential difference' OR 'voltage' for emf	1	AO1-1a
	a search coil needs (to be cut by) changing <u>flux</u> OR search coil is not cut by changing <u>flux</u> OR <u>flux</u> (cutting coil) is constant or wtte $_2$✓	for $_2$✓ accept ϕ for flux; do not insist on 'flux linkage'; do not allow 'field' for 'flux'; 'current (in the coil on frame) must be ac' is neutral; the suggestion that a search coil cannot be connected to a data logger is neutral	1	AO3-1b
	alternative approach: search coil **is** suitable or wtte: suggests a valid method that changes the flux cutting the search coil eg rotate either coil / turn (dc) current off / move either coil relative to other coil $_1$✓ states their method changes <u>flux</u> through search coil OR if search coil is cut by changing <u>flux</u> or wtte $_2$✓	alternative approach: $_1$✓and $_2$✓ can be earned independently but are contingent on a statement that the search coil is suitable		

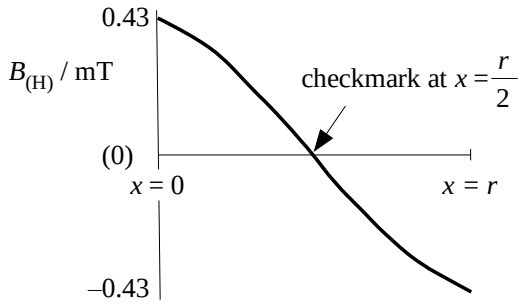
Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	use of $1 - \cos 25(°)$ or $1 - \sin 65(°)$ in a calculation of percentage change $_1$✓	for $_1$✓ expect either ≥ 3 sf rounding to $1 - 0.906$ OR $1 - 0.91$ seen in working OR $100 - 90.6$ or $100 - 91$ seen in working;	2	AO2-1h
	$(-)\ 9.4$ (%) CAO $_2$✓	for $_2$✓ expect min 2 sf rounding to $(-)\ 9.4$; allow $(-)\ 9.0$ if $1 - 0.91$ seen in working; do not insist on minus sign or 'decrease' on answer line allow $_2$✓ for unsupported answer of $(-)\ 9.4$; if no other mark is awarded allow $_{12}$✓ use of $1 - \sin 25(°)$ or $1 - \cos 65(°)$ in a % difference calculation leading to 58%		

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	uncertainty (in a single reading / judgement) is ½° $_1$✓	for $_1$ ✓accept 0.5 seen in numerator of % calculation OR absolute uncertainty is 2×0.5; allow a larger uncertainty up to $3°$ if justified with a comment about difficulty in judging the reading due to parallax, thickness of frame etc	1	AO1-1a
	(measurement of) θ is based on (difference between) <u>two</u> readings / judgements OR absolute uncertainty in θ (or $\Delta\theta$) = 2 × uncertainty in each reading / judgement $_2$✓	for $_2$ ✓accept 2×0.5 OR 2 × their uncertainty in (a single) reading seen in numerator OR evidence for use of 2 × their uncertainty in result of % calculation; 'measured twice' is ambiguous	2	AO1-1b
	correct percentage uncertainty calculation based on 100 × their absolute uncertainty divided by 25 $_3$✓	for $_3$ ✓ allow 1 sf result; $\frac{2\times0.5}{25}\times100=4\%$ (use of $0.5°$) earns $_1$✓$_2$✓$_3$✓ $\frac{0.5}{25}\times100=2\%$ (missing $2\times$) earns $_1$✓$_2$✗$_3$✓ $\frac{2\times1}{25}\times100=8\%$ ($1°$ unexplained) earns $_1$✗$_2$✓$_3$✓ $\frac{1}{25}\times100=4\%$ ($1°$ unexplained) earns $_1$✗$_2$✗$_3$✓ $_{123}$✓✓✓ for two-judgement explanation leading to $1°$ used in a correct % uncertainty calculation		

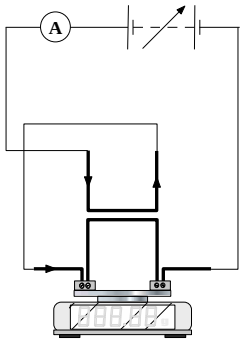
Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	r in range 67 to 69 mm OR $x_{0.5}$ in range 50 to 55 mm $_1$ ✓ $\frac{x_{0.5}}{r}$ in range 0.73 to 0.81 $_2$ ✓	$\frac{x_{0.5}}{r}$ in range gets both marks for $_1$ ✓ either value can be seen in working OR on (along horizontal axis in) **Figure 13** for $_2$ ✓ answer with no unit and minimum 2 sf	2	AO3-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
03.5	**use of Figure 11:** adds B_{H1} for experiment 1 to B_{H2} for experiment 2 at any point between x = 17 and x = 51 (mm); resultant B_H, minimum 2 sf, in range 0.91 to 0.99 (mT) $_1$✓ resultant B_H, minimum 2 sf, in range 0.93 to 0.97 (mT) $_2$✓	ignore any sign given with result	2	AO3-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
03.6	for more than 2 ideas mark as a list (field lines are) parallel or wtte $_1$✓ evenly-spaced or wtte $_2$✓	for $_1$✓ accept ‘in the same direction’ / ‘uniform-direction’; ‘horizontal' / ‘directed to the right’ / ‘straight’ / ‘linear’ / ‘perpendicular to the coil’ are neutral for $_2$✓ accept ‘equally-spaced’ / ‘equidistant’ / ‘uniform-spacing’ / ‘equal distance between lines’ or wtte; ‘close together’ / ‘do not touch’ are neutral; ‘uniform field’ / ‘field lines are uniform’ / ‘they are uniform’ are neutral	2	AO1-1a

Question	Answers	Additional comments/Guidelines	Mark	AO
03.7	a vertical axis drawn (at any point between $x = 0$ and $x = r$); continuous line (accept poorly-marked) between $x = 0$ and $x = r$ (by eye); intersecting or meeting horizontal axis / $B_{(H)} = 0$ at $x = \frac{r}{2}$ 1✓ vertical axis drawn, labelled with symbol B; negative gradient, line continuous between $x = 0$ and $x = r$; 2-quadrant graph 2✓ vertical axis drawn with symbol and unit eg $B_{(H)}$ / mT; continuous line between $x = 0$ and $x = r$; $B_{(H)} = 0.43 \pm 0.01$ at $x = 0$ OR $B_{(H)} = -0.43 \pm 0.01$ at $x = r$ 3✓ 2-quadrant graph, continuous line between $x = 0$ and $x = r$; approximately correct shape: see opposite; their y-value at $x = 0$ equal and **opposite** to their y-value at $x = r$ (by eye) 4✓	for 1✓ use checkmark on axis for guidance; for 2✓ allow 'magnetic flux density' in words; condone any flat section ≤ $r/4$ (judge by eye); allow (always) positive gradient for 1✓ and 2✓ allow a straight line; single quadrant can score 1✓ or 3✓ for 3✓apply usual symbol-separator-unit convention / allow $B_{(H)} = 4.3 \times 10^{-4}$ etc; adjust criteria for positive gradient graph for 4✓ if no values are marked on the axis, assume $B_{(H)} = 0$ is aligned horizontally with the x-axis (judge by eye); condone missing vertical axis 	MAX 3	AO3-2b
Total			**16**	

01.1	assumption is that ruler is <u>uniform</u> / <u>mass</u> evenly distributed **OR** <u>weight</u> acts at the centre/mid-point/middle **OR** <u>centre of mass</u> / gravity is at the centre/mid-point/middle $_3$✓	49, for use of LH end of ruler expect 30 or 50 don't insist on seeing masses in kg, distances in m or the inclusion of 9.81 or g in the working; condone g seen on one side only rounding to 127 g earns $_1$✓ and $_2$✓	**3**
01.2	<u>force</u> on wire is <u>upwards</u> **OR** ↑ $_1$✓ <u>current</u> is <u>from **P** to **Q**</u> **OR** <u>rightwards</u> **OR** (left) to (the) right **OR** →$_2$✓ states direction of force and direction of current (or $_3$✓= 0) and makes a suitably justified deduction, eg using <u>left-hand rule</u> **OR** LH rule **AND** B is <u>into the page</u> **OR** into plane of **Figure 3 OR** ⊗$_3$✓	for $_1$✓ condone 'motion is upwards' for $_2$✓ 'towards Q' **OR** 'positive to negative' are not enough allow logically correct (using LH rule) $_3$✓ for either <u>downwards</u> force with correct current **AND/OR** <u>upwards</u> force with wrong current increased flux density below wire is acceptable alternative to LH rule	**3**
01.3	gradient calculated from ΔM divided by ΔI, condone read off errors of ± 1 division; minimum I step ≥ 2.0 A $_1$✓ evidence of g = 9.81 or 9.8 <u>correctly</u> used in working for σ or B $_2$✓ $\lvert B \rvert$ in range 1.76 × 10^{-2} to 1.87 × 10^{-2} or 1.8 × 10^{-2} (T) $_3$✓	for $_1$✓ expect (–)0.28 (g A^{-1}); do not penalise for missing – sign for $_2$✓ look for σ = their gradient × 9.81 (× 10^{-3} N) **OR** B = $\frac{\text{their gradient} \times 9.81\left(\times 10^{-3}\right)}{15(\times 10^{-2})}$; condone POT errors for $_3$✓CAO by correct method only; ignore – sign if provided; no limit on maximum sf	**3**

<table>
<tr><th>Question</th><th>Answers</th><th>Additional Comments/Guidelines</th><th>Mark</th></tr>
<tr><td>01.4</td><td>
<table>
<tr><th></th><th>Reduced</th><th>No effect</th><th>Increased</th></tr>
<tr><td>Force acting on wire</td><td></td><td>1✓</td><td></td></tr>
<tr><td>Force acting on prism</td><td>2✓</td><td></td><td></td></tr>
<tr><td>Gradient of graph</td><td>3✓</td><td></td><td></td></tr>
<tr><td>Vertical intercept</td><td>4✓</td><td></td><td></td></tr>
</table>
</td><td>1✓ = 1 mark
2✓ = 1 mark
3✓and 4✓= 1 mark
allow any distinguishing mark as long as only one per row
for ✓ and × in same row ignore ×
for ✓ and ✓ in same row give no mark
ignore any crossed-out response unless only distinguishing mark on row</td><td>3</td></tr>
<tr><td>01.5</td><td>any complete circuit connecting the power supply in Figure 6 to X and to Y that produces currents in X and in Y that travel left to right 1✓
wiring correct so that X and Y are in series (see below) 2✓
  </td><td>allow parallel circuit for 1✓ but reject use of additional power supply
if X and/or Y is/are short-circuited award no marks;
for impractical circuits eg voltmeter added in series, award no marks
ignore any current arrows added to diagram</td><td>2</td></tr>
</table>

Question	Answers	Additional Comments/Guidelines	Mark
01.6	strategy: states that readings of M (as the dependent variable) will be measured for different values of independent variable, I or d only $_1$✓ clearly identifies the correct control variable, d or I only; condone $\frac{d}{L}$ = constant if I varied **OR** I^2L **OR** IL = constant if d varied; it must be clear how the value of the control variable is known $_2$✓ states that L will be measured or gives value eg L = 5.0 cm $_3$✓ use of g to convert M reading to F; evidence may be found in expression for k $_4$✓	for $_1$✓ condone F identified as the dependent variable or as the balance reading; reject 'measure change in mass / change in F' failure to make M or F the dependent variable cannot score $_1$✓ or $_2$✓ for $_2$✓if d is being varied and I = 5.0 A is stated, this can be taken to mean I is the control variable and the value is known for $_1$✓ and for $_3$✓ insist that M and L are being read **OR** measured **OR** recorded for $_4$✓ 'work out force' is not enough; reject 'acceleration' for g	**MAX 3**
	analysis: suggests a plot with M or F [by itself or combined with another factor] on the vertical axis and some valid manipulation of their independent variable on the horizontal axis $_5$✓ identifies correctly how k can be found using the gradient of their graph; k must be the subject of the expression given $_6$✓ **OR** if suggesting a plot with log M or log F on the vertical axis etc identifying correctly how k can be found from the graph intercept $_6$✓ **OR** suggesting a plot with M or F on the vertical axis etc and identifying correctly how k is found using the area under the line $_{56}$✓ = 1 MAX	the intention to plot M against I^2 is taken to mean that M is the dependent variable and is plotted on the vertical axis examples: plot M against I^2 will earn $_5$✓ and then $k = \frac{g \times d \times \text{gradient}}{L}$ will earn $_6$✓ or plot F against $\frac{1}{d}$ will earn $_5$✓ and then $k = \frac{\text{gradient}}{I^2 \times L}$ will earn $_6$✓ (note that when F is the dependent variable g will not appear in the expression for k)	**2**
Total			**19**

Question	Answers	Additional Comments/Guidelines	Mark
	technique: at least one instance seen where a metre ruler is made vertical using a set-square in contact with the floor $_1$✓ strategy: (use a metre ruler to) measure the height of the free end of the tape (above the floor) and the height of the tape at the bench [height of the bench]; y = <u>difference</u> between these heights $_2$✓ **OR** use a metre ruler or straight edge placed alongside the tape measure	for $_1$✓ allow use of plumb line or spirit level; don't insist on the set-square being used against two mutually perpendicular faces of the metre ruler the floor is assumed to be horizontal if the deflection is found from the difference between two vertical measurements for $_2$✓ allow metre ruler B made horizontal by use of set-square against vertical ruler A; ruler B establishes vertical position of free end of tape; ruler A is used to measure y directly either or both marks can be earned for suitable	

C

C

A

B

D

D

C

C

22	A	one

23	D	The peak-to-peak voltage is $650\ \text{V}$.

24	B	$\frac{9}{2}P$

25	B	200 0.45

23	B (AO2)	1	

24	B (AO2)	P

22	A	☐	

23	D	600 μV

24	D	395 V

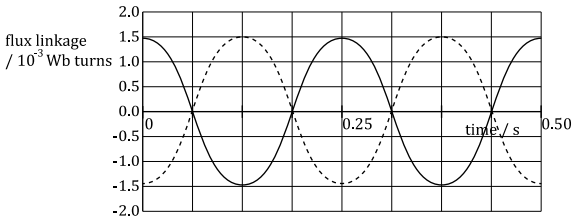
27	C	0.174 A

12	B	decreasing the frequency of the ac input voltage

21	A	0	AO2

22	D	6.25 μV	AO2

23	A	80%	AO2

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-

03.1	Max 2 from one route ✓✓ **Alternative 1** • $\Phi = BA\cos\theta = 4.9\times10^{-5}\times(2\times8.0)\times\cos 68° = 2.9(4)\times10^{-4}$ (Wb) OR $\Phi = BA = 4.9\times10^{-5}\times(2\times8.0) = 7.84\times10^{-4}$ (Wb) • Time to fall to the ground = 1.3 (1.28) (s) • $\varepsilon = \frac{\Delta\Phi}{\Delta t}$ with their $\Delta\Phi$ and t **Alternative 2** • $\varepsilon = Blv$ or $\varepsilon = Blv\cos\theta$ seen • $v = \sqrt{2g\Delta h}$ OR $\sqrt{2as} = 12.5$ (m s^{-1}) OR Time to fall to the ground = 1.3 (1.28) (s) • $v_{avg} = \frac{v}{2}$ with their v OR $v_{avg} = \frac{s}{t}$ for their t $\varepsilon = 2.3\times10^{-4}$ ✓ (V)	Marks can only be awarded from one route. mp1 and 2 the mark can be awarded from seeing a substitution. For mp1 condone $\sin 68°$ in both routes $t = \left(\frac{2s}{a}\right)^{\frac{1}{2}} = \left(\frac{2\times8.0}{9.81}\right)^{\frac{1}{2}} = 1.28$ In 3rd bullet do **not** allow $\varepsilon = \frac{\Delta B}{\Delta t}$ or $\varepsilon = \frac{\Delta B\cos\theta}{\Delta t}$ but condone any value for A.	3	1 × AO1a 1 × AO2a 1 × AO3-1a

<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidelines</th><th>Mark</th><th>AO</th></tr>
<tr><td>03.2</td><td>Max 4✓✓✓✓
Fall to the left
<table>
<tr><td>Statement</td><td>Explanation</td></tr>
<tr><td>the direction of the emf changes</td><td>the rod cuts across the magnetic field in both directions / passes parallel point</td></tr>
<tr><td>the emf goes through a zero (when $68°$ to the vertical)</td><td>momentarily the rod travels parallel to the field or does not cut lines of flux / 0 change in flux</td></tr>
<tr><td>emf reduces (and then increases)</td><td>as (direction of) velocity or motion gets closer to being parallel to field / same direction as field / cuts less flux per unit time</td></tr>
</table>
Fall to the right
<table>
<tr><td>Statement</td><td>Explanation</td></tr>
<tr><td>the direction of the emf stays the same</td><td>the rod cuts across the magnetic field always in the same direction</td></tr>
<tr><td>Idea that the emf goes through a maximum (when $22°$ to the vertical)</td><td>the rod cuts across the magnetic field at right angles or the cutting of field line is a maximum</td></tr>
<tr><td>emf increases (and then decreases)</td><td>as (direction of) velocity or motion gets closer to perpendicular to field / cuts more flux per unit time</td></tr>
</table></td><td>All marking points are to be OWTTE.
Ignore comments about different direction falling left and right.
Statement and explanation are separate marking points.
Explanation must not contradict statement to be awarded.

Condone emf increases as speed of fall increases (Blv) or smaller time $\left(N\frac{\Delta\Phi}{\Delta t}\right)$✓ ✓ for either direction but not both.
Allow the following statement and explanation as an alternative to either a fall to the left or to the right but not both:
Statement – when falling left the average emf is less than falling to the right.
Explanation – as the total change in flux / number of flux lines cut is less than when falling to the right.</td><td>4</td><td>2 × AO2g
2 × AO3-1a</td></tr>
<tr><td>Total</td><td></td><td></td><td>7</td><td></td></tr>
</table>

Question	Answers	Additional comments/Guidelines	Mark	AO

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.		

04.1	Magnetic flux density at $0.070\ \text{m} = 0.07 \pm 0.005\ \text{T}$ ✓ (use of flux linkage $N\Phi = BAN$ $= 0.07 \times 3.5 \times 10^{-5} \times 200$) Flux linkage $= 4.9 \pm 0.2 \times 10^{-4}$ (Wb-turns) ✓	shown calculated to at least 2 sig figs	2	3.7.5.3 AO2 1d ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	(As the coil moves) there is a rate of change of flux through the coil ✓$_1$ (owtte) The induced emf is proportional to the rate of change of flux (linkage) so the (magnitude) of the emf decreases ✓$_2$ (owtte)	✓$_1$ The first part ie the induced emf is proportional to the rate of change of flux linkage may be given in a number of ways eg emf $= N\frac{\Delta\Phi}{\Delta t}$ or $N\frac{\Delta(BA)}{\Delta t}$ or simply saying 'because of Faraday's law'. Ignore the sign of the emf ✓$_2$ It's not enough to say the emf decreases Connection between rate of change of flux and change of flux with distance must be made	2	3.7.5.4 AO1 1b AO2 1c

Question	Answers	Additional comments/Guidelines	Mark	AO
04.3	Finding a gradient from a tangent ✓$_1$ Attempting to use Faraday's law emf = $N\frac{\Delta(BA)}{\Delta t}$ OR incorporating velocity into Faraday's law $NA\left(\frac{\Delta B}{\Delta x}\right)v$ ✓$_2$ emf = $\left(200 \times 3.5 \times 10^{-5}(0.693) \times 0.80\right)$ emf = 3.6 to 4.2×10^{-3} (V) ✓$_3$ The maximum emf (in the range considered) is the greatest at x = 0.10 m (as the gradient is the greatest) So No ✓$_4$ owtte	✓$_1$ This can be calculated at any x eg at x = 0.10 m gives $\frac{\Delta B}{\Delta x} = \left(\frac{0.095}{0.137}\right) = 0.69(3)$ (T m^{-1}) ✓$_2$ The mark is given for an attempt to use Faraday's law. Allow errors provided the form of the equation remains correct. ✓$_3$ The expected value is $3.8(8) \times 10^{-3}$ V {range to be decided at standardisation} ✓$_4$ No and an indication that the emf at x = 0.10 m is the maximum available. This could come earlier in the answer and can be inferred by a reference to the maximum gradient in the range considered. No ecf. If no marks are awarded allow 1 mark if candidate states that the largest emf is expected at x = 0.10 m If only the second mark is awarded allow a mark for finding $\frac{\Delta B}{\Delta t}$ or $N\frac{\Delta \phi}{\Delta t}$ between x = 0.07 and 0.10 m (e.g. $\frac{200 \times 3.5 \times 10^{-5}(0.07-0.024)}{0.0375}$)	4	3.7.5.4 AO2 1d ×2 AO3 1a ×2

Total			8

16

Question	Answers	Additional comments/Guidelines	Mark	AO

04.1	$V_{rms}\left(=\frac{V_{peak}}{\sqrt{2}}=\frac{15}{\sqrt{2}}\right)=10.6$ (V) ✓ {allow 11 V to 2 sig figs}		1	AO1.1b
04.2	(Peak voltage 3 divisions corresponding to 15 V) y-voltage gain = 5 (V div^{-1}) ✓		1	AO2.1d M2
04.3	A horizontal line drawn at 10.6 V ✓	Tolerance – must be between 10 and 11 up from the centre Allow ecf from 04.1	1	AO2.1d M2
04.4	(Period T = corresponds to 8 divisions $T = 8 \times 5.0 \times 10^{-4}$ s = 0.0040 s Frequency = 1/T = 1/0.0040) = 250 (Hz) ✓	Answer only gains the mark.	1	AO2.1h M2

04.5	~~Time constant = 4×10^{-4} (s) ✓1 {only needs 1 sig fig}~~ The second and third mark can come from the following alternatives. Note the mark is for the method so allow arithmetic slips and imprecise measurements. Make use of the equation $V_t = V_o e^{-\frac{t}{\text{time constant}}}$ ✓2a Substitute values for V_t and V_o (confirmed by the graph) and calculate the (unknown) time constant. ✓3a OR $\text{Ln}2\ (= 0.69) = = \frac{t_{\frac{1}{2}}}{\text{time constant}}$ ✓2b Substute time for *V* to decrease to half its value (confirmed by the graph) and calculate the time constant ✓3b OR The voltage falls to $1/e$ or 37% in a time constant ✓2c {owtte} Find the time that corresponds to this fall in voltage confirmed by the graph (normally the start of the discharge This gives the τ directly) ✓3c	To use a number of small divisions rather than grid divisions is not an arithmetic error. This error comes from not knowing how the oscilloscope is used. Full marks can be awarded from consideration of the charging part of the cycle. The equation can be presented in a number of variations using RC or τ for example. Typical calculation might be: $\frac{V_t}{V_o} = \frac{1}{12}$ in 2 time divisions. Substitution into the equation will give τ V_t and V_o both need to be defined in relation to the graph OR *V* halves its value in 0.5 time divisions. Substituting gives τ $t_{\frac{1}{2}}$ needs to be defined in relation to the graph OR 37% of 3 divisions is 1.1 divisions which occurs in time ¾ time divisions giving τ	3	AO2.1g AO2.1h AO3.1a M2 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.6	Reduce the time-base setting ✓1a Uncertainty is due to the smallness of the divisions and this action means the waveform/trace stretched horizontally/in x-direction. ✓2a {owtte} OR Increase the y-gain ✓1b Uncertainty is due to the smallness of the divisions and this action means the waveform/trace stretched vertically/in y-direction. (The trace will need to be moved vertically to fit on the screen) ✓2b {owtte}	1 Stated answer must be a practicable change 2 Explanation must refer to both the trace and its relation to uncertainty and follow a correct change.	2	AO3.2b ×2
Total			9	

18

Question	Answers	Additional comments/Guidelines	Mark	AO

05.1	Core – idea that it provides greater linkage/increases linkage of magnetic flux/field (from the primary coil to the secondary coil compared to an air core)✓1 OWTTE Secondary coil – (a conductor) has a varying/alternating/changing magnetic flux/field passing through/linking with it ✓2 OWTTE Producing an induced emf / induces an emf that is determined by the number of turns in (the primary and) the secondary coils ✓3 OWTTE	✓1 This can be expressed using terms such as “channels/directs/concentrates/focuses/funnels”. In MP1 the reference to an air core can be inferred. Condone “ links all/most flux”. ✓2 ‘varying’ is important for this mark. ✓3 errors may cancel this mark eg ‘this increases the power output’, will not gain this mark. Do not allow reference to “induced voltage” or "induced current" in MP3. When no other mark awarded, MAX 1 for “this is a step-up transformer/the voltage is less on the primary than on the secondary because there are more secondary turns than primary turns”	3	3 x AO1 3.7.5.6

Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	MAX 3 Design feature 1✓1a Link to efficiency ✓1b Design feature 2✓2a Link to efficiency ✓2b Award ✓a only once for "thin sheets/ laminations of iron are used".	For each example ✓b is contingent on ✓a Example A ✓a The (sheets) of material **M /** laminations are made from insulator/high resistivity material ✓b reduces/limits (eddy) currents or charge flowing in the core. Example B: ✓a thin sheets/ laminations of iron are used ✓b so smaller emf's are induced in the core Example C ✓a thin sheets/ laminations of iron are used ✓b so resistance is high causing lower (eddy) currents If no other marks awarded, give 1 MAX for ✓ Iron is used which magnetises and demagnetises easily OR ✓ Eddy currents produce a magnetic field that opposes the magnetic field supplied to the core	3 max	1 x AO1 2 x AO3 3.7.5.6

Question	Answers	Additional comments/Guidelines	Mark	AO
05.3	If the voltage is lower/$33\ \mathrm{kV}$ then power is transmitted at high current. So energy/power is wasted/lost in the cable by (I^2R) heating. ✓$_1$ OWTTE If the voltage is made too high this will create major insulation/isolation difficulties. ✓$_2$ OWTTE	These two points can be expressed the other way round. They could state why the voltage needs to be high and then why it should not be low. Do not accept 'changes affect the resistance (of the cable)'. In ✓$_2$ accept "taller pylons", "transformers that have better insulation against spark/flash over", "more expensive equipment"	2	1 x AO1 1 x AO3 3.7.5.6

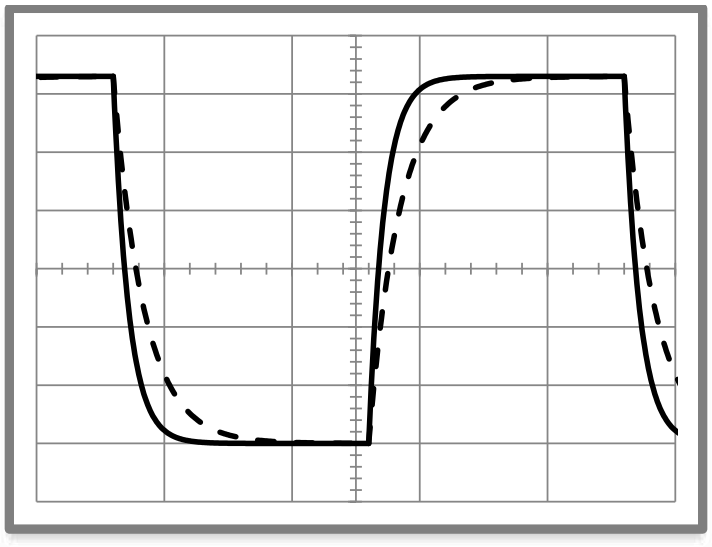
Question	Answers	Additional comments/Guidelines	Mark	AO
05.4	Correct use of efficiency $\eta = \frac{\text{power}_{out}}{\text{power}_{in}}$ once ✓1 Correct use of $I = P/V$ with their values once at any point ✓2 I = 3200 (A) (correct answer only, no ecf) ✓3	✓1 examples could be: power at 132 kV = 72 / 0.98 = 73.5 MW OR at transmission line start = 73.5 / 0.94 = 78.2 MW OR at 25 kV = 78.2 / 0.98 = 79.8 MW OR in single stage Power at 25 kV = 72 / (0.94 × 0.98^2) = 79.8 MW) ✓2 eg at consumers I = 72 × 10^6 / 11 × 10^3 = 6545 A (Calculator value: 3190.16 A)	3	3 x AO2 3.7.5.6
Total			11	

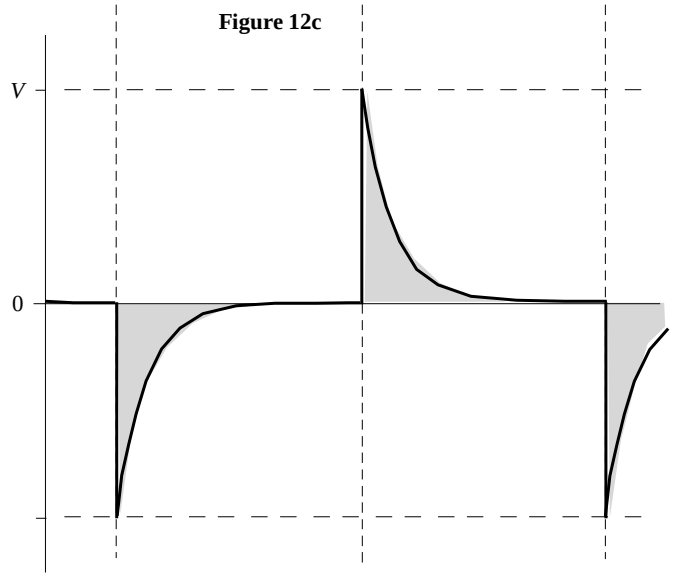
Question	Answers	Additional comments/Guidelines	Mark	AO

02.1	peak (to peak) voltage = 0.3(0) (V)	accept any answer that rounds to 0.3 V do not allow power of ten errors, eg 0.0063 V	1
02.2	period = 8 divisions (= 8 × 0.5 × 10^{-3} (s)) = 4 ms $_1$✓ $\left(f = \frac{1}{T} = \frac{1}{0.004} \right)$ = 250 (Hz) $_2$✓	award both marks if 250 Hz seen accept 4.0(0) ms for $_1$✓ but reject 4.05, 3.95 etc ecf$_2$✓ for wrong period	2

02.3	any valid approach leading to *RC* in range 2.1 ×10^{-4} to 3.4 ×10^{-4} or 3 ×10^{-4} (s) OR their *T* in 02.2 × 0.069 ± 10 % $_{12}$✓✓ 1 mark can be awarded for use of any valid approach in which *RC* is seen with substitutions or with rearranged equations, eg $0.5 = 6.3e^{\frac{-6\times10^{-3}}{RC}}$ or $RC = \frac{-t}{\ln\left(\frac{V}{V_0}\right)}$ or $RC = \frac{t}{\ln\left(\frac{V_0}{V}\right)}$ OR $1.75\times10^{-4} = RC\times\ln 2$ OR $RC = \frac{t_{0.5}}{\ln(2)}$	valid approaches; reads off *t* when *C* starts to discharge and *t* at a lower value of *V*: rearranges $V = V_0 e^{\frac{-\Delta t}{RC}}$ to calculate *RC* for ecf $_2$✓ Δt used must correspond to interpretation of time base used in determining the frequency in 02.2; there is no ecf for misinterpretation of the voltage scale OR reads off *t* when *C* starts to charge and *t* at a higher value of *V*: rearranges $V = V_0\left(1 - e^{\frac{-\Delta t}{RC}}\right)$ to calculate *RC* etc OR determines half-life $t_{0.5}$ and finds *RC* from $\frac{t_{0.5}}{\ln(2)}$ for ecf $_2$✓ $t_{0.5}$ used must correspond to etc OR uses idea that during discharge *V* falls to 0.37V_0 in one time constant: determines suitable *V* and reads off *RC* directly for ecf $_2$✓ time interval used must correspond to etc OR uses idea that during charging *V* rises to 0.63V_0 in one time constant: determines suitable *V* and reads off *RC* directly reject idea that *V* falls to zero in 5*RC*	2

02.4	qualitative comment idea that the waveform will stretch horizontally $_1$✓ quantitative comment by a factor of $\left(\frac{0.5}{0.2}=\right)$ 2.5 $_2$✓ OR half a cycle now covers 10 (horizontal) divisions on the screen $_2$✓ (and also earns $_1$✓) (so the) <u>resolution</u> of the time axis has <u>increased</u> $_3$✓ (and also earns $_1$✓) measuring <u>larger distance</u> / across <u>more divisions</u> from the screen <u>reduces</u> (percentage) <u>uncertainty</u> in reading the <u>time</u> (constant / interval / half life) $_4$✓	for $_1$✓ look for reference to time axis or direction waveform is re-scaled accept 'graph is longer/stretched' or '<u>will</u> not see whole cycle' or 'fewer cycles shown' or 'period takes <u>more space</u>' or 'distance being measured is larger' or 'time per division is less' or 'larger in *x* direction' or 'time is stretched' reject 'waveform becomes <u>larger</u>' or '<u>may</u> not see whole cycle' or 'measuring larger <u>time</u>' for $_2$✓ there needs to be valid quantitative detail award $_{12}$✓✓ for '<u>half</u> a cycle now <u>fills the screen</u>' or '<u>half</u> a cycle is displayed' as these clearly recognise the stretching is along the time axis and 'half' is quantitative accept 'new distance (on screen corresponding to half life or time constant) is <u>2.5</u> × answer shown in working for 02.3' the candidate who realises that half a wave now covers the complete width of the screen cannot claim this is a disadvantage; they would still be able to bring either half cycle into view by using the X-shift and find *RC* for $_3$✓ uses technical language correctly ignore (but do not penalise) 'times are more precise' or 'more accurate' reject 'smaller resolution' or 'lower resolution' for $_4$✓ there needs to be a qualifying explanation for the comment about uncertainty reject 'advantage because the (time) scale is easier to read'	3 MAX

02.5	valid sketch on **Figure 11** showing discharge time <u>to 0 V reduced</u> and charging time <u>to peak voltage reduced</u> (see right) $_1$✓ connecting resistor in parallel with R <u>halves</u> [reduces by <u>50%</u>] circuit [total] resistance [time constant] $_2$✓	 do not insist on seeing second discharge although if shown this must look correct	2

02.6	amendment to **Figure 12** showing waveform across R with approximately the correct shape, amplitude ± *V* and the correct phase correct waveform shown while signal generator output is low (0 V): only the complete negative half cycle needs to be shown but if second negative half cycle is included it must be correct $_1$✓ correct waveform shown while voltage across signal generator output is high; condone no signal or signal = 0 V before going to −*V* for the first time $_2$✓	Figure 12c  don't insist on seeing vertical lines	2
02.7	reduce the (sensitivity of) (Y-voltage)) gain $_1$✓ (change) to 2 V division^{-1} $_2$✓ (and earns $_1$✓) adjust the Y (vertical) shift $_3$✓	'make (Y-) gain smaller' or 'increase the volts per division' or 'reduce the Y-resolution' are acceptable substitutes for 'reduce the (Y-)gain' increase the (Y-) gain to 2 V division^{-1} $_2$✓ not $_1$✓ reduce the (Y-) gain to 0.5 V division^{-1} $_1$✓ not $_2$✓ ignore any comment about time base or 'X-gain' if all positive waveform is given for 02.6 allow sensible comment about triggering/stability control, eg waveform may not be stable $_1$✓; adjust triggering $_2$✓	2 MAX

16

Question	Answer	Additional Comments/Guidance	Mark

D

D

25	C (AO1)		the gravitational force of the parachutist on the Earth

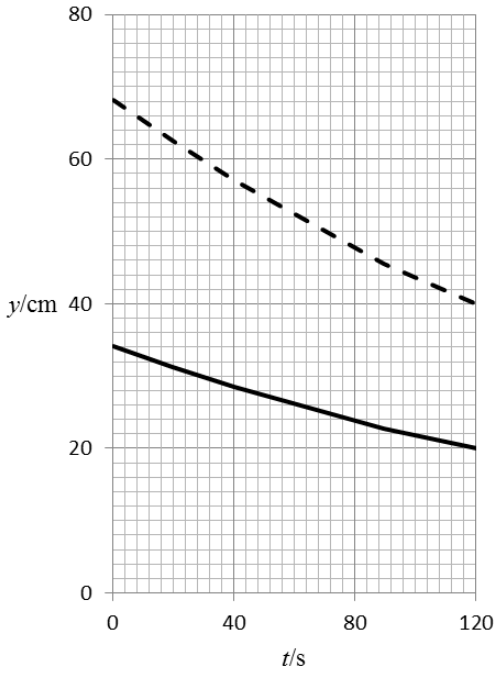
25	B		maximum		minimum		AO1

02.1		reject 'weigh'/ weighed	
	method to reduce uncertainty in volume $_3$✓	read water level at <u>bottom of the meniscus</u> (or wtte or allow sketch); don't penalise further use of 'beaker' treat as neutral: 'dry cylinder before use' OR procedure to avoid systematic error in determining mass, eg tare / reset / zero the balance with empty beaker on pan / find mass of beaker empty and subtract from mass of beaker plus water; don't penalise further use of 'weigh'/ 'scales' allow 'use balance on a <u>horizontal</u> surface'	AO2-1c = MAX 2
	method to reduce uncertainty in time $_4$✓	ensure stopwatch is zeroed / reset before use	
	added detail $_5$✓$_6$✓$_7$✓	collect large(r) <u>volume</u> / for long(er) <u>time</u> / ≥ 60 s $_5$✓ this reduces <u>percentage</u> / <u>fractional</u> uncertainty $_6$✓ read at <u>eye level</u> or wtte, to reduce <u>parallax</u> $_7$✓	

12

02.2	sensible mark identifying second box indicating ($\mathrm{N\ m^{-2}\ s}$) only	**auto marked question**	AO3-1a = 1
02.3	19.8% (from $4 \times 2.9\% + 1.8\% + 6.4\%$) earns both marks ✓✓	don't insist on seeing '%' unless 0.198 etc allow final answer rounded to 20% allow 1 mark for 0.198 or 0.20 but reject 1 sf 0.2 for incorrect answer the following can earn one mark: (percentage uncertainty in d =) $4 \times 2.9\%$ / 11.6% / 12% seen in working but wrong final answer OR missing $\times$ 4 eg $2.9\% + 1.8\% + 6.4\% = 11(.1)\%$ OR incorrect multiplier applied to 2.9 eg $2 \times 2.9\%$ OR with $\times$ 4 applied wrongly eg 2.9 + (1.8 x 4) + 6.4 = 16.5 % or 17 % / 2.9 + 1.8 + (6.4 x 4) = 30(.3) %	AO3-1b = 2
02.4	appropriate use (ie close to and parallel with the vertical side of the tube, but not necessarily in contact with the tube) of: a metre ruler made vertical using a set-square in <u>contact with the bench</u> / <u>floor</u> / (flat) <u>surface</u> OR a plumb line / weight on <u>vertical</u> string (reject 'pendulum') OR a spirit level ✓	the mark can be awarded for a convincing sketch, eg use of a very large set square without ruler accept 'tri-square' for set square the only acceptable horizontal reference is the bench: don't allow use of horizontal T, eg set square placed on T even if sketch looks convincing no credit for attempt to show graduations on tube are horizontal / use of 'protractor' for set-square / 'each side of meniscus at same level' / use of clamp stand rod or wall as vertical reference	AO2-1g = 1

02.5	attempted use of $y = y_0 e^{-\lambda \Delta t}$ with substitution of values of y, y_0 and Δt obtained **directly** from **Figure 10** / plausible values obtained from **Figure 13** OR tangent drawn on **Figure 10** to find $\frac{dy}{dt}$; use of $\frac{dy}{dt} = (-)\lambda \times y^*$ and y^* is where tangent meets the curve $_1$✓ valid calculation **seen** leading to a result for λ that rounds to 3 sf in range 4.45 to 4.55×10^{-3} (s^{-1}); award if seen in body of answer $_2$✓	for $_1$✓ do not penalise y / y_0 interchanged, read off errors, manipulation errors / $\Delta t = t$ / t_0 / $\frac{t}{t_0}$ or use of incorrect symbols eg A, N for y; no ecf for $_2$✓ allow use of **Figure 13** $y_0 = 60.0$ cm, $y = 52.2$ cm; $\Delta t = 60 - 29 = 31$ s $52.2 = 60\ e^{-31\lambda}$; $\therefore \lambda = 4.49 \times 10^{-3}\ s^{-1}$ if the intermediate step is seen, eg $\lambda = \frac{1}{\Delta t} \times \ln\left(\frac{y_0}{y}\right) = \frac{1}{31} \times \ln\left(\frac{60}{52.2}\right)$ accept 'log' for 'ln' no credit allowed for reverse-working method in a 'Show that' problem no credit for assuming straight line and $y = mx + c$, measuring the gradient then by determining the equation of the line or by using $m = \frac{y_2 - y_1}{t_2 - t_1}$ determines the half life; finds λ from $\frac{\ln 2}{\text{half life}}$ no credit for common error λ = gradient × 2 for $_2$✓ look for any answer in the body that deserves credit (for a 'Show that' we can overlook truncation in the value given on the answer line)	AO2-1h = 1 AO3-1b = 1
	variation on use of use of $y = y_0 e^{-\lambda \Delta t}$ for $_1$✓: λ can be found if points t_1, y_1 and t_2, y_2 are used and the values substituted into $\frac{y_1}{e^{-\lambda t_1}} = \frac{y_2}{e^{-\lambda t_2}}$; if this approach is used substitute the data into $\lambda = \frac{1}{\Delta t} \times \ln\left(\frac{y_0}{y}\right)$ to confirm that the result for λ is correct before awarding $_2$✓		

02.6	use of $T_{½} = \frac{\ln 2}{\lambda}$ OR $\frac{\ln 0.5}{-\lambda}$ with substitution of **recognisable** λ; evaluated to ≥ 2 sf in range 140 s to 170 s ✓	calculation can have any subject; accept use of 2 sf $\lambda = 4.5 \times 10^{-3}$ usually leading to 154 but allow correctly truncated to 150 or 1.5×10^{2}	AO3-1a = 1
02.7	(mostly) continuous line drawn on **Figure 13**; below dashed line and with negative gradient between t = 0 and t = 120; do not penalise linear line or shaky / thick / hairy line or slight discontinuities; accept ≈ horizontal after 100 s 1✓ line passes through: t/s | y/cm min | y/cm max 0 | 33 | 35 AND through EITHER of t/s | y/cm min | y/cm max 60 | 24 | 28 120 | 17 | 23 2✓		AO2-1d = 2
Total			**13**

Question	Answers	Additional Comments/Guidelines	Mark
	f (from $\frac{1}{T}$) in range 61 ± 1 Hz $_1$✓$_2$✓ OR 61 ± 3 Hz $_{12}$✓ maximum 1 mark for POT error OR incorrect rounding	for $_1$✓$_2$✓ **require ≥ 2 sf** that rounds to not less than 60 and not more than 62 for $_{12}$✓ **require ≥ 2 sf** that rounds to not less than 58 but less than 60 OR for ✓ **require ≥ 2 sf** that rounds to more than 62	AO3-1a =

03.1	no credit for 1 sf; treat 60 as 2 sf unless clearly rounded to 6×10^1	for $_{12}$✓ **require ≥ 2 sf** that rounds to more than 62 but not more than 64 if incorrect rounding leads to 60 treat this as 1 sf and give no credit use of $\frac{1}{T}$ does not have to be seen; marks are for final answer seen	AO3-1a = 2
03.2	(figures) 804 and 226 seen in working $_1$✓ λ = difference between their readings $\times$ 2; given to nearest mm; expect 1.156 (m) OR to nearest cm; expect 1.16 (m) $_2$✓	for $_1$✓ 578 is not enough for $_2$✓ range is based on $x = (804 - 226 =) 578 \pm 2$ mm; give no credit for POT errors eg 115.6 / 116 etc accept 1156 mm etc if unit on answer line is amended	AO3-1b = 2
03.3	c correctly evaluated to ≥ 2 sf from their $f \times$ their λ ✓	substituted data may be from 03.1/2 final answers or unrounded (intermediate) data from working expected answer = $61 \times 0.578 \times 2 = 70.5$ m s^{-1}	AO2-1d = 1

03.4	μ correct to 2 sf based on their f and their λ earns both marks $_1$✓$_2$✓ for incorrect / missing μ EITHER use of $c = \sqrt{\frac{T}{\mu}}$ OR use of $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ $_{12}$✓	for $_1$✓ their value of μ can be given to ≥ 2 sf but must agree with $\frac{0.5 \times g}{(\text{their } f \times \lambda)^2}$ OR $\frac{0.5 \times g}{(\text{their } c)^2}$ **when rounded to 2 sf**; use of g = 9.81 or 9.8 only; no ecf for mixed units expected answer $\mu = 9.9 \times 10^{-4}$ (kg m^{-1}): be wary of which approach has been taken by the candidate for $_{12}$✓ 'use of' means allow **either** rearranges so that μ is the subject eg $\mu = \frac{T}{c^2}$ (accept $\mu = \frac{mg}{c^2}$, $\frac{T}{c^2} = \mu$ etc) **or** substitution of all relevant data including their c into a correct expression with μ as the only unknown for T allow 4.9 / 4.91 / 4.905 (accept 0.5 × 9.81 or 0.5 × 9.8); allow mixed units; allow 0.5g OR 'use of' means allow **either** rearranges to $\mu = \frac{T}{(2 \times l \times f)^2}$ OR $\frac{T}{4 \times l^2 \times f^2}$ **or** substitution of all relevant data including their l and f leaving μ as the unknown; allow sub of λ for $2l$ watch for possible error $\lambda = L$	AO2-1d = 2

03.5	0.71 (mm) ✓	only answer that gets mark	AO3-1b = 1

03.6	ANY TWO FROM repeat readings at different points along the rod and calculate an average / mean $_1$✓ repeat readings in different directions (perpendicular to the rod) and calculate an average / mean $_2$✓ reject / discard anomalous readings before calculating an average / mean $_3$✓ award $_{123}$✓= 1 MAX for checking at different points / in different directions to confirm that the rod is uniform / that there are no anomalies	allow ‘cylinder’ / ‘wire’ etc for rod for $_1$✓ $_2$✓ and $_3$✓ averaging idea only needs to be seen once; if averaging idea missing then allow ‘repeat at different points and in different directions, then remove anomalies’ $_{123}$✓= 1 MAX if ‘calculate’ is not seen allow ‘work out’ / /‘determine’ / ‘compute’; anything that sounds like a mathematical process is ok; ’find’ / ‘obtain’ / ‘take’ / ‘do an average’ are just ok; ‘get’ is not ok for $_1$✓ allow repeat at ‘different positions’ / ‘down / along the rod’ for $_2$✓ allow (repeat in different directions) ‘around the rod’ / ‘different orientations’ / ‘angles’ / ‘planes’ / ‘sides’ for $_3$✓ allow ‘ignore anomalies’; ‘outlier’ = ‘anomaly’ reject ‘calculate an average to eliminate effect of anomalies’ treat as neutral: ‘turn the wheel to close the callipers’ / suggestions about calibration treat as neutral: ‘zero callipers before use’ this is a procedure to eliminate a source of systematic error	AO2-1g = MAX 2

03.7	(for use of expected 0.71) $\rho = 8.9(41) \times 10^{3}$ (kg m^{-3}) OR (for use of 0.53) $\rho = 1.6(05) \times 10^{4}$ (kg m^{-3}) OR $\rho = \frac{4.51\times10^{-3}}{(\text{their } d \text{ from} 03.5)^2}$ 123✓✓✓ OR attempts to use μ OR $3.5(4) \times 10^{-3}$ divided by their (recognisable) cross-sectional area 1✓ AND/OR evidence showing cross-sectional area = $\frac{\pi d^2}{4}$ using their d from 03.5 (allow πr^2 using their d) 2✓	correct answer scores 123✓✓✓ for 123✓✓✓ allow an answer that rounds to the correct 2 sf value sample results for expected d d/mm: 0.71; 0.53 A/m^2: 3.96×10^{-7}; 2.21×10^{-7} ρ/kg m^{-3}: $8.9(41) \times 10^{3}$; $1.6(05) \times 10^{4}$ for 1✓ accept use of symbols, eg $\rho = \frac{\mu}{A}$ / $= \frac{3.54\times10^{-3}}{A(\times1)}$ / $= \frac{4\times\mu}{\pi\times d^2}$ / $= \frac{4\times3.54\times10^{-3}}{\pi\times d^2(\times1)}$ $= \frac{3.54\times10^{-3}}{\pi\times r^2(\times1)}$ for 2✓ expect correct value of A seen or correct values of A or d in working, eg $\rho = \frac{3.54\times10^{-3}}{3.96\times10^{-7}(\times1)}$ / $= \frac{4\times3.54\times10^{-3}}{\pi\times(0.71\times10^{-3})^2\times(1)}$ accept values ≥ 2 sf for A; allow ecf d and don't penalise POT error in A or d (eg missing 10^{-7}, 10^{-3})	AO3-1a = 1 / AO2-1h = 2
Total			**13**

03.1	tick in **first** box (2.7 V) ✓	[cao]	1	AO2-1d

Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	move position until needle / pointer hides / is aligned with its reflection in the mirror or wtte $_1$✓ this reduces / eliminates <u>parallax</u> error OR to ensure scale is read from directly above $_2$✓	for $_1$✓ allow 'view scale so needle / pointer hides reflection'; condone 'there is no reflection' for $_2$✓ reject 'reduces / eliminates human error' allow 'reading is made when at right angles' / 'perpendicular to the scale'; reject 'view scale at eye level' / 'so not looking at an angle' / 'so ~~not~~ looking straight at needle'	2	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	average $T_{½}$ correct OR uncertainty in $T_{½}$ correct $_1$✓	for $_1$✓ average $T_{½}$ = 12.04 (s); reject 12.0 allow credit for correct $T_{½}$ seen in working for percentage uncertainty; uncertainty in $T_{½}$ (from half range) = 0.11 (s)	1	AO2-1h
	percentage uncertainty in $T_{½}$ correct $_2$✓	for $_2$✓ minimum 2 sf; correct answer rounds to 0.91(4)%	1	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	time constant = $\frac{\text{their mean } T_{½}}{\ln 2}$ OR $\frac{-(\text{their mean } T_{½})}{\ln 0.5}$ ✓	expect 17.37 (s); allow minimum 3 sf 17.4 / use of ln 2 = 0.69 for leading to 17.45; reject use of $T_{½}$ = 12 leading to 17.31; reject $\frac{\text{their mean } T_{½}}{\ln 0.5}$ (ignoring –sign in result)	1	AO2-1d

Question	Answers	Additional comments/Guidelines	Mark	AO
03.5	ways ensure pd across **C** doesn't exceed $3\ \text{V}$ before connecting **C** to **X** $_1$✓ as **X** is connected $_2$✓	for $_1$✓ discharge **C** / connect flying lead to **Y** / 'reset to $0\ \text{V}$' (before reconnecting); reject 'reset equipment' for $_2$✓ reduce the output pd / socket **X** (or wtte) to $\leq 3\ \text{V}$ (then reconnect **C** and adjust pd so meter reads full-scale); reject 'only charge **C** to 3 V' idea of adding resistance to limit pd is neutral	MAX 3	AO3-2b
	suggests timing for $\Delta V > 1.5\ \text{V}$ or wtte $_{3a}$✓ OR take repeated readings (of $T_{½}$ or time constant); any valid processing eg calculate an average value / reject anomalies / check results are concordant or wtte $_{3b}$✓ check / correct / compensate for any zero error (on the voltmeter) $_4$✓	for $_{3a}$✓ accept 'increase timing interval' / time for concurrent half lives or wtte; reject 'measure time for **C** to fully discharge' for $_{3b}$✓ accept 'repeat the experiment and calculate a mean' only if this refers to $T_{½}$ reject 'repeat etc to get more reliable result' for $_4$✓ accept 'check etc for systematic error' 'student' is repeating previous experiment so reject idea of making V the dependent variable / plot V against t / using data logging		

	suggests a valid quantitative test of theory by comparison with the result obtained using the 15 V range $_5$✓	(theory will be correct if) half-life / time constant is one fifth / 20% (of previous value) / about 3.5 s / time constant reduced by 80% / ratio of time constant to range / ratio of half-life to range is same / similar reject 'plot ln V against t, find (–gradient^{-1})'	1	AO2-1d

Question	Answers	Additional comments/Guidelines	Mark	AO
03.6	in answer space 1: any valid comment about the values of V in **Table 2** $_1$✓ corresponding explanation $_2$✓ (contingent on $_1$✓) in answer space 2: different valid comment about the values of V in **Table 2** $_3$✓ corresponding explanation $_4$✓ (contingent on $_3$✓) only credit one comment and explanation per answer space comments about the number of data sets are neutral	give credit for any good physics, eg V recorded to nearest volt $_1$✓ because of (low) scale resolution / hard to interpolate between markings; reject 'values easier to plot' $_2$✓ different / decreasing intervals between values of V / more lower values of V $_3$✓ to make intervals between t readings about the same / or wtte; allow 'to distribute data on graph' or wtte / to allow (convenient interval for) t to be read / recorded $_4$✓ no readings for $V < 2$ V / smallest $V = 2$ V $_5$✓ because difficult to establish exact moment to read stopwatch / needle is moving too slowly / sensible comment about parallax $_6$✓ V data over wide range / from 14 to 2 (V) $_7$✓	4	AO2-1g

		to maximise evidence available (for graph / **Figure 8**) or wtte $_{8}$✓ no readings for V > 14 V / largest V = 14 V $_{9}$✓ can begin discharge **C** before starting stopwatch $_{10}$✓		

Question	Answers	Additional comments/Guidelines	Mark	AO
03.7	attempts gradient calculation using $\Delta\ln(V / \text{V})$ divided by Δt; use of $\lvert\text{gradient}\rvert = \left\lvert\frac{-1}{R \times C}\right\rvert$ $_{1a}$✓ OR reads off ln V_0, ln V and corresponding Δt from **Figure 8**; use of $V = V_0 e^{-\frac{t}{RC}}$ $_{1b}$✓	for $_{1a}$✓ expected gradient is -0.077; condone one read-off error in gradient calculation or missing sign; allow any subject / (at least) substitution of their gradient into a valid calculation for R condone missing / wrong POT for capacitance for $_{1b}$✓ condone one read off error; allow any subject / (at least) substitution of all their data into a valid calculation for R condone missing / wrong POT for capacitance $_{1b}$✓variation below: reads off ln V_0 and finds V_0 = 14.1 (V); $V = 0.37V_0$ when $t = RC$ $\therefore V = 0.37V_0 = 5.2$ V	1	AO2-1h

	valid working leading to voltmeter resistance ≥ 3 sf in range 15.0 kΩ to 16.6 kΩ $_2$✓ voltmeter resistance ≥ 3 sf in range 15.5 kΩ to 16.1 kΩ $_3$✓	reads of ln 5.2 = 1.65; $\Delta t \approx 13$ (s) $\therefore R = \frac{13}{C}$ accept > 3 sf that rounds to 3 sf in range allow $_{23}$✓ = 1 MAX for POT error allow $_{123}$✓ = 1 MAX for using **Table 2** data	2	AO3-a1a

Question	Answers	Additional comments/Guidelines	Mark	AO
03.8	reads ln(V_{10} / V) from **Figure 8**; deduces V_{10} in range 6.36 to 6.69 (V) $_1$✓	for $_1$✓ V_{10} to ≥ 3 sf required; accept > 3 sf that rounds to 3 sf in range; accept V_0 from ln V_0 read off and V_{10} deduced from $V_{10} = V_0 e^{\frac{-10}{CR}}$; condone use of V_0 = 15(V); if V_{10} is not recorded allow $_1$✓ for use of $e^{\ln V_{10}}$ in the calculation of I_{10} where ln(V_{10} / V) is in the range 1.85 to 1.90	1	AO1-1b
	≥ 2 sf result in range 3.9 to 4.3 × 10^{-4} (A) $_2$✓	for $_2$✓ allow use of resistance = 16 × 10^3 (Ω); accept ≥ 3 sf result that rounds to 2 sf in range	1	AO2-1g

		allow ECF if V_{10} is **correctly obtained** from an incorrect $\ln(V_{10} / \text{V})$ read off and I_{10} calculated using $\frac{\text{their } V_{10}}{\text{their voltmeter resistance}}$		

Total			**19**