GuideMyGrades

YOUR GOALS. OUR EXPERTISE.

AQA A LEVEL PHYSICS (7408): QUESTIONS BY TOPIC

Mechanics and materials (3.4)

A Level Physics (7408) · Section 3.4

208 questions · 845 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
3.4.1.1	**SCALARS AND VECTORS**			4 Qs · 15 marks	**8**
1.	**Q20**		7408/1 June 2018	1	**9**
2.	**Q20**		7408/1 November 2021	1	**10**
3.	**Q20**		7408/1 June 2023	1	**11**
4.	**Q5**		7408/1 June 2024	12	**12**
3.4.1.2	**MOMENTS**			12 Qs · 38 marks	**16**
5.	**Q18**		7408/1 June 2017	1	**17**
6.	**Q21**		7408/1 June 2018	1	**18**
7.	**Q12**		7408/1 June 2019	1	**19**
8.	**Q20**		7408/1 November 2020	1	**20**
9.	**Q21**		7408/1 November 2021	1	**21**
10.	**Q22**		7408/1 November 2021	1	**22**
11.	**Q22**		7408/1 June 2023	1	**23**
12.	**Q19**		7408/1 June 2024	1	**24**
13.	**Q24**		7408/1 June 2025	1	**25**
14.	**Q5**		7408/1 June 2017	8	**26**
15.	**Q5**	*also 3.6*	7408/1 June 2018	8	**28**
16.	**Q3**		7408/1 June 2022	13	**29**
3.4.1.3	**MOTION ALONG A STRAIGHT LINE**			5 Qs · 14 marks	**34**
17.	**Q19**		7408/1 June 2017	1	**35**
18.	**Q23**		7408/1 June 2017	1	**36**
19.	**Q13**		7408/1 June 2019	1	**37**
20.	**Q22**		7408/1 June 2024	1	**38**
21.	**Q2**		7408/1 June 2023	10	**39**
3.4.1.4	**PROJECTILE MOTION**			5 Qs · 18 marks	**42**
22.	**Q21**		7408/1 June 2017	1	**43**
23.	**Q23**	*also 3.5*	7408/1 June 2018	1	**44**
24.	**Q23**	*also 3.5*	7408/1 November 2021	1	**45**
25.	**Q20**	*also 3.5*	7408/1 June 2024	1	**46**
26.	**Q5**	*also 3.5*	7408/1 November 2021	14	**47**
3.4.1.5	**NEWTON'S LAWS OF MOTION**			9 Qs · 9 marks	**52**
27.	**Q20**		7408/1 June 2017	1	**53**
28.	**Q22**		7408/1 June 2018	1	**54**

	QUESTION		SOURCE	MARKS	PAGE
29.	**Q14**		7408/1 June 2019	1	**55**
30.	**Q24**		7408/1 June 2022	1	**56**
31.	**Q25**	*also 3.7*	7408/1 June 2022	1	**57**
32.	**Q23**		7408/1 June 2023	1	**58**
33.	**Q24**	*also 3.5*	7408/1 June 2023	1	**59**
34.	**Q23**		7408/1 June 2024	1	**60**
35.	**Q21**	*also 3.5*	7408/1 June 2025	1	**61**
3.4.1.6	**MOMENTUM**			8 Qs · 34 marks	**62**
36.	**Q22**		7408/1 June 2017	1	**63**
37.	**Q16**	*also 3.7*	7408/1 June 2019	1	**64**
38.	**Q25**		7408/1 November 2021	1	**65**
39.	**Q19**	*also 3.1*	7408/1 June 2023	1	**66**
40.	**Q24**		7408/1 June 2024	1	**67**
41.	**Q6**		7408/1 June 2018	8	**68**
42.	**Q6**		7408/1 June 2025	8	**70**
43.	**Q5**		7408/1 June 2019	13	**72**
3.4.1.7	**WORK, ENERGY, POWER AND CONSERVATION OF ENERGY**			12 Qs · 43 marks	**75**
44.	**Q18**		7408/1 June 2019	1	**76**
45.	**Q27**		7408/1 June 2019	1	**77**
46.	**Q6**	*also 3.1*	7408/1 November 2020	1	**78**
47.	**Q23**		7408/1 November 2020	1	**79**
48.	**Q7**	*also 3.1*	7408/1 June 2022	1	**80**
49.	**Q9**		7408/1 June 2022	1	**81**
50.	**Q26**	*also 3.5*	7408/1 June 2022	1	**82**
51.	**Q8**	*also 3.6*	7408/2 June 2023	1	**83**
52.	**Q11**		7408/1 June 2025	1	**84**
53.	**Q6**	*also 3.5*	7408/1 June 2017	10	**85**
54.	**Q1**	*also 3.5*	7408/1 June 2018	12	**88**
55.	**Q4**	*also 3.5*	7408/1 June 2019	12	**91**
3.4.2	**MATERIALS: BULK PROPERTIES AND THE YOUNG MODULUS**			13 Qs · 30 marks	**94**
56.	**Q24**		7408/1 June 2017	1	**95**
57.	**Q19**		7408/1 June 2019	1	**96**
58.	**Q20**		7408/1 June 2019	1	**97**
59.	**Q26**	*also 3.1*	7408/1 November 2020	1	**98**
60.	**Q26**		7408/1 November 2021	1	**99**
61.	**Q27**		7408/1 June 2022	1	**100**
62.	**Q28**		7408/1 June 2022	1	**101**
63.	**Q26**		7408/1 June 2023	1	**102**
64.	**Q25**		7408/1 June 2024	1	**103**
65.	**Q26**		7408/1 June 2024	1	**104**

	QUESTION		SOURCE	MARKS	PAGE
66.	**Q31**	*also 3.6*	7408/1 June 2025	1	**105**
67.	**Q4**	*also 3.1*	7408/1 June 2025	9	**106**
68.	**Q5**		7408/1 June 2023	10	**108**
3.4.S	**SYNOPTIC AND CROSS-TOPIC QUESTIONS**			140 Qs · 644 marks	**111**
69.	**Q12**	*also 3.2*	7408/1 June 2017	1	**112**
70.	**Q30**	*also 3.6*	7408/1 June 2017	1	**113**
71.	**Q31**	*also 3.6*	7408/1 June 2017	1	**114**
72.	**Q14**		7408/2 June 2017	1	**115**
73.	**Q17**	*also 3.7*	7408/2 June 2017	1	**116**
74.	**Q22**	*also 3.5 & 3.7*	7408/2 June 2017	1	**117**
75.	**Q24**		7408/2 June 2017	1	**118**
76.	**Q25**	*also 3.5 & 3.7*	7408/2 June 2017	1	**119**
77.	**Q13**	*also 3.2*	7408/1 June 2018	1	**120**
78.	**Q14**	*also 3.2 & 3.3*	7408/1 June 2018	1	**121**
79.	**Q29**	*also 3.3 & 3.6*	7408/1 June 2018	1	**122**
80.	**Q30**	*also 3.6*	7408/1 June 2018	1	**123**
81.	**Q31**	*also 3.6 & 3.7*	7408/1 June 2018	1	**124**
82.	**Q11**	*also 3.6*	7408/2 June 2018	1	**125**
83.	**Q12**		7408/2 June 2018	1	**126**
84.	**Q16**	*also 3.7*	7408/2 June 2018	1	**127**
85.	**Q17**	*also 3.7*	7408/2 June 2018	1	**128**
86.	**Q19**		7408/2 June 2018	1	**129**
87.	**Q28**	*also 3.7*	7408/2 June 2018	1	**130**
88.	**Q31**	*also 3.8*	7408/2 June 2018	1	**131**
89.	**Q9**	*also 3.2 & 3.8*	7408/1 June 2019	1	**132**
90.	**Q10**	*also 3.2*	7408/1 June 2019	1	**133**
91.	**Q11**	*also 3.2*	7408/1 June 2019	1	**134**
92.	**Q22**	*also 3.2 & 3.8*	7408/1 June 2019	1	**135**
93.	**Q28**		7408/1 June 2019	1	**136**
94.	**Q29**	*also 3.6*	7408/1 June 2019	1	**137**
95.	**Q8**	*also 3.7*	7408/2 June 2019	1	**138**
96.	**Q11**	*also 3.6 & 3.7*	7408/2 June 2019	1	**139**
97.	**Q13**	*also 3.7*	7408/2 June 2019	1	**140**
98.	**Q24**	*also 3.7*	7408/2 June 2019	1	**141**
99.	**Q25**	*also 3.6*	7408/2 June 2019	1	**142**
100.	**Q31**	*also 3.8*	7408/2 June 2019	1	**143**
101.	**Q8**	*also 3.2*	7408/1 November 2020	1	**144**
102.	**Q12**	*also 3.2 & 3.8*	7408/1 November 2020	1	**145**
103.	**Q13**	*also 3.2 & 3.3*	7408/1 November 2020	1	**146**
104.	**Q25**		7408/1 November 2020	1	**147**

	QUESTION		SOURCE		MARKS	PAGE
105.	**Q9**	*also 3.6*	7408/2	November 2020	1	**148**
106.	**Q23**	*also 3.7*	7408/2	November 2020	1	**149**
107.	**Q26**	*also 3.5 & 3.7*	7408/2	November 2020	1	**150**
108.	**Q16**	*also 3.2 & 3.3*	7408/1	November 2021	1	**151**
109.	**Q17**	*also 3.3*	7408/1	November 2021	1	**152**
110.	**Q31**	*also 3.6*	7408/1	November 2021	1	**153**
111.	**Q10**	*also 3.6*	7408/2	November 2021	1	**154**
112.	**Q12**	*also 3.7*	7408/2	November 2021	1	**155**
113.	**Q13**	*also 3.7*	7408/2	November 2021	1	**156**
114.	**Q19**	*also 3.2 & 3.7*	7408/2	November 2021	1	**157**
115.	**Q25**	*also 3.7*	7408/2	November 2021	1	**158**
116.	**Q26**	*also 3.8*	7408/2	November 2021	1	**159**
117.	**Q31**	*also 3.2 & 3.8*	7408/2	November 2021	1	**160**
118.	**Q14**	*also 3.2*	7408/1	June 2022	1	**161**
119.	**Q19**	*also 3.3*	7408/1	June 2022	1	**162**
120.	**Q8**	*also 3.6*	7408/2	June 2022	1	**163**
121.	**Q13**	*also 3.7*	7408/2	June 2022	1	**164**
122.	**Q14**	*also 3.7*	7408/2	June 2022	1	**165**
123.	**Q22**	*also 3.7*	7408/2	June 2022	1	**166**
124.	**Q13**	*also 3.3*	7408/1	June 2023	1	**167**
125.	**Q14**	*also 3.3*	7408/1	June 2023	1	**168**
126.	**Q31**	*also 3.6*	7408/1	June 2023	1	**169**
127.	**Q19**	*also 3.8*	7408/2	June 2023	1	**170**
128.	**Q20**	*also 3.7*	7408/2	June 2023	1	**171**
129.	**Q21**	*also 3.7 & 3.8*	7408/2	June 2023	1	**172**
130.	**Q23**	*also 3.5 & 3.7*	7408/2	June 2023	1	**173**
131.	**Q24**	*also 3.5 & 3.6 & 3.7*	7408/2	June 2023	1	**174**
132.	**Q27**	*also 3.7*	7408/2	June 2023	1	**175**
133.	**Q9**	*also 3.2*	7408/1	June 2024	1	**176**
134.	**Q10**	*also 3.2*	7408/1	June 2024	1	**177**
135.	**Q29**		7408/1	June 2024	1	**178**
136.	**Q8**	*also 3.6*	7408/2	June 2024	1	**179**
137.	**Q12**	*also 3.7*	7408/2	June 2024	1	**180**
138.	**Q15**	*also 3.5*	7408/2	June 2024	1	**181**
139.	**Q16**	*also 3.6 & 3.7*	7408/2	June 2024	1	**182**
140.	**Q23**	*also 3.7*	7408/2	June 2024	1	**183**
141.	**Q24**	*also 3.7*	7408/2	June 2024	1	**184**
142.	**Q10**	*also 3.2 & 3.8*	7408/1	June 2025	1	**185**
143.	**Q14**	*also 3.3*	7408/1	June 2025	1	**186**
144.	**Q25**	*also 3.6 & 3.7*	7408/1	June 2025	1	**187**

	QUESTION		SOURCE	MARKS	PAGE
145.	**Q30**	*also 3.2*	7408/1 June 2025	1	**188**
146.	**Q7**	*also 3.7*	7408/2 June 2025	1	**189**
147.	**Q20**	*also 3.7*	7408/2 June 2025	1	**190**
148.	**Q21**	*also 3.5 & 3.6 & 3.7*	7408/2 June 2025	1	**191**
149.	**Q22**	*also 3.5 & 3.7*	7408/2 June 2025	1	**192**
150.	**Q23**	*also 3.5 & 3.7*	7408/2 June 2025	1	**193**
151.	**Q28**	*also 3.8*	7408/2 June 2025	1	**194**
152.	**Q4**	*also 3.8*	7408/1 June 2024	4	**195**
153.	**Q2**	*also 3.7*	7408/2 June 2017	5	**196**
154.	**Q6**	*also 3.6*	7408/1 June 2019	5	**198**
155.	**Q1**	*also 3.6*	7408/2 June 2023	5	**200**
156.	**Q3**	*also 3.6*	7408/1 June 2025	5	**201**
157.	**Q3**	*also 3.6 & 3.7*	7408/2 June 2017	6	**202**
158.	**Q5**	*also 3.5 & 3.6 & 3.7*	7408/2 June 2019	6	**204**
159.	**Q2**		7408/1 June 2017	7	**207**
160.	**Q1**	*also 3.6*	7408/2 June 2018	7	**209**
161.	**Q2**		7408/3 Section A June 2022	7	**211**
162.	**Q3**	*also 3.5 & 3.7*	7408/2 June 2024	7	**214**
163.	**Q4**	*also 3.5 & 3.6 & 3.7*	7408/2 June 2018	8	**216**
164.	**Q4**	*also 3.5 & 3.7*	7408/2 November 2021	8	**219**
165.	**Q4**	*also 3.7 & 3.8*	7408/2 June 2023	8	**222**
166.	**Q5**	*also 3.6 & 3.7*	7408/2 June 2024	8	**225**
167.	**Q7**	*also 3.6*	7408/1 June 2025	8	**228**
168.	**Q1**	*also 3.3*	7408/3 Section A June 2025	8	**231**
169.	**Q4**	*also 3.5*	7408/1 June 2017	9	**235**
170.	**Q5**	*also 3.2 & 3.3 & 3.8*	7408/2 June 2017	9	**238**
171.	**Q2**	*also 3.7*	7408/2 June 2018	9	**241**
172.	**Q1**	*also 3.6*	7408/2 June 2019	9	**244**
173.	**Q6**	*also 3.6*	7408/1 June 2023	9	**247**
174.	**Q2**	*also 3.2*	7408/1 June 2024	9	**252**
175.	**Q1**	*also 3.1 & 3.6*	7408/2 June 2024	9	**254**
176.	**Q1**	*also 3.2 & 3.3 & 3.8*	7408/2 June 2025	9	**256**
177.	**Q7**		7408/1 June 2017	10	**259**
178.	**Q1**	*also 3.6*	7408/2 June 2017	10	**262**
179.	**Q3**	*also 3.3*	7408/1 June 2018	10	**265**
180.	**Q1**	*also 3.6*	7408/2 November 2020	10	**269**
181.	**Q5**	*also 3.8*	7408/2 November 2020	10	**272**
182.	**Q2**	*also 3.6 & 3.7*	7408/2 November 2021	10	**275**
183.	**Q5**	*also 3.7 & 3.8*	7408/2 November 2021	10	**278**
184.	**Q2**	*also 3.6*	7408/2 June 2022	10	**281**

	QUESTION		SOURCE	MARKS	PAGE
185.	**Q3**	*also 3.7*	7408/2 June 2023	10	**282**
186.	**Q6**	*also 3.2 & 3.8*	7408/2 June 2023	10	**285**
187.	**Q7**	*also 3.6 & 3.8*	7408/2 June 2023	10	**287**
188.	**Q4**	*also 3.8*	7408/2 June 2017	11	**291**
189.	**Q6**	*also 3.2 & 3.8*	7408/2 June 2019	11	**293**
190.	**Q3**	*also 3.6 & 3.7*	7408/2 November 2020	11	**296**
191.	**Q4**	*also 3.6*	7408/1 November 2021	11	**301**
192.	**Q5**	*also 3.6*	7408/1 June 2022	11	**304**
193.	**Q5**	*also 3.7*	7408/2 June 2022	11	**308**
194.	**Q3**	*also 3.5*	7408/1 June 2023	11	**311**
195.	**Q6**	*also 3.5*	7408/1 June 2024	11	**315**
196.	**Q2**	*also 3.6*	7408/2 June 2025	11	**318**
197.	**Q3**	*also 3.5 & 3.8*	7408/2 June 2025	11	**320**
198.	**Q1**	*also 3.2*	7408/1 November 2021	12	**323**
199.	**Q6**	*also 3.7*	7408/2 June 2024	12	**325**
200.	**Q2**	*also 3.1 & 3.7*	7408/3 Section A June 2019	13	**329**
201.	**Q6**	*also 3.6 & 3.7*	7408/2 June 2025	13	**336**
202.	**Q3**	*also 3.6*	7408/3 Section A June 2018	14	**341**
203.	**Q2**	*also 3.6*	7408/2 June 2019	14	**345**
204.	**Q4**	*also 3.7*	7408/2 June 2019	14	**347**
205.	**Q1**	*also 3.1 & 3.6*	7408/3 Section A November 2020	15	**350**
206.	**Q3**	*also 3.7*	7408/3 Section A June 2024	15	**356**
207.	**Q3**	*also 3.1 & 3.7*	7408/3 Section A June 2023	16	**362**
208.	**Q1**	*also 3.7*	7408/3 Section A June 2018	19	**369**

QUESTIONS

208 questions · 845 marks · 9 sub-topics

SUB-TOPIC 3.4.1.1

SCALARS AND VECTORS

Sub-topic 3.4.1.1 · 4 questions · 15 marks · lowest tariff first

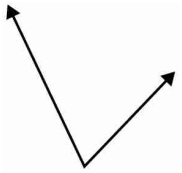
2 0 Three coplanar forces F_1, F_2 and F_3 act on a point object.

Which combination of forces can never produce a resultant force of zero?

[1 mark]

	F_1 / N	F_2 / N	F_3 / N	
A	3	4	5	⬭
B	8	8	8	⬭
C	2	10	10	⬭
D	3	6	10	⬭

2 0 The diagram shows a vector diagram of two forces acting on an object.
The diagram is drawn to scale.
The magnitude of the smaller force is 5.0 N.



What is the magnitude of the resultant force on the object?

[1 mark]

A 3.2 N ⬭

B 7.5 N ⬭

C 8.6 N ⬭

D 9.6 N ⬭

2 0 Which is a pair of vectors?

[1 mark]

A weight and work ⬭

B force and energy ⬭

C displacement and momentum ⬭

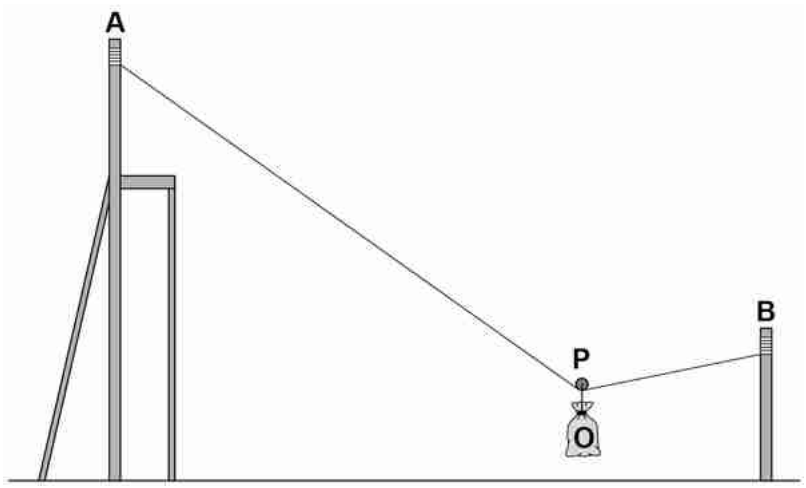
D acceleration and power ⬭

0 5 A cable system is to be used to transfer supplies across a river. A model of the proposed system is built in order to test its performance.

The model consists of a cable attached to two vertical posts **A** and **B**, as shown in **Figure 3**.
A pulley **P** of negligible mass is attached to the cable.

In this question the length of the cable does not change and the weight of the cable can be ignored.

Figure 3



An object **O** is attached to **P**. In one test, **O** and **P** are at rest in the position shown in **Figure 3**.
The weight of **O** is 350 N.

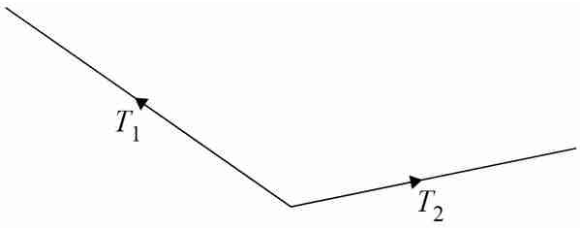
Question 5 continues on the next page

0 5 . 1 **Figure 4** is a force diagram drawn to scale. It represents the magnitudes and directions of the tensions T_1 and T_2 in the cable when **O** is at rest in the position shown in **Figure 3**. At this position, resistive forces are zero.

Complete the force diagram.
Go on to determine, using your diagram, the magnitudes of T_1 and T_2.

[4 marks]

Figure 4



$T_1 =$ _____ N

$T_2 =$ _____ N

0 5 . 2 In a second test, pulley **P** with **O** attached is released from **A**.
P and **O** move along the cable to **B**.

The change in height of the centre of mass of **O** between **A** and **B** is $4.5\ \text{m}$.
The distance travelled along the cable is $18\ \text{m}$.

The speed of **O** when it reaches **B** is $6.5\ \text{m s}^{-1}$.

Calculate the average resistive force on **O** and **P** as they move from **A** to **B**.

[5 marks]

average resistive force = _____ N

Question 5 continues on the next page

0 5 . 3 **O** contains a fragile item packed in suitable material.

Explain how the material can prevent damage to the fragile item when **O** stops suddenly at **B**.

[3 marks]

SUB-TOPIC 3.4.1.2

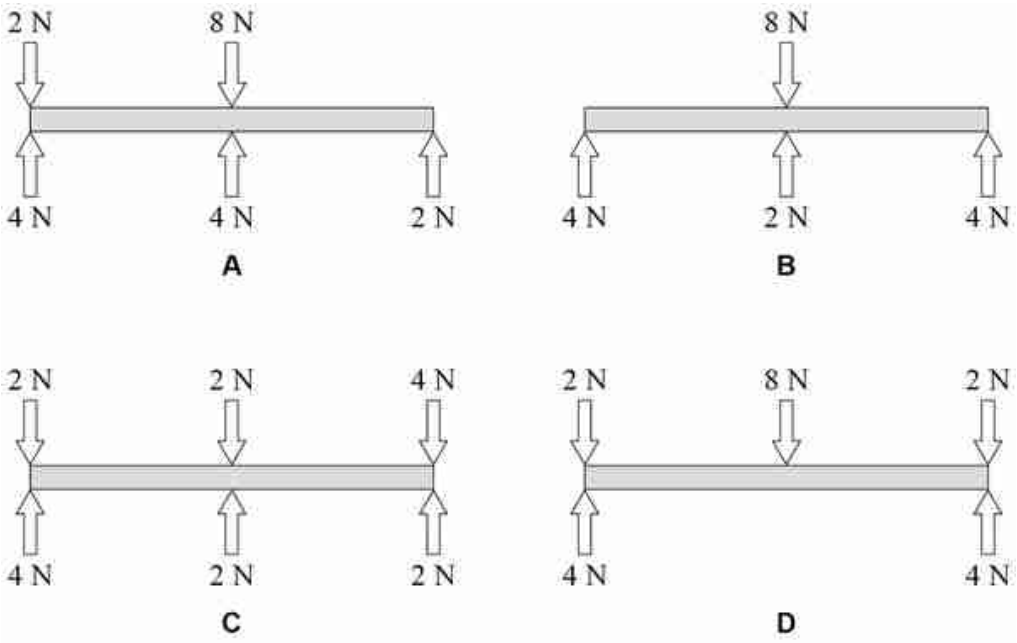
MOMENTS

Sub-topic 3.4.1.2 · 12 questions · 38 marks · lowest tariff first

1 8 A light uniform rigid bar is pivoted at its centre. Forces act on the bar at its ends and at the centre.

Which diagram shows the bar in equilibrium?

[1 mark]



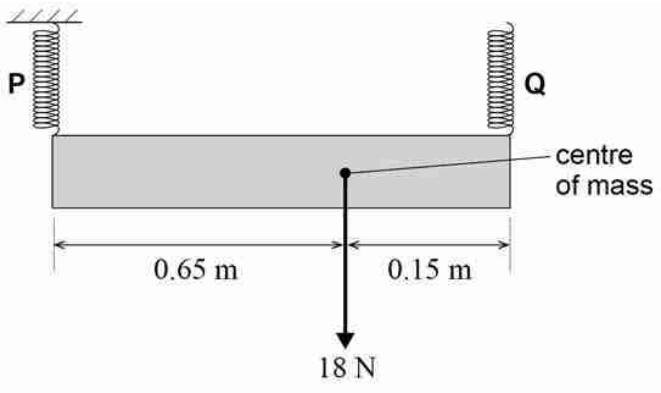
A ⬭

B ⬭

C ⬭

D ⬭

2 1 A non-uniform sign is $0.80\ \text{m}$ long and has a weight of $18\ \text{N}$
It is suspended from two vertical springs **P** and **Q**. The springs obey Hooke's law and the spring constant of each spring is $240\ \text{N m}^{-1}$



The top end of spring **P** is fixed and the top end of spring **Q** is adjusted until the sign is horizontal and in equilibrium.

What is the extension of spring **Q**?

[1 mark]

A $0.014\ \text{m}$ ⬭

B $0.038\ \text{m}$ ⬭

C $0.049\ \text{m}$ ⬭

D $0.061\ \text{m}$ ⬭

1 2 Which statement about a couple is **not** true?

[1 mark]

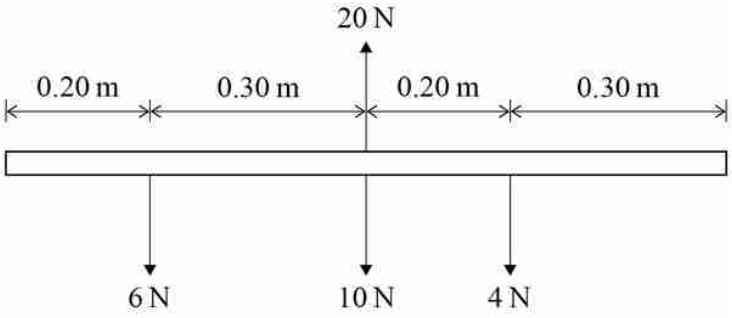
A It must consist of coplanar forces. ⬭

B It can produce rotational motion. ⬭

C It can produce translational motion. ⬭

D It has a moment with units $\mathrm{N\ m}$. ⬭

2 0 The diagram shows the forces acting on a uniform rod.



Which statement is correct?

[1 mark]

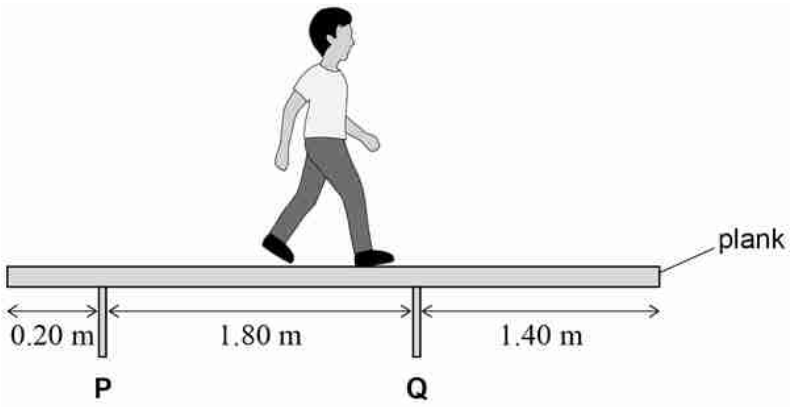
A The rod is in equilibrium. ⬭

B For equilibrium, an anticlockwise moment of $1.0\ \text{N m}$ is needed. ⬭

C For equilibrium, a clockwise moment of $1.0\ \text{N m}$ is needed. ⬭

D For equilibrium, the $10\ \text{N}$ force should be increased to $20\ \text{N}$. ⬭

2 1 A uniform plank weighs 1200 N and rests on two pillars **P** and **Q**.
P and **Q** are 1.80 m apart.
P is 0.20 m from one end of the plank. **Q** is 1.40 m from the other end of the plank.
A man weighs 800 N and walks along the plank away from pillar **P**.



What is the horizontal distance between pillar **P** and the centre of mass of the man when the plank starts to tip?

[1 mark]

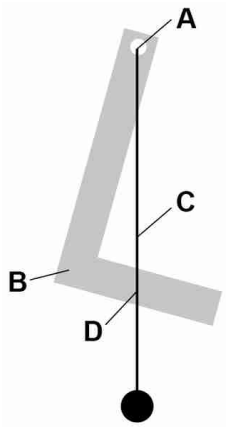
A 0.45 m ⬭

B 2.25 m ⬭

C 2.45 m ⬭

D 3.15 m ⬭

2 2 A uniform piece of card in the shape of the letter L is suspended freely from a horizontal pin.
A plumb line is also suspended from the pin.
The diagram shows the card in its equilibrium position.



What is the position of the centre of mass of the piece of card?

[1 mark]

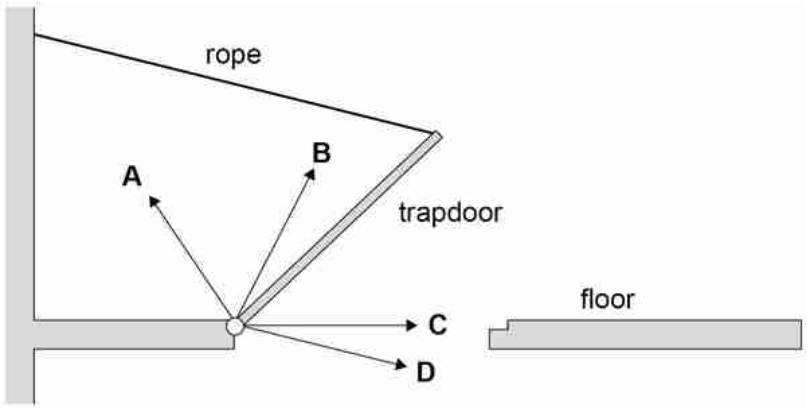
A ⬭

B ⬭

C ⬭

D ⬭

2 2 A heavy uniform trapdoor is hinged to the floor. It is held open by a rope as shown.



Which arrow shows the direction of the reaction force of the hinge on the trapdoor?

[1 mark]

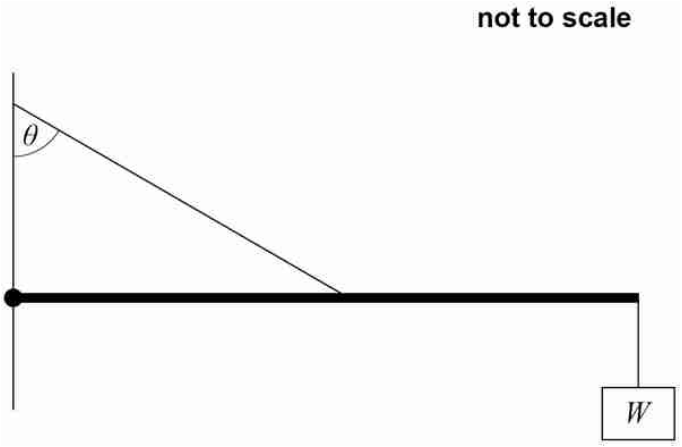
A ⬭

B ⬭

C ⬭

D ⬭

1 9 The weight of a uniform bar is W.
An object also of weight W is attached to one end.
The bar is pivoted at the other end and held horizontal by a rope attached to its centre.
The tension in the rope is $4W$.



What is angle θ?

[1 mark]

A 41° ⬭

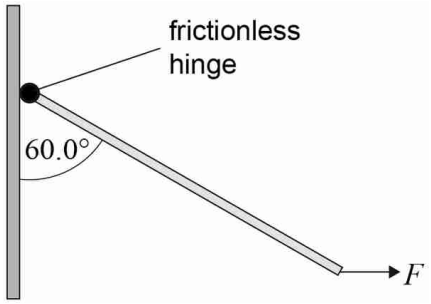
B 45° ⬭

C 60° ⬭

D 71° ⬭

2 4 A uniform wooden rod of mass $0.55\ \text{kg}$ and length $1.3\ \text{m}$ is attached to a wall by a light frictionless hinge.

A horizontal force F acts so that the rod hangs at an angle of $60.0°$ to the vertical.



What is the magnitude of F?

[1 mark]

A $0.95\ \text{N}$ ⬭

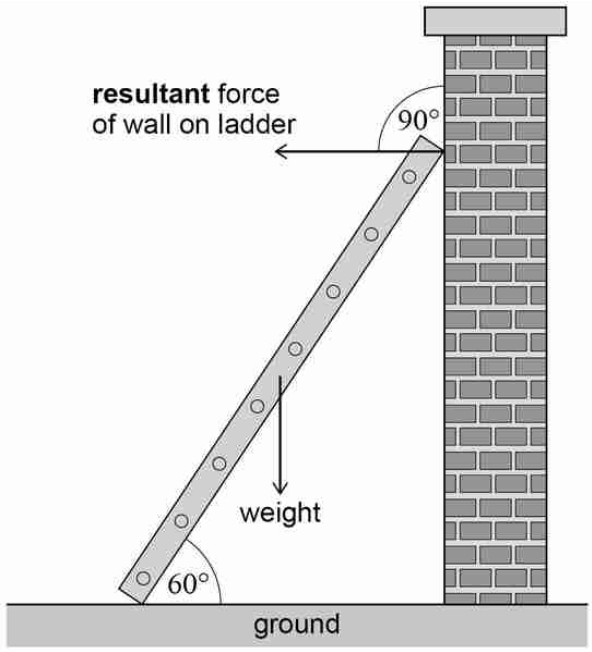
B $1.6\ \text{N}$ ⬭

C $2.7\ \text{N}$ ⬭

D $4.7\ \text{N}$ ⬭

0 5 **Figure 7** shows two of the forces acting on a uniform ladder resting against a vertical wall. The ladder is at an angle of $60°$ to the ground.

Figure 7



0 5 . 1 Explain how **Figure 7** shows that the friction between the ladder and the wall is negligible.

[1 mark]

0 5 . 2 The forces acting on the ladder are in equilibrium.

Draw an arrow on **Figure 7** to show the direction of the resultant force from the ground acting on the ladder. Label your arrow **G**.

[2 marks]

0 5 . 3 The ladder is 8.0 m long and weighs 390 N.

Calculate the magnitude of the resultant force from the wall on the ladder.

[2 marks]

resultant force = _____ N

0 5 . 4 Suggest the changes to the forces acting on the ladder that occur when someone climbs the ladder.

[3 marks]

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

Figure 8

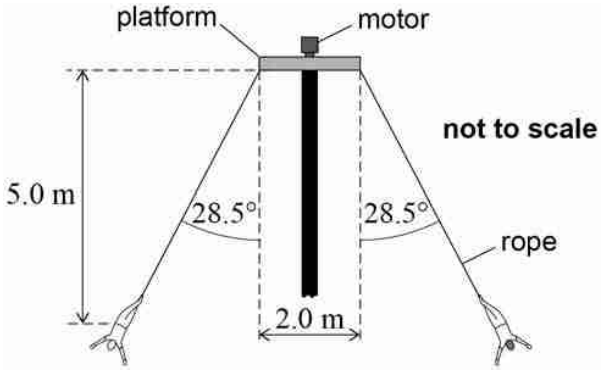
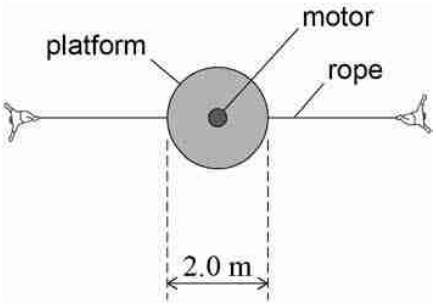


Figure 9



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

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

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

[2 marks]

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

[3 marks]

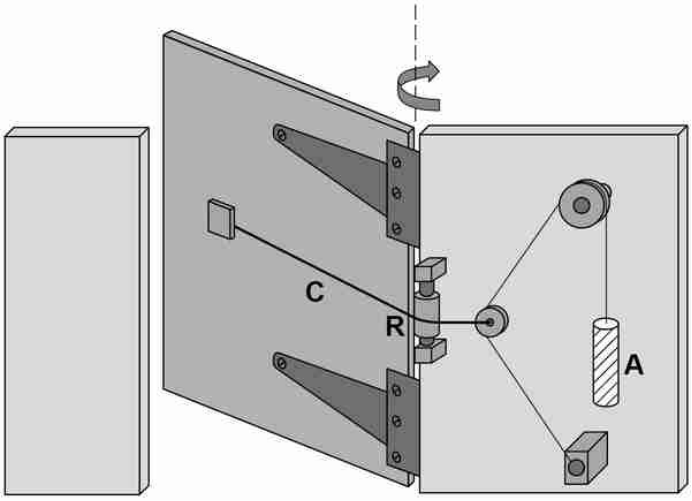
tension = _____ N

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

[3 marks]

0 3 **Figure 3** shows a garden gate with a pulley system designed to close the gate.

Figure 3



The pulley system raises weight **A** when the gate is opened. When the gate is released, **A** falls. The horizontal cable **C** passes over pulley **R**. The tension in cable **C** causes the gate to close.

Weight **A** is a solid cylinder with the following properties:

diameter = 4.8×10^{-2} m
length = 0.23 m
weight = 35 N

Table 2 gives the density of three available materials.

Table 2

Material	Density / kg m^{-3}
concrete	2.4×10^3
iron	7.8×10^3
brass	8.6×10^3

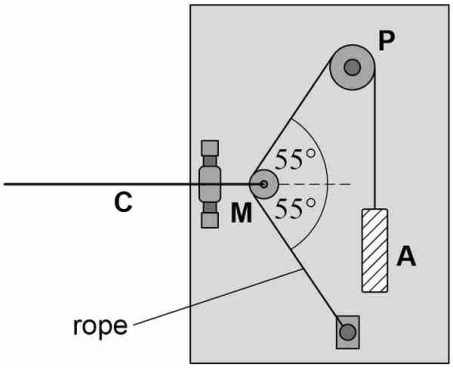
0 3 . 1 Deduce which **one** of the three materials is used for **A**.

[3 marks]

Question 3 continues on the next page

Figure 4 shows the pulley arrangement when the gate is closed.

Figure 4



Pulleys **P** and **M** are frictionless so that the tension in the rope attached to **A** is equal to the weight of **A**.
A weighs 35 N and the weight of moveable pulley **M** is negligible.

0 3 . 2 Calculate the tension in the horizontal cable **C** when the gate is closed.

[2 marks]

tension = _____ N

0 3 . 3 Pulley **M** is pulled to the left as the gate is opened.

Explain why this increases the tension in the horizontal cable **C**.

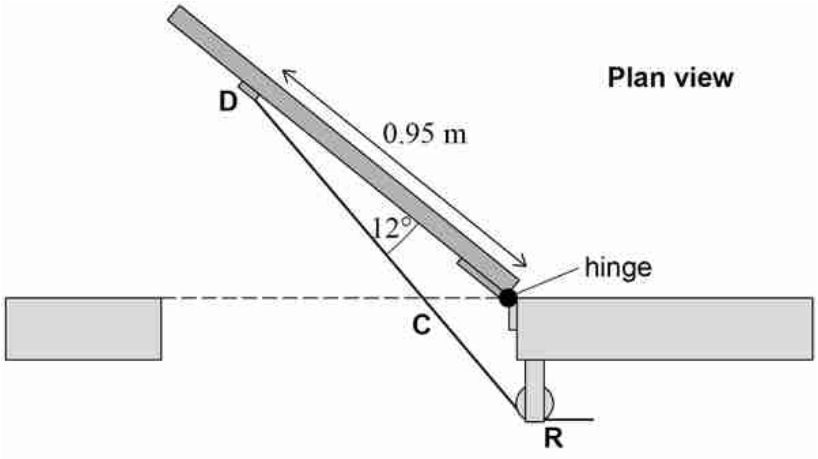
[2 marks]

Question 3 continues on the next page

0 3 . 4 **Figure 5** shows a plan view with the gate open. The horizontal cable **C** passes over pulley **R** and is attached to the door at **D**.
The angle between the door and the horizontal cable **C** is 12°.

The horizontal distance between the hinge and **D** is 0.95 m.

Figure 5



The tension in the horizontal cable **C** is now 41 N.

Calculate the moment of the tension about the hinge.

[2 marks]

moment = _____ N m

0 3 . 5 The same system is attached to an identical gate with stiffer hinges. Now the system does not supply a sufficiently large moment to close the gate.

Discuss **two** independent changes to the design to increase the moment about the hinges due to horizontal cable **C**.

[4 marks]

1 _____

_____

_____

_____

_____

2 _____

SUB-TOPIC 3.4.1.3

MOTION ALONG A STRAIGHT LINE

Sub-topic 3.4.1.3 · 5 questions · 14 marks · lowest tariff first

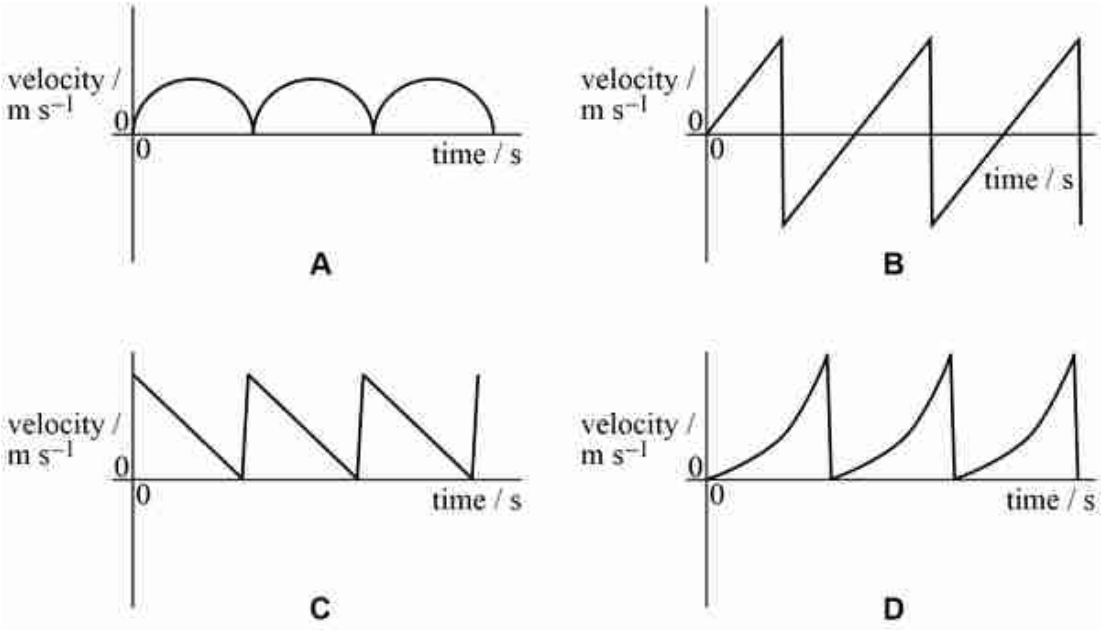
1 9 Which row gives two features of graphs that provide the same information?

[1 mark]

	Feature 1	Feature 2	
A	Gradient of a displacement–time graph	Area under a velocity–time graph	⬭
B	Gradient of a displacement–time graph	Area under an acceleration–time graph	⬭
C	Gradient of a velocity–time graph	Area under a displacement–time graph	⬭
D	Gradient of a velocity–time graph	Area under an acceleration–time graph	⬭

2 3 Which graph best represents the velocity–time graph for a ball that is dropped from rest and bounces repeatedly?

[1 mark]



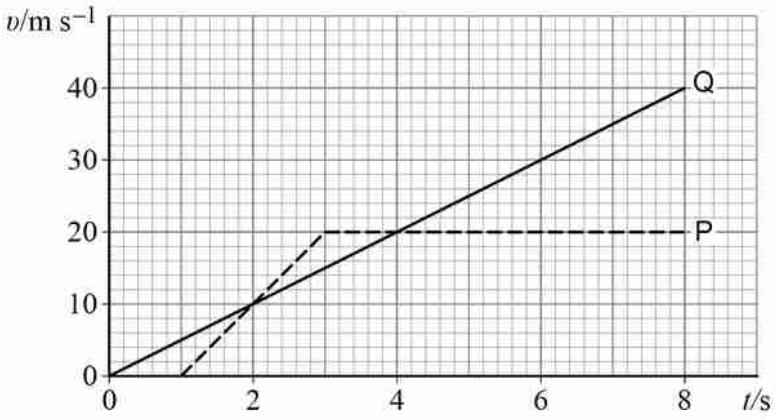
A ⬭

B ⬭

C ⬭

D ⬭

1 3 Two cars **P** and **Q** leave from the same point and travel in the same direction.
Q leaves at time $t = 0$ and **P** leaves one second later.
The figure shows the velocity–time graph for **P** and **Q**.



What is the distance between **Q** and **P** when $t = 8$ s?

[1 mark]

A 40 m ⬭

B 80 m ⬭

C 160 m ⬭

D 180 m ⬭

2 2 An object is thrown vertically upwards at time $t = 0$

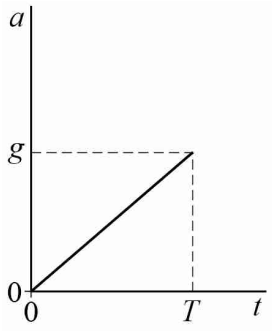
The object reaches its maximum height when $t = T$ and reaches its terminal speed on the way down.

The magnitude of the object's acceleration is a.

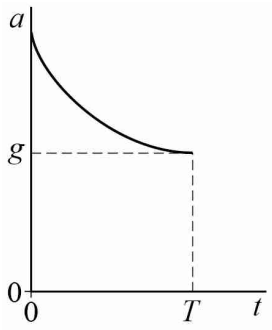
Which graph shows the variation of a with t?

[1 mark]

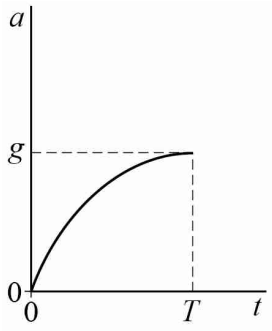
A



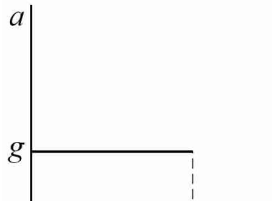
B



C



D



0 2 In 2021 the world land speed record was $1230\ \text{km h}^{-1}$.
This was the average speed achieved by a jet-powered car in two runs. Each run was measured over a distance of $1.61\ \text{km}$.

0 2 . 1 The average speed for one of these runs was $343\ \text{m s}^{-1}$.

Calculate, in s, the time taken for the car to complete the other run.

[2 marks]

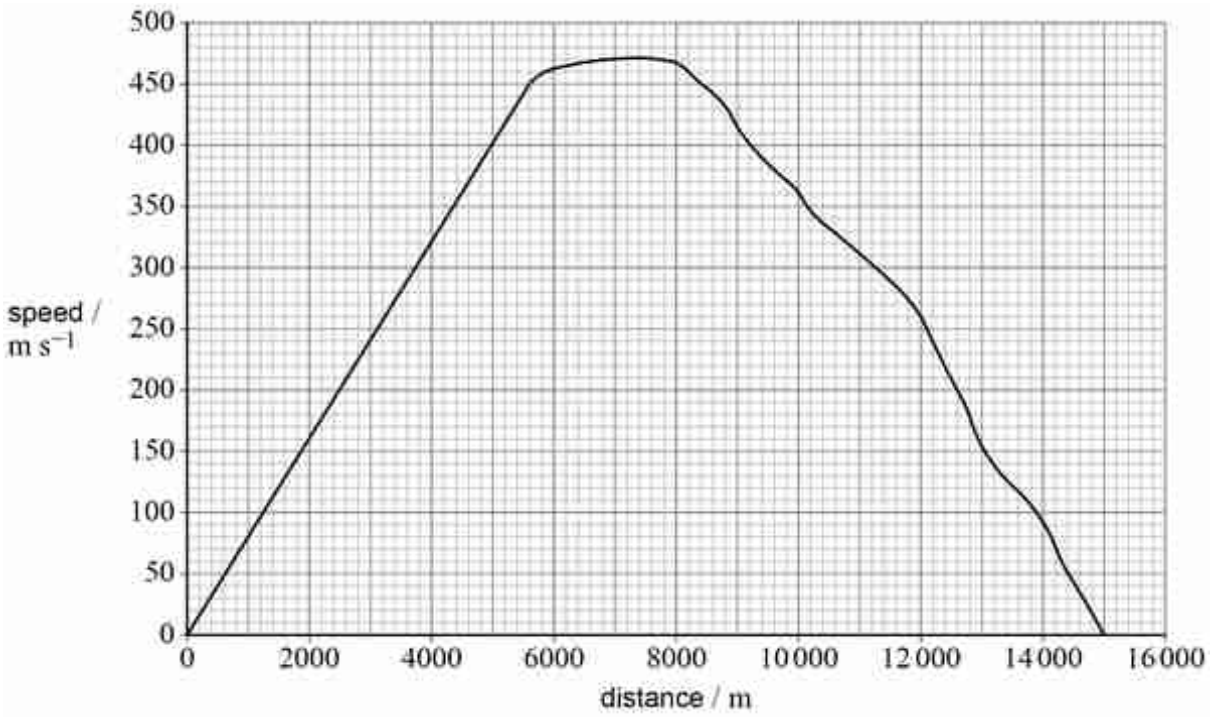
time = _____ s

Question 2 continues on the next page

0 2 . 2 Engineers are designing a new jet-powered car to break this record.

Figure 1 shows the variation of speed with distance for the car, as predicted by the engineers.

Figure 1



The car reaches its maximum acceleration when it is 5600 m from the start.
At this point the mass of the car is 6.50×10^3 kg.

Determine the kinetic energy of the car at its maximum acceleration.

[2 marks]

kinetic energy = _____ J

0 2 . 3 At any point on the graph in **Figure 1**, the acceleration is given by:

acceleration = speed × gradient of line

When the car is at its maximum acceleration, the power input to the jet engines is 640 MW.

Calculate the percentage of the input power used to accelerate the car at its maximum acceleration.

[4 marks]

percentage of input power = _____ %

0 2 . 4 Scientists recommend that the average deceleration of the driver of the car should be less than $3g$.

Deduce whether the average deceleration is less than $3g$.

[2 marks]

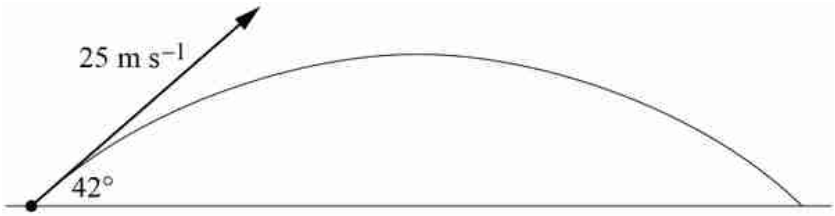
SUB-TOPIC 3.4.1.4

PROJECTILE MOTION

Sub-topic 3.4.1.4 · 5 questions · 18 marks · lowest tariff first

2 1 **Figure 12** shows the path of a projectile launched from ground level with a speed of $25\ \text{m s}^{-1}$ at an angle of $42°$ to the horizontal.

Figure 12



What is the horizontal distance from the starting point of the projectile when it hits the ground?

[1 mark]

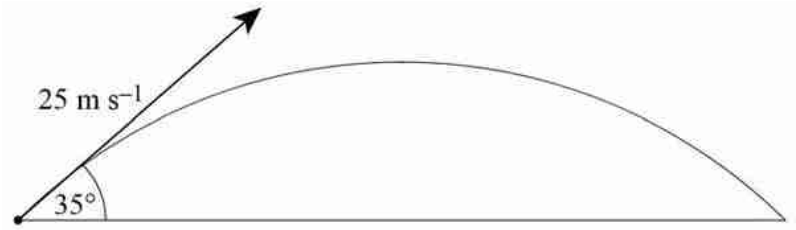
A 23 m ⬭

B 32 m ⬭

C 47 m ⬭

D 63 m ⬭

2 3 A projectile is launched with a speed of $25\ \text{m s}^{-1}$ at an angle of $35°$ to the horizontal, as shown in the diagram.



Air resistance is negligible.

What is the time taken for the projectile to return to the ground?

[1 mark]

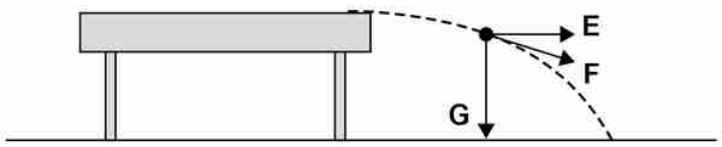
A 1.5 s ⬭

B 2.1 s ⬭

C 2.9 s ⬭

D 4.2 s ⬭

2 3 A coin is projected horizontally from the top of a desk.
The diagram shows the coin at one point in its path. The air resistance is negligible.



The arrows **E**, **F** and **G** represent different directions.

Which row gives the direction of the acceleration and the direction of the momentum of the coin at this point?

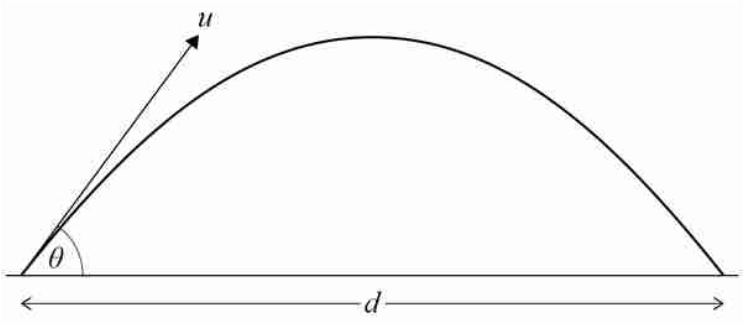
[1 mark]

	Acceleration	Momentum	
A	**F**	**F**	⬭
B	**F**	**E**	⬭
C	**G**	**F**	⬭
D	**G**	**E**	⬭

2 0 A projectile is fired from ground level over horizontal ground.

Its initial velocity is u at an angle θ to the horizontal.

The range of the projectile is d.



A second projectile is fired with a velocity $2u$ at the same angle.

What is the range of this projectile?
Assume that air resistance is negligible.

[1 mark]

A $\sqrt{2}d$ ⬭

B $2d$ ⬭

C $2\sqrt{2}d$ ⬭

D $4d$ ⬭

0 5 **Figure 8** shows the H-shaped posts used in a game of rugby.

Figure 8

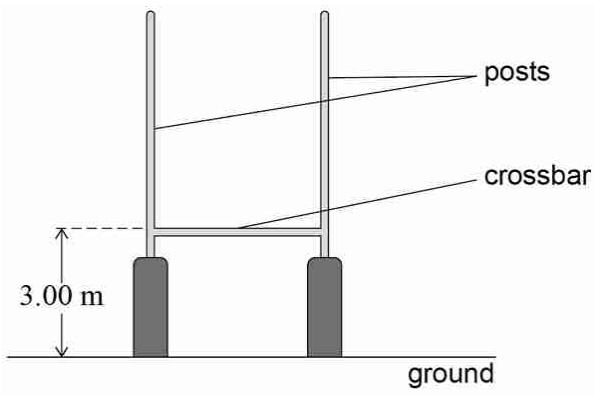
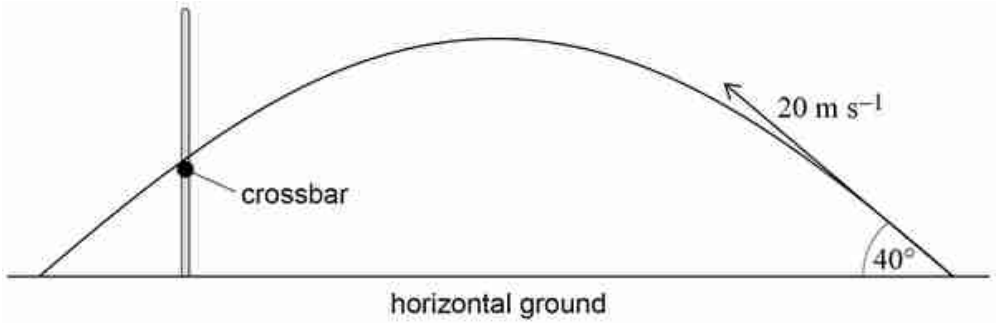


Figure 9 shows the path of a ball that is kicked and just passes over the crossbar. The initial velocity of the ball is $20.0\ \text{m s}^{-1}$ at an angle of $40.0°$ to the ground.

You should consider air resistance to be negligible and treat the ball as a simple projectile.

Figure 9



The top of the crossbar is $3.00\ \text{m}$ above the horizontal ground.

0 5 . 1 Show that the minimum speed of the ball in flight is about $15\ \text{m s}^{-1}$.

Explain your answer.

[2 marks]

0 5 . 2 The ball just passes over the crossbar at a time t after it is kicked.

Show that t must satisfy the following equation:

$$4.91t^2 - 12.9t + 3.00 = 0$$

[2 marks]

Question 5 continues on the next page

0 5 . 3 There are two solutions to the equation

$$4.91t^2 - 12.9t + 3.00 = 0$$

Discuss which of the two solutions is the time taken for the ball to pass over the crossbar from when it is kicked.

In your answer you should

- state the value for t given by each solution
- explain the physical significance of the other solution.

[4 marks]

solution 1 = _____ s

solution 2 = _____ s

0 5 . 4 Another attempt is made to kick the ball over the crossbar. The initial velocity of the ball is the same as in the first attempt.
This kick is made from a horizontal distance of $38\ \text{m}$ from the posts.

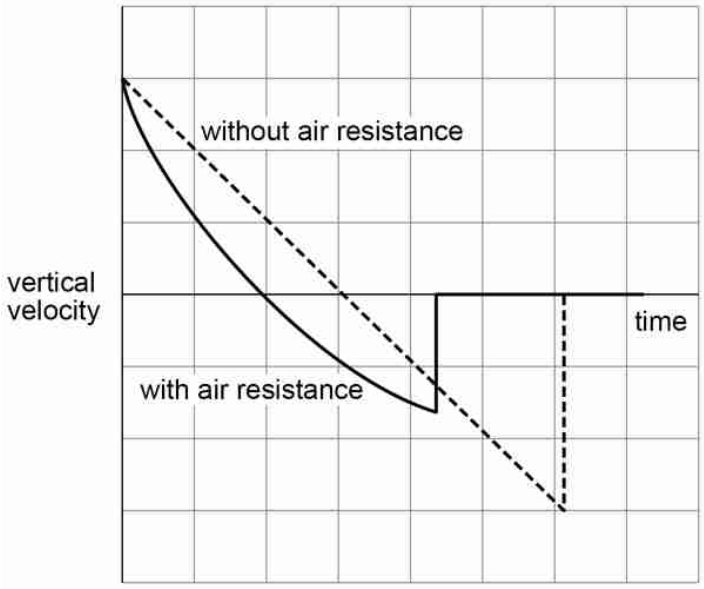
Deduce whether the ball can pass over the crossbar.

[1 mark]

Question 5 continues on the next page

0 5 . 5 **Figure 10** shows the variations with time of the vertical velocity of a ball with and without air resistance.

Figure 10



Discuss the features of the motion of the ball shown by the two graphs.

In your answer you should refer to

- the gradients of the graphs
- the area between each line and the time axis.

[5 marks]

SUB-TOPIC 3.4.1.5

NEWTON'S LAWS OF MOTION

Sub-topic 3.4.1.5 · 9 questions · 9 marks · lowest tariff first

2 0 A rocket of mass $12\ 000\ \text{kg}$ accelerates vertically upwards from the surface of the Earth at $1.4\ \text{m s}^{-2}$.

What is the thrust of the rocket?

[1 mark]

A $1.7 \times 10^4\ \text{N}$ ⬭

B $1.0 \times 10^5\ \text{N}$ ⬭

C $1.3 \times 10^5\ \text{N}$ ⬭

D $1.6 \times 10^5\ \text{N}$ ⬭

2 2 Immediately after take-off from the surface of the Earth, a rocket of mass $12\ 000\ \text{kg}$ accelerates vertically upwards at $1.4\ \text{m s}^{-2}$

What is the thrust produced by the rocket motor?

[1 mark]

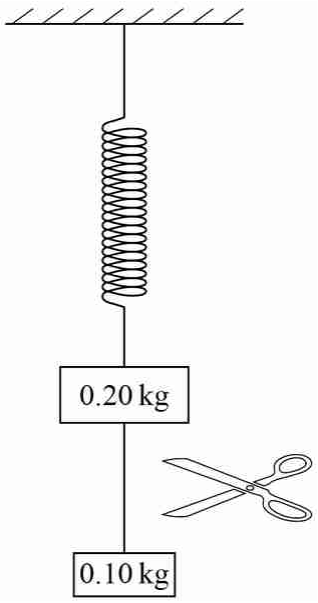
A $1.7 \times 10^4\ \text{N}$ ⬭

B $1.0 \times 10^5\ \text{N}$ ⬭

C $1.3 \times 10^5\ \text{N}$ ⬭

D $1.6 \times 10^5\ \text{N}$ ⬭

1 4 A $0.20\ \text{kg}$ mass is suspended from a spring. A $0.10\ \text{kg}$ mass is suspended from the $0.20\ \text{kg}$ mass using a thread of negligible mass.
The system is in equilibrium and the thread is then cut.



What is the upward acceleration of the $0.20\ \text{kg}$ mass at the instant that the thread is cut?
[1 mark]

A $3.3\ \text{m s}^{-2}$ ⬭

B $4.9\ \text{m s}^{-2}$ ⬭

C $6.5\ \text{m s}^{-2}$ ⬭

D $9.8\ \text{m s}^{-2}$ ⬭

2 4 A truck of mass 2.1×10^3 kg tows a car of mass 1.3×10^3 kg along a horizontal road.
The total resistive force on the car is 1100 N.
The acceleration of the car and truck is 2.3 m s^{-2}.



What is the tension in the tow rope?

[1 mark]

A 3000 N ⬭

B 4100 N ⬭

C 7800 N ⬭

D 8900 N ⬭

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 3 A sphere of mass m falls with speed v.
The resistive force on the sphere is kv, where k is a constant.

What is the terminal speed of the sphere?

[1 mark]

A $\frac{mg}{k}$ ⬭

B $\frac{km}{g}$ ⬭

C kmg ⬭

D $\frac{k}{mg}$ ⬭

2 4 A trolley moves down a slope with constant acceleration.
The mass of the trolley is doubled and the trolley moves down the same slope again.
Air resistance and friction are negligible.

Which is correct?

[1 mark]

A The accelerating force is unchanged. ⬭

B The accelerating force is halved. ⬭

C The acceleration is unchanged. ⬭

D The acceleration is halved. ⬭

2 3 A man has a mass of 75.0 kg.
He stands on weighing scales in a lift that accelerates upwards at 2.60 m s^{-2}.

What is the reading on the scales during the acceleration?

[1 mark]

A 195 N ⬭

B 541 N ⬭

C 736 N ⬭

D 931 N ⬭

2 1 A skydiver is falling at a terminal velocity v_1.
When she is at a height h_1 she opens her parachute.
When she is at a height h_2 she reaches a new terminal velocity v_2.

Which is true?

[1 mark]

A The increased air resistance when her height is h_1 causes her initially to move upwards. ⬭

B The drag force when her velocity is v_2 is equal to the drag force when her velocity is v_1. ⬭

C At v_1, her weight and the drag force are an action–reaction pair according to Newton's third law. ⬭

D Between h_1 and h_2, the work done by the drag force is equal to the change in the kinetic energy of the parachute and skydiver. ⬭

SUB-TOPIC 3.4.1.6

MOMENTUM

Sub-topic 3.4.1.6 · 8 questions · 34 marks · lowest tariff first

2 2 A car of mass 580 kg collides with the rear of a stationary van of mass 1200 kg.

Following the collision, the van moves with a velocity of 6.20 m s^{-1} and the car recoils in the opposite direction with a velocity of 1.60 m s^{-1}.

What is the initial speed of the car?

[1 mark]

A 5.43 m s^{-1} ⬭

B 11.2 m s^{-1} ⬭

C 12.8 m s^{-1} ⬭

D 14.4 m s^{-1} ⬭

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]

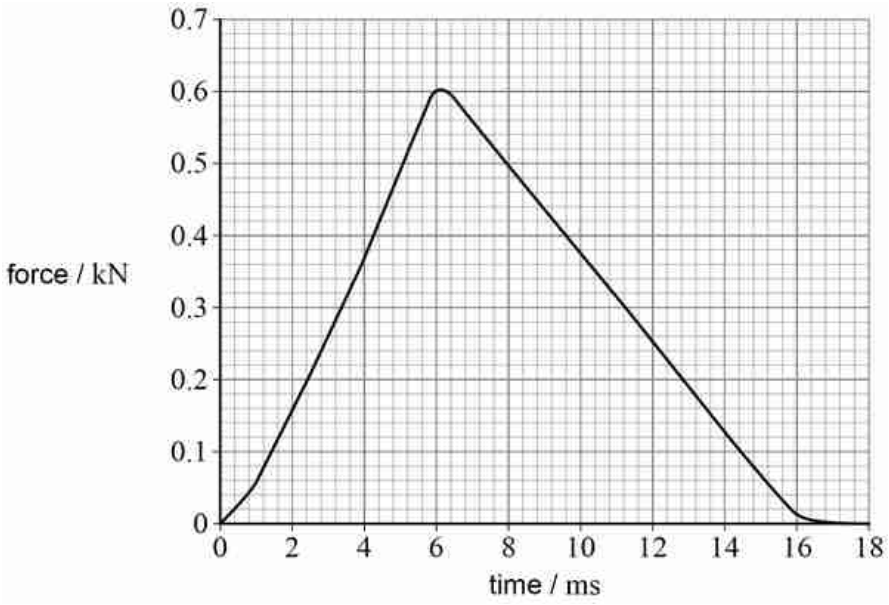
A kinetic energy. ⬭

B mass. ⬭

C gravitational potential energy. ⬭

D weight. ⬭

2 5 A golf ball has a mass of 46 g and is initially stationary.
The diagram shows the variation with time of the force acting on the golf ball as it is hit with a golf club.



What is an estimate of the kinetic energy of the golf ball immediately after it is hit?

[1 mark]

A 5 J ⬭

B 50 J ⬭

C 250 J ⬭

D 500 J ⬭

1 9 An object is moving in a straight line. A graph is plotted to show the variation of the momentum of the object with time.

Which quantities can be calculated from the gradient of the graph and the area under the graph?

[1 mark]

	Gradient of graph	Area under graph	
A	power	mass × displacement	⬭
B	force	work done × time	⬭
C	power	work done × time	⬭
D	force	mass × displacement	⬭

2 4 An average force of $42\ \text{kN}$ acts on the air passing through a jet engine. This force causes the speed of the air to increase by $540\ \text{m s}^{-1}$.

What mass of air passes through the engine in one minute?

[1 mark]

A $7.7 \times 10^{-2}\ \text{kg}$ ⬭

B $4.7\ \text{kg}$ ⬭

C $78\ \text{kg}$ ⬭

D $4700\ \text{kg}$ ⬭

0 6 **Figure 10** shows two railway trucks **A** and **B** travelling towards each other on the same railway line which is straight and horizontal.

Figure 10



The trucks are involved in an inelastic collision. They join when they collide and then move together.

The trucks move a distance of $15\ \text{m}$ before coming to rest.

Truck **A** has a total mass of $16\ 000\ \text{kg}$ and truck **B** has a total mass of $12\ 000\ \text{kg}$

Just before the collision, truck **A** was moving at a speed of $2.8\ \text{m s}^{-1}$ and truck **B** was moving at a speed of $3.1\ \text{m s}^{-1}$

0 6 . 1 State the quantity that is **not** conserved in an inelastic collision.

[1 mark]

0 6 . 2 Show that the speed of the joined trucks immediately after the collision is about $0.3\ \text{m s}^{-1}$

[3 marks]

0 6 . 3 Calculate the impulse that acts on each truck during the collision.
Give an appropriate unit for your answer.

[2 marks]

impulse = _____ unit _____

0 6 . 4 Explain, without doing a calculation, how the motion of the trucks immediately after the collision would be different for a collision that is perfectly elastic.

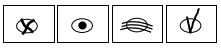
[2 marks]

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 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.
Do **not** use additional sheets for this working.

0 6 A person kicks a stationary football horizontally.

During the kick, the person gives an impulse of $6.55\ \text{N s}$ to the ball during a contact time of $12.0\ \text{ms}$.
The mass of the football is $410\ \text{g}$.
Assume that friction forces are negligible.

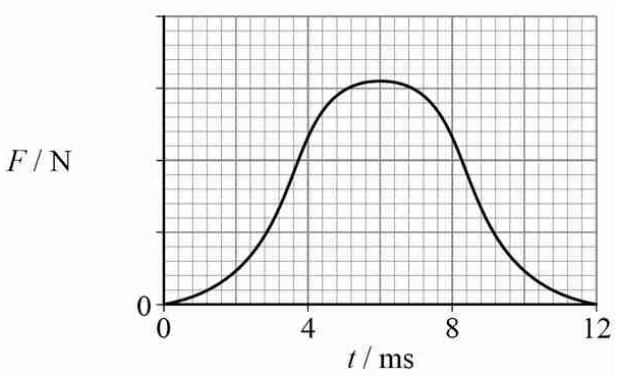
0 6 . 1 Calculate the kinetic energy transferred to the ball during the kick.

[2 marks]

kinetic energy = _____ J

0 6 . 2 **Figure 8** shows how the force F acting on the ball varies with time t.

Figure 8



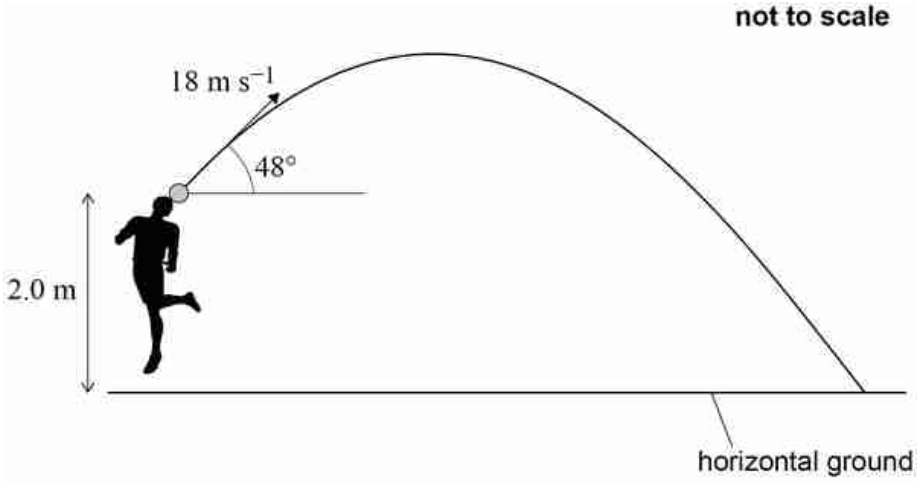
Determine the scale for the F / N axis and add your scale to **Figure 8**.

[3 marks]

0 6 . 3 A player jumps up to head a football when it is $2.0\ \text{m}$ above the ground.
The initial velocity of the ball is $18\ \text{m s}^{-1}$ at an angle of $48°$ to the horizontal.

Figure 9 shows the path of the ball above horizontal ground.

Figure 9



Determine the time that the ball takes to reach the ground from the instant it leaves the player's head.

Assume that the frictional forces acting on the ball are negligible.

[3 marks]

time = _____ s

0 5 Safety barriers are used on UK motorways to prevent vehicles crossing from one carriageway to the other carriageway. The barriers also absorb some of the kinetic energy of a vehicle and deflect vehicles along the barrier.

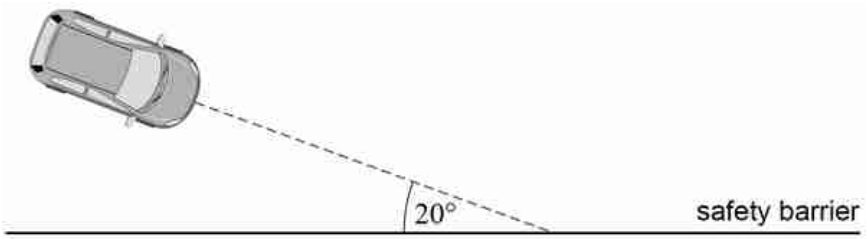
The standard test of a safety barrier uses a vehicle that contains dummies. The total mass of the vehicle and its contents is 1.5×10^3 kg and its initial speed is 110 km h^{-1}.

0 5 . 1 Show that the initial kinetic energy of the test vehicle is 700 kJ.

[2 marks]

0 5 . 2 The test vehicle hits a steel safety barrier at an angle of $20°$, as shown in **Figure 7**.

Figure 7



Calculate the component of the momentum of the test vehicle in a direction along the line of the safety barrier.
Give an appropriate unit for your answer.

[3 marks]

momentum = _____ unit _____

0 5 . 3 Immediately after the collision, the test vehicle moves along the safety barrier with no change in its momentum in this direction.

Show that the kinetic energy lost in the collision is about $80\ \text{kJ}$.

[3 marks]

0 5 . 4 The steel safety barrier deforms during the collision. For the barrier to pass the test, the test vehicle should not move more than $1.5\ \text{m}$ towards the other carriageway.

The barrier can apply an average force of $60\ \text{kN}$ at right angles to the carriageway.

Deduce whether the safety barrier will pass the test.

[3 marks]

Question 5 continues on the next page

0 5 . 5 A different safety barrier uses a solid concrete wall which does not deform. The same standard test is carried out on a concrete wall.

Discuss which type of barrier would cause less damage to the dummies in the test.

[2 marks]

SUB-TOPIC 3.4.1.7

WORK, ENERGY, POWER AND CONSERVATION OF ENERGY

Sub-topic 3.4.1.7 · 12 questions · 43 marks · lowest tariff first

1 8 Which is a correct statement about mechanical power?

[1 mark]

A It is a vector quantity. ⬭

B It is measured in J. ⬭

C In fundamental units, its unit is $\mathrm{kg\ m^2\ s^{-3}}$ ⬭

D It can be calculated from force × distance moved. ⬭

2 7 An electric motor lifts a load of weight W through a vertical height h in time t.
The potential difference across the motor is V and the current through it is I.

What is the efficiency of the motor?

[1 mark]

A $\frac{Wht}{VI}$ ⬭

B $\frac{VI}{Wht}$ ⬭

C $\frac{Wh}{VIt}$ ⬭

D $\frac{VIt}{Wh}$ ⬭

0 6 Mechanical power

[1 mark]

A is a vector quantity. ⬭

B is measured in J. ⬭

C has base units of $\mathrm{kg\ m^2\ s^{-3}}$. ⬭

D can be calculated from force × distance moved. ⬭

2 3 An electric motor lifts a load of weight W through a vertical height h in time t.
The potential difference across the motor is V and the current in it is I.

What is the efficiency of the motor?

[1 mark]

A $\frac{Wh}{VIt}$ ⬭

B $\frac{VI}{Wht}$ ⬭

C $\frac{Wht}{VI}$ ⬭

D $\frac{VIt}{Wh}$ ⬭

0 7 Which two quantities have the base unit $\mathrm{kg\ m^2\ s^{-2}}$?

[1 mark]

A kinetic energy and momentum ⬭

B kinetic energy and Young modulus ⬭

C work done and the moment of a couple ⬭

D work done and pressure ⬭

0 9 A car travels at $100\ \text{km}\ \text{h}^{-1}$ on a motorway.

What is an estimate of its kinetic energy?

[1 mark]

A 10^4 J ⬭

B 10^6 J ⬭

C 10^8 J ⬭

D 10^{10} J ⬭

13

2 6 A tennis ball has a mass of 58 g.
The ball is dropped from rest from a height of 1.8 m above the ground and falls vertically.
The ball rebounds vertically to a height of 1.1 m.
The effect of air resistance is negligible.

What is the change in momentum of the ball during its collision with the ground?

[1 mark]

A 0.040 N s ⬭

B 0.075 N s ⬭

C 0.215 N s ⬭

D 0.614 N s ⬭

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

What mass of water is heated?

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

[1 mark]

A 1.0 kg ⬭

B 13 kg ⬭

C 60 kg ⬭

D 110 kg ⬭

1 1 A force F moves through a distance x in the direction of F.

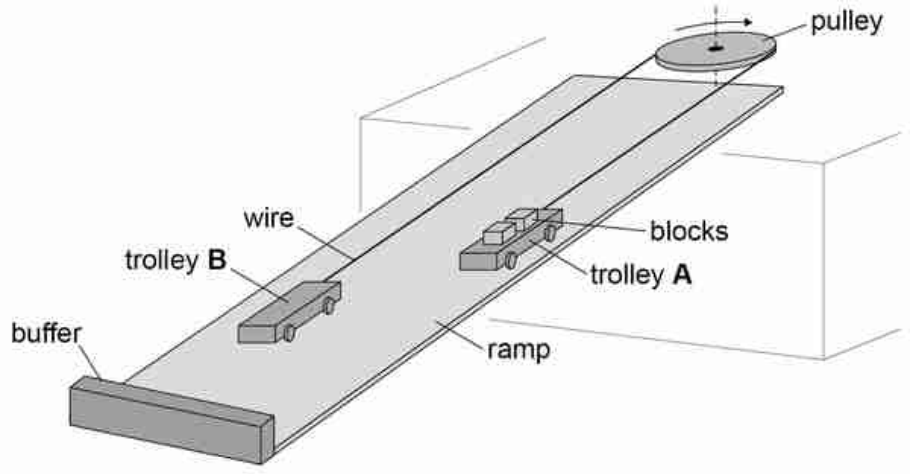
In which row is the work done by the force 1 J?

[1 mark]

	F	x	
A	1 mN	1 km	⬭
B	100 kN	100 μm	⬭
C	100 MN	100 nm	⬭
D	1 GN	1 fm	⬭

0 6 **Figure 8** shows a model of a system being designed to move concrete building blocks from an upper to a lower level.

Figure 8



The model consists of two identical trolleys of mass M on a ramp which is at $35°$ to the horizontal. The trolleys are connected by a wire that passes around a pulley of negligible mass at the top of the ramp.

Two concrete blocks each of mass m are loaded onto trolley **A** at the top of the ramp. The trolley is released and accelerates to the bottom of the ramp where it is stopped by a flexible buffer. The blocks are unloaded from trolley **A** and two blocks are loaded onto trolley **B** that is now at the top of the ramp. The trolleys are released and the process is repeated.

Figure 9 shows the side view of trolley **A** when it is moving **down** the ramp.

Figure 9

0 6 . 1 The tension in the wire when the trolleys are moving is T.

Draw and label arrows on **Figure 9** to represent the magnitudes and directions of any forces and components of forces that act on trolley **A** parallel to the ramp as it travels down the ramp.

[1 mark]

0 6 . 2 Assume that no friction acts at the axle of the pulley or at the axles of the trolleys and that air resistance is negligible.

Show that the acceleration a of trolley **B** along the ramp is given by

$$a = \frac{mg \sin 35^\circ}{M + m}$$

[2 marks]

0 6 . 3 Compare the momentum of loaded trolley **A** as it moves downwards with the momentum of loaded trolley **B**.

[2 marks]

Question 6 continues on the next page

0 6 . 4 In practice, for safety reasons there is a friction brake in the pulley that provides a resistive force to reduce the acceleration to 25% of the maximum possible acceleration.

The distance travelled for each journey down the ramp is 9.0 m.

The following data apply to the arrangement.

Mass of a trolley M = 95 kg
Mass of a concrete block m = 30 kg

Calculate the time taken for a loaded trolley to travel down the ramp.

[3 marks]

time = _____ s

0 6 . 5 It takes 12 s to remove the blocks from the lower trolley and reload the upper trolley.

Calculate the number of blocks that can be transferred to the lower level in 30 minutes.

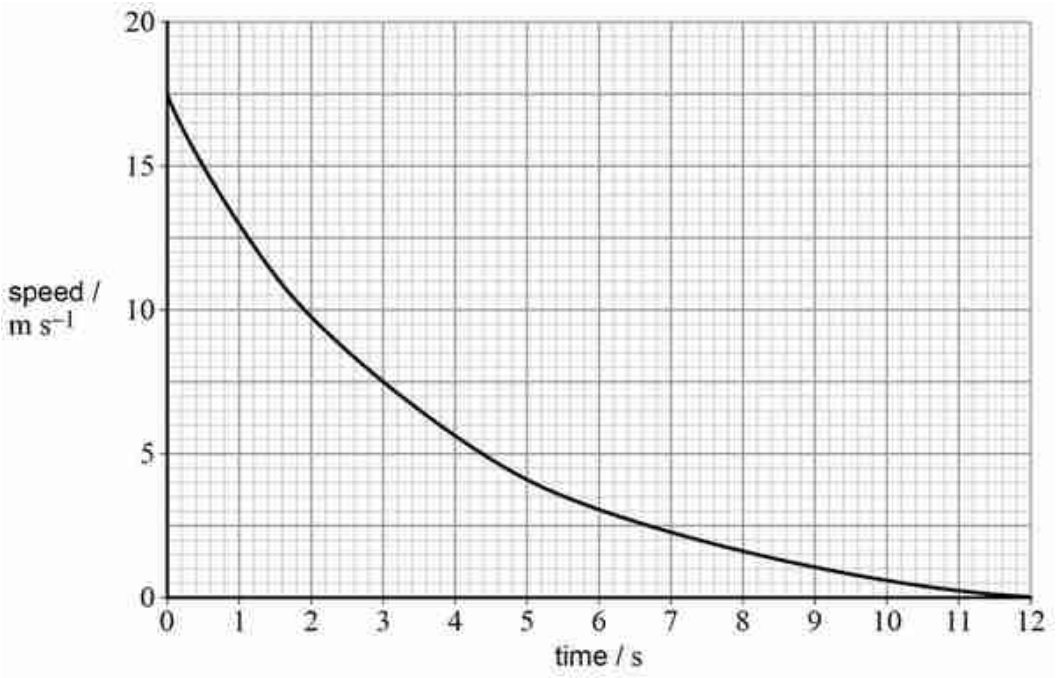
[2 marks]

number = _____

0 1 Horizontal escape lanes made of loose gravel have been constructed at the side of some roads on steep hills so that vehicles can stop safely when their brakes fail.

Figure 1 shows an engineer's prediction of how the speed of an unpowered vehicle of mass 1.8×10^4 kg will vary with time as the vehicle comes to rest in an escape lane.

Figure 1



0 1 . 1 Determine the force decelerating the vehicle 2.0 s after entering the escape lane.

[3 marks]

force decelerating the vehicle = _____ N

0 1 . 2 Deduce whether a lane of length $85\ \text{m}$ is long enough to stop the vehicle, assuming that the engineer's graph is correct.

[3 marks]

0 1 . 3 Discuss the energy transfers that take place when a vehicle is decelerated in an escape lane.

[2 marks]

Question 1 continues on the next page

0 1 . 4 An alternative to an escape lane containing gravel is an escape lane that consists of a ramp. An escape ramp is a straight road with a concrete surface that has a constant upward gradient.

One escape ramp makes an angle of $25°$ to the horizontal and is $85\ \text{m}$ long.

Deduce whether this escape ramp is sufficient to stop the vehicle.

Assume that any frictional forces and air resistance that decelerate the vehicle are negligible.

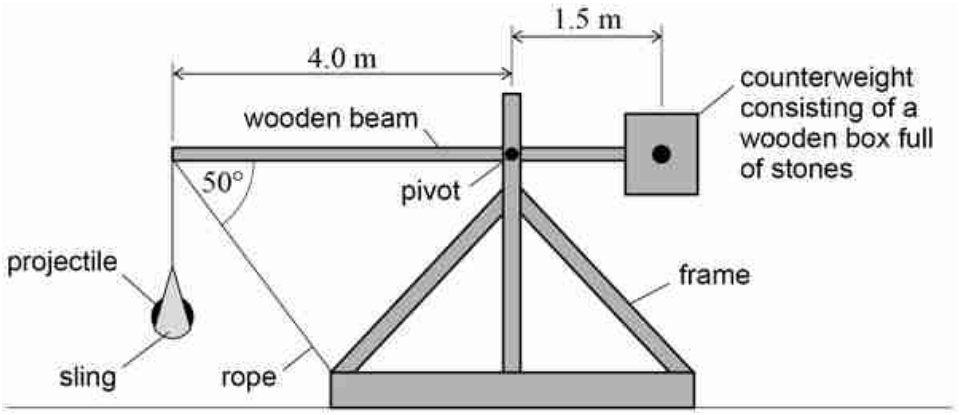
[3 marks]

0 1 . 5 Discuss whether an escape lane containing gravel or an escape ramp would provide the safer experience for the driver of the vehicle as it comes to rest.

[1 mark]

0 4 **Figure 5** shows a simplified catapult used to hurl projectiles a long way.

Figure 5



The counterweight is a wooden box full of stones attached to one end of the beam.
The projectile, usually a large rock, is in a sling hanging vertically from the other end of the beam. The weight of the sling is negligible.
The beam is held horizontal by a rope attached to the frame.

0 4 . 1 The catapult is designed so that the weight of the beam and the weight of the **empty** wooden box have no effect on the tension in the rope.

Suggest how the pivot position achieves this.

[2 marks]

Question 4 continues on the next page

0 4 . 2 The stones in the counterweight have a total mass of $610\ \text{kg}$ and the projectile weighs $250\ \text{N}$.

Calculate the tension in the rope.

[5 marks]

tension = _____ N

0 4 . 3 When the rope is cut, the counterweight rotates clockwise. When the beam is vertical it is prevented from rotating further. The projectile is then released horizontally with a velocity of $18\ \text{m s}^{-1}$, as shown in **Figure 6**.

The projectile is released at a height of $7.5\ \text{m}$ above ground level.

Figure 6

The range of the catapult is the horizontal distance between the point where the projectile is released to the point where it lands.

Calculate the range.
Ignore air resistance.

[2 marks]

range = _____ m

0 4 . 4 In another release, the sling is adjusted so that a projectile of the same mass is released just before the wooden beam is vertical. The projectile is not released horizontally.

Discuss the effect this change has on the range of the catapult.

[3 marks]

SUB-TOPIC 3.4.2

MATERIALS: BULK PROPERTIES AND THE YOUNG MODULUS

Sub-topic 3.4.2 · 13 questions · 30 marks · lowest tariff first

2 4 A sample of wire has a Young modulus E. A second sample of wire made from an identical material has three times the length and half the diameter of the first sample.

What is the Young modulus of the second sample of wire in terms of E?

[1 mark]

A $0.25E$ ⬭

B E ⬭

C $6E$ ⬭

D $12E$ ⬭

1 9 A load of $50\ \text{N}$ is suspended from a wire that has an area of cross-section of $1\ \text{mm}^2$.

The stress in the wire, in Pa, is between

[1 mark]

A 10^0 and 10^3 ⬭

B 10^3 and 10^6 ⬭

C 10^6 and 10^9 ⬭

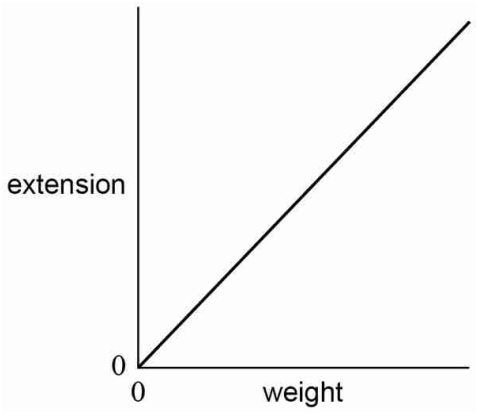
D 10^9 and 10^{12} ⬭

2 0 Which combination of properties would produce the smallest extension of a wire when the same tensile force is applied to the wire?

[1 mark]

	Cross-sectional area	Length	Young modulus of material	
A	X	$3L$	E	⬭
B	$2X$	L	E	⬭
C	X	$3L$	$4E$	⬭
D	$2X$	L	$4E$	⬭

2 6 An experiment is carried out to determine the Young modulus E of steel using a vertical wire of initial length L and cross-sectional area A. Various weights are suspended from the wire. A graph of extension against weight is plotted.



What does the gradient of the graph represent?

[1 mark]

A E ⬭

B $\frac{1}{E}$ ⬭

C $\frac{EA}{L}$ ⬭

D $\frac{L}{EA}$ ⬭

2 6 Two wires **X** and **Y** have the same extension for the same load.
X has a diameter d and is made of a metal of density ρ and Young modulus E.
Y has the same mass and length as **X** but its diameter is $2d$.

What are the density and the Young modulus of the metal from which **Y** is made?

[1 mark]

	Density	Young modulus	
A	$\frac{\rho}{2}$	$\frac{E}{4}$	⬭
B	$\frac{\rho}{2}$	$4E$	⬭
C	$\frac{\rho}{4}$	$\frac{E}{4}$	⬭
D	$\frac{\rho}{4}$	$4E$	⬭

2 7 A mass M is suspended from a spring. When the mass is at rest at the equilibrium position, the elastic potential energy stored is E.
An extra mass of $2M$ is added to the spring and the spring extends while still obeying Hooke's law.

What is the total elastic energy stored when the system is at rest at the new equilibrium position?

[1 mark]

A $2E$ ⬭

B $3E$ ⬭

C $4E$ ⬭

D $9E$ ⬭

2 8 Two wires P and Q are made of the same material and have the same cross-sectional area.
P has an original length L and is subject to a tensile force F. P extends a distance x.
Q has an original length $2L$ and is subject to a tensile force $2F$.

Which statement is correct?

[1 mark]

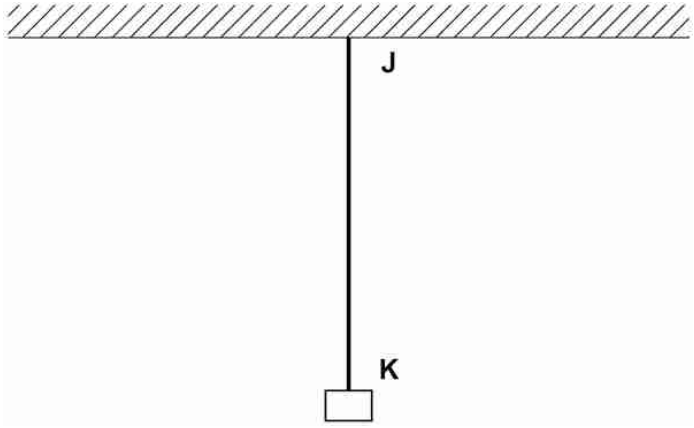
A The stress in P and the stress in Q are the same. ⬭

B The extension of Q is $2x$. ⬭

C The strain of Q is double the strain of P. ⬭

D The value of $\frac{\text{stress}}{\text{strain}}$ for P is half that of Q. ⬭

2 6 A heavy cable is attached to a fixed support and carries a load at its lower end.

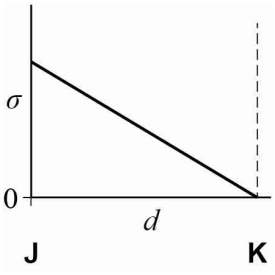


The weight of the cable is **not** negligible.
The cable has constant cross-sectional area and density.

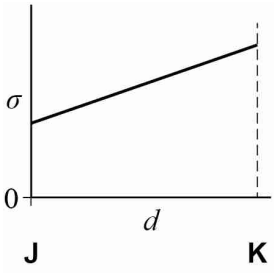
Which graph shows the variation of tensile stress σ in the cable with distance d from **J** to **K**?

[1 mark]

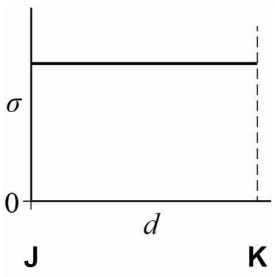
A



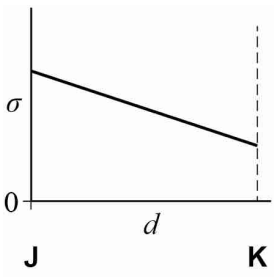
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

2 5 A uniform wire is stretched by a load F.
The elastic strain energy stored in the wire is E.

The load is increased from F to $2F$.
The wire obeys Hooke's law.

What is the increase in the elastic strain energy stored in the wire?

[1 mark]

A E ⬭

B $2E$ ⬭

C $3E$ ⬭

D $4E$ ⬭

2 6 A spring is compressed by a force F. The spring has stiffness k and its length changes by ΔL during the compression. When the force is removed the spring returns to its original length in time t.

What is the average power developed by the spring as it returns to its original length?

[1 mark]

A $\frac{k\Delta L}{2t}$ ⬭

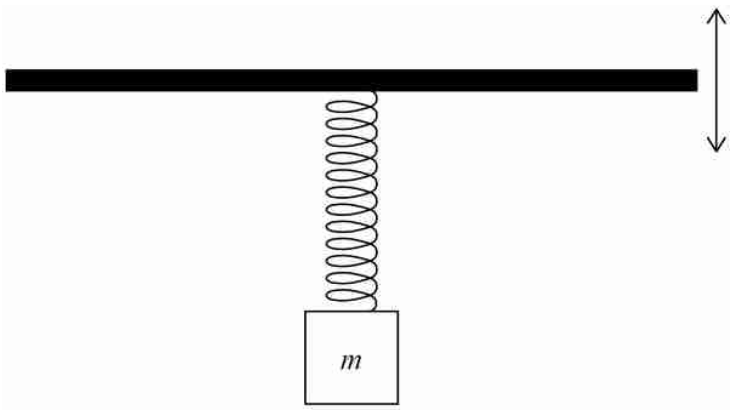
B $\frac{k\Delta L}{t}$ ⬭

C $\frac{k(\Delta L)^2}{2t}$ ⬭

D $\frac{k(\Delta L)^2}{t}$ ⬭

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

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



What is m?

[1 mark]

A 190 g ⬭

B 370 g ⬭

C 490 g ⬭

D 590 g ⬭

0 4 . 1 Explain why the Young modulus and the breaking stress of a wire have the same SI unit.

[1 mark]

Table 1 contains data about four metal wires **W**, **X**, **Y** and **Z**.

Table 1

Wire	Length / m	Diameter / mm	Stiffness / N m^{-1}	Density / kg m^{-3}
W	3.10	1.7	4.90×10^4	2.71×10^3
X	2.17	1.4	5.25×10^4	1.93×10^4
Y	2.50	1.2	5.25×10^4	8.91×10^3
Z	2.50	1.2	3.08×10^4	2.71×10^3

0 4 . 2 The metal used to make wire **X** costs £75 per gram.

Calculate, in £, the cost of wire **X**.

[3 marks]

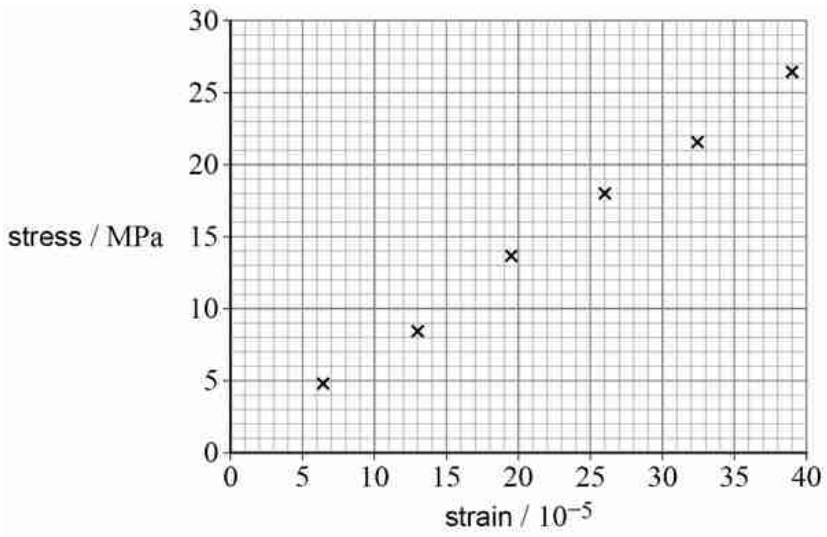
cost = £ _____

0 4 . 3 State and explain which of the wires in **Table 1** are made from the same material.

[1 mark]

0 4 . 4 One of the wires in **Table 1** was used to obtain the stress–strain data shown in **Figure 5**.

Figure 5

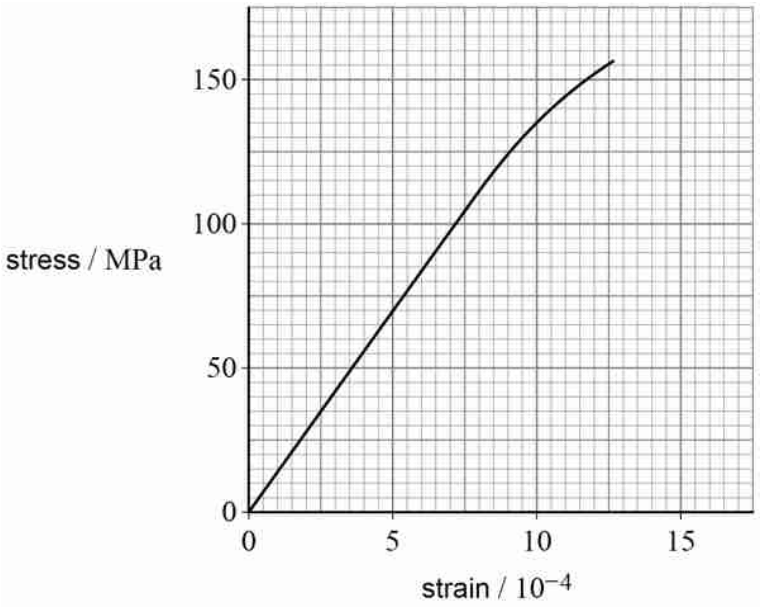


Draw a line of best fit on **Figure 5**.
Go on to deduce, using your line of best fit and **Table 1**, whether wire **W** could have been used to produce **Figure 5**.

[4 marks]

0 5 **Figure 11** shows the stress–strain graph for a metal in tension up to the point at which it fractures.

Figure 11



0 5 . 1 Determine, using **Figure 11**, the Young modulus of the metal.

[1 mark]

Young modulus = _____ Pa

0 5 . 2 Explain how the graph shows that this metal is brittle.

[1 mark]

_____

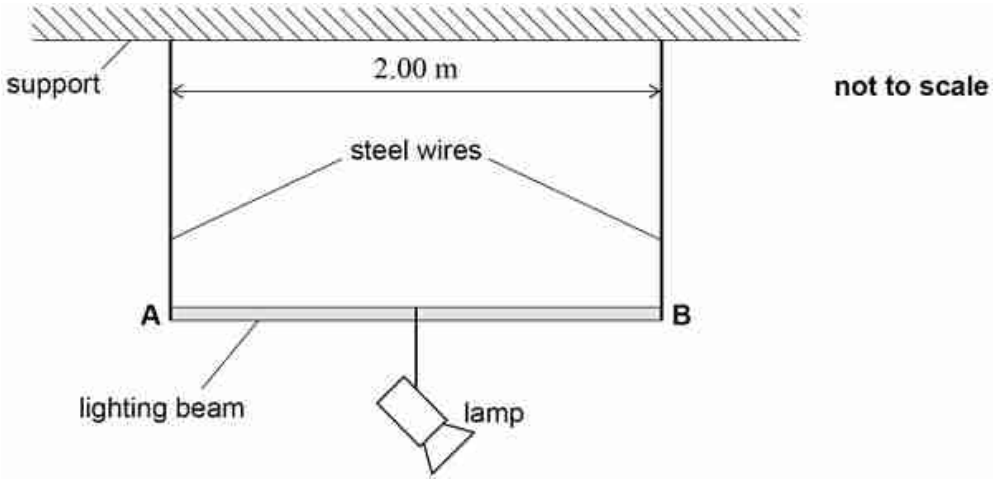
_____

_____

Question 5 continues on the next page

Figure 12 shows a uniform rigid lighting beam **AB** suspended from a fixed horizontal support by two identical vertical steel wires. A lamp is attached to the midpoint of **AB**.

Figure 12



The unloaded length of each steel wire was 1.20 m before it was attached to **AB**. **AB** is horizontal.

mass of **AB** = 4.4 kg
mass of lamp = 16.0 kg
distance between wires = 2.00 m
diameter of each wire = 0.800 mm
Young modulus of steel = 2.10×10^{11} Pa

0 5 . 3 Calculate the extension of each wire.

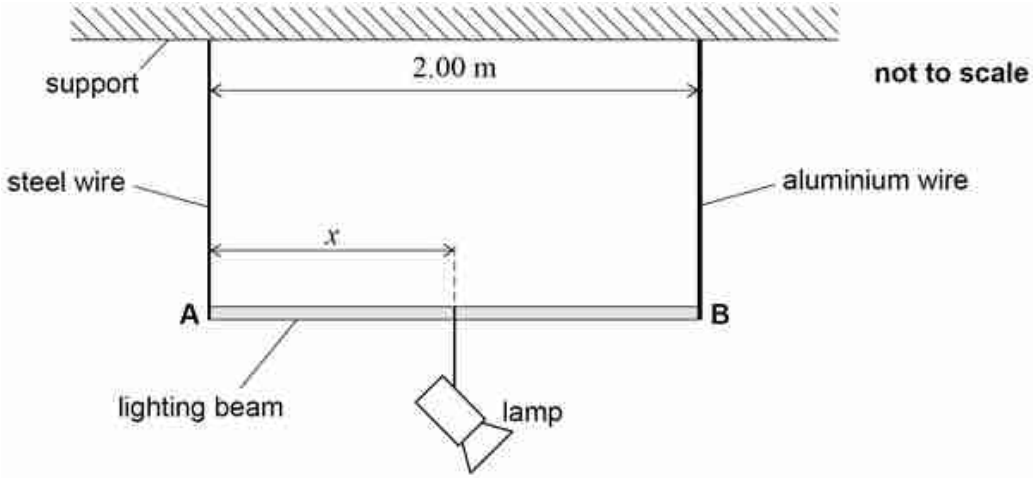
[3 marks]

extension = _____ m

0 5 . 4 The right-hand steel wire is removed and replaced with an aluminium wire of diameter $1.60\ \text{mm}$. The unloaded length of the aluminium wire is the same as that of the original steel wire.

When the lamp is at the midpoint of **AB**, one of the wires extends more than the other so that **AB** is not horizontal. To make **AB** horizontal the lamp has to be moved to a distance x from **A**. **Figure 13** shows the new arrangement.

Figure 13



The Young modulus of aluminium is $7.00 \times 10^{10}\ \text{Pa}$.

Deduce distance x.

[5 marks]

$x =$ _____ m

SUB-TOPIC 3.4.S

SYNOPTIC AND CROSS-TOPIC QUESTIONS

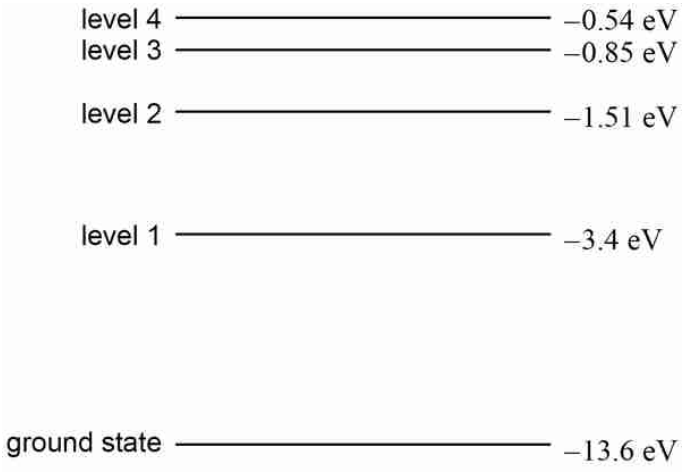
Sub-topic 3.4.S · 140 questions · 644 marks · lowest tariff first

1 2 The diagram shows an energy level diagram for a hydrogen atom.

Electrons with energy $13.0\ \text{eV}$ collide with atoms of hydrogen in their ground state.

What is the number of different wavelengths of electromagnetic radiation that could be emitted when the atoms de-excite?

[1 mark]



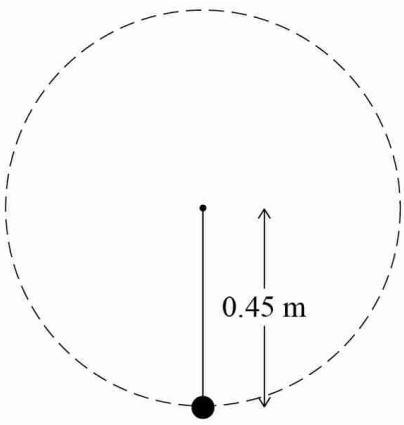
A 0 ⬭

B 3 ⬭

C 6 ⬭

D 7 ⬭

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



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

[1 mark]

A 5.8 N ⬭

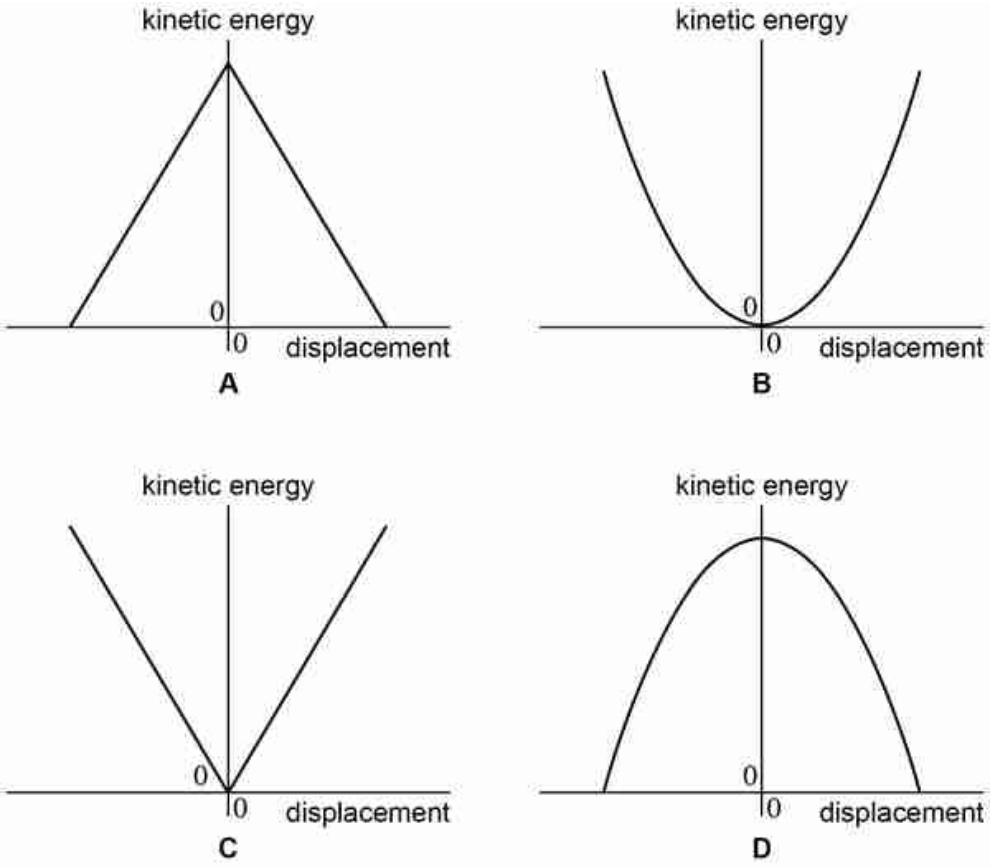
B 31 N ⬭

C 36 N ⬭

D 40 N ⬭

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

[1 mark]



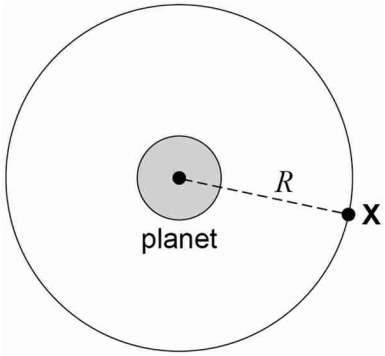
A ⬭

B ⬭

C ⬭

D ⬭

1 4 A satellite **X** of mass m is in a concentric circular orbit of radius R about a planet of mass M.



What is the kinetic energy of **X**?

[1 mark]

A $\frac{GMm}{2R}$ ⬭

B $\frac{GMm}{R}$ ⬭

C $\frac{2GMm}{R}$ ⬭

D $\frac{4GMm}{R}$ ⬭

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

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

Figure X

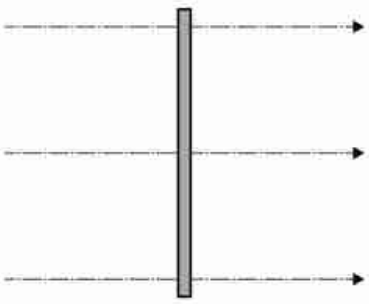
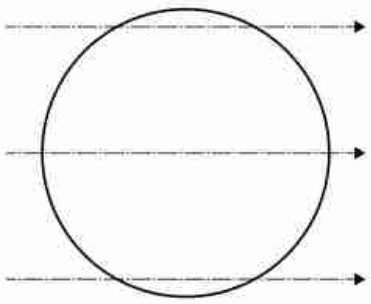


Figure Y



The coil is rotated about a vertical axis by $90°$ in a time of $0.20\ \text{s}$ 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 $1.3\ \text{mV}$ ⬭

C $25\ \text{mV}$ ⬭

D $100\ \text{mV}$ ⬭

2 4 The National Grid is used to transfer electrical energy from power stations to consumers.

What conditions for the transmission voltage and the transmission current give the most efficient transfer of energy through the National Grid?

[1 mark]

	Transmission voltage	Transmission current	
A	High	High	⬭
B	High	Low	⬭
C	Low	High	⬭
D	Low	Low	⬭

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]

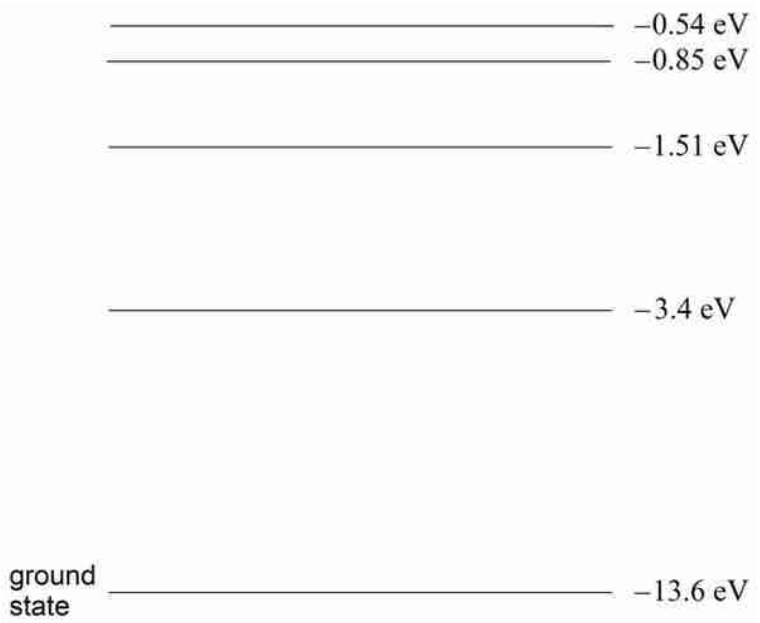
A 12 W ⬭

B 24 W ⬭

C 48 W ⬭

D 96 W ⬭

1 3 The diagram shows an energy-level diagram for a hydrogen atom.



Electrons, each having a kinetic energy of 2.0×10^{-18} J, collide with atoms of hydrogen in their ground state. Photons are emitted when the atoms de-excite.

How many different wavelengths can be observed with incident electrons of this energy?

[1 mark]

A 1 ⬭

B 3 ⬭

C 6 ⬭

D 7 ⬭

1 4 Photons of wavelength $290\ \text{nm}$ are incident on a metal plate. The work function of the metal is $4.1\ \text{eV}$

What is the maximum kinetic energy of the emitted electrons?

[1 mark]

A $0.19\ \text{eV}$ ⬭

B $4.3\ \text{eV}$ ⬭

C $6.9\ \text{eV}$ ⬭

D $8.4\ \text{eV}$ ⬭

2 9 A body performs simple harmonic motion.

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

[1 mark]

A 0 ⬭

B $\frac{\pi}{4}$ rad ⬭

C $\frac{\pi}{2}$ rad ⬭

D π rad ⬭

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

What is the maximum value of its kinetic energy?

[1 mark]

A $5.7 \times 10^{-3}\ \text{J}$ ⬭

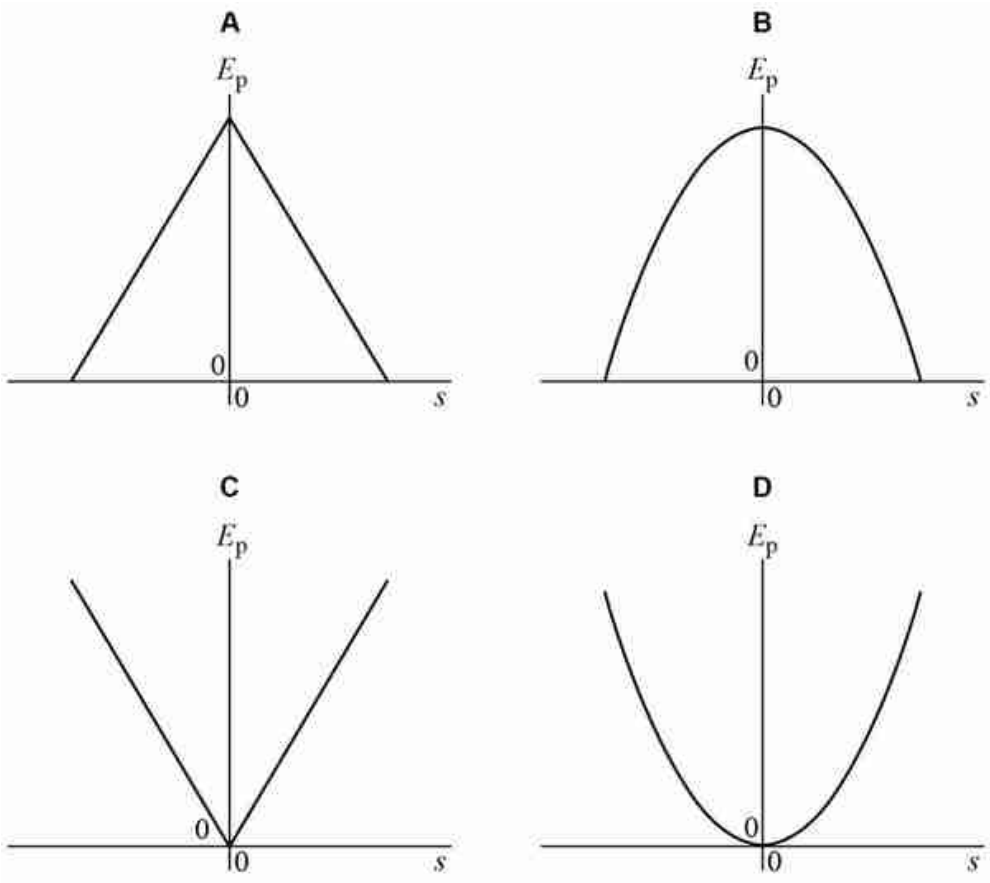
B $11 \times 10^{-3}\ \text{J}$ ⬭

C $0.57\ \text{J}$ ⬭

D $11\ \text{J}$ ⬭

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

[1 mark]



A ⬭

B ⬭

C ⬭

D ⬭

END OF QUESTIONS

Copyright information

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

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

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

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

What is the cause of this observation of Brownian motion?

[1 mark]

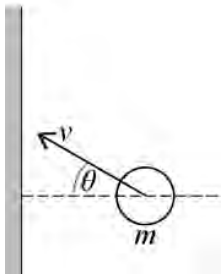
A Smoke particles gaining kinetic energy by the absorption of light ⬭

B Collisions between smoke particles and air molecules ⬭

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

D The smoke particles moving randomly due to their temperature ⬭

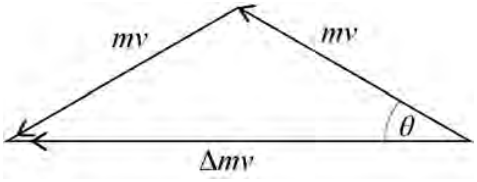
1 2 The diagram shows a gas particle about to collide elastically with a wall.



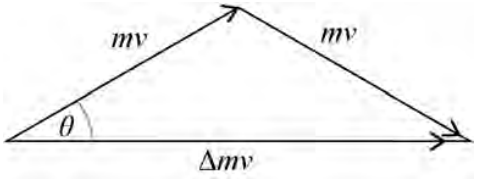
Which diagram shows the correct change in momentum Δmv that occurs during the collision?

[1 mark]

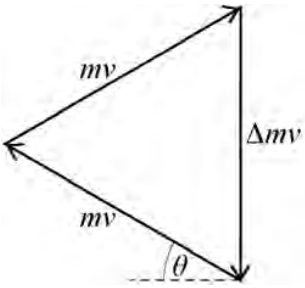
A



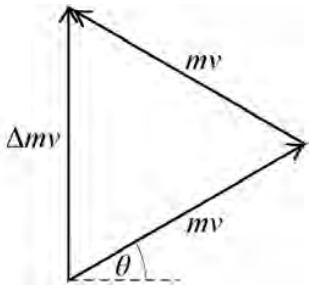
B



C



D



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 9 The Earth can be assumed to be a uniform sphere of radius R.

What is the mean density of the Earth?

[1 mark]

A $\frac{3g}{4\pi RG}$ ⬭

B $\frac{3RG}{4\pi g}$ ⬭

C $\frac{3G}{4\pi Rg}$ ⬭

D $\frac{3Rg}{4\pi G}$ ⬭

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	⬭

3 1 During a single fission event of uranium-235 in a nuclear reactor the total mass lost is 0.23 u. The reactor is 25% efficient.

How many events per second are required to generate 900 MW of power?

[1 mark]

A 1.1×10^{14} ⬭

B 6.6×10^{18} ⬭

C 1.1×10^{20} ⬭

D 4.4×10^{20} ⬭

0 9 An electron collides with an isolated atom and raises an orbiting electron to a higher energy level.

Which statement is correct?

[1 mark]

A The colliding electron is captured by the nucleus of the atom. ⬭

B A photon is emitted when the electron rises to the higher energy level. ⬭

C An electron is emitted when the excited electron returns to the ground state. ⬭

D Energy is transferred from the colliding electron to the orbiting electron. ⬭

1 0 Light of frequency 2.0×10^{15} Hz is incident on a metal surface. The work function of the metal is 4.6×10^{-19} J.

Which statement is correct?

[1 mark]

A No photoelectrons are released. ⬭

B Photoelectrons are released with a maximum kinetic energy of 3.1×10^{-19} J. ⬭

C Photoelectrons are released with a maximum kinetic energy of 8.7×10^{-19} J. ⬭

D Photoelectrons are released with a maximum kinetic energy of 18×10^{-19} J. ⬭

1 1 A photon of ultraviolet radiation has a frequency of 1.5×10^{15} Hz.

What is the momentum of the photon?

[1 mark]

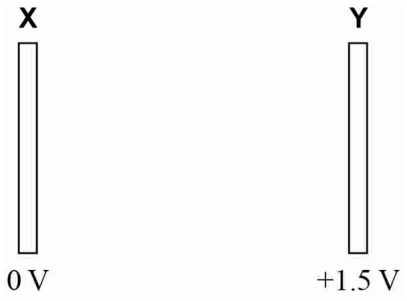
A 3.3×10^{-41} kg m s^{-1} ⬭

B 1.3×10^{-40} kg m s^{-1} ⬭

C 3.3×10^{-27} kg m s^{-1} ⬭

D 1.3×10^{-26} kg m s^{-1} ⬭

2 2 Charged plates **X** and **Y** have a potential difference $1.5\ \text{V}$ between them.



Which particle gains $3.0\ \text{eV}$ of kinetic energy when moving from **Y** to **X**?

[1 mark]

A proton ⬭

B positron ⬭

C electron ⬭

D alpha particle ⬭

2 8 An object of mass m moves in a circle of radius r. It completes n revolutions every second.

What is the kinetic energy of the object?

[1 mark]

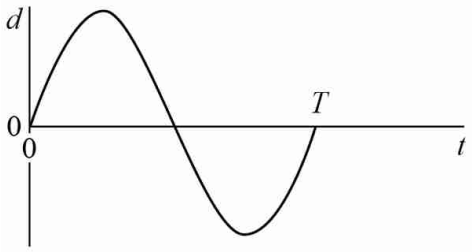
A $\frac{mn^2r^2}{8\pi^2}$ ⬭

B $\frac{mn^2r^2}{4\pi^2}$ ⬭

C $2m\pi^2n^2r^2$ ⬭

D $4m\pi^2n^2r^2$ ⬭

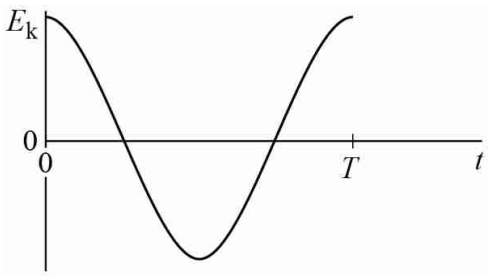
2 9 The graph shows the variation of displacement d with time t for a particle moving with simple harmonic motion of period T.



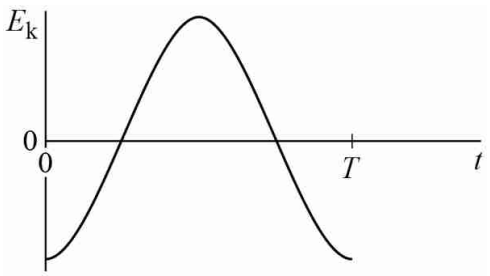
Which graph shows the variation of kinetic energy E_k of the particle with time?

[1 mark]

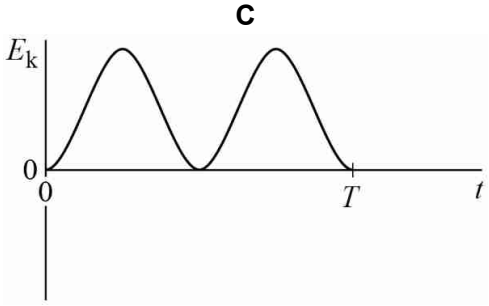
A



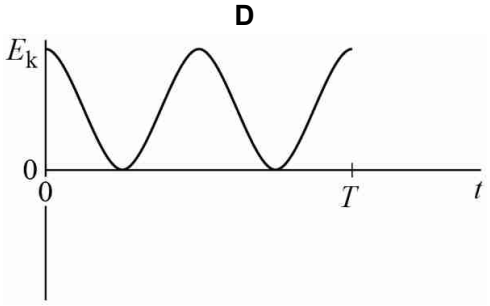
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

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	⬭

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

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

[1 mark]

A gravitational force on the satellite ⬭

B angular speed ⬭

C kinetic energy ⬭

D orbital period ⬭

1 3 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 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 5 Which is **not** an assumption about gas particles in the kinetic theory model for a gas?

[1 mark]

A They collide elastically with the container walls. ⬭

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

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

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

3 1 What effect are the control rods intended to have on the average kinetic energy and number of fission neutrons in a thermal nuclear reactor?

[1 mark]

	Average kinetic energy of fission neutrons	Number of fission neutrons	
A	unchanged	unchanged	⬭
B	reduced	unchanged	⬭
C	unchanged	reduced	⬭
D	increased	reduced	⬭

END OF QUESTIONS

0 8 A photon has energy of 1×10^{18} eV.
An object of mass 0.03 kg has kinetic energy equal to the energy of the photon.

What is the speed of the object?

[1 mark]

A $1\ \text{m s}^{-1}$ ⬭

B $3\ \text{m s}^{-1}$ ⬭

C $10\ \text{m s}^{-1}$ ⬭

D $30\ \text{m s}^{-1}$ ⬭

1 2 An electron collides with an isolated atom and raises an atomic electron to a higher energy level.

Which statement is correct?

[1 mark]

A The colliding electron is captured by the nucleus of the atom. ⬭

B A photon is emitted when the electron rises to the higher energy level. ⬭

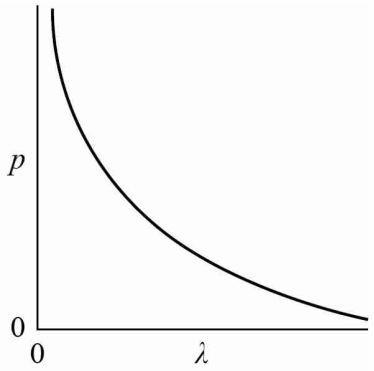
C An electron is emitted when the excited electron returns to the ground state. ⬭

D The colliding electron transfers energy to the atomic electron. ⬭

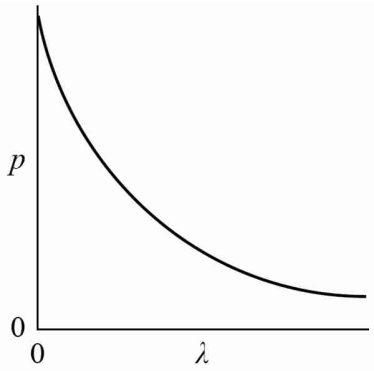
1 3 Which graph shows the variation of momentum p with wavelength λ of a photon?

[1 mark]

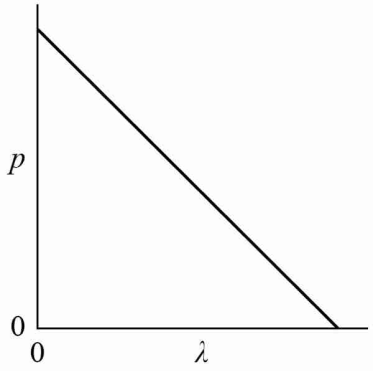
A



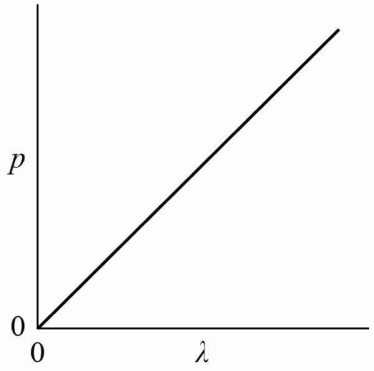
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

2 5 A mass of $0.90\ \text{kg}$ is suspended from the lower end of a light spring of stiffness $80\ \text{N m}^{-1}$.

When the mass is displaced vertically and released, it undergoes vertical oscillations of small amplitude.

What is the frequency of the oscillations?

[1 mark]

A $0.071\ \text{Hz}$ ⬭

B $0.67\ \text{Hz}$ ⬭

C $1.50\ \text{Hz}$ ⬭

D $14\ \text{Hz}$ ⬭

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

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

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

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

[1 mark]

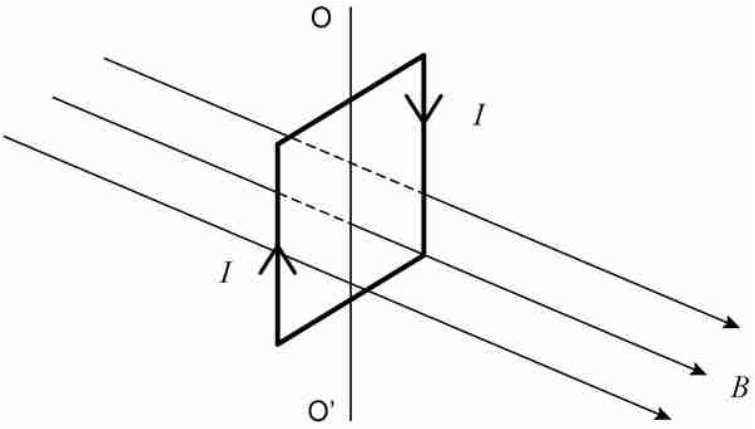
A $\frac{2}{3}E$ ⬭

B $\frac{3}{4}E$ ⬭

C $\frac{4}{3}E$ ⬭

D $\frac{3}{2}E$ ⬭

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]

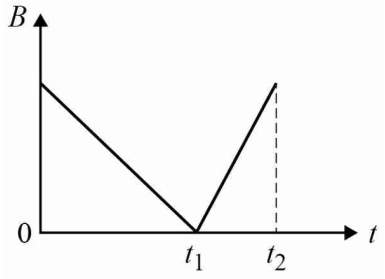
A The forces on the vertical sides of the coil are equal in magnitude and opposite in direction. ⬭

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. ⬭

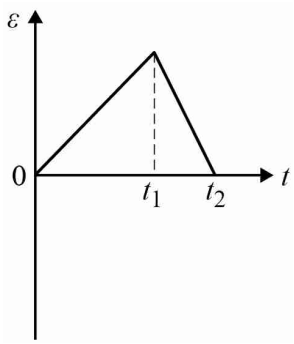
2 6 The diagram shows the variation with time t of the magnetic flux density B of the field linking a coil.



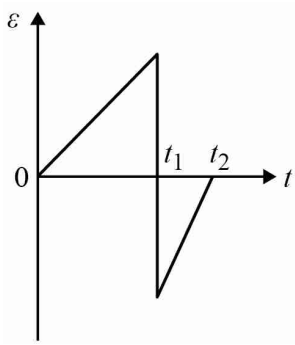
Which graph shows the variation of induced emf ε in the coil during this time interval?

[1 mark]

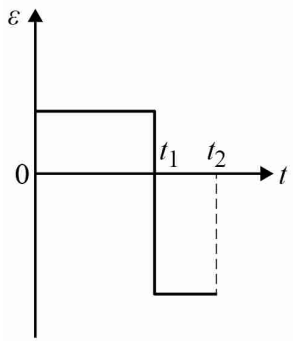
A



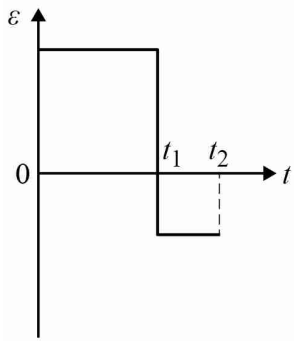
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

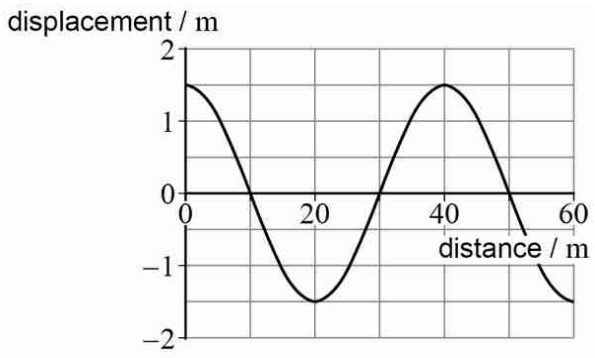
1 6 A muon and an electron are travelling at the same speed.

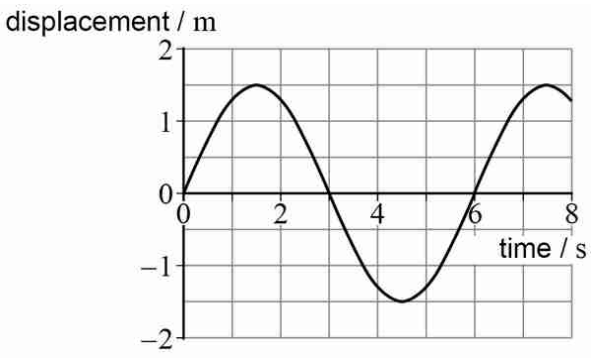
Which row gives the particle with the greater kinetic energy and the particle with the longer de Broglie wavelength?

[1 mark]

	Greater kinetic energy	Longer de Broglie wavelength	
A	muon	muon	⬭
B	muon	electron	⬭
C	electron	muon	⬭
D	electron	electron	⬭

1 7 The diagrams show the displacement–distance graph for a wave and the displacement–time graph for a point in the wave.





Which is correct for this wave?

[1 mark]

A The amplitude is $3.0\ \text{m}$. ⬭

B The wavelength is $6\ \text{m}$. ⬭

C The speed is $8.3\ \text{m s}^{-1}$. ⬭

D The frequency is $0.17\ \text{Hz}$. ⬭

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

What is the maximum kinetic energy of the particle?

[1 mark]

A $\frac{mA^2}{2T^2}$ ⬭

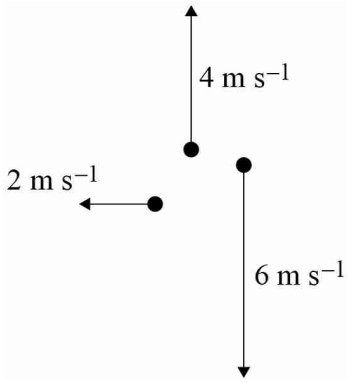
B $\frac{\pi^2 mA^2}{2T^2}$ ⬭

C $\frac{2mA^2}{T^2}$ ⬭

D $\frac{2\pi^2 mA^2}{T^2}$ ⬭

END OF QUESTIONS

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



What is the root mean square speed of the particles?

[1 mark]

A 4.3 m s^{-1} ⬭

B 7.5 m s^{-1} ⬭

C 19 m s^{-1} ⬭

D 56 m s^{-1} ⬭

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]

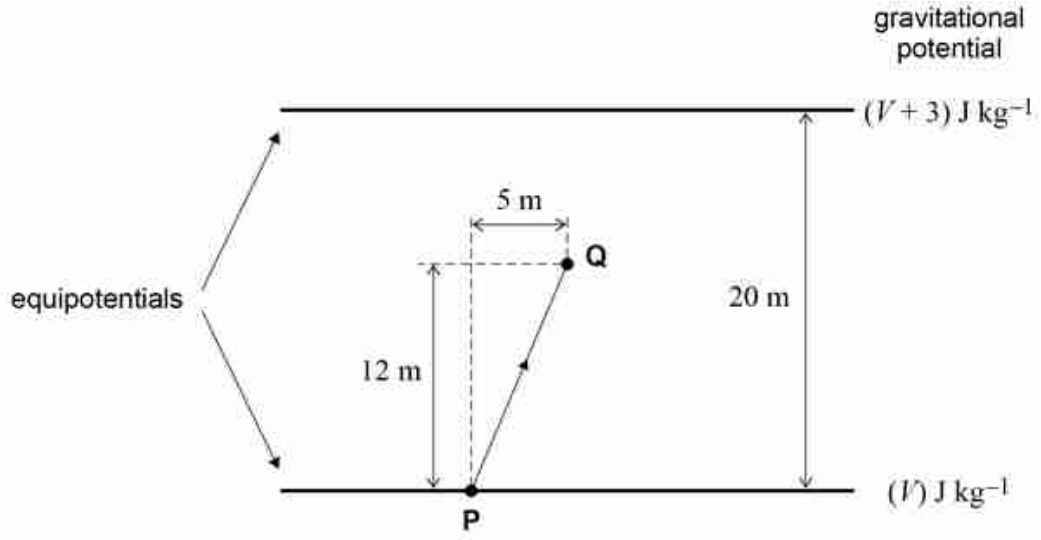
A $2g$ ⬭

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]

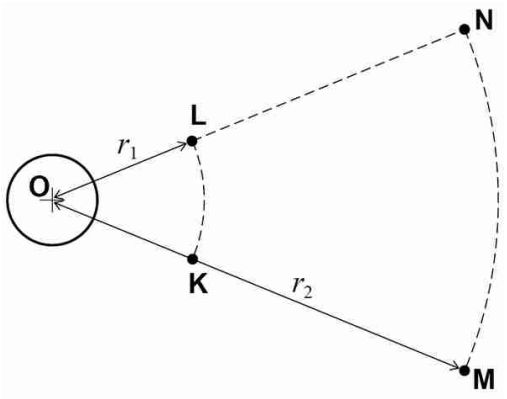
A 7.2 J ⬭

B 7.8 J ⬭

C 10.2 J ⬭

D 36 J ⬭

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**. ⬭

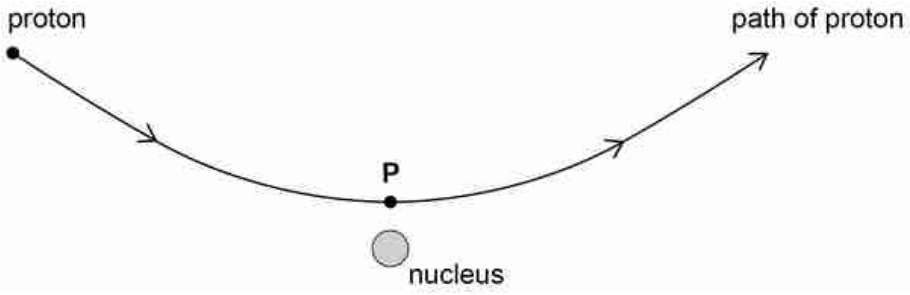
2 5 The primary winding of a transformer has 200 turns and the secondary winding has 1600 turns.
A root mean square (rms) alternating voltage of 25 V is applied to the primary winding causing a primary rms current of 4.0 A. The transformer is 90% efficient.

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 6 The diagram shows the path of a proton being deflected by the nucleus of an atom. Point **P** is the position of the proton when it is closest to the nucleus.



What is **not** true about the proton along its path at **P**?

[1 mark]

A Its rate of change of momentum is at a minimum. ⬭

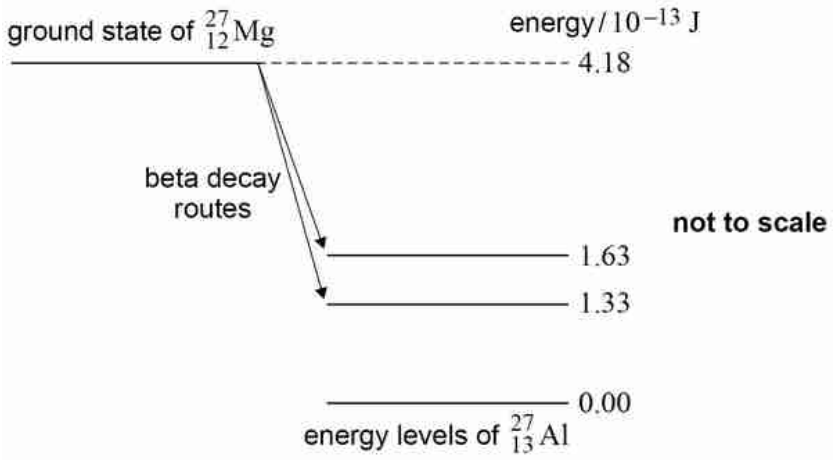
B Its kinetic energy is at a minimum. ⬭

C Its potential energy is at a maximum. ⬭

D Its acceleration is at a maximum. ⬭

3 1 $^{27}_{12}\text{Mg}$ can decay by beta minus emission to one of two possible excited states of $^{27}_{13}\text{Al}$.

Both excited states decay by the emission of a gamma photon directly to the ground state.



The diagram shows the energy levels and two routes for the beta decay.

One route results in the emission of a gamma photon with a higher frequency than the other photon.

What is the maximum possible kinetic energy for the beta particle emitted in this route?

[1 mark]

A 1.33×10^{-13} J ⬭

B 1.63×10^{-13} J ⬭

C 2.55×10^{-13} J ⬭

D 2.85×10^{-13} J ⬭

END OF QUESTIONS

1 4 In photoelectricity, V_s is the stopping potential.

What quantity is eV_s?

[1 mark]

A energy of an incident photon ⬭

B maximum kinetic energy of a photoelectron ⬭

C threshold frequency × the Planck constant ⬭

D work function ⬭

1 9 The frequency of the first harmonic of a standing wave on a string is f.
The tension in the string is T.
The tension is increased to $4T$ without changing the length or mass of the string.

Which harmonic has a frequency $2f$ after this change?

[1 mark]

A first ⬭

B second ⬭

C third ⬭

D fourth ⬭

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

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

[1 mark]

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

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 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 $3.9 \times 10^{-2}\ \text{T}$ ⬭

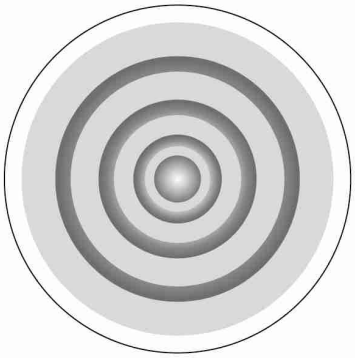
C $2.2 \times 10^{-2}\ \text{T}$ ⬭

D $4.0 \times 10^{-3}\ \text{T}$ ⬭

1 3 Electrons with a certain kinetic energy pass through a powdered crystalline sample and are incident on a fluorescent screen.
The diagram shows a sketch of the diffraction pattern produced.



A change is made and this second pattern is produced.



Which change could produce the second pattern?

[1 mark]

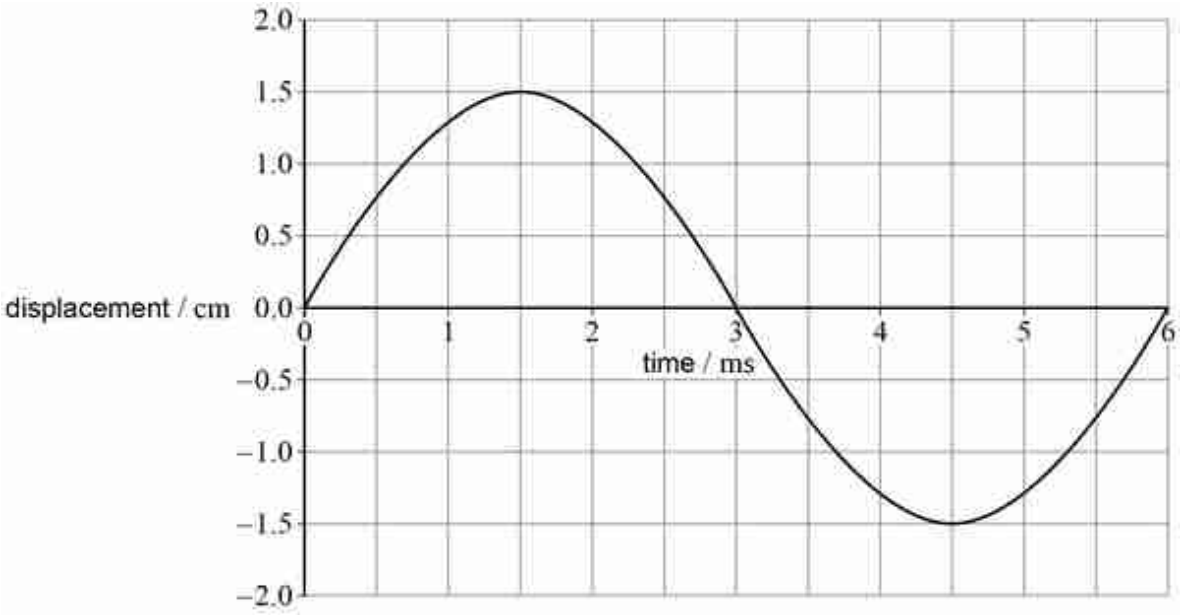
A decreasing the kinetic energy of the electrons ⬭

B replacing the electrons with protons with the same kinetic energy ⬭

C using a crystalline sample with a wider spacing between its atoms ⬭

D moving the screen closer to the crystalline sample ⬭

1 4 A string with a length of 1.2 m vibrates at its second harmonic.
The diagram shows the displacement–time graph for a point on the string.

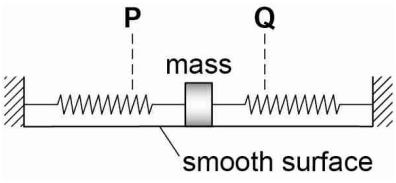


What are the wavelength and frequency of the wave on the string?

[1 mark]

	Wavelength / m	Frequency / kHz	
A	0.6	0.17	⬭
B	0.6	0.34	⬭
C	1.2	0.17	⬭
D	1.2	0.34	⬭

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



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

[1 mark]

A the acceleration of the mass ⬭

B the kinetic energy of the mass ⬭

C the potential energy of the mass–spring system ⬭

D the resultant force of the springs on the mass ⬭

END OF QUESTIONS

1 9 An alpha particle is moving towards a stationary gold nucleus. The alpha particle has a kinetic energy of 9.0×10^{-13} J when it is a large distance from the gold nucleus.
The gold nucleus contains 79 protons.

What is the closest possible distance of approach of the alpha particle to the gold nucleus?
[1 mark]

A 2.5×10^{-16} m ⬭

B 2.0×10^{-14} m ⬭

C 4.0×10^{-14} m ⬭

D 2.0×10^{-7} m ⬭

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

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

What is the magnetic flux density of the field?

[1 mark]

A $6.0 \times 10^{-6}\ \text{T}$ ⬭

B $6.0 \times 10^{-3}\ \text{T}$ ⬭

C $1.7 \times 10^{2}\ \text{T}$ ⬭

D $1.7 \times 10^{5}\ \text{T}$ ⬭

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. ⬭

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 ⬭

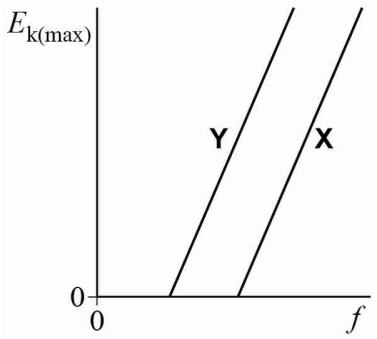
D 5.75 A ⬭

0 9 In two separate experiments, electromagnetic radiation of variable frequency f is incident on the surfaces of plates made from metals **X** and **Y**.
The work function of **X** is greater than the work function of **Y**.

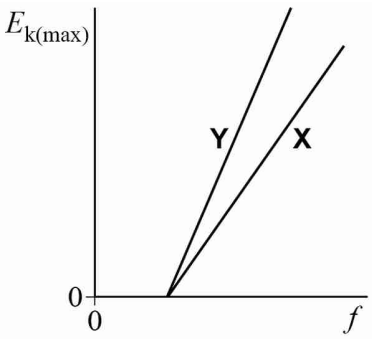
Which graph shows how the maximum kinetic energy $E_{k(max)}$ of photoelectrons emitted from the surfaces of the plates varies with f?

[1 mark]

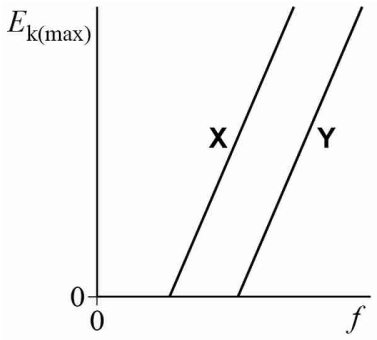
A



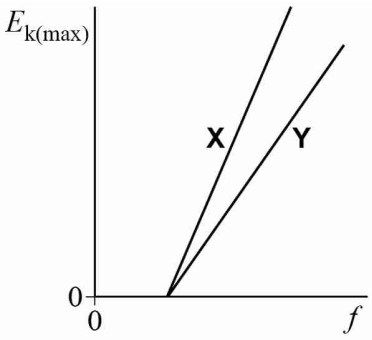
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

1 0 Monochromatic light is incident on a metal surface in a vacuum and photoelectrons are emitted from the surface. The photoelectric current I is the rate of flow of charge from the surface.
The maximum kinetic energy of the photoelectrons is $E_{k(max)}$.
$E_{k(max)}$ and I are measured.

The frequency of the light is then increased. There is no change to the rate at which energy is incident on the surface.

What happens to $E_{k(max)}$ and I when the frequency is increased?

[1 mark]

	$E_{k(max)}$	I	
A	increases	decreases	⬭
B	increases	no change	⬭
C	no change	no change	⬭
D	no change	decreases	⬭

2 9 A particle of mass m moves in a circle of radius r. The number of revolutions completed per second is f.

What is the kinetic energy of the particle?

[1 mark]

A $4\pi^2 mf^2 r^2$ ⬭

B $2\pi^2 mf^2 r^2$ ⬭

C $\frac{mf^2 r^2}{4\pi^2}$ ⬭

D $\frac{mf^2 r^2}{2}$ ⬭

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

[1 mark]

A doubling the pressure at constant volume ⬭

B doubling the volume at constant pressure ⬭

C doubling the absolute temperature at constant volume ⬭

D doubling the pressure at constant temperature ⬭

1 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 ⬭

1 5 A transmission cable consists of many strands of wire. Electrical energy is transmitted along the cable at a frequency of 50 Hz.

Which change gives the largest increase in the efficiency of the electrical energy transfer along the cable?

[1 mark]

A doubling the transmission voltage of the cable ⬭

B doubling the current in the cable ⬭

C halving the resistivity of the material of the wires ⬭

D halving the number of wires in the cable ⬭

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]

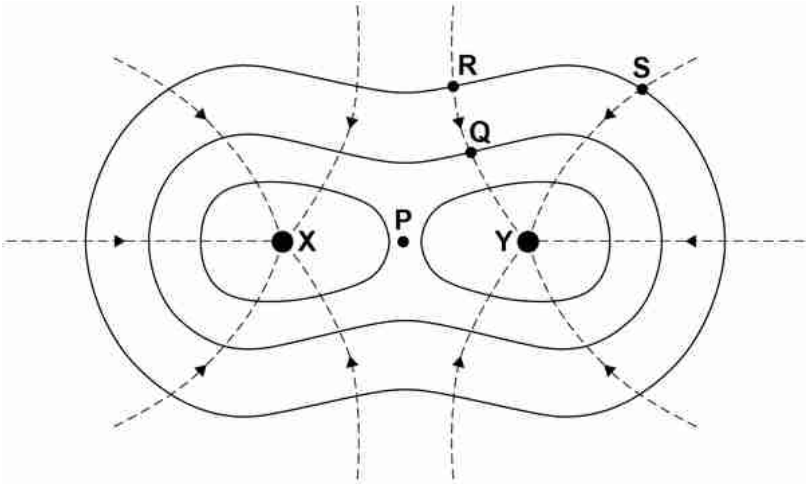
A $\frac{2\pi m_e}{Be}$ ⬭

B $\frac{2\pi r}{v}$ ⬭

C $\frac{v}{\pi r}$ ⬭

D $\frac{Be}{2\pi m_e}$ ⬭

2 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. ⬭

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 ⬭

1 0 In β^- decay:

[1 mark]

A energy is conserved. ⬭

B an up quark changes into a down quark. ⬭

C the interaction occurs outside the nucleus of an atom. ⬭

D momentum is not conserved. ⬭

1 4 In an investigation of stationary waves on different wires, the frequency f of the first harmonic is measured.

Which quantity produces a straight-line graph through the origin when plotted against f? In each case all other variables are kept constant.

[1 mark]

A $\dfrac{1}{\text{diameter of the wire}}$ ⬭

B (mass per unit length of the wire)^2 ⬭

C length of the wire ⬭

D (tension in the wire)^2 ⬭

2 5 A pendulum is oscillating with simple harmonic motion.

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

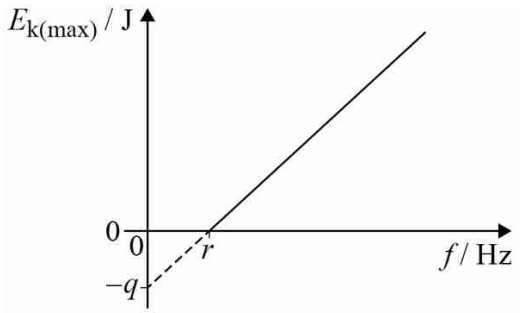
[1 mark]

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

3 0 In a photoelectric experiment, the maximum kinetic energy $E_{k(max)}$ of the emitted electrons and the frequency f of the incident radiation are measured.

A graph of the variation of $E_{k(max)}$ with f has:

- a gradient p
- an intercept $-q$ on the $E_{k(max)}$ axis
- an intercept r on the f axis.



What is the value of the Planck constant?

[1 mark]

A $\frac{p}{r}$ ⬭

B $\frac{r}{p}$ ⬭

C $\frac{r}{q}$ ⬭

D $\frac{q}{r}$ ⬭

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 $\frac{2}{9}v$ ⬭

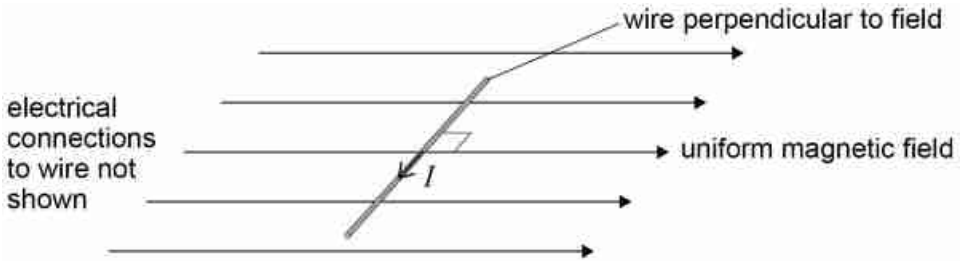
B $\frac{\sqrt{2}}{3}v$ ⬭

C $\sqrt{\frac{2}{3}}v$ ⬭

D $\frac{2}{\sqrt{3}}v$ ⬭

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]

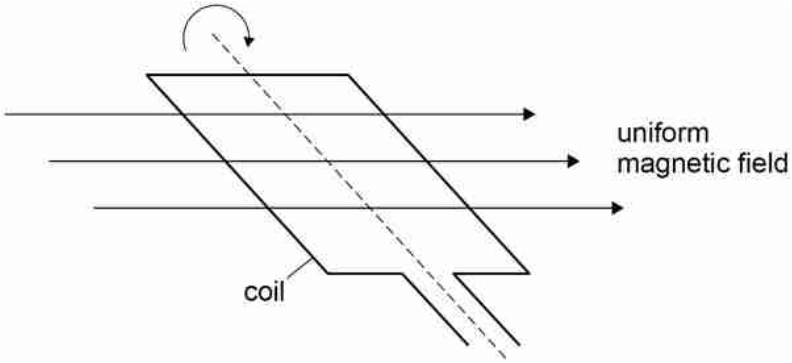
A $\frac{I}{2}$ ⬭

B I ⬭

C $2I$ ⬭

D $4I$ ⬭

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]

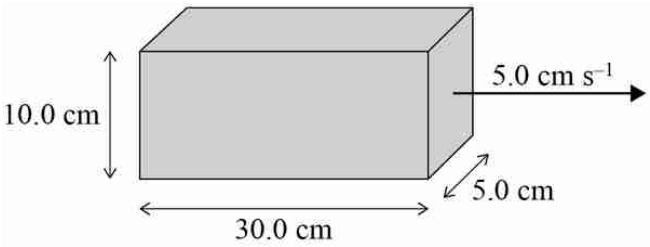
A 0 ⬭

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% ⬭

2 8 Polonium-210 decays into lead-206 by emitting an alpha particle.

mass of nucleus of polonium-210 = 209.983 u
mass of nucleus of lead-206 = 205.975 u
mass of alpha particle = 4.003 u

Assume that the recoil speed of the lead nucleus is negligible.

What is the kinetic energy of the emitted alpha particle?

[1 mark]

A 5.0 meV ⬭

B 4.0 MeV ⬭

C 4.7 MeV ⬭

D 3.7 GeV ⬭

0 4 The deuterium–tritium (D–T) reaction is a nuclear reaction between two isotopes of hydrogen.
The D–T reaction is

$$^{2}_{1}\mathrm{H} + ^{3}_{1}\mathrm{H} \rightarrow ^{4}_{2}\mathrm{He} + \mathrm{n}$$

The energy from this reaction is transferred to the kinetic energy of the helium nucleus and the kinetic energy of the neutron.
Assume that the kinetic energies of the hydrogen nuclei are zero just before the reaction occurs.

0 4 . 1 Show that the kinetic energy of the neutron represents approximately 80% of the total energy transferred.

[2 marks]

0 4 . 2 The combined kinetic energy of the helium nucleus and the neutron is 2.82×10^{-12} J.

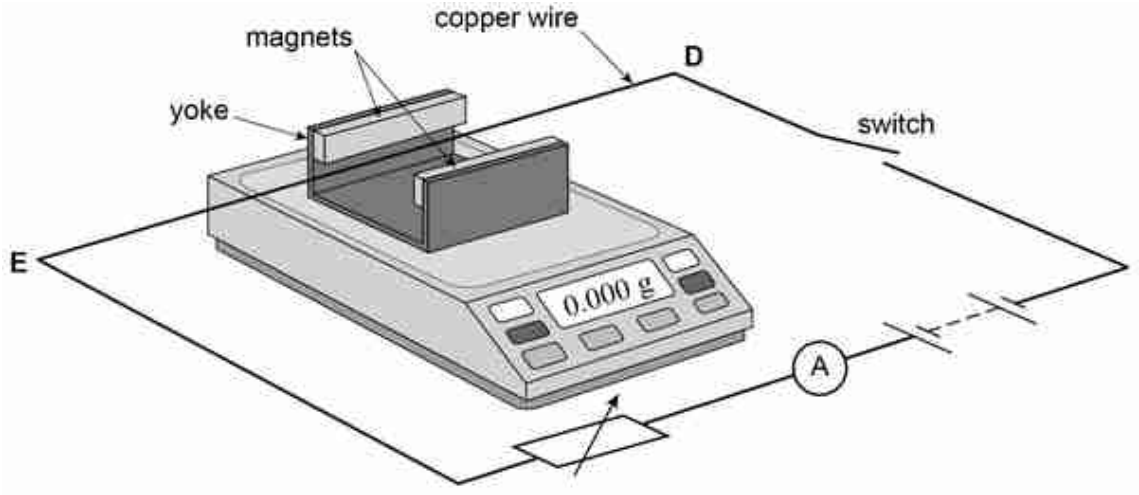
Calculate the initial speed of the neutron.

[2 marks]

initial speed = _____ $\mathrm{m\ s^{-1}}$

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

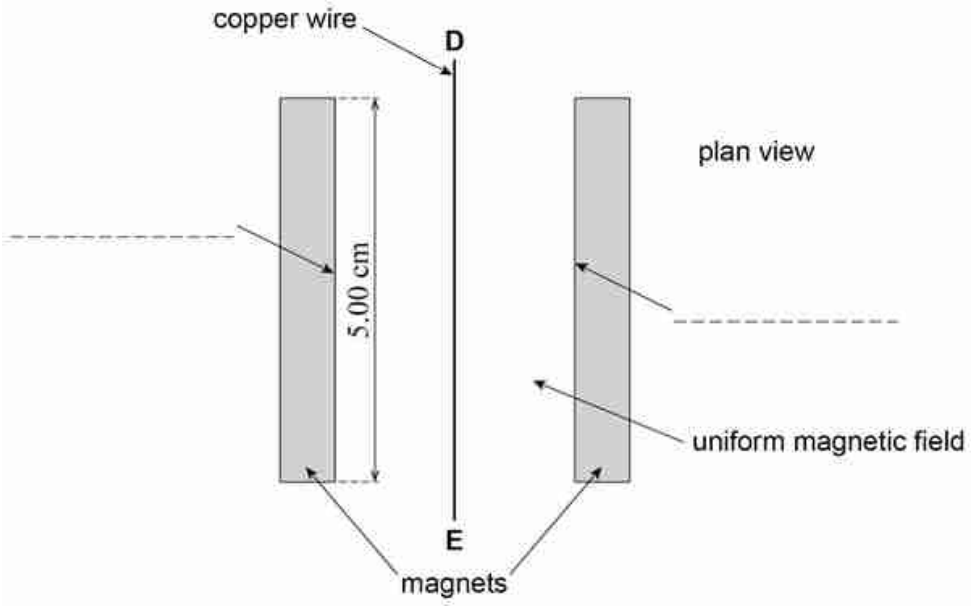
Figure 2



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 cm long. When the current in the wire is 3.43 A the reading on the electronic balance is 0.620 g.

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

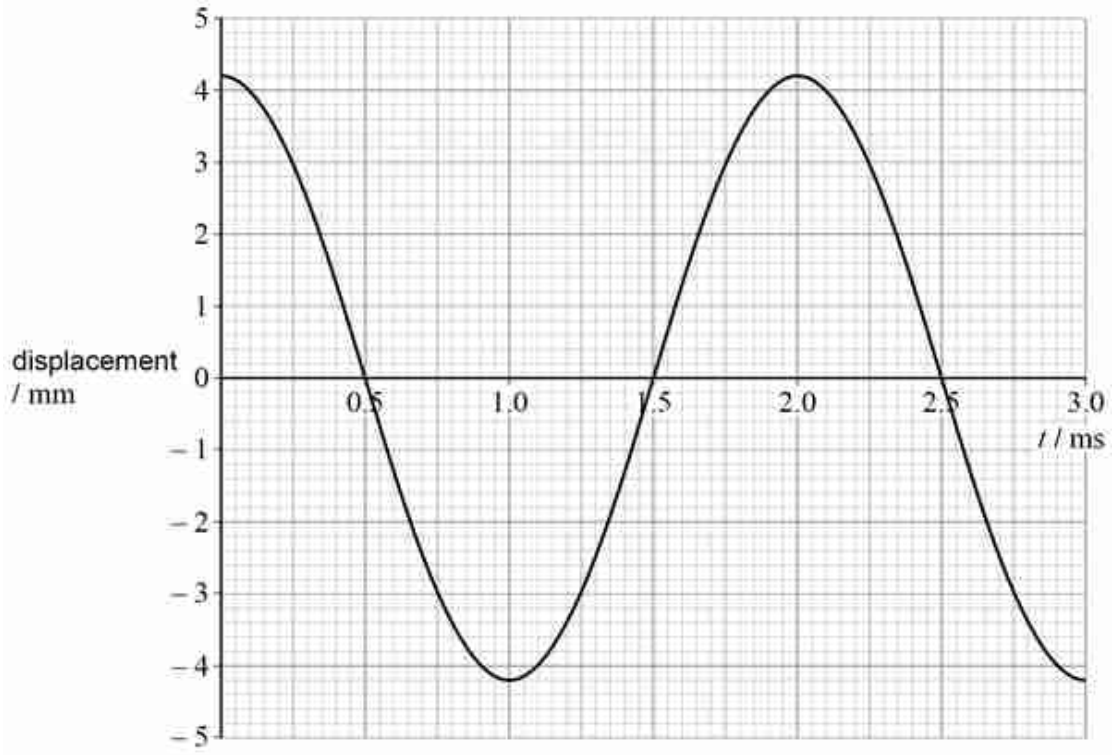
Calculate the magnetic flux density between the magnets.

[2 marks]

magnetic flux density = _____ T

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

Figure 8



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

time = _____ ms

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

acceleration = _____ m s^{-2}

Question 6 continues on the next page

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

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

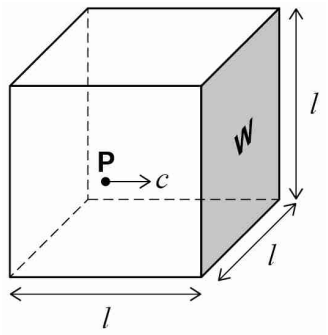
[1 mark]

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

[1 mark]

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

Figure 1



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

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

[1 mark]

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

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

[1 mark]

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

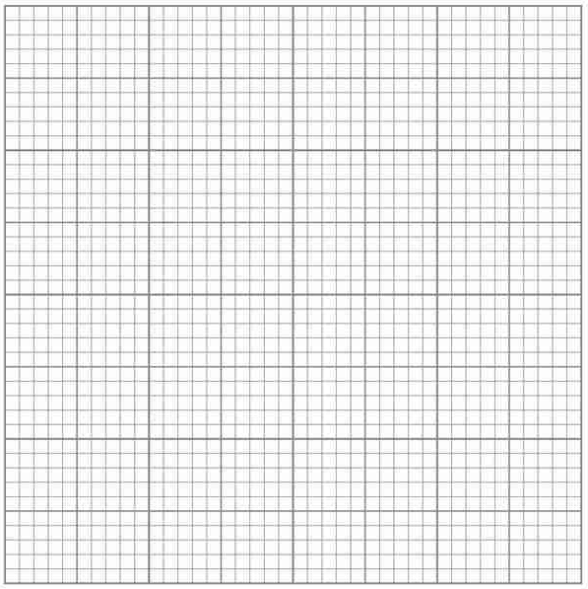
[2 marks]

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

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

[4 marks]

Figure 4



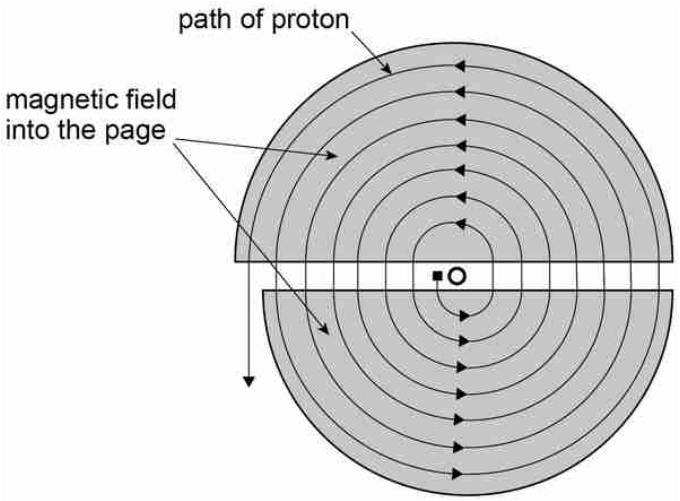
0 3 . 2 Label, with a **P**, a point on your graph where the mass has 50% of its maximum kinetic energy.

[1 mark]

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

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

Figure 4



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

[1 mark]

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

[3 marks]

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

Ignore any relativistic effects.

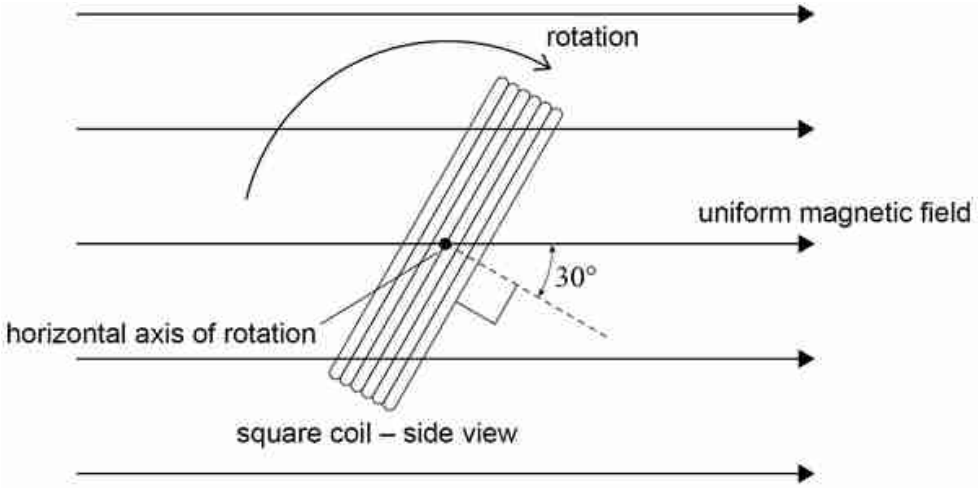
Calculate the maximum speed of a proton when it leaves the cyclotron.

[2 marks]

maximum speed = _____ m s^{-1}

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

Figure 4



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

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

Calculate the number of turns in the coil.

[2 marks]

number of turns = _____

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

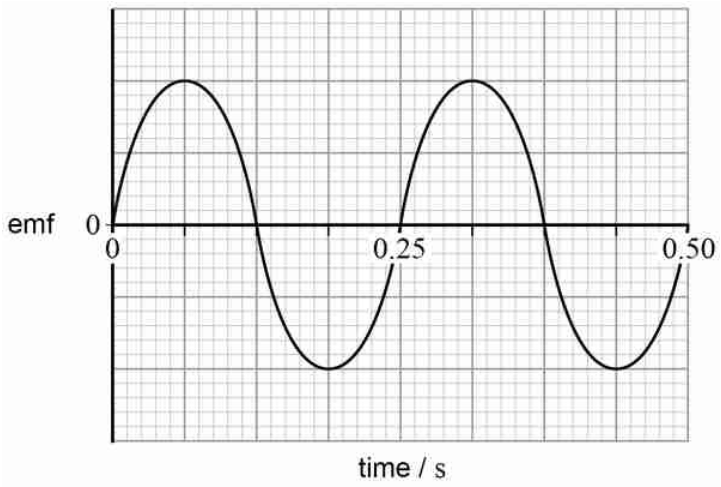
[1 mark]

flux linkage = _____ Wb turns

Question 5 continues on the next page

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

Figure 5



Calculate the peak value of the emf generated.

[2 marks]

emf = _____ V

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

[1 mark]

Figure 6

0 2 **Figure 1** shows an arrangement used by a student to investigate vibrations in a stretched nylon string of fixed length l. He measures how the frequency f of first-harmonic vibrations for the string varies with the mass m suspended from it.

Figure 1

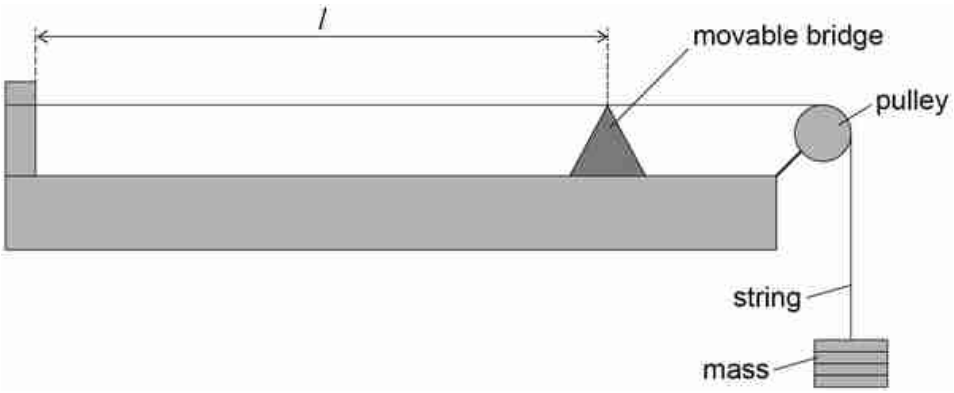


Table 1 shows the results of the experiment.

Table 1

m / kg	f / Hz
0.50	110
0.80	140
1.20	170

0 2 . 1 Show that the data in **Table 1** are consistent with the relationship

$$f \propto \sqrt{T}$$

where T is the tension in the nylon string.

[2 marks]

0 2 . 2 The nylon string used has a density of $1150\ \text{kg m}^{-3}$ and a uniform diameter of $5.0 \times 10^{-4}\ \text{m}$.

Determine the length l of the string used.

[3 marks]

l = _____ m

0 2 . 3 The student uses the relationship in question **02.1** to predict frequencies for tensions that are much larger than those used in the original experiment.

Explain how the actual frequencies produced would be different from those that the student predicts.

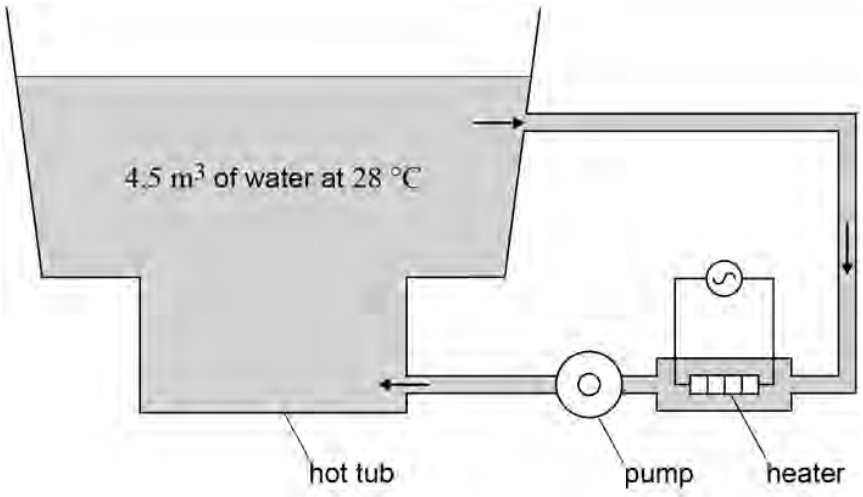
[2 marks]

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

[2 marks]

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

Figure 1



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

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

Assume that no heat is transferred to the surroundings.

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

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

[3 marks]

temperature rise = _____ K

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

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

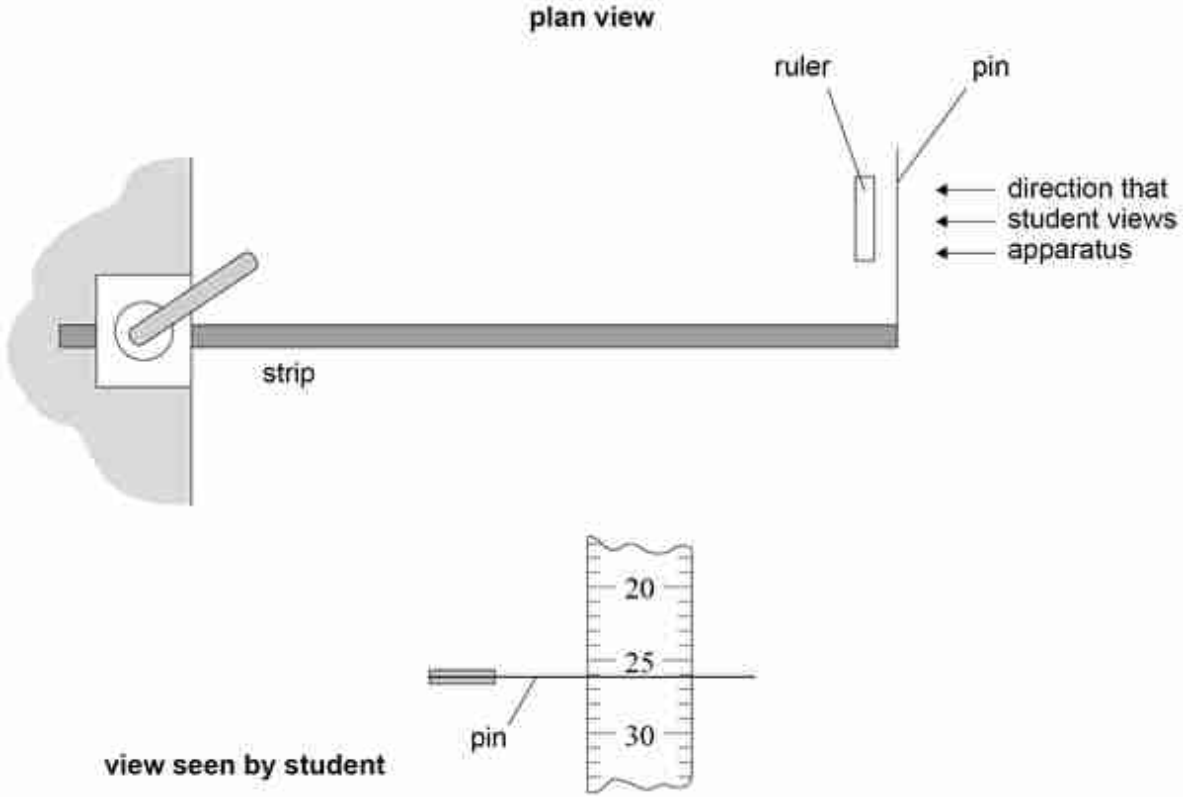
[2 marks]

0 2 **Figure 5** shows a strip of steel of rectangular cross-section clamped at one end. The strip extends horizontally over the edge of a bench.

Figure 5

0 2 . 1 A mass m is suspended from the free end of the strip.
This produces a vertical displacement y.
A student intends to measure y with the aid of a horizontal pin fixed to the free end of the steel strip.
She positions a clamped vertical ruler behind the pin, as shown in **Figure 6**.

Figure 6



Explain a procedure to avoid parallax error when judging the reading indicated by the position of the pin on the ruler.
You may add detail to **Figure 6** to illustrate your answer.

[2 marks]

Question 2 continues on the next page

0 2 . 2 It can be shown that

$$y = \frac{4mgL^3}{Ewt^3}$$

where:

L is the distance between the free end of the **unloaded** strip and the blocks
w is the width of the strip and is approximately $1\ \text{cm}$
t is the thickness of the strip and is approximately $1\ \text{mm}$
E is the Young modulus of the steel.

A student is asked to determine E using the arrangement shown in **Figure 5** with the following restrictions:

- only one steel strip of approximate length $30\ \text{cm}$ is available
- m must be made using a $50\ \text{g}$ mass hanger and up to four additional $50\ \text{g}$ slotted masses
- the experimental procedure must involve only **one** independent variable
- a graphical method must be used to get the result for E.

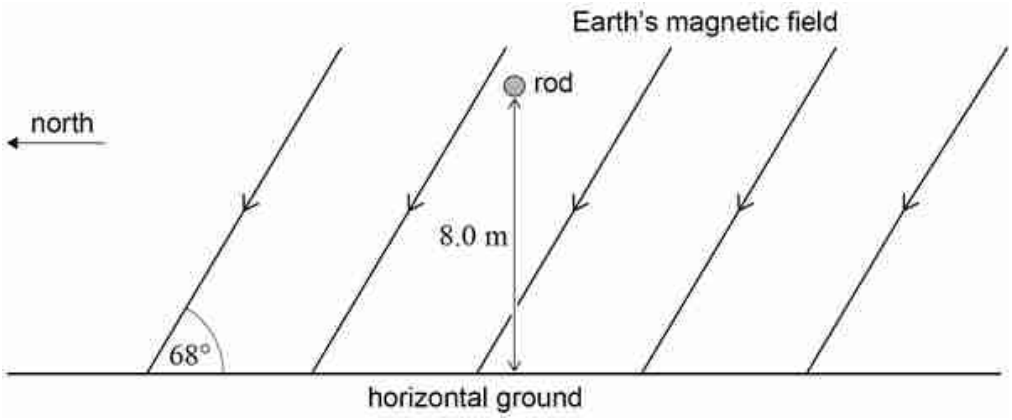
Explain what the student must do to determine E.

[5 marks]

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.

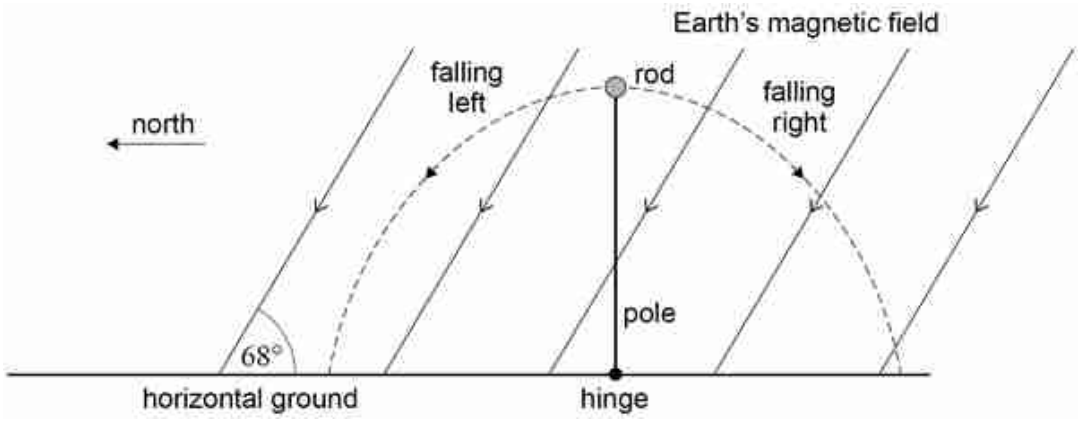
Determine the average emf across the rod during its fall to the ground.
Assume that air resistance is negligible.

[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 _____

_____

_____

_____

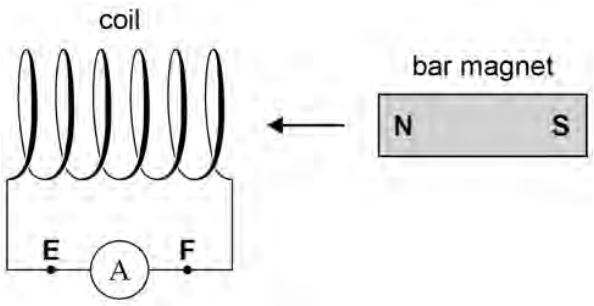
right _____

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]

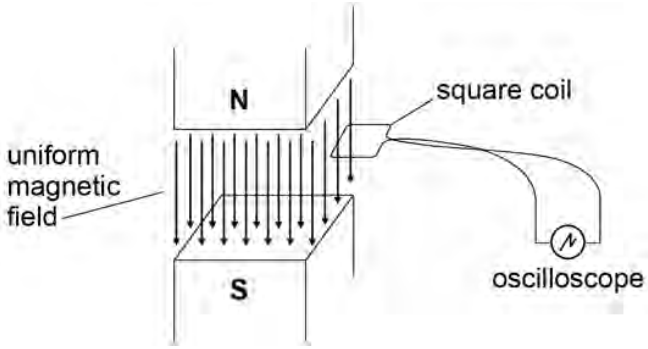
0 4 . 3 During the demonstration an induced current is detected by the ammeter. The induced current is in the direction **E** to **F**.

Explain how this demonstrates Lenz's law.

[2 marks]

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

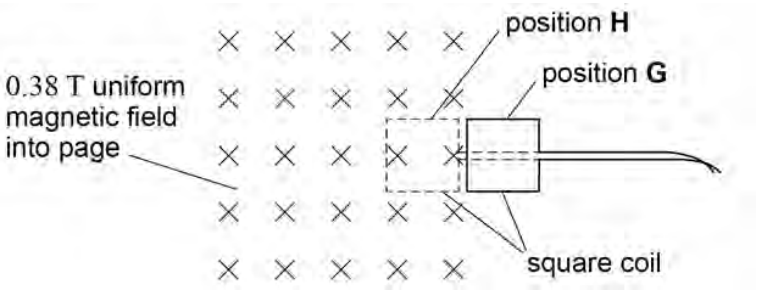
Figure 7



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**.

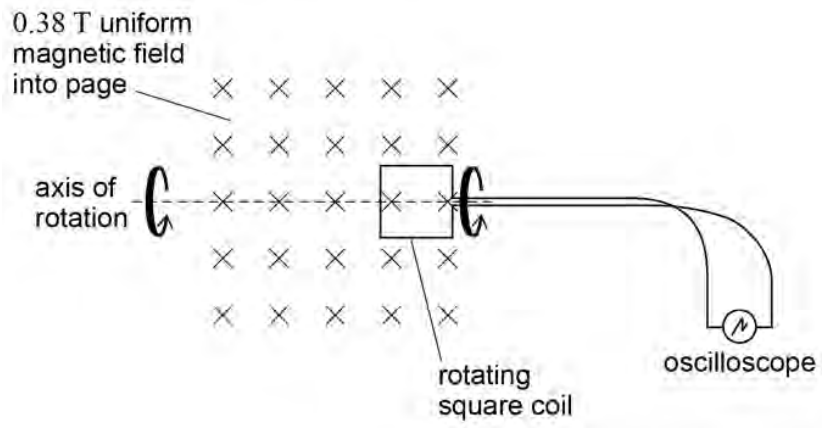
[2 marks]

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



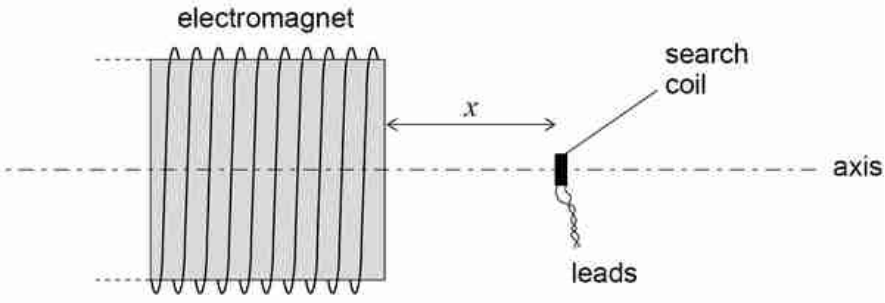
Calculate the angular speed of the coil when the maximum reading on the oscilloscope is 5.1 mV

[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]

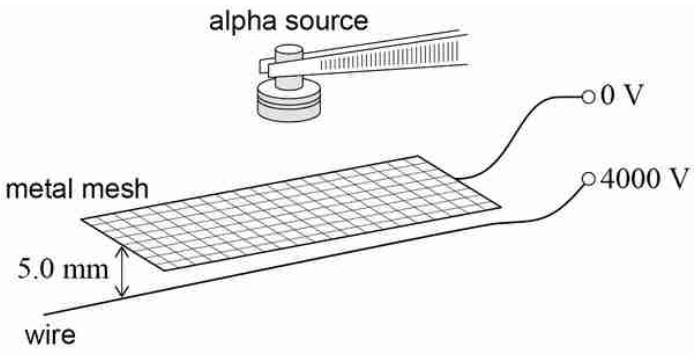
0 4 . 3 The search coil passes through the position where $x = 0.10\ \text{m}$.

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

[4 marks]

0 4 **Figure 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.

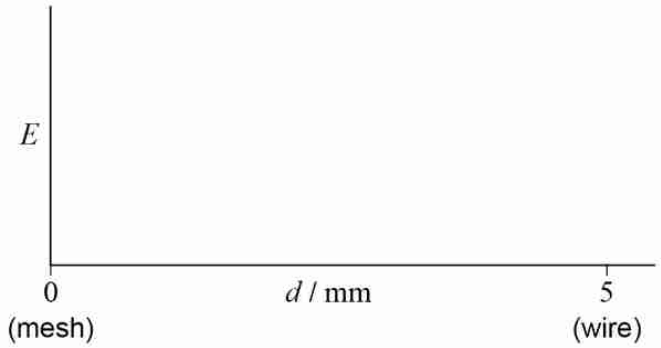
Figure 5

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 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

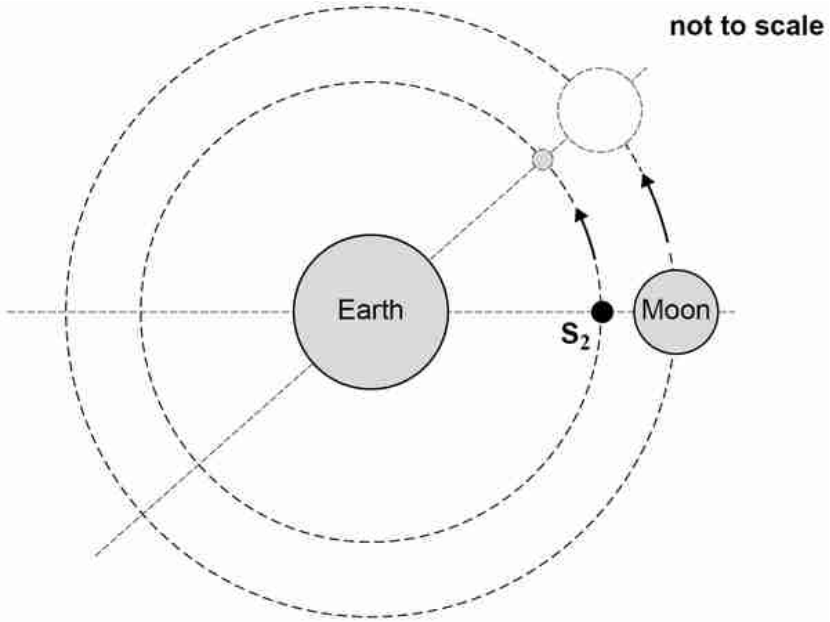
[2 marks]

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.

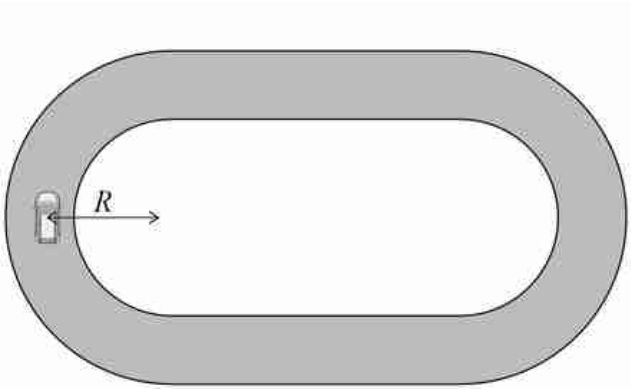
[3 marks]

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

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

Figure 10

not to scale



The car has kinetic energy E_k.

The resultant force acting on the car is F.

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

[2 marks]

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

The minimum value of R is 230 m.

$m = 1600$ kg

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

Deduce the speed of the car.

[1 mark]

speed = _____ m s^{-1}

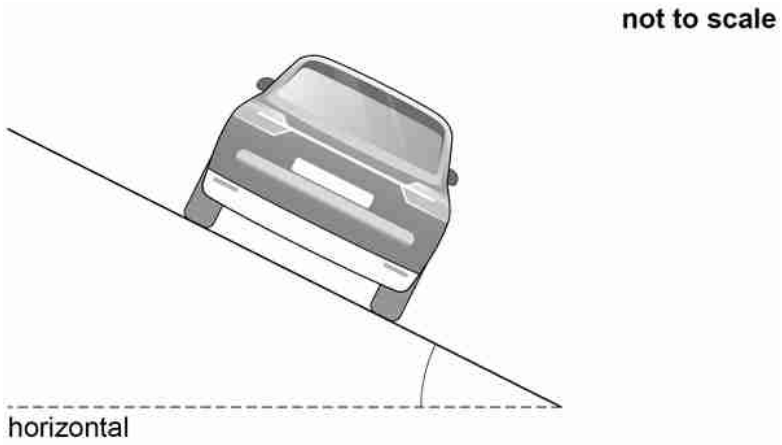
0 7 . 3 The driver wishes to drive this car around the curved section of the track, without slipping, at a speed greater than your answer to Question **07.2**.

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

[1 mark]

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

Figure 11



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

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

[2 marks]

Question 7 continues on the next page

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

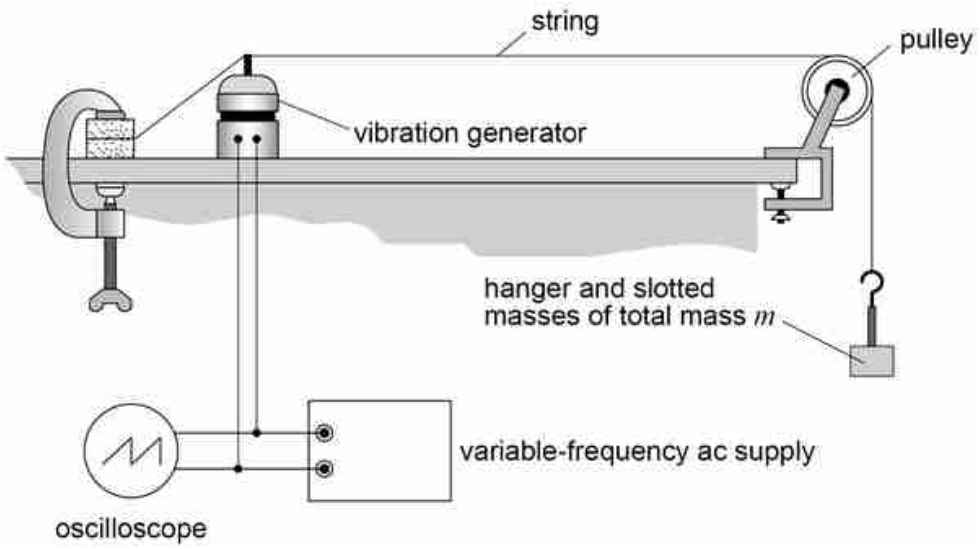
Explain why.

[2 marks]

0 1 This question is based on an investigation into how the frequency of the first-harmonic stationary wave on a string varies with tension (required practical activity 1).

Figure 1 shows the arrangement for this investigation.

Figure 1



The tension in the string is equal to the weight mg of the total mass m tied to the string.

The frequency is changed until the first-harmonic stationary wave appears on the string. This frequency f is determined using the oscilloscope.

The process is repeated for different values of m.

0 1 . 1 Identify **two** control variables for the arrangement shown in **Figure 1**.

You may annotate **Figure 1** as part of your answer.

[2 marks]

1 _____

_____

2 _____

_____

0 1 . 2 The total mass m is made from a mass hanger and up to three slotted masses.

One 20 g, one 50 g and one 100 g slotted mass are provided.
The hanger has a mass of 100 g.

The hanger must not be removed from the string.

Which statement is correct?

Tick (✓) **one** box.

[1 mark]

m has a maximum range of 170 g. ☐

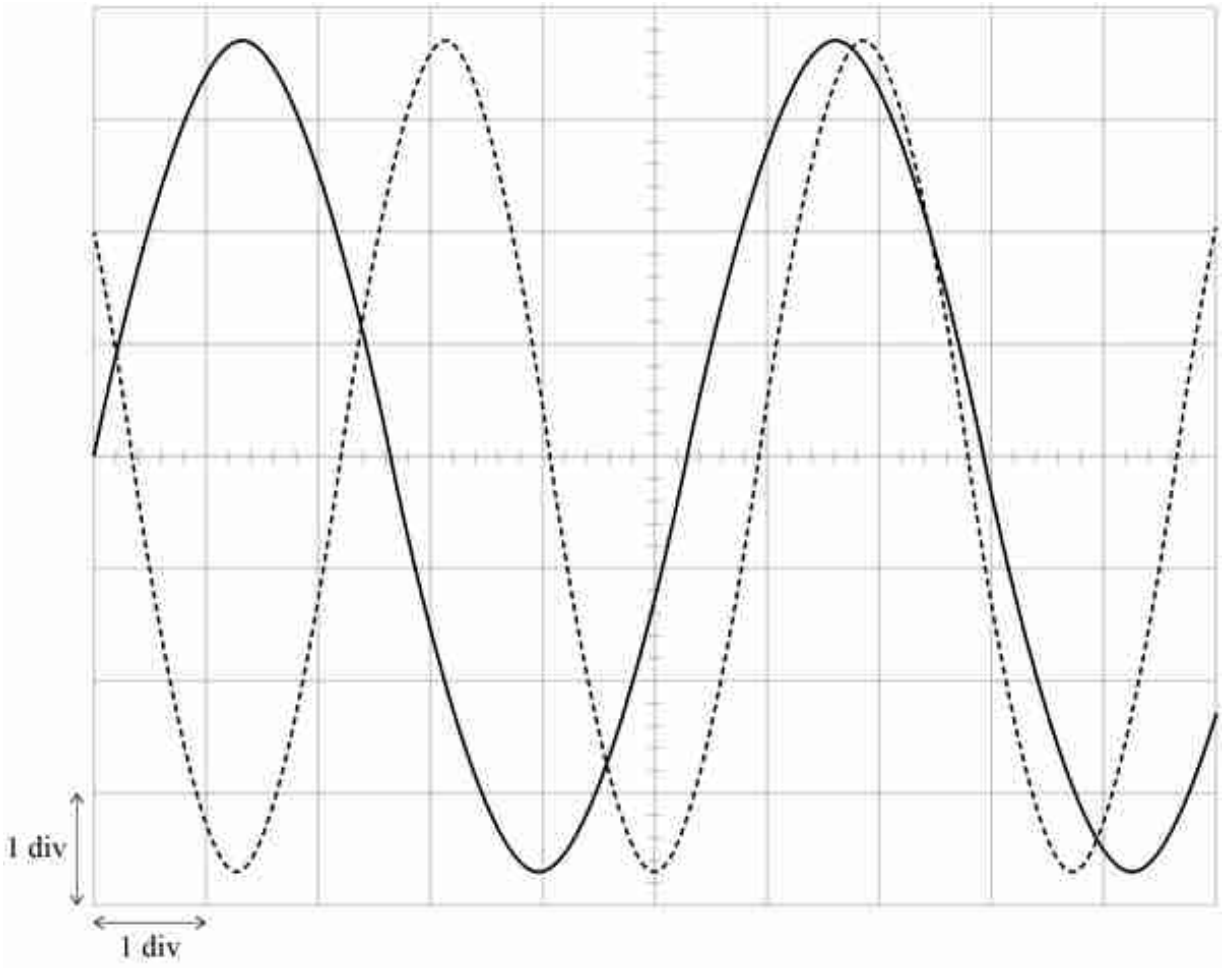
m has a maximum of 7 different values. ☐

m values are evenly distributed across the range. ☐

Question 1 continues on the next page

The frequency f is calculated using the waveform displayed on the oscilloscope.
Figure 2 shows the waveforms displayed on the oscilloscope when $m = 100$ g and when $m = 200$ g.

Figure 2



——— $m = 100$ g
---------- $m = 200$ g

The y-voltage gain setting is 5 V div^{-1}.
The time-base setting is 20 ms div^{-1}.

0 1 . 3 Determine V_{rms}, the root mean square voltage of the ac supply.

[2 marks]

V_{rms} = _____ V

0 1 . 4 Determine the period of the waveform on **Figure 2** when $m = 100$ g.

[1 mark]

period = _____ ms

0 1 . 5 Deduce whether **Figure 2** shows the expected result of doubling m from 100 g to 200 g.

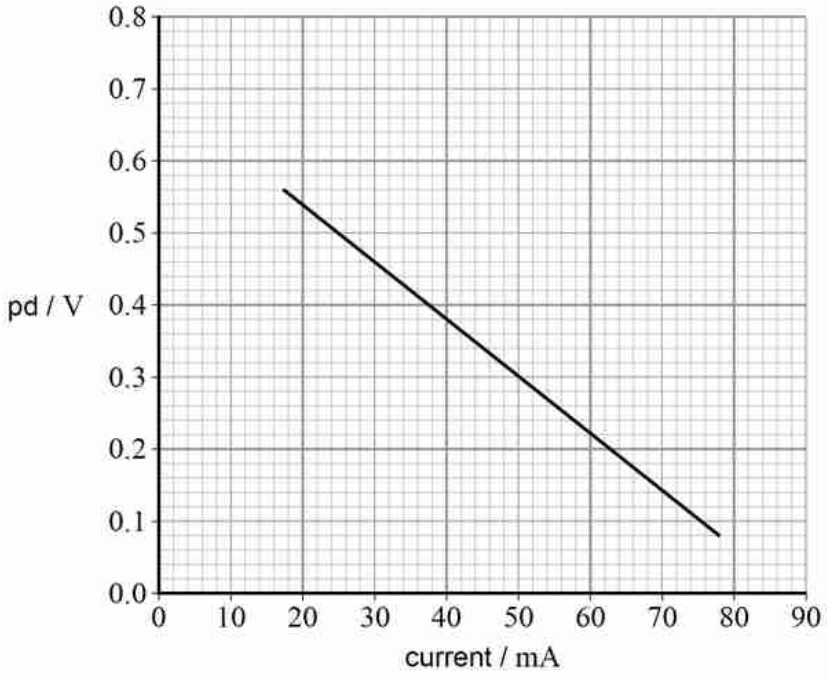
[2 marks]

0 4 An engineer wants to use solar cells to provide energy for a filament lamp in a road sign.

The engineer first investigates the emf and internal resistance of a solar cell under typical operating conditions.

The engineer determines how the potential difference across the solar cell varies with current. The results are shown in the graph in **Figure 4**.

Figure 4



The engineer uses the graph to deduce that when operating in typical conditions a single solar cell produces an emf of 0.70 V and has an internal resistance of $8.0\ \Omega$.

0 4 . 1 Explain how the engineer uses the graph to obtain the values for the emf and internal resistance of the solar cell.

[2 marks]

Question 4 continues on the next page

To operate effectively the lamp in the road sign needs a minimum current of $75\ \text{mA}$. At this current the resistance of the filament lamp is $6.0\ \Omega$.

The engineer proposes to try the two circuits shown in **Figure 5** and **Figure 6**.

Figure 5

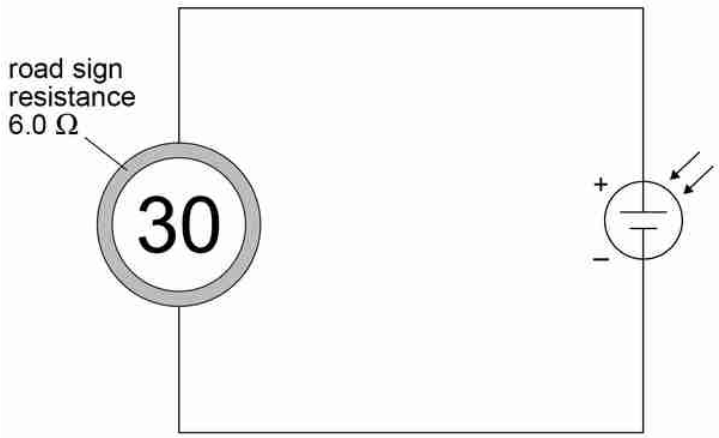


Figure 6

0 4 . 2 Deduce, using calculations, whether the circuits in **Figure 5** and **Figure 6** are suitable for this application.

[4 marks]

0 4 . 3 Solar cells convert solar energy to useful electrical energy in the road sign with an efficiency of 4.0%.
The solar-cell supply used by the engineer has a total surface area of $32\ \text{cm}^2$.

Calculate the minimum intensity, in W m^{-2}, of the sunlight needed to provide the minimum current of $75\ \text{mA}$ to the road sign when it has a resistance of $6.0\ \Omega$.

[3 marks]

intensity = _____ W m^{-2}

0 5 . 1 Calculate the binding energy, in MeV, of a nucleus of $^{59}_{27}\text{Co}$.

nuclear mass of $^{59}_{27}\text{Co}$ = 58.93320 u

[3 marks]

binding energy = _____ MeV

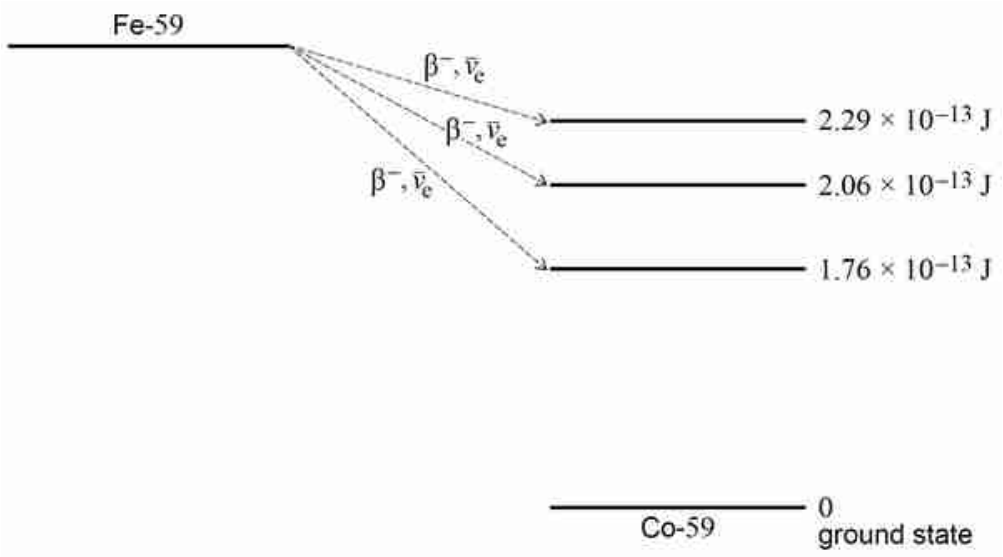
Question 5 continues on the next page

0 5 . 2 A nucleus of iron Fe-59 decays into a stable nucleus of cobalt Co-59. It decays by β^- emission followed by the emission of γ-radiation as the Co-59 nucleus de-excites into its ground state.

The total energy released when the Fe-59 nucleus decays is 2.52×10^{-13} J.

The Fe-59 nucleus can decay to one of three excited states of the cobalt-59 nucleus as shown in **Figure 5**. The energies of the excited states are shown relative to the ground state.

Figure 5



Calculate the maximum possible kinetic energy, in MeV, of the β^- particle emitted when the Fe-59 nucleus decays into an excited state that has energy above the ground state.

[2 marks]

maximum kinetic energy = _____ MeV

0 5 . 3 Following the production of excited states of $^{59}_{27}\mathrm{Co}$, γ-radiation of discrete wavelengths is emitted.

State the maximum number of discrete wavelengths that could be emitted.

[1 mark]

maximum number = _____

0 5 . 4 Calculate the longest wavelength of the emitted γ-radiation.

[3 marks]

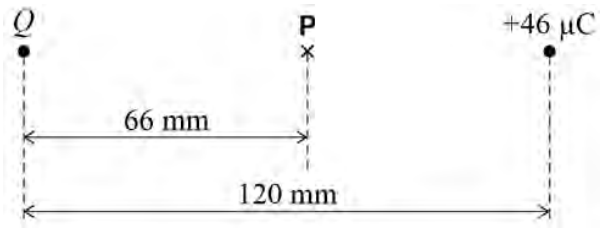
longest wavelength = _____ m

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**.

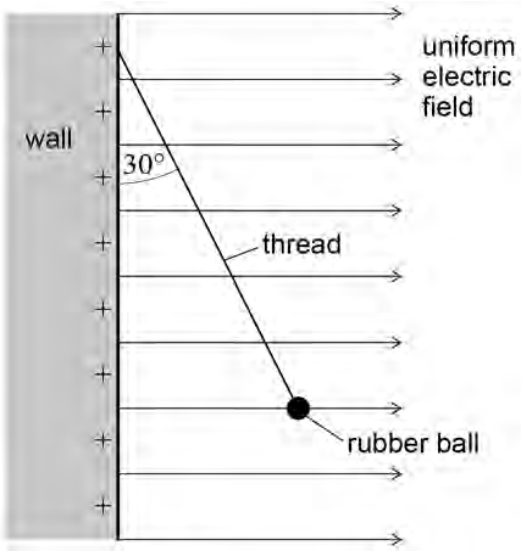
[2 marks]

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

Figure 1

0 1 . 1 The nitrogen is heated from $70\ \text{K}$ and is completely turned into a gas after $890\ \text{s}$.

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

specific latent heat of vaporisation of nitrogen $= 2.0 \times 10^5\ \text{J kg}^{-1}$

boiling point of nitrogen $= 77\ \text{K}$

[5 marks]

specific heat capacity = _____ unit = _____

Question 1 continues on the next page

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

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

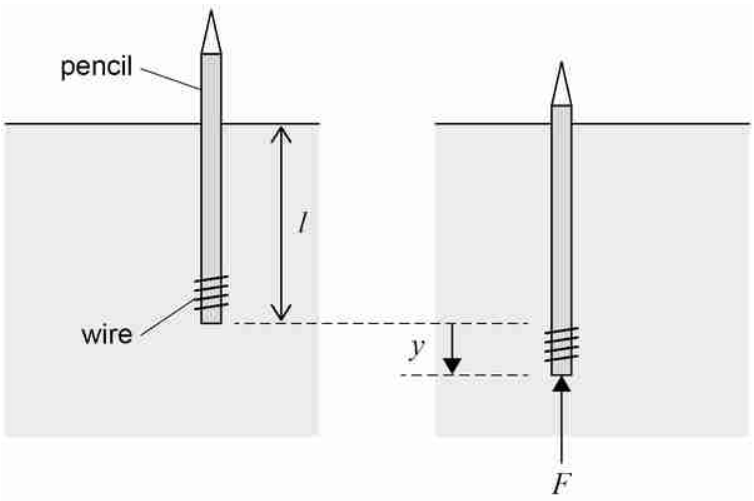
density of liquid nitrogen at its boiling temperature = $810\ \text{kg m}^{-3}$

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

[4 marks]

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

Figure 14 **Figure 15**



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

$$F = A\rho gy$$

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

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

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

[2 marks]

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

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

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

Calculate the maximum acceleration of the pencil.

[2 marks]

maximum acceleration = _____ m s^{-2}

Question 6 continues on the next page

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

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

0 6 . 3 Explain what is meant by resonance.

[2 marks]

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

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

Figure 16

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

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

There are two options:

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

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

[3 marks]

END OF SECTION A

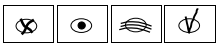
Section B

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

For each question select the best response.

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

CORRECT METHOD 

WRONG METHODS 

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

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

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

0 2 A positive pion collides with a neutron and the following interaction is observed:

$$\pi^+ + n \rightarrow K^+ + \Sigma^0$$

Σ^0 is a neutral sigma particle with a strangeness of -1

The interaction can be used to deduce the classifications of the Σ^0.

0 2 . 1 Identify the classifications of each particle in **Table 1**.
Tick (✓) the appropriate boxes for each particle.

[2 marks]

Table 1

Particle	Baryon	Hadron	Lepton	Meson
π^+				
n				
K^+				
Σ^0				

0 2 . 2 A conservation rule predicts that the following interaction **cannot** occur:

$$\pi^- + n \rightarrow K^- + \Sigma^0$$

State the conservation rule.
Go on to explain your answer.

[3 marks]

Question 2 continues on the next page

One way in which neutral pions decay is

$$\pi^0 \rightarrow e^- + e^+ + \gamma$$

0 2 . 3 Compare the rest energies of the particles involved in this decay.

[2 marks]

0 2 . 4 The decay of the neutral pion leads to the production of further gamma photons.

Explain why.

[1 mark]

0 2 . 5 The Standard Model is a theory that classifies elementary particles.
Evidence for the theory has been collected since about 1950. However, the term Standard Model has only been used since 1973.

Suggest why progress in particle physics is slow.

[1 mark]

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

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

[1 mark]

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

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

[3 marks]

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

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

[2 marks]

change of temperature = _____ K

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

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

Table 1

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

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

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

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

[3 marks]

heat energy removed = _____ J

0 1 Information about the radius of a nucleus can be deduced from the closest approach of alpha particles and from electron diffraction.

0 1 . 1 Alpha particles, each with a kinetic energy of $5.59\ \text{MeV}$, are fired at a thin foil made of gold $\left({}^{197}_{79}\text{Au}\right)$ atoms.

Some of the alpha particles are scattered through an angle of $180°$.

Estimate the radius of a ${}^{197}_{79}\text{Au}$ nucleus from this information.

[3 marks]

radius of nucleus = _____ m

0 1 . 2 Explain why your answer to Question **01.1** is an estimate.

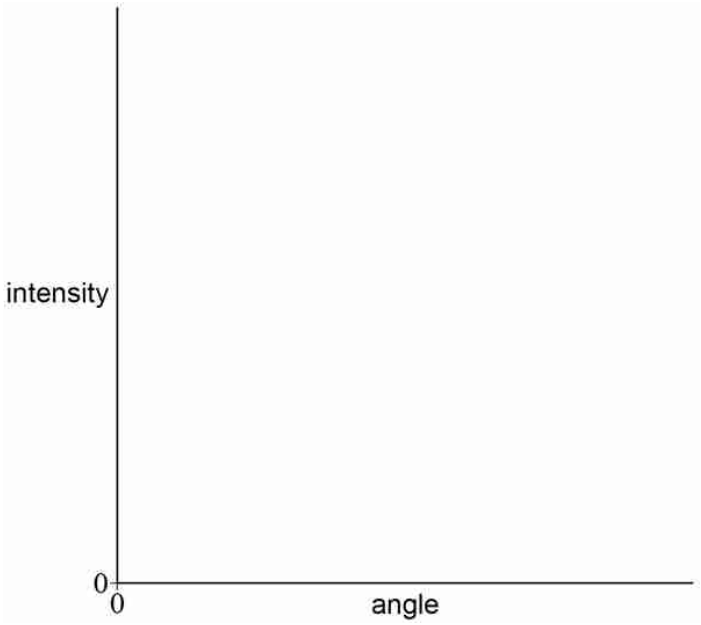
[2 marks]

0 1 . 3 Electron diffraction gives a more precise value for the radius of the nucleus.

Sketch, on **Figure 1**, a graph of intensity against angle for electron diffraction by a nucleus.
Go on to state the feature of this graph that is used to determine the radius of the nucleus.

[2 marks]

Figure 1



Question 1 continues on the next page

0 1 . 4 Results from electron-diffraction experiments lead to the equation:

$$R = R_0 A^{\frac{1}{3}}$$

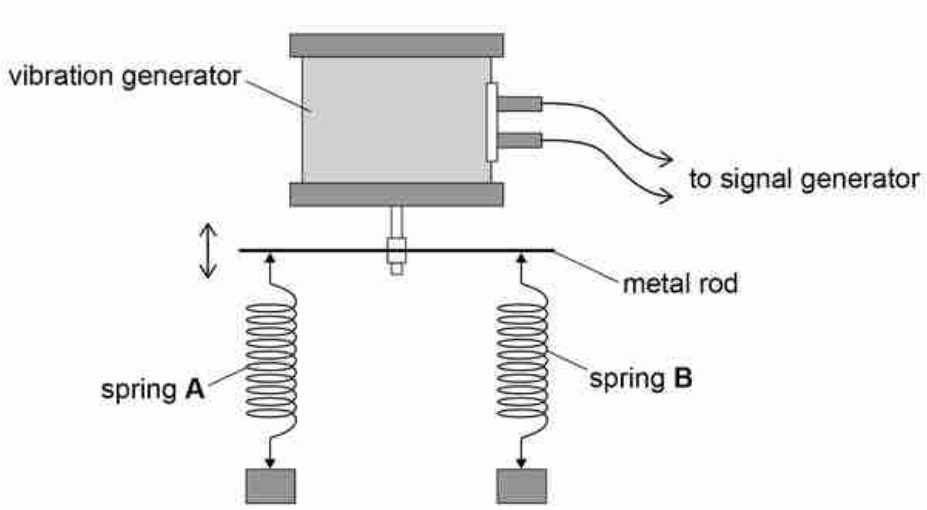
Show that the equation provides evidence for the constant density of nuclear material.

[2 marks]

1

0 7 A student is investigating forced vertical oscillations in springs.
Two springs, **A** and **B**, are suspended from a horizontal metal rod that is attached to a vibration generator. The stiffness of **A** is k, and the stiffness of **B** is $3k$.
Two equal masses are suspended from the springs as shown in **Figure 10**.

Figure 10



The vibration generator is connected to a signal generator. The signal generator is used to vary the frequency of vibration of the metal rod. When the signal generator is set at 2.0 Hz, the mass attached to spring **A** oscillates with a maximum amplitude of 2.5×10^{-2} m and has a maximum kinetic energy of 54 mJ.

0 7 . 1 Deduce the spring constant k for spring **A** and the mass m suspended from it.
[4 marks]

k = _____ N m^{-1}

m = _____ kg

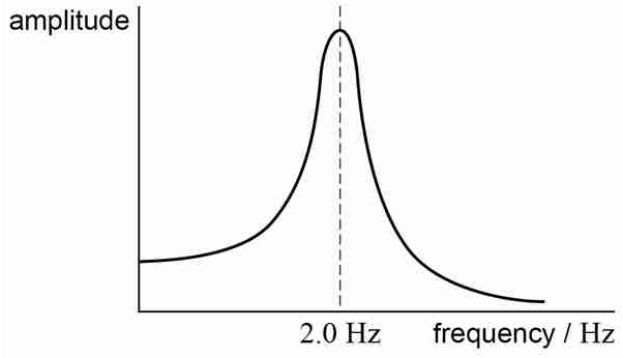
0 7 . 2 Calculate the frequency at which the mass attached to spring **B** oscillates with maximum amplitude.

[2 marks]

frequency = _____ Hz

0 7 . 3 **Figure 11** shows how the amplitude of the oscillations of the mass varies with frequency for spring **A**.

Figure 11



The investigation is repeated with the mass attached to spring **B** immersed in a beaker of oil.

A graph of the variation of the amplitude with frequency for spring **B** is different from the graph in **Figure 11**.

Explain **two** differences in the graph for spring **B**.

[4 marks]

Difference 1 _____

_____

_____

Difference 2 _____

_____

_____

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.
Do **not** use additional sheets for this working.

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

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

[1 mark]

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

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

Figure 1

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

[2 marks]

number of molecules = _____

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

[2 marks]

change in temperature = _____ K

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

[2 marks]

_____

_____

Question 1 continues on the next page

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

[3 marks]

0 3 **Figure 4** shows the structure of a violin and **Figure 5** shows a close-up image of the tuning pegs.

Figure 4

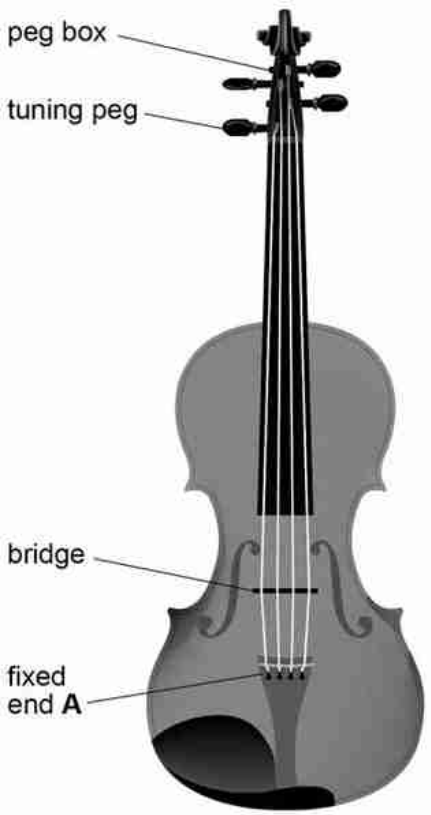
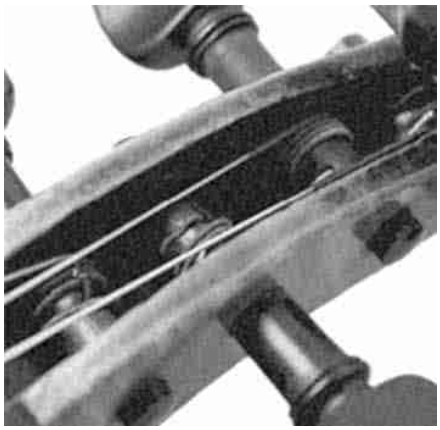


Figure 5



The strings are fixed at end **A**. The strings pass over a bridge and the other ends of the strings are wound around tuning pegs that have a circular cross-section. The tension in the strings can be increased or decreased by rotating the tuning pegs.

0 3 . 1 Explain how a stationary wave is produced when a stretched string is plucked.

[3 marks]

0 3 . 2 The vibrating length of one of the strings of a violin is $0.33\ \text{m}$
When the tension in the string is $25\ \text{N}$, the string vibrates with a first-harmonic frequency of $370\ \text{Hz}$

Show that the mass of a $1.0\ \text{m}$ length of the string is about $4 \times 10^{-4}\ \text{kg}$

[2 marks]

0 3 . 3 Determine the speed at which waves travel along the string in question **03.2** when it vibrates with a first-harmonic frequency of $370\ \text{Hz}$

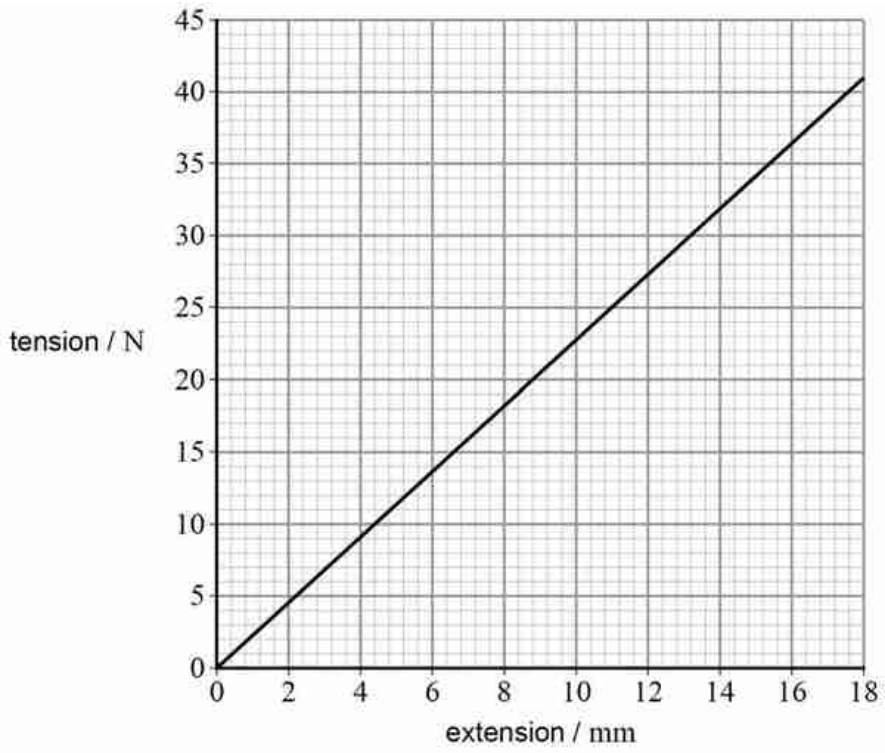
[1 mark]

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

Question 3 continues on the next page

0 3 . 4 **Figure 6** shows how the tension in the string in question **03.2** varies with the extension of the string.

Figure 6



The string with its initial tension of 25 N is vibrating at a frequency of 370 Hz
The diameter of the circular peg is 7.02 mm

Determine the higher frequency that is produced when the string is stretched by rotating the tuning peg through an angle of 75°

Assume that there is no change in the diameter of the string.

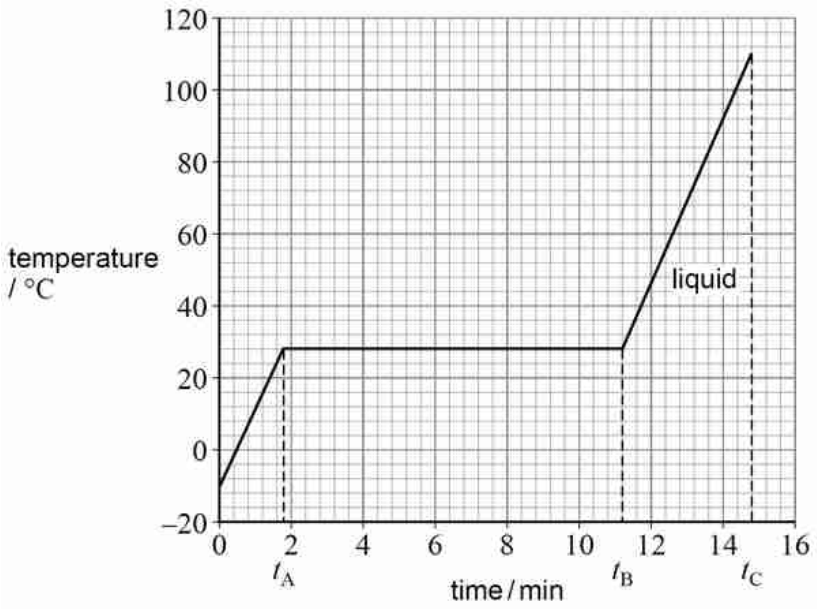
[4 marks]

frequency = _____ Hz

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

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

Figure 1



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

[1 mark]

temperature = _____ °C

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

[1 mark]

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

[2 marks]

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

[1 mark]

Question 1 continues on the next page

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

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

[3 marks]

specific heat capacity = _____ unit = _____

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

Table 1

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

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

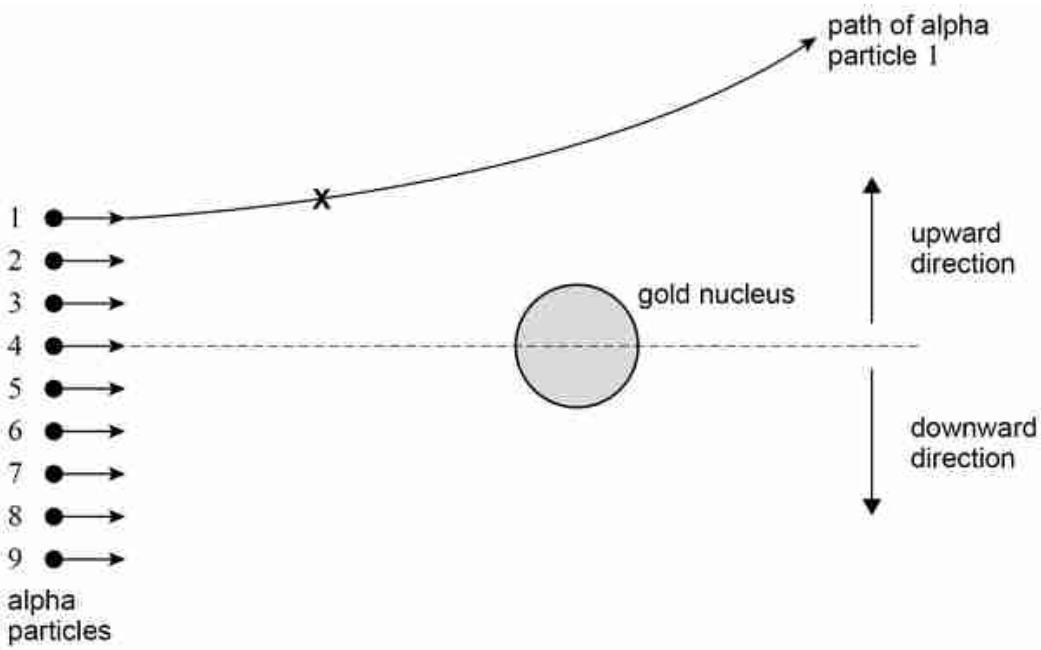
Identify **M**.

[2 marks]

M = _____

0 5 **Figure 11** shows alpha particles all travelling in the same direction at the same speed.
The alpha particles are scattered by a gold ($^{197}_{79}Au$) nucleus.
The path of alpha particle **1** is shown.

Figure 11



0 5 . 1 State the fundamental force involved when alpha particle **1** is scattered by the nucleus in **Figure 11**.

[1 mark]

0 5 . 2 Draw an arrow at position **X** on **Figure 11** to show the direction of the rate of change in momentum of alpha particle **1**

[1 mark]

0 5 . 3 Suggest **one** of the alpha particles in **Figure 11** which may be deflected downwards with a scattering angle of $90°$

Justify your answer.

[2 marks]

alpha particle number = _____

_____

_____

_____

_____

0 5 . 4 Alpha particle **4** comes to rest at a distance of 5.5×10^{-14} m from the centre of the $^{197}_{79}Au$ nucleus.

Calculate the speed of alpha particle **4** when it is at a large distance from the nucleus. Ignore relativistic effects.

mass of alpha particle = 6.8×10^{-27} kg

[3 marks]

speed = _____ m s^{-1}

Question 5 continues on the next page

0 5 . 5 The nuclear radius of $^{197}_{79}\text{Au}$ is 6.98×10^{-15} m.

Calculate the nuclear radius of $^{107}_{47}\text{Ag}$.

[2 marks]

radius = _____ m

0 5 . 6 All nuclei have approximately the same density.

State **one** conclusion about the nucleons in a nucleus that can be deduced from this fact.

[1 mark]

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.

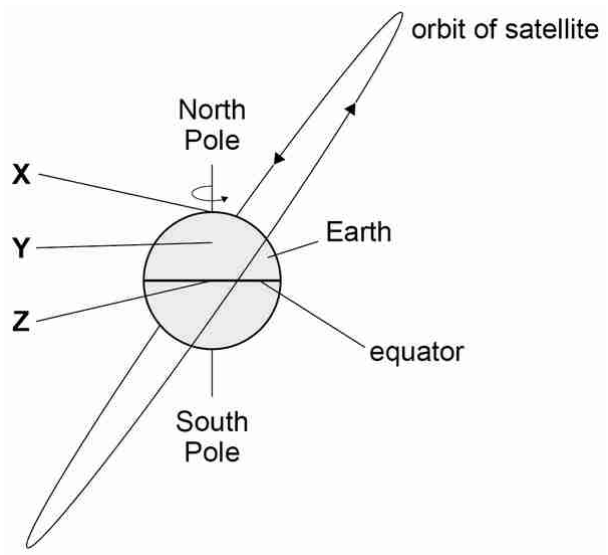
[2 marks]

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.

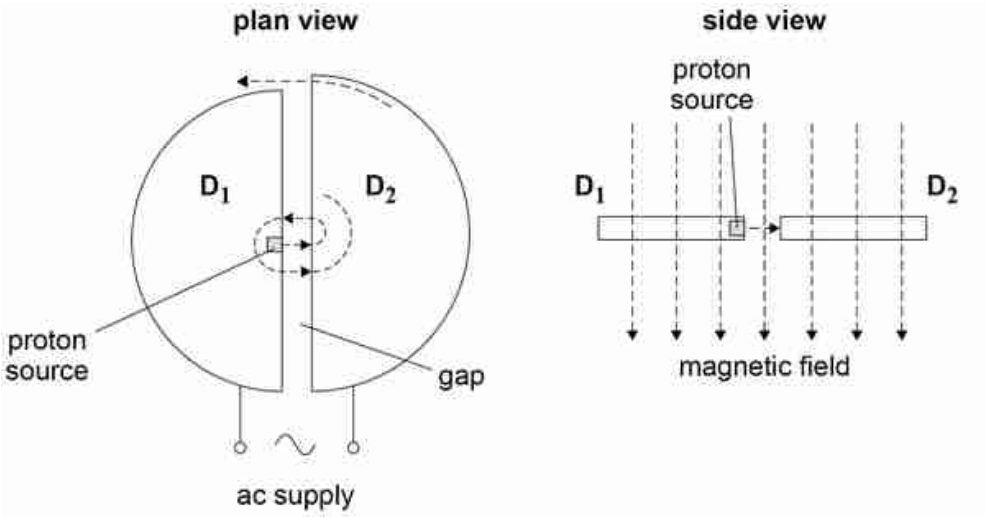
Explain how the linear speed of this satellite compares with the linear speed of the satellite in Question **02.1**.

[2 marks]

0 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' $\mathbf{D_1}$ and $\mathbf{D_2}$. 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 2 . 1 In the kinetic theory model, it is assumed that there are many identical particles moving at random.

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

[2 marks]

1 _____

_____

_____

2 _____

_____

_____

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

[3 marks]

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

Calculate the amount of gas in the container.

[3 marks]

amount of gas = _____ mol

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

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

[2 marks]

Figure 2

0 3 . 1 Describe **two** properties of a radial gravitational field.

[2 marks]

1 _____

_____

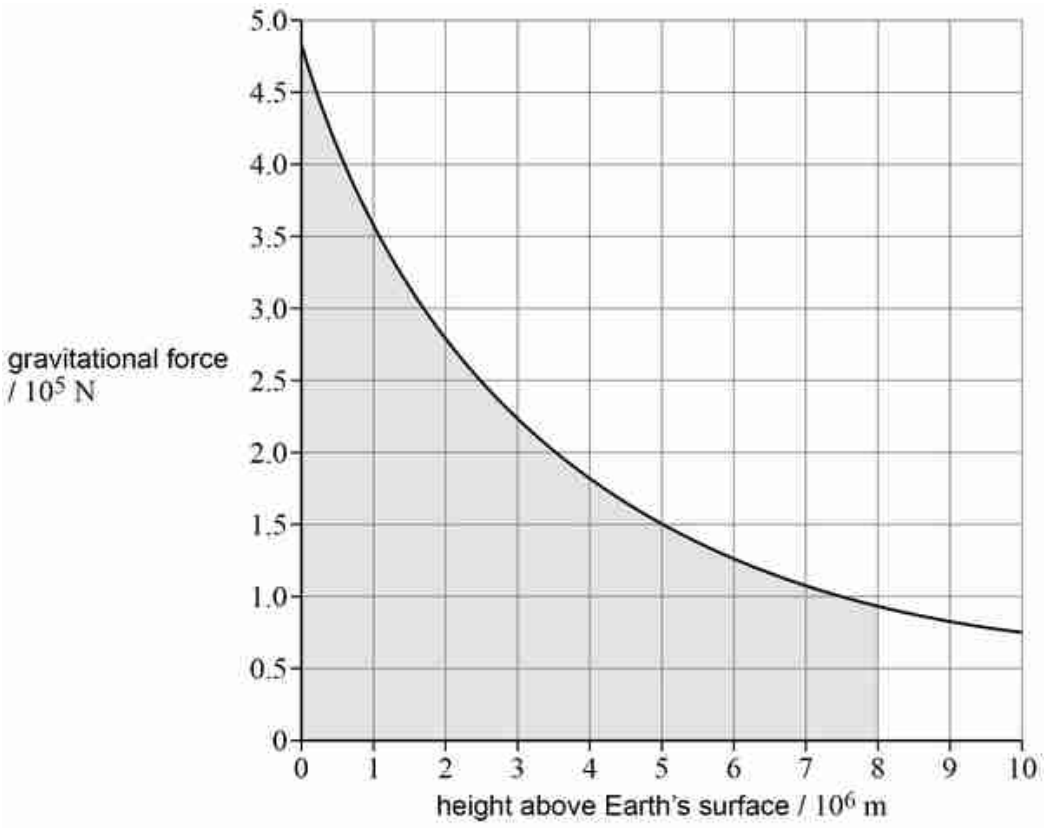
2 _____

_____

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 6 . 1 Nuclear radii can be estimated using either alpha particles or high-energy electrons.

State **two** advantages of using high-energy electrons rather than alpha particles for this estimate.

[2 marks]

1 _____

_____

_____

2 _____

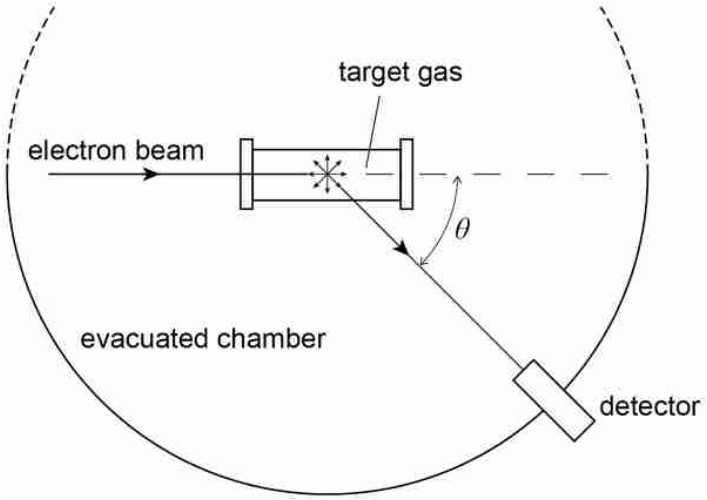
_____

_____

Question 6 continues on the next page

0 6 . 2 **Figure 11** shows a beam of electrons, each with the same high energy, incident on a target gas.
The electrons are diffracted by the nuclei in the gas.
The intensities of these diffracted electrons are measured at various angles θ.
The data are used to determine the nuclear radius R of the atoms in the gas.

Figure 11



Sketch on **Figure 12** a graph showing how the electron intensity varies with θ.

[2 marks]

Figure 12

0 6 . 3 The radius R of a nucleus is related to its nucleon number by $R = R_0 A^{\frac{1}{3}}$.

Show that this equation is consistent with the idea that all nuclei have the same density.

[2 marks]

0 6 . 4 The equation $R = R_0 A^{\frac{1}{3}}$ is derived from experimental data.

Suggest **one** reason why the constant density of nuclear material derived from this equation is only approximate.

[1 mark]

0 6 . 5 The measured radius R of $^{35}_{17}\text{Cl}$ is 4.02×10^{-15} m.

Calculate an estimate of

- the constant R_0
- the density of nuclear material.

[3 marks]

$R_0 =$ _____ m density = _____ kg m^{-3}

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

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

[1 mark]

_____

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

[2 marks]

1 _____

_____

2 _____

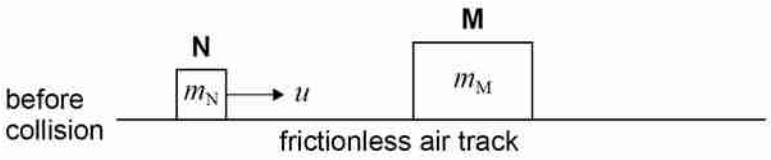
_____

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

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

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

Figure 13

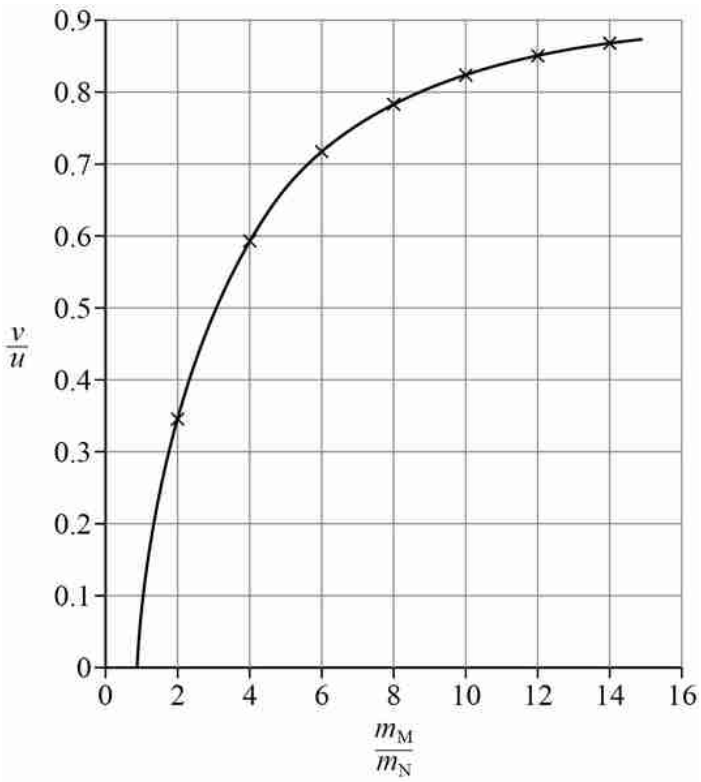


The gliders collide. **N** rebounds with speed v as shown in **Figure 14**.

Figure 14

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

Figure 15



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

[2 marks]

Question 7 continues on the next page

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

The final kinetic energy E_f of the neutron is

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

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

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

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

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

[3 marks]

$y =$ _____

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

[2 marks]

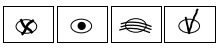
END OF SECTION A

Section B

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

For each question select the best response.

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

CORRECT METHOD  WRONG METHODS 

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

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

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

0 4 The core of a thermal nuclear reactor contains a number of components that are exposed to moving neutrons.

0 4 . 1 State what happens to a neutron that is incident on the moderator.

[1 mark]

0 4 . 2 State what happens to a neutron that is incident on a control rod.

[1 mark]

0 4 . 3 A slow-moving neutron is in collision with a nucleus of an atom of the fuel which causes fission.

Describe what happens in the process.

[3 marks]

0 4 . 4 A thermal nuclear reactor produces radioactive waste.

State the source of this waste and discuss some of the problems faced in dealing with the waste at various stages of its treatment.

Your answer should include:

- the main source of the most dangerous waste
- a brief outline of how waste is treated
- problems faced in dealing with the waste, with suggestions for overcoming these problems.

[6 marks]

Extra space is available on the next page if needed

0 6 A thermal nuclear reactor uses a moderator to lower the kinetic energy of fast-moving neutrons.

0 6 . 1 Explain why the kinetic energy of neutrons must be reduced in a thermal nuclear reactor.

[1 mark]

0 6 . 2 As a result of a collision with an atom of a particular moderator, a neutron loses 63% of its kinetic energy.

A neutron has an initial kinetic energy of 2.0 MeV.

Calculate the kinetic energy of the neutron after five collisions.

[2 marks]

kinetic energy = _____ eV

Question 6 continues on the next page

0 6 . 3 The kinetic energy of a neutron in a thermal nuclear reactor is reduced from about 2 MeV to about 1 eV.

Explain why the number of collisions needed to do this depends on the nucleon number of the moderator atoms.

[2 marks]

0 6 . 4 One fission process which can occur in a thermal nuclear reactor is represented by the equation

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} = {}^{142}_{54}\mathrm{Xe} + {}^{90}_{38}\mathrm{Sr} + 4\,{}^{1}_{0}\mathrm{n}$$

Calculate in MeV the energy released in this fission process.

mass of $^{235}_{92}\mathrm{U}$ = 235.044 u

mass of $^{142}_{54}\mathrm{Xe}$ = 141.930 u

mass of $^{90}_{38}\mathrm{Sr}$ = 89.908 u

mass of $^{1}_{0}\mathrm{n}$ = 1.0087 u

[3 marks]

energy released = _____ MeV

Question 6 continues on the next page

0 6 . 5 Many magazine and newspaper articles focus on the risks of using nuclear power.

State **three benefits** of using nuclear power.

[3 marks]

1 _____

_____

_____

2 _____

_____

_____

3 _____

_____

_____

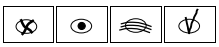
END OF SECTION A

Section B

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

For each question select the best response.

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

CORRECT METHOD  WRONG METHODS 

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

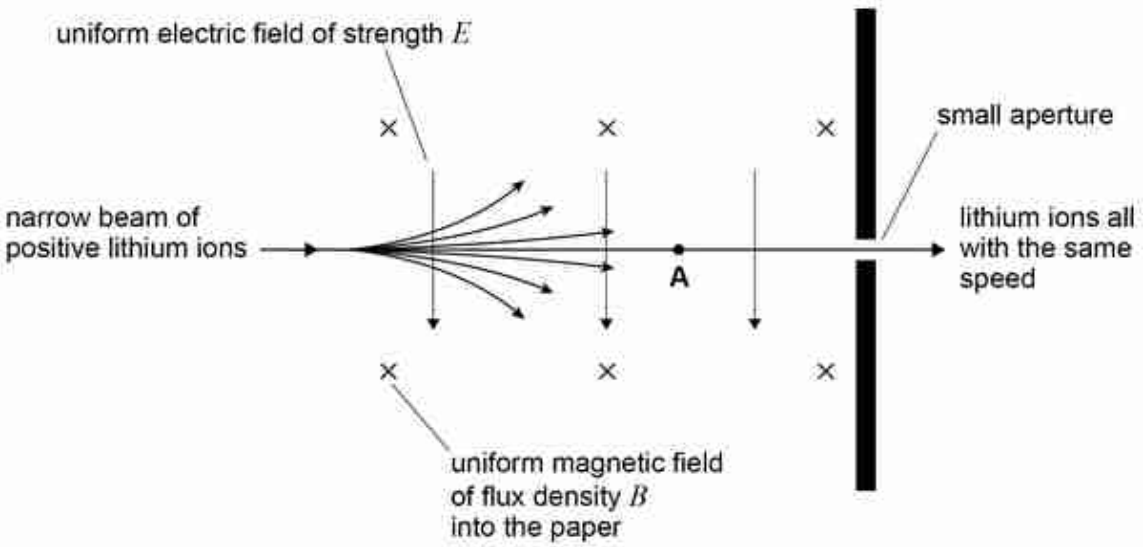
If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown. 

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

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

Figure 3 shows one part of a mass spectrometer.

Figure 3



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

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

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

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

[1 mark]

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

Calculate E.

$B = 0.12$ T

[2 marks]

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

Question 3 continues on the next page

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

Figure 4

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

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

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

[1 mark]

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

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

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

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

$B = 0.12\ \mathrm{T}$

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

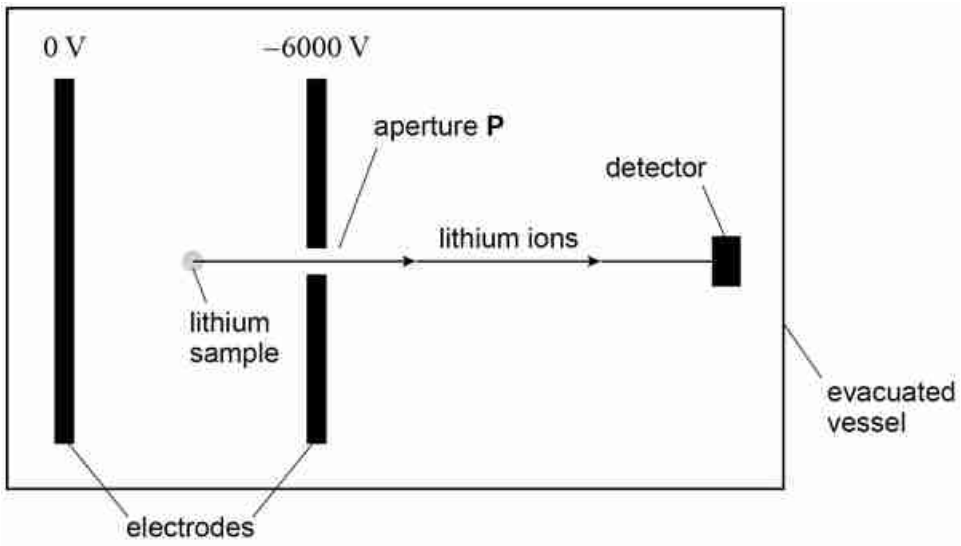
[2 marks]

distance = _____ m

Question 3 continues on the next page

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

Figure 5



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

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

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

[3 marks]

speed = _____ m s^{-1}

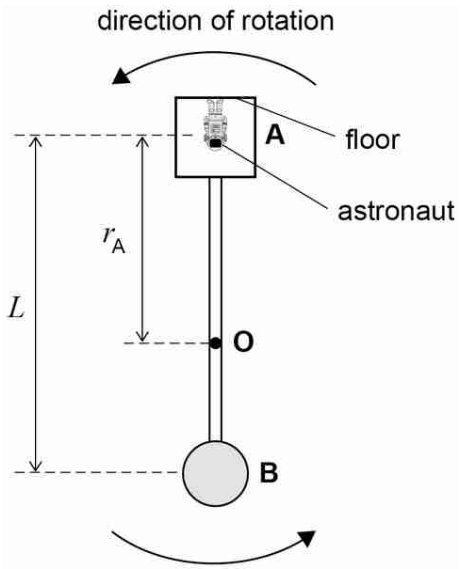
0 3 . 6 $^{6}_{3}\mathrm{Li}^{+}$ and $^{7}_{3}\mathrm{Li}^{+}$ ions are produced in the sample simultaneously and travel a distance L from aperture **P** to the detector.
For each type of ion, the time interval between production and detection is measured.

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

[2 marks]

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

Figure 6



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

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

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

Explain why.

[2 marks]

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

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

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

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

[2 marks]

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

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

[2 marks]

Question 4 continues on the next page

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

When loaded,

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

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

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

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

Figure 7

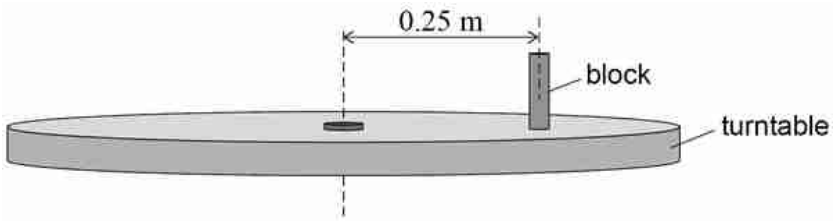
0 4 . 4 Suggest a suitable diameter for the rod.
Justify your answer.

[5 marks]

diameter = _____ m

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

Figure 9



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

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

[2 marks]

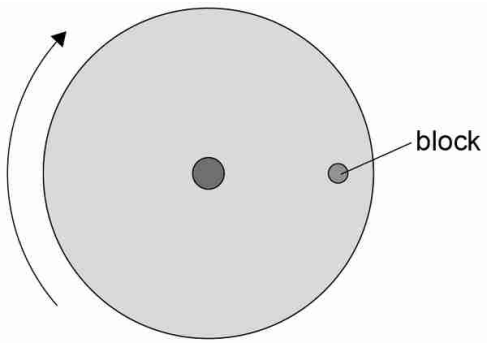
time = _____ s

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

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

[1 mark]

Figure 10



0 5 . 3 The mass of the block is 0.12 kg.

Calculate the magnitude of the resultant force on the block.

[2 marks]

magnitude of force = _____ N

Question 5 continues on the next page

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

[2 marks]

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

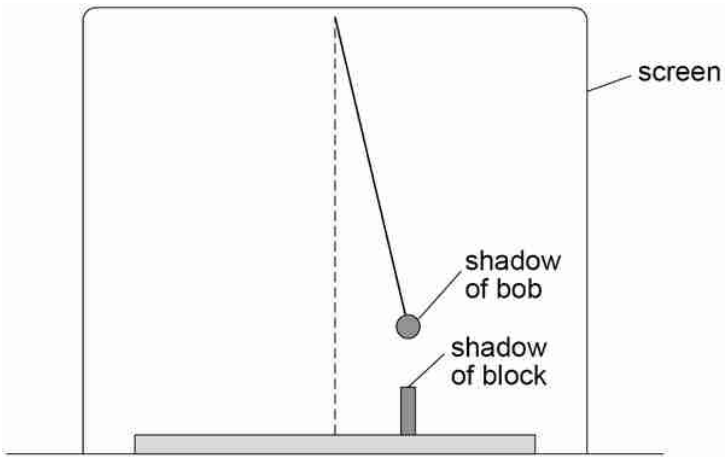
Calculate the length of the simple pendulum.

[2 marks]

length = _____ m

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

Figure 11



Initially the shadows move in phase with the same amplitude.

Air resistance affects the motion of the pendulum.

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

[2 marks]

amplitude _____

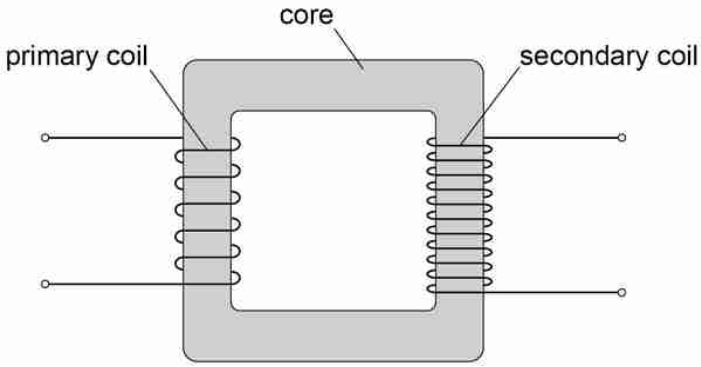
_____

_____

phase _____

0 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

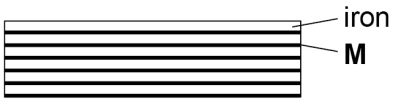
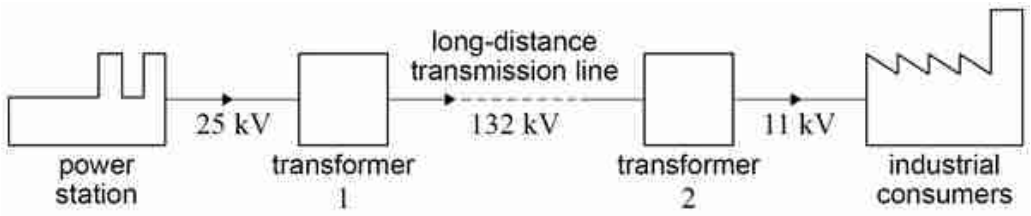


Figure 9 shows a schematic diagram of a power transmission system.

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%.

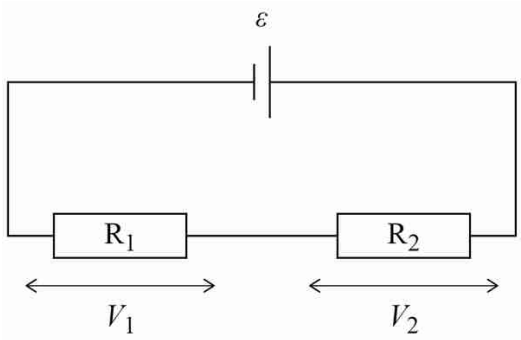
Calculate the current in the 25 kV line from the power station.

[3 marks]

current = _____ A

0 3 . 1 In **Figure 2** the cell has emf ε and internal resistance r.

Figure 2



The current in the circuit is I.

The potential difference (pd) across R_1 is V_1 and the pd across R_2 is V_2.

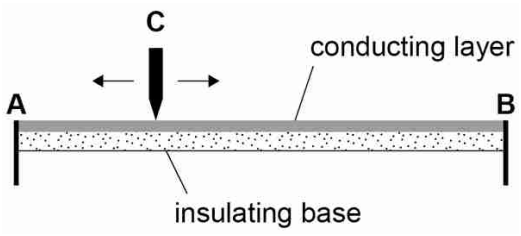
Explain how the law of conservation of energy applies in this circuit.
You should consider the movement of one coulomb of charge around the circuit.

[2 marks]

Question 3 continues on the next page

Figure 3 shows a variable resistor made with a thin conducting layer on an insulating base.

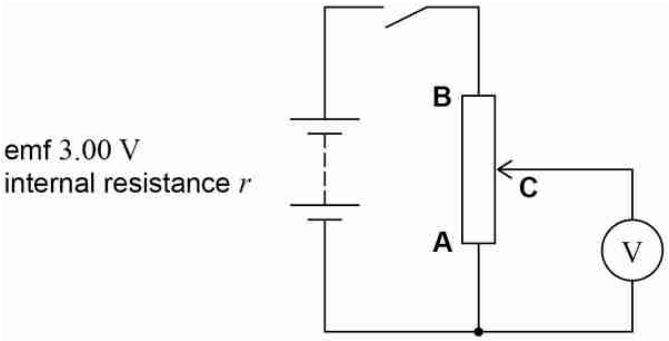
Figure 3



The conducting layer has constant width and thickness and has connections at the ends **A** and **B**.
C is a sliding contact that can move along the surface of the conducting layer between **A** and **B**.

Figure 4 shows a circuit that uses the variable resistor as a potential divider.

Figure 4



The variable resistor is connected to a battery of emf $3.00\ \text{V}$ and internal resistance r.
The resistance of the conducting layer between **A** and **B** is $125\ \Omega$.

0 3 . 2 The sliding contact **C** is moved to end **B** of the variable resistor. The switch is closed. The digital voltmeter reads $2.89\ \text{V}$.

Show that r is approximately $4.8\ \Omega$.

[3 marks]

0 3 . 3 **C** is set at $\frac{1}{5}$ of the distance between **A** and **B**. The thickness of the conducting layer is uniform so the resistance between **A** and **C** is $25.0\ \Omega$.

Determine the voltmeter reading at this setting.

[2 marks]

voltmeter reading = _____ V

Question 3 continues on the next page

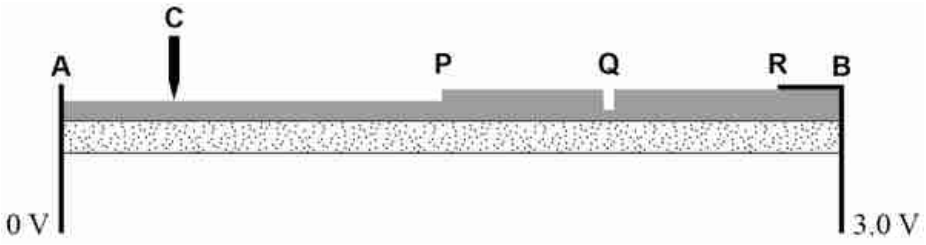
0 3 . 4 **Figure 5** shows a variable resistor similar to the one shown in **Figure 3** but with the following three manufacturing faults:

- at **P** the conducting layer changes in thickness so that **AP** is thinner than **PB**
- at **Q** there is a scratch into the surface of the conducting layer and across its full width
- from **R** to **B** the conducting connector is laid over the conducting layer.

The width of the conducting layer is constant.

A pd of 3.0 V is applied across **A** and **B**.
C is moved from **A** to **B**.

Figure 5



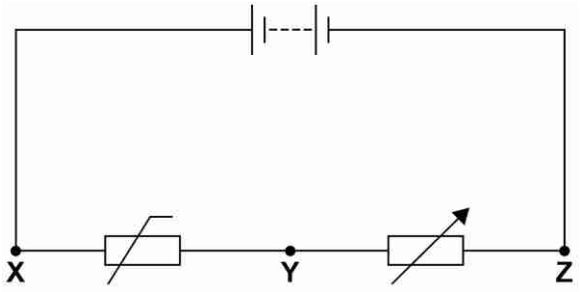
Sketch, on the axes in **Figure 6**, a graph to show how the pd between **A** and **C** varies as **C** is moved from **A** to **B**.

[4 marks]

Figure 6

0 6 The circuit in **Figure 5** is used as part of a temperature sensor.
The battery has an emf of 6.5 V and negligible internal resistance.

Figure 5



The initial temperature of the thermistor is 22 °C.
At this temperature the resistance of the thermistor is 350 Ω and the circuit current is 12 mA.

0 6 . 1 Calculate the resistance of the variable resistor.

[2 marks]

resistance = _____ Ω

Question 6 continues on the next page

0 6 . 2 The resistance R of the thermistor at temperature θ in K is given by:

$$R = R_0 e^{B\left(\frac{1}{\theta} - \frac{1}{\theta_0}\right)}$$

where R_0 is the resistance at the initial temperature θ_0 in K, and B is a constant.

The temperature of the thermistor is increased to 318 K.
The variable resistor is adjusted so that the circuit current is again 12 mA.
The potential difference across the thermistor is now 3.2 V.

Determine B.
State an appropriate unit for your answer.

[5 marks]

$B =$ _____ unit = _____

0 6 . 3 Explain why the current in the thermistor needs to be controlled.

[2 marks]

0 6 . 4 Explain how ammeters and voltmeters can be used in the circuit in **Figure 5** to demonstrate the conservation of charge and the conservation of energy.

Refer to points **X**, **Y** and **Z** in your answer.

[2 marks]

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

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

State what is meant by random particle motion.

[2 marks]

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

[2 marks]

1

2

Question 2 continues on the next page

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

Explain this expansion using the kinetic theory model.

[3 marks]

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

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

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

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

[1 mark]

change in average kinetic energy = _____ J

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

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

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

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

[3 marks]

0 3 A radioisotope thermoelectric generator (RTG) uses radioactive decay to generate electrical energy.

A vehicle that is used to examine the surface of Mars includes an RTG that initially contains 3.23×10^{24} atoms of plutonium-238 $\left({}^{238}_{94}\mathrm{Pu}\right)$.

0 3 . 1 Determine the initial mass of plutonium-238 in the RTG.

[2 marks]

initial mass = _____ kg

0 3 . 2 The plutonium-238 undergoes alpha decay.
The energy released by this decay is converted into electrical energy with an efficiency of 4.58%.

The power provided by the RTG decreases over time as the plutonium-238 decays.

The vehicle requires a minimum electrical power of 29.6 W to operate.

Calculate the initial activity of the plutonium-238.
Go on to determine, in Earth years, the time for which the RTG can provide sufficient power for the vehicle to operate.

decay constant of plutonium-238 $= 2.51 \times 10^{-10}\ s^{-1}$
energy of alpha particle emitted by plutonium-238 $= 8.94 \times 10^{-13}\ J$

[5 marks]

initial activity = _____ Bq

time = _____ Earth years

Question 3 continues on the next page

0 3 . 3 The vehicle has a battery-powered laser that is used to vaporise small samples of ice. On Mars, ice changes directly from solid to vapour at a temperature of $0\ °C$. The ice does not form a liquid.

The energy required to vaporise $1.0\ g$ of solid ice directly into water vapour is the same as the total energy required to melt $1.0\ g$ of ice and then to vaporise the melted ice.

The laser produces an output power of $1.0\ kW$ for a maximum time of $3.0\ s$ before its battery needs to be recharged.

The laser heats the ice from an initial temperature of $-25\ °C$ to a temperature of $0.0\ °C$. The laser then transfers energy to vaporise the ice at $0.0\ °C$.

Determine whether the laser is able to vaporise $1.0\ g$ of the ice that is initially at $-25\ °C$ before the battery needs to be recharged.

specific heat capacity of ice $= 2.1\ kJ\ kg^{-1}\ K^{-1}$
specific latent heat of fusion of ice $= 334\ kJ\ kg^{-1}$
specific latent heat of vaporisation $= 2500\ kJ\ kg^{-1}$

[4 marks]

0 1 Cosmic rays are high-energy particles that come from space. Most of these particles are protons. There are other particles in cosmic rays, including atomic nuclei.

Table 1 gives the data for one particular nucleus **X**.

Table 1

Mass / kg	8.02×10^{-26}
Specific charge / C kg^{-1}	4.39×10^{7}
Kinetic energy / MeV	215

0 1 . 1 Determine the number of neutrons in nucleus **X**.

[3 marks]

number of neutrons = _____

0 1 . 2 Calculate the speed of **X**.
Ignore relativistic effects.

[3 marks]

speed = _____ m s^{-1}

A pion (π^+) and a kaon (K^+) are produced when cosmic rays interact with the upper atmosphere.

0 1 . 3 The π^+ decays to produce a positron and an electron neutrino.

Show how the conservation laws apply to this decay.

[2 marks]

0 1 . 4 The K^+ decays to produce an anti-muon and a muon neutrino.

Explain how strangeness applies in this decay.

[2 marks]

0 1 . 5 Write an equation for a K^+ decay that involves only hadrons.

[2 marks]

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

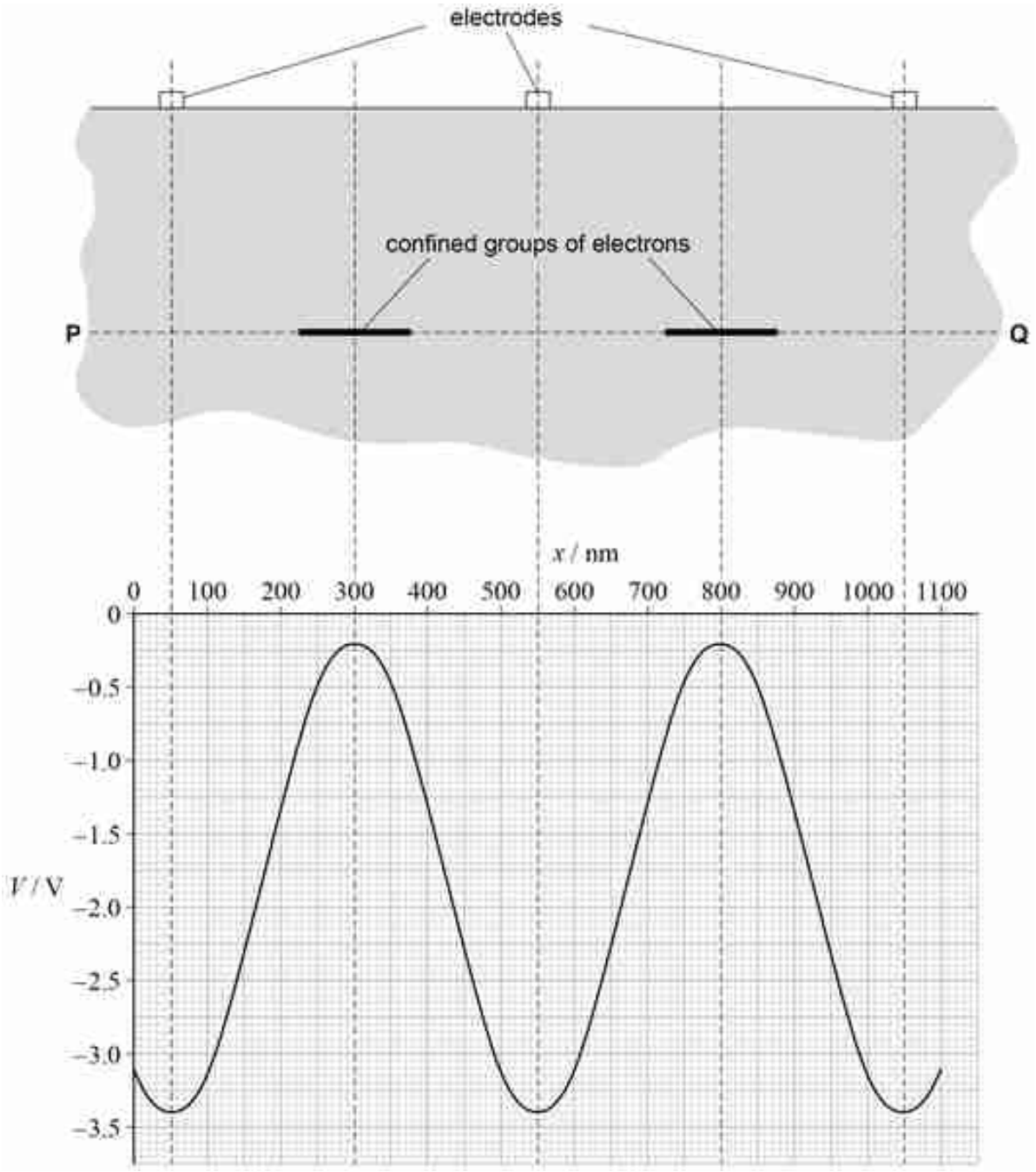
Explain what is meant by this statement.

[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

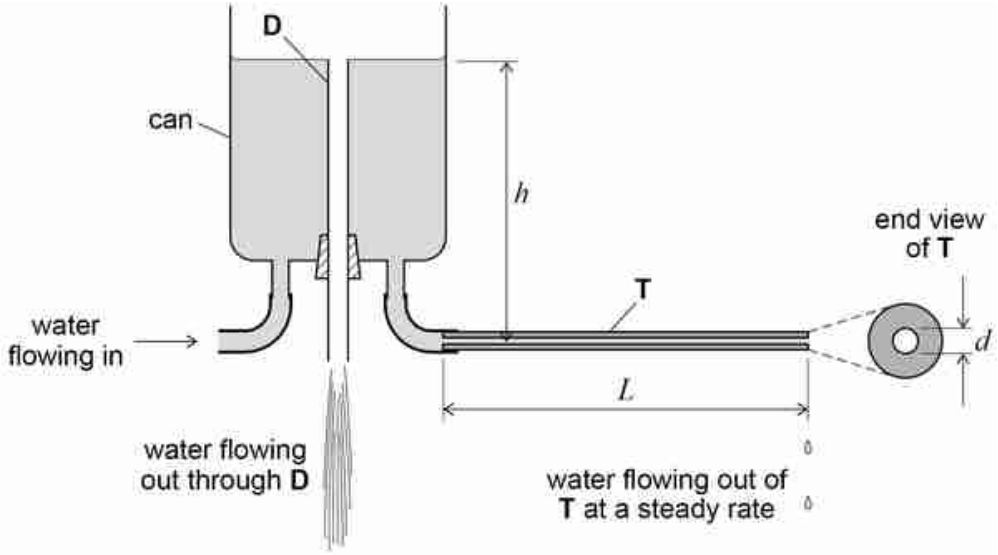
0 6 . 4 One of the confined electrons is at $x = 350$ nm.

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 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]

$\text{N m}^{-1}\text{ s}$ ☐

$\text{N m}^{-2}\text{ s}$ ☐

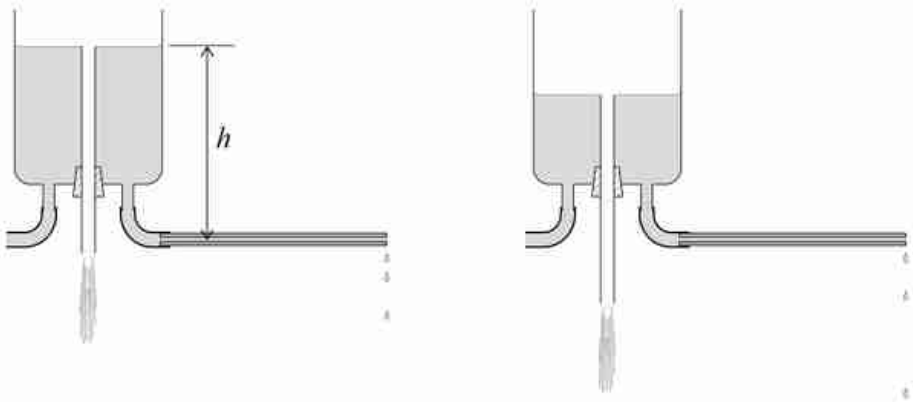
$\text{N m}^{-1}\text{ s}^{-1}$ ☐

$\text{N m}^{-2}\text{ s}^{-1}$ ☐

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.

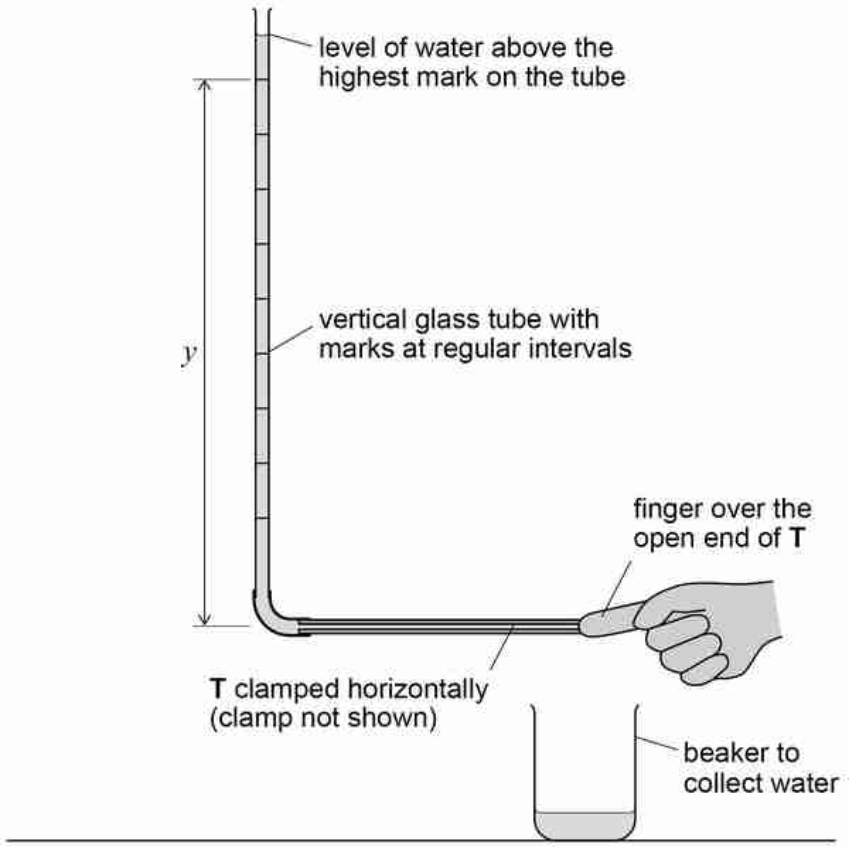
[2 marks]

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.

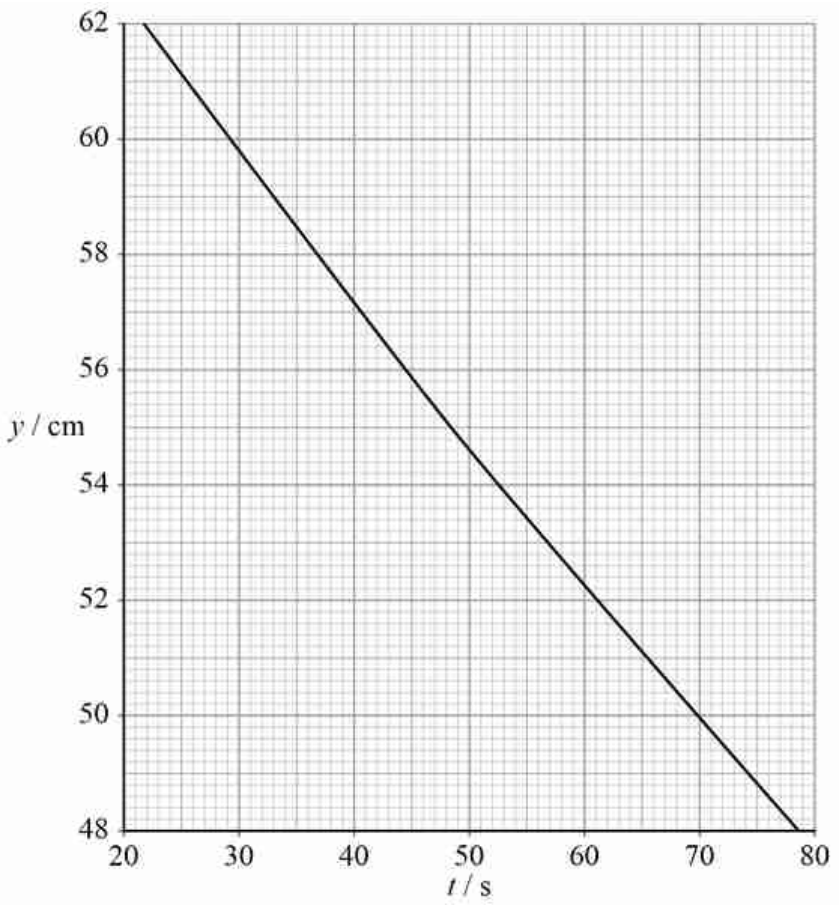
Explain how the student could check that the glass tube was vertical.
You may wish to add detail to **Figure 9** to illustrate your answer.

[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.

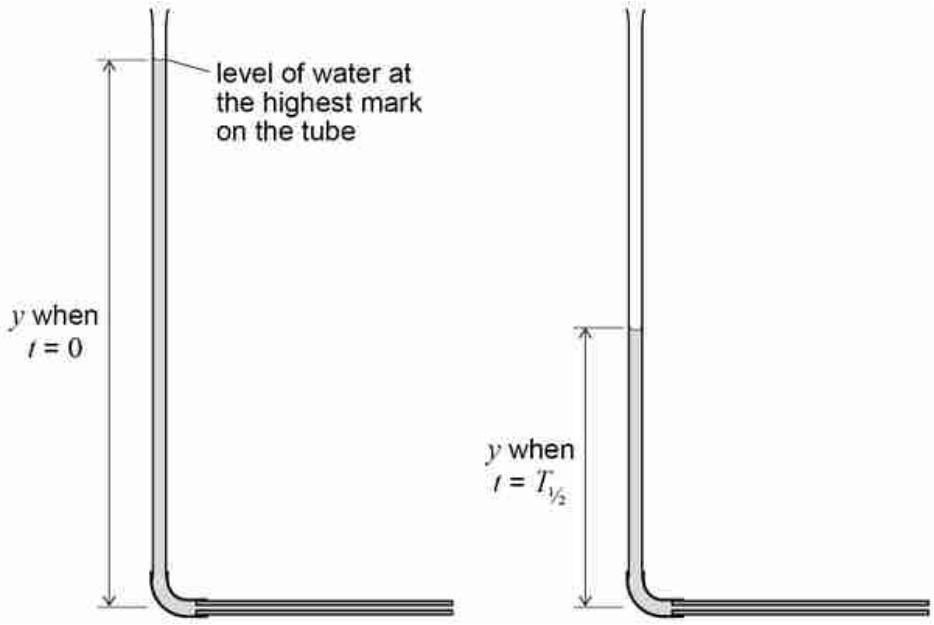
Show that λ, the decay constant for this process, is about 4.5×10^{-3} s^{-1}.

[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 $T_{1/2}$.

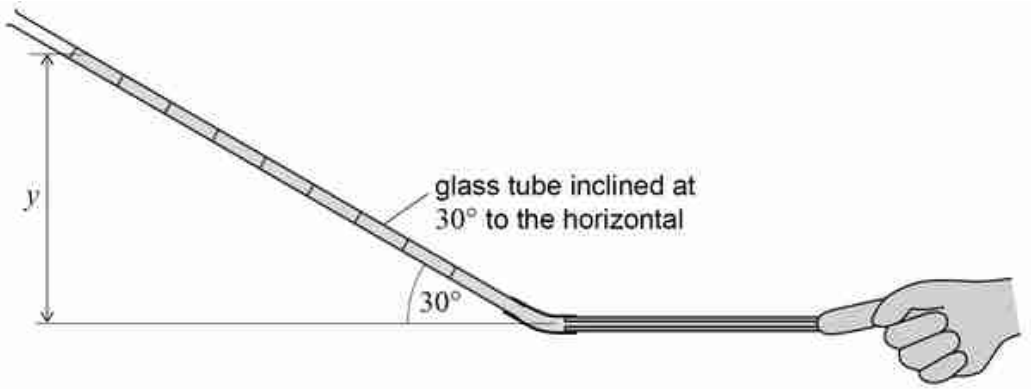
[1 mark]

$T_{1/2}$ = _____ 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.

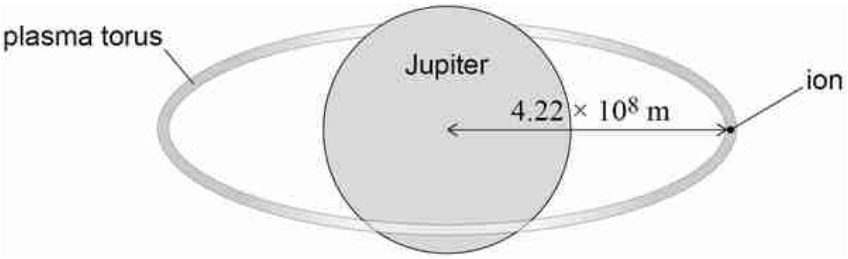
Draw a line on **Figure 13** to show the graph produced using the modified apparatus. The dashed line is the original graph when the glass tube was vertical as shown in **Figure 9**.

[2 marks]

Figure 13

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

Figure 6



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

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

Deduce whether this suggestion is correct.

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

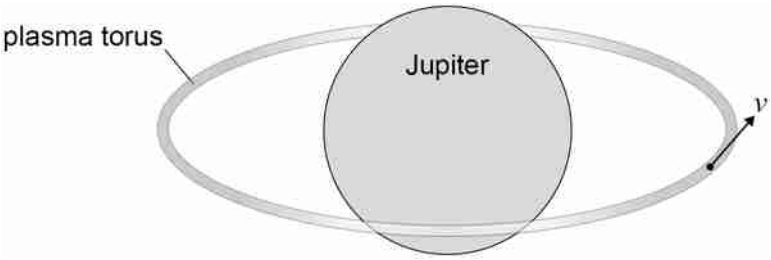
[3 marks]

Question 6 continues on the next page

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

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

Figure 7



The ion has a positive charge.

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

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

[1 mark]

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

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

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

[3 marks]

magnetic flux density = _____ unit = _____

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

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

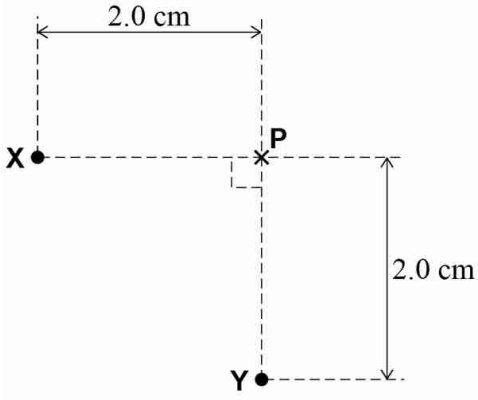
[3 marks]

acceleration = _____ m s^{-2}

Question 6 continues on the next page

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

Figure 8



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

[3 marks]

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

END OF SECTION A

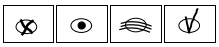
Section B

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

For each question select the best response.

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

CORRECT METHOD 

WRONG METHODS 

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

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

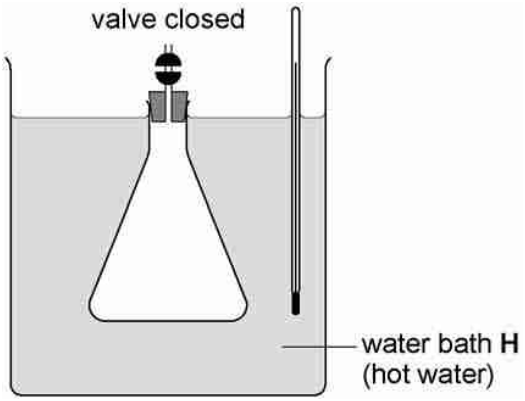
You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.

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

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

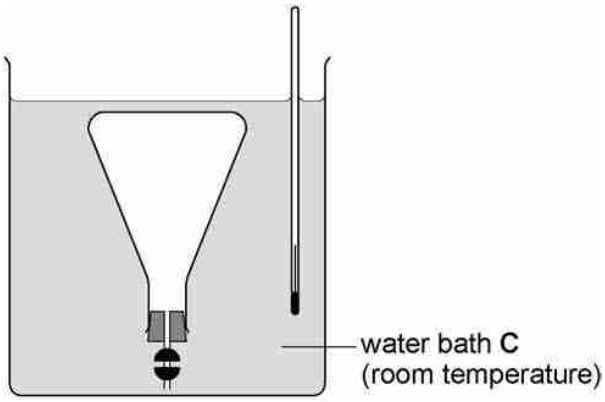
An empty flask fitted with a tube and an open valve is placed in water bath **H** containing hot water. The air inside the flask is allowed to come into thermal equilibrium with the water.
The valve is then closed, trapping a certain volume of air, as shown in **Figure 9a**.

Figure 9a



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

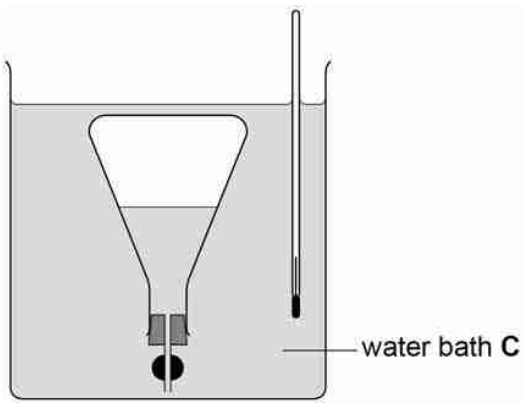
Figure 9b



Question 3 continues on the next page

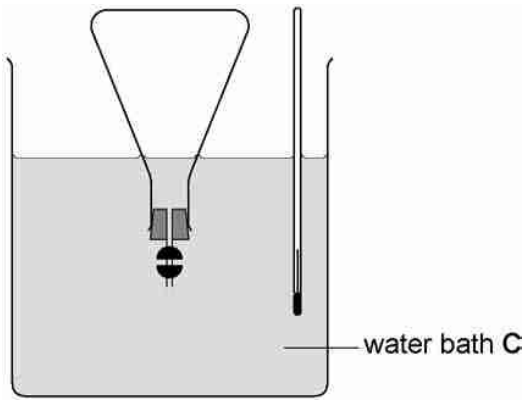
The valve is opened and some water enters the flask, as shown in **Figure 9c**.

Figure 9c



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

Figure 9d



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

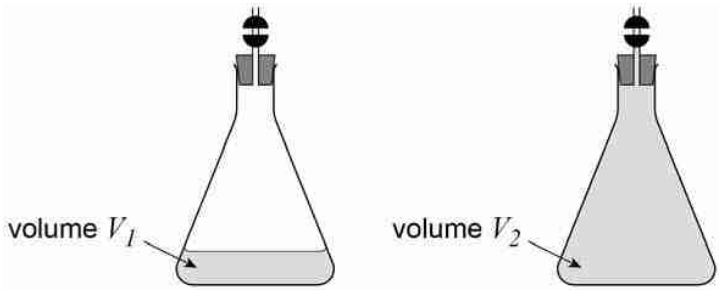
[2 marks]

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

[2 marks]

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

Figure 10



Explain how V_1 and V_2 can be determined.

In your answer you should

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

[3 marks]

Question 3 continues on the next page

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

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

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

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

[3 marks]

Figure 11

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

[1 mark]

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

[3 marks]

value of absolute zero = _____ °C

END OF QUESTIONS

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

[2 marks]

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

Describe these two interpretations of absolute zero of temperature.

[2 marks]

Question 2 continues on the next page

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

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

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

[3 marks]

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

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

[1 mark]

_____

_____

_____

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

[3 marks]

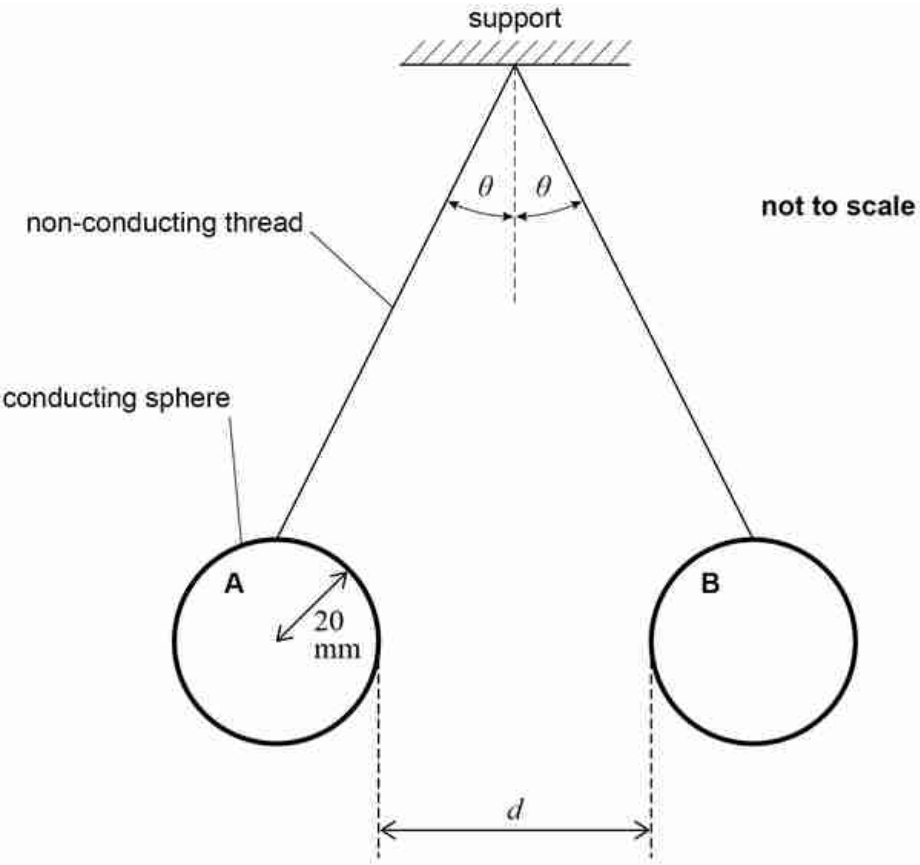
0 2 . 6 The mixture of gases in the cylinder stays the same.

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

[3 marks]

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.

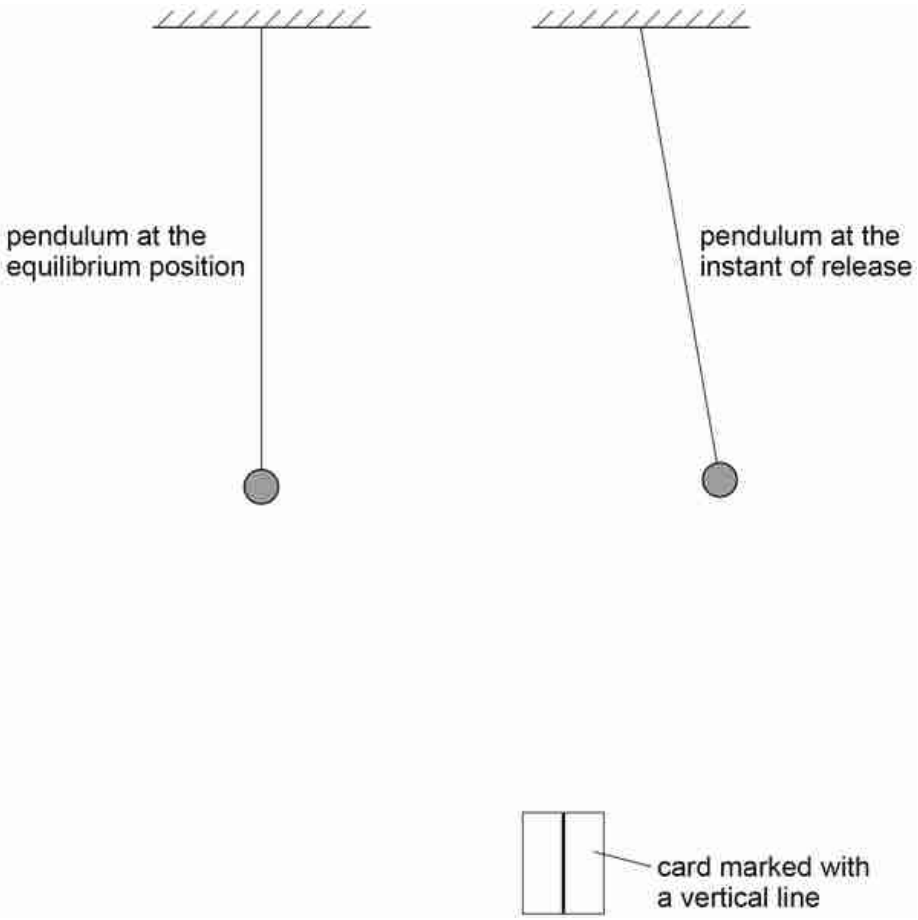
Deduce with a calculation whether this statement is valid.

[2 marks]

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

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

Figure 1



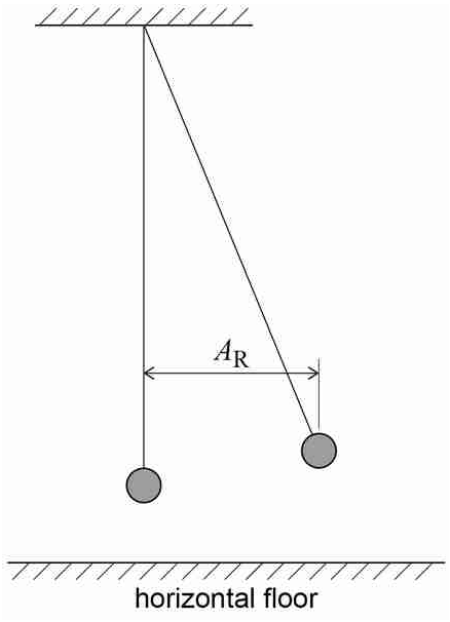
0 1 . 1 The card can be used as a fiducial mark to reduce uncertainty in the measurement of T.

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

[2 marks]

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

Figure 2



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

[2 marks]

Question 1 continues on the next page

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

Figure 3

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

[3 marks]

percentage increase = _____ %

Question 1 continues on the next page

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

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

Table 1

A_5 / m	0.217	0.247	0.225	0.223	0.218	0.224

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

[3 marks]

$A_5 =$ _____ m

percentage uncertainty = _____ %

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

Table 2

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

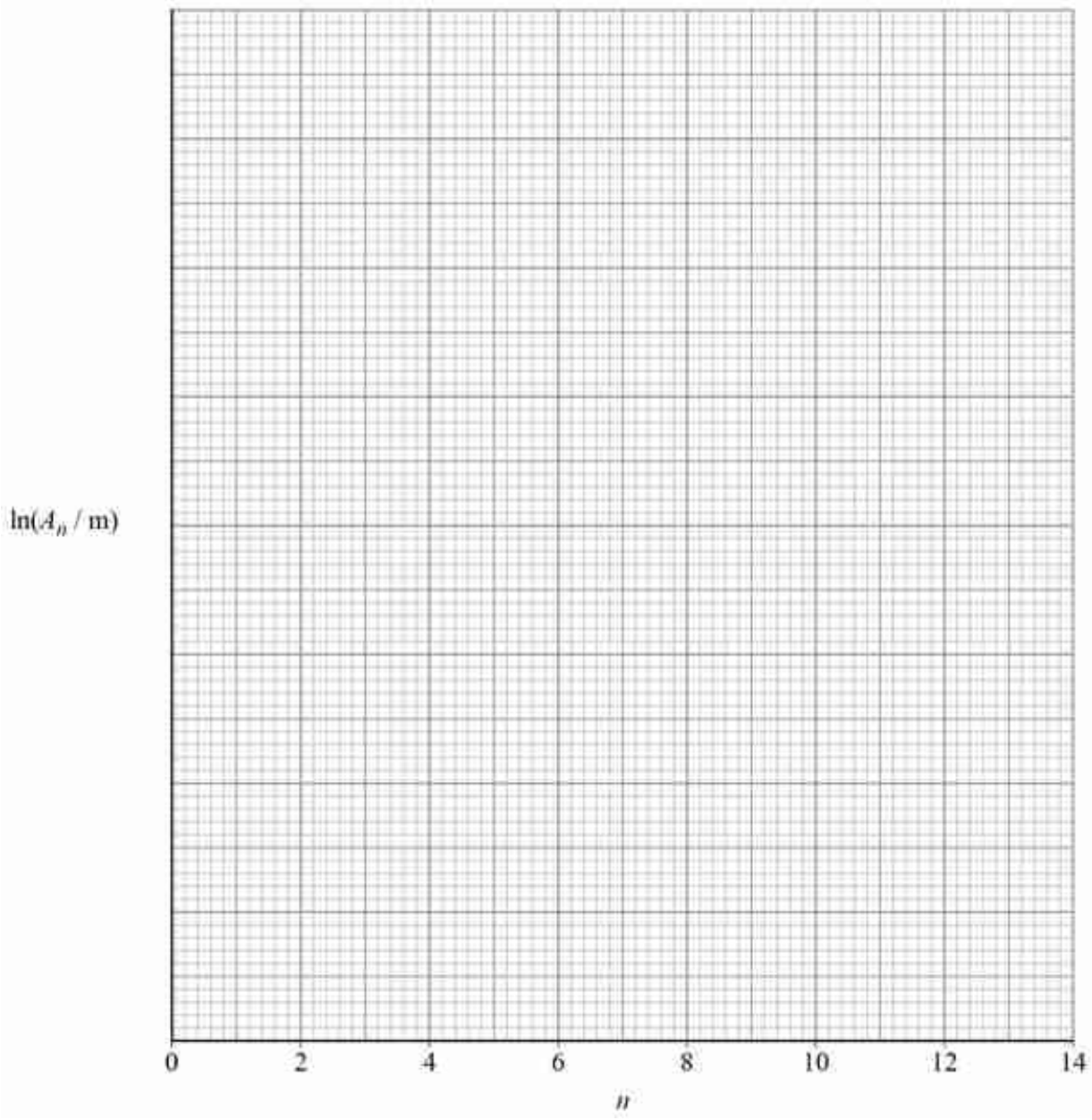
Complete **Table 2**.

[1 mark]

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

[2 marks]

Figure 4



Question 1 continues on the next page

0 1 . 7 It can be shown that

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

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

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

[2 marks]

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**.

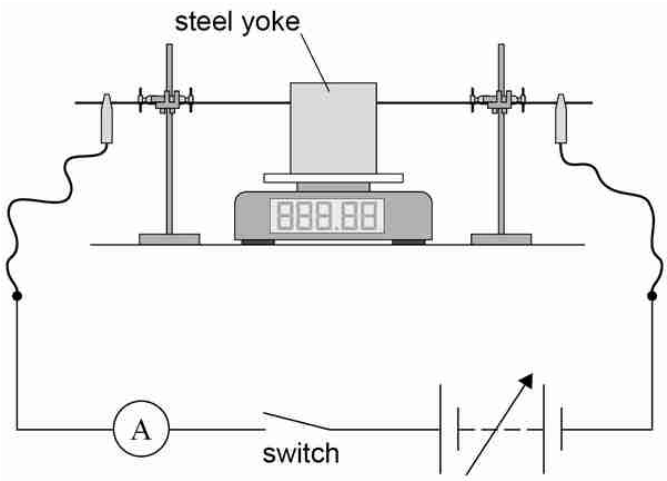
[3 marks]

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.

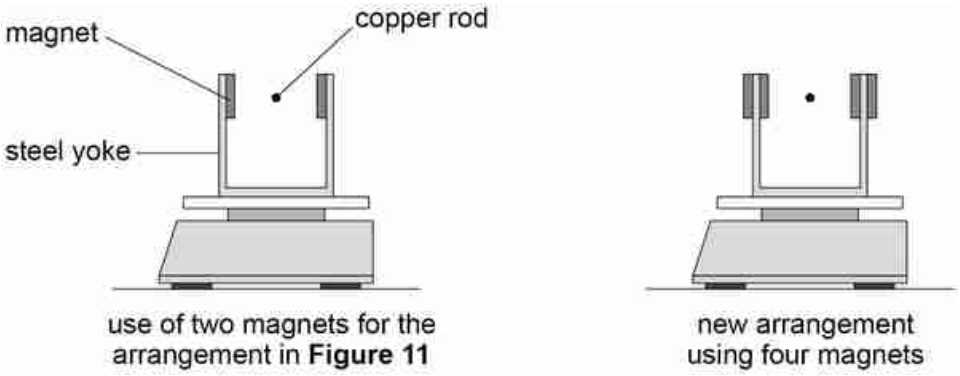
[3 marks]

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]

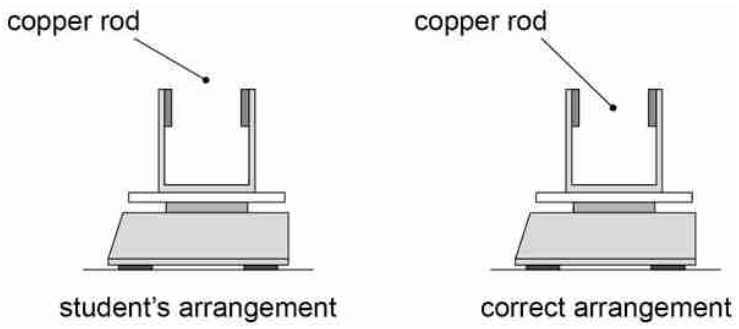
Y = _____ g

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.

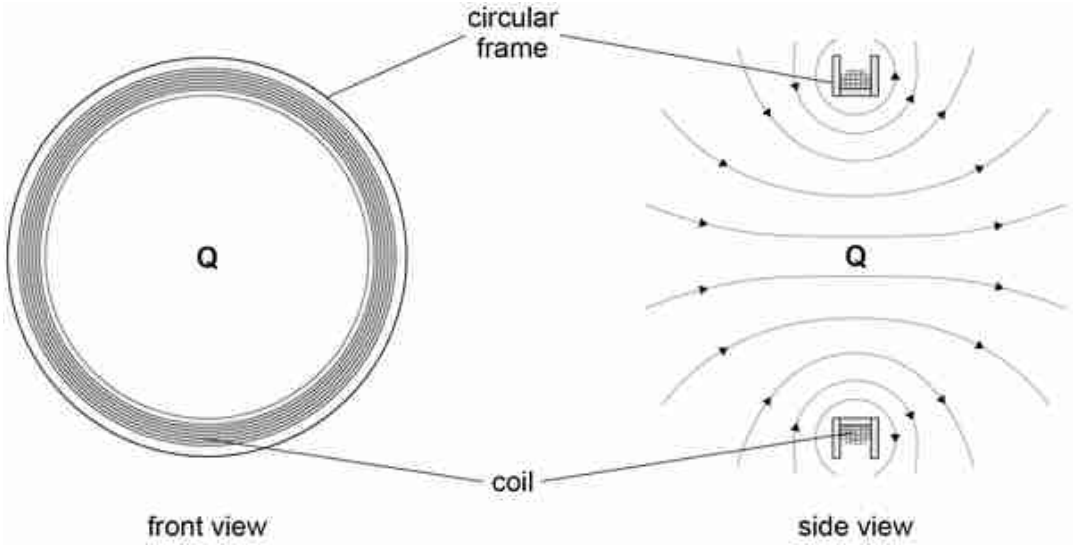
[3 marks]

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.

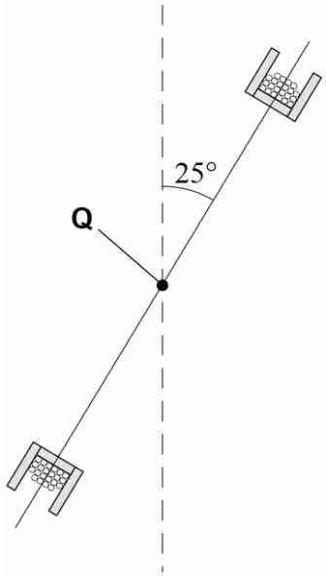
[2 marks]

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.

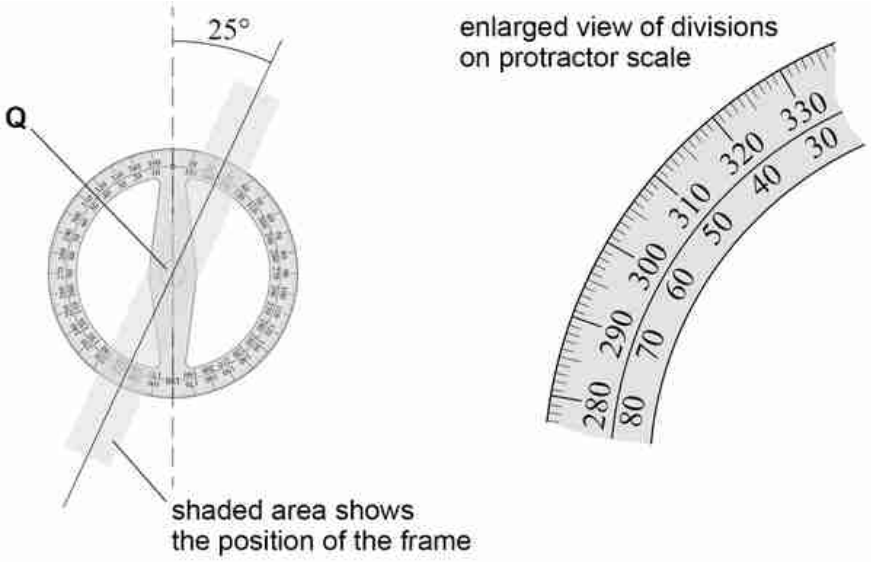
0 3 . 2 Determine the percentage change in B_H produced by this rotation of the coil.
Show your working.

[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.

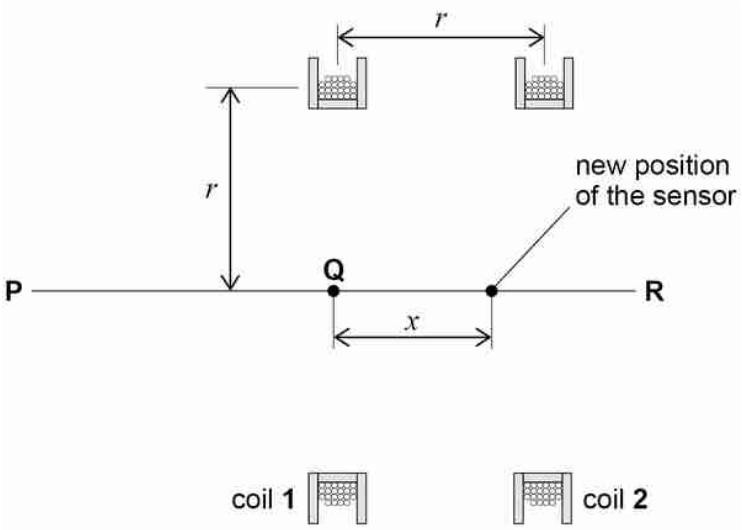
[3 marks]

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**.

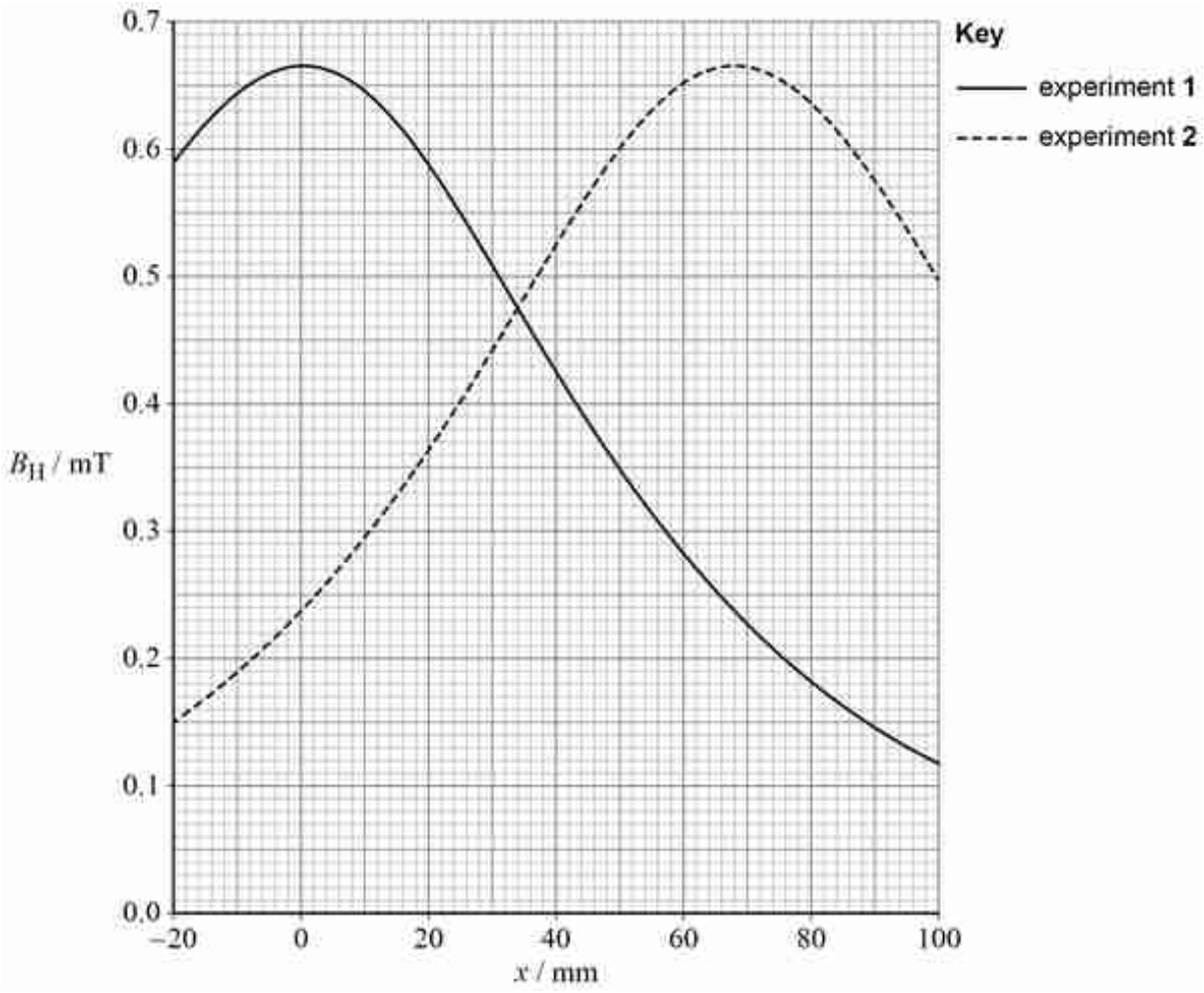
The four different experiments investigate how B_H varies with x, the displacement of the sensor from **Q** along **PR**.

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 _____

_____

_____

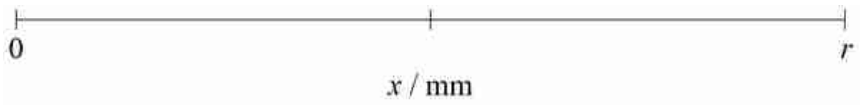
2 _____

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]

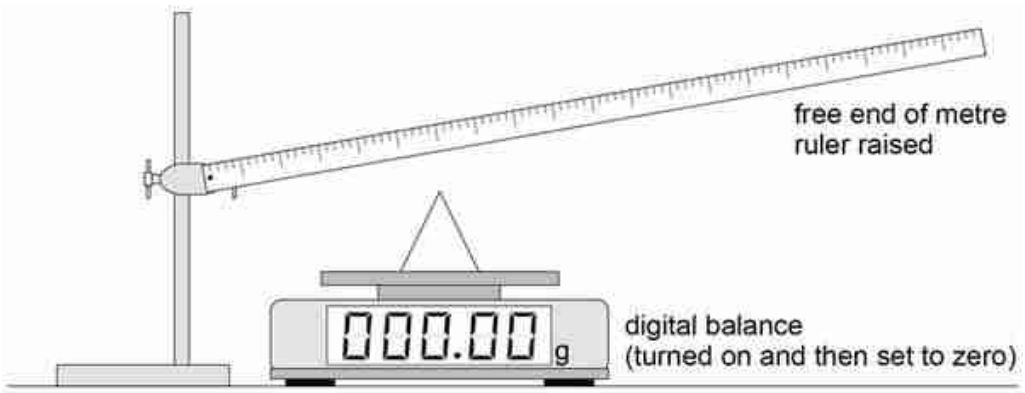


END OF QUESTIONS

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 $1.0\ \text{cm}$ 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 $30.0\ \text{cm}$ 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

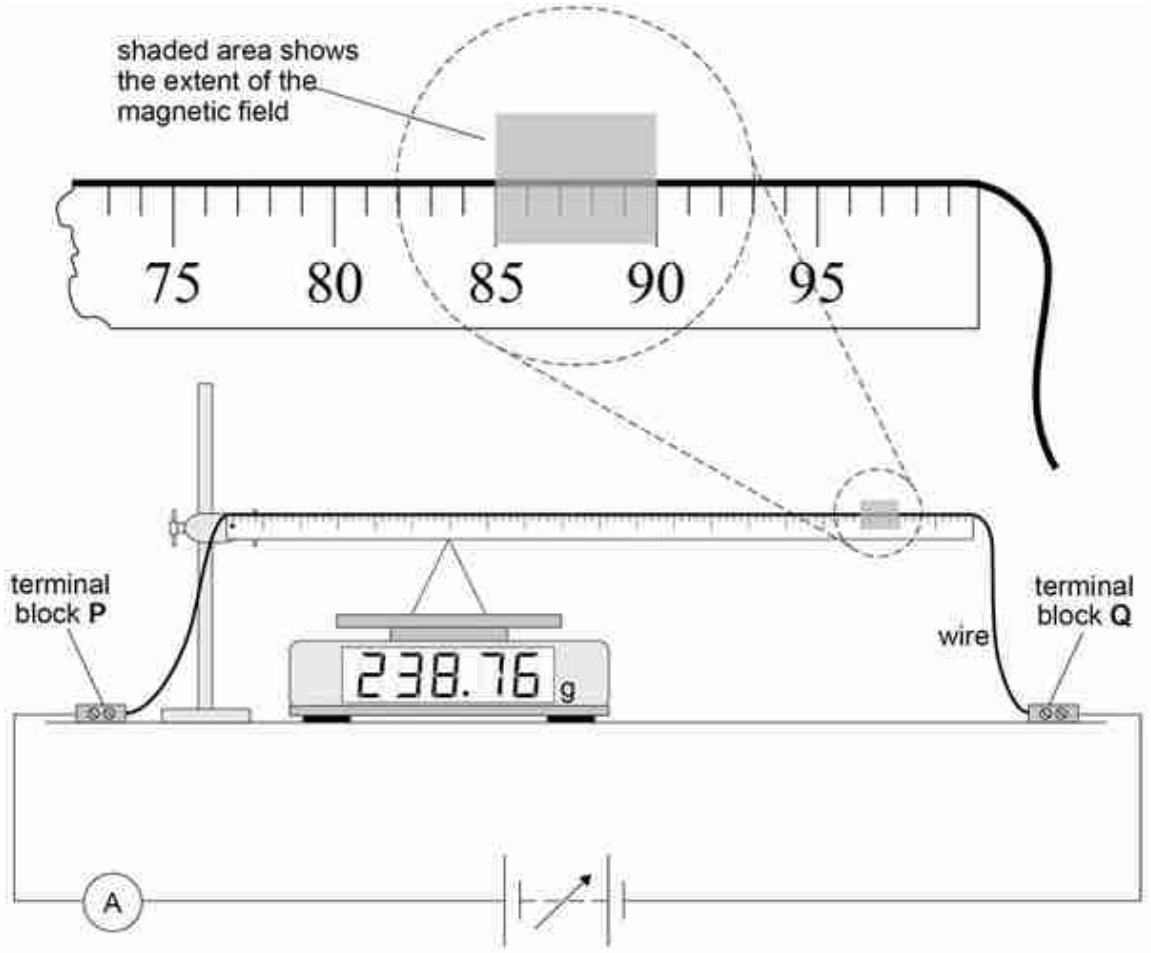
0 1 . 2 The student attaches a uniform wire to the upper edge of the ruler, as shown in **Figure 3**.

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.

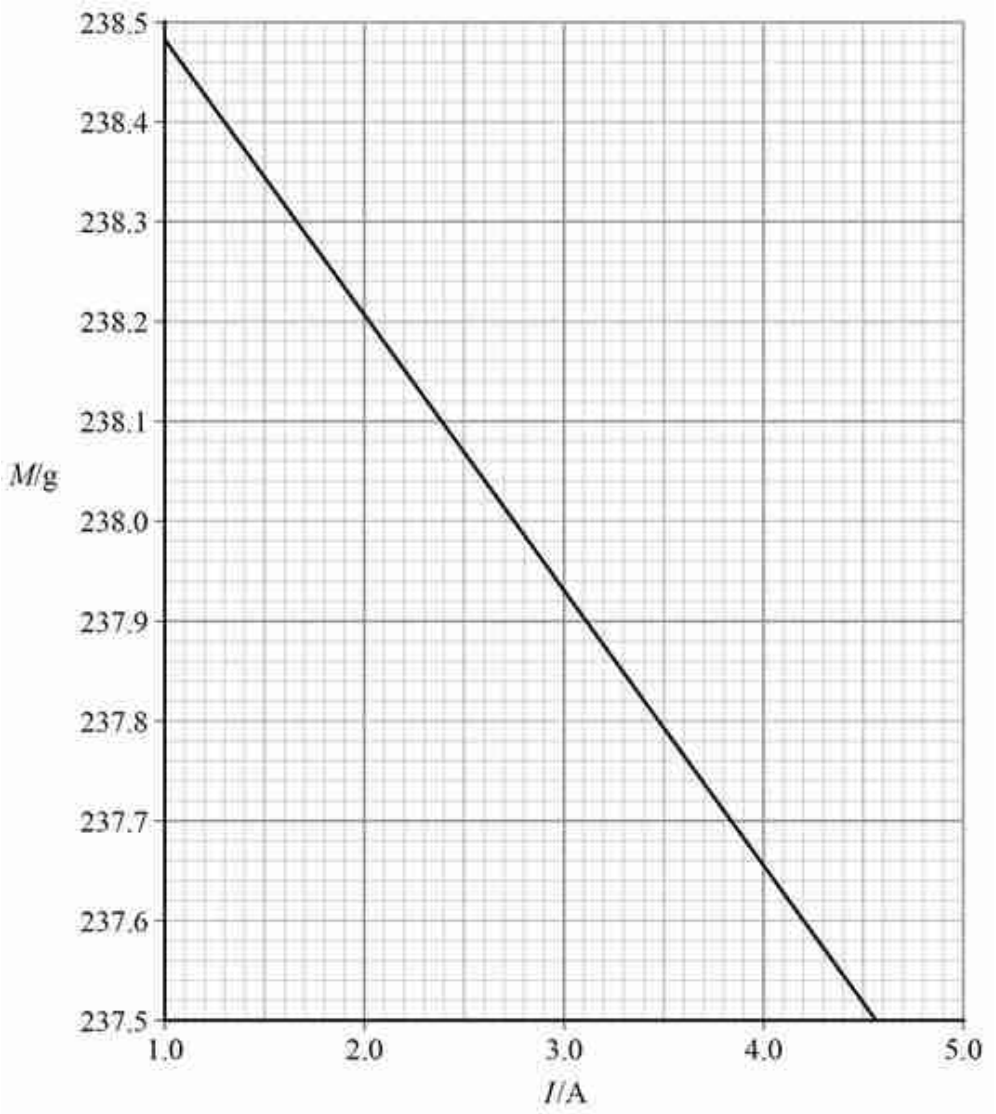
A horizontal uniform magnetic field is applied, perpendicular to the wire, between the 85 cm and 90 cm marks, as shown in the close-up diagram in **Figure 3**.

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.

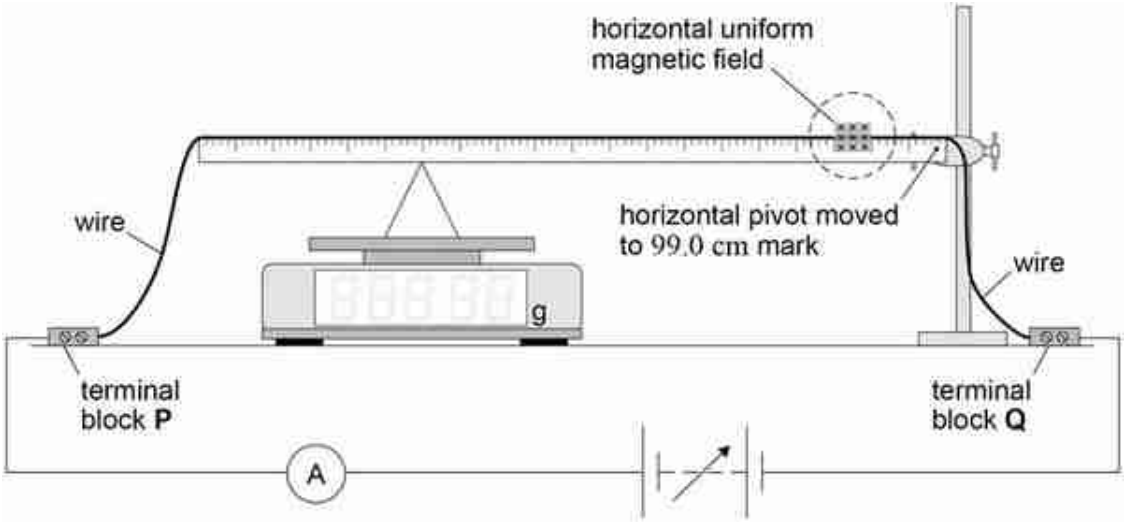
[3 marks]

$B =$ _____ 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]

MARK SCHEMES

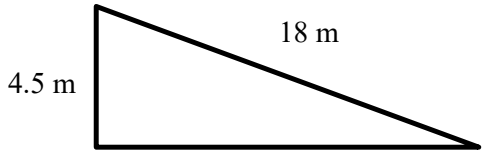
official mark schemes

D

20	D	9.6 N

20	C	displacement and momentum

05.1	Formation of a parallelogram OR triangle to draw W 1✓ Use of their W to obtain the scale at which force diagram is drawn 2✓ Use of their scale to obtain T_1 and T_2 3✓ $T_1 = 480$ N AND $T_2 = 400$ N 4✓ **Alternative Approach 1** Formation of a parallelogram OR triangle to draw W 1✓ Both angles measured correctly/evaluated to be (34 — 35)° and (11 — 12)° 2✓ $T_1 \sin 34 + T_2 \sin 11 = 350$ AND $T_1 \cos 34 = T_2 \cos 11$ 3✓ $T_1 = 480$ N AND $T_2 = 400$ N 4✓	Correct by eye. If a hybrid approach is used, note that MP2 is given for a measurement of their W used to determine a scale OR for the measurement of the two angles within range. If correct values in range seen for MP4, then it can be assumed that a scale was used to obtain T_1 and T_2, MP3 can be awarded Expect to see: $\frac{350}{35}$mm $= 10$ N mm^{-1} $T_1 = 48$ mm $\times 10$ $T_2 = 40$ mm $\times 10$ Range: allow T_1 470 – 490 N and T_2 390 – 410 N Allow complementary angles where quoted. In MP3 allow their angle values OR angle symbols consistent with labels on their diagram. Allow correct application of sine or cosine rules. Range: allow T_1 470 – 490 N and T_2 390 – 410 N	4	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	Max 4 from: • $m = \frac{350}{g}$ ✓ • their m to give KE with v = 6.5 m s^{-1} at B ✓ • 350 N and 4.5 m in GPE equation✓ • evidence of *their* Δ*GPE* – *their* Δ*KE* to give work done against friction ✓ • evidence of friction force $= \frac{\text{their work done}}{18}$ ✓ Calculates average force = 46 N ✓	Expect to see 36 kg Expect to see 754 J Expect to see 1575 J Expect to see 821 J Alternative for first **four** marks. Must see a labelled diagram indicating use of this approach:  If the diagram is not seen, mark according to the main scheme (in the 'Answers' column). Max 4 from: • $m = \frac{350}{g}$ ✓ • Use of suvat to obtain a = 1.17 m s^{-2}✓ • Uses $F = ma$ to obtain their effective resultant force✓ • Uses 350 × (4.5÷18) or equivalent to obtain their effective component of weight✓ • Subtracts their resultant force from their component of weight✓ Accept answers that round to 46 N.	5	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
05.3	Idea that contact time or distance travelled during contact is increased ✓ Generic mark scheme for MP2 and MP3 • reference to physical principle ✓ • application of principle to explain why force is reduced ✓	**Momentum approach (time increased)** • reference to Force is rate of change of momentum • change in momentum/impulse/ $F \times \Delta t$ constant therefore force decreased **Energy approach (distance increased)** • reference to force × distance = change in KE/work done • change in KE/work done/$F \times s$ constant so force reduced **Newton 2 approach (time/distance increased)** • reference to Force = mass × acceleration • change in velocity constant, so acceleration reduced so force reduced	3	AO3
Total			**12**	

18

Question	Answers	Additional comments/Guidelines	Mark	AO

A

D

C

20	C

21	B	2.25 m

22	C		

22	B	B

26

		mg

19	A	41°	AO2

24	D	4.7 N	AO2

05.1	force is at right angles/horizontal to wall (and so no component along the wall)✓		1
05.2	arrow drawn upwards from point of contact with ground✓ between ladder and vertical which when extended would pass through 'on ladder' part of label✓	Must be vertical or pointing to right for first mark	1 1
05.3	(*use of sum of clockwise moments = sum of anticlockwise moments*) EITHER $F \times 8.0\sin 60$ OR $390 \times 4.0 \cos 60$ ✓ $F = 390 \times 4.0 \cos 60 / 8.0 \sin 60 = 110\ (113)$ N✓	Either moment correct gets first mark (does not have to be evaluated)	1 1
05.4	**ANY 3** (vertical reaction) force from ground increases✓ direction of arrow of resultant force from ground changes (as ladder is ascended)✓ friction force/horizontal component of G between ladder and ground would increase✓ the (reaction) force from the wall increases✓ weight (of system)/load on ladder increases✓ as person climbs they exert a force along the ladder✓		MAX 3
Total			**8**

Question	Answers	Additional Comments/Guidelines	Mark

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

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

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

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

03.1	Volume of A = area × length = 4.16×10^{-4} m^3 OR Mass of A = W/g = 3.6 kg ✓ Use density equation ✓ Compares a calculated property of brass (e.g. weight, length or diameter) with A OR the calculated density of A with density of brass OR the calculated mass of A with the calculated mass of brass and therefore brass ✓ Example: Volume of A = area × length = 4.16×10^{-4} m^3✓ Mass if brass = density × volume = 3.58 kg✓ Weight = 3.58 × 9.81 = 35 N (which is weight of A) and therefore brass is correct. ✓	Condone POT error in MP1 Do not allow use of weight in density equation Do not accept 8.3 x 10^3 for density of A . Award zero marks for an unsupported answer “Brass” Only award MP3 if answer “brass” given.	3	3 x AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	Use of $T = (35) \cos 55$ ✓ 2 x their T ($= 40$ N) ✓		2	2 x AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	Angle (to horizontal) decreases ✓ (Weight/tension in rope remains constant at 35 N) So horizontal components (from tension in rope) increase ✓ (Therefore tension in cable must increase)	Do not award MP2 if answer suggests that tension in rope increases. Do not allow "tension increases" for credit.	2	2 x AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	Component of the force at right angle to door $= 41 \cos (90-12) / 41 \sin (12)$ $= 8.5$ N ✓ Moment $= 8.5 \times 0.95 = 8.1$ (N m) ✓ Allow ecf from their value of weight component .	Alternative: Perpendicular distance $= 0.95 \sin (12)$ $= 0.198$ m ✓ Moment $= 41 \times 0.198 = 8.1$ ✓ Allow ecf from their value of perpendicular distance. (Calculator value is 8.098 160 3) Award zero marks for simply multiplying 41 N × 0.95 m.	2	2 x AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
03.5	ALTERNATIVE 1 Increase weight / density / mass / volume of **A** ✓ Increases tension (and therefore moment) ✓ ALTERNATIVE 2 Position pulley **R** further (out) from gate hinges / increase diameter of pulley **R** ✓ Increases angle and therefore bigger perpendicular component (and therefore moment). ✓ ALTERNATIVE 3 Decrease angle of rope eg by putting P and fixed point closer together / further to right ✓ Increases tension (and therefore moment) ✓ ALTERNATIVE 4 Move **D** further from hinge/**R** OR make **C** longer ✓ Increases perpendicular distance (and therefore moment) ✓	Any 2 alternatives If more than two answers given, mark first two. Ignore the 1 and 2 in answer lines.	4	4 x AO3
Total			**13**	

Question	Answers	Additional comments/Guidelines	Mark	AO
		Condone use of W for P		

B

B

A

22	B		

02.1	Conversion of $1230\ \text{km h}^{-1}$ to m s^{-1} OR Calculates time for $343\ \text{m s}^{-1}$ run OR Calculates total time (using total distance, $3.22\ \text{km}$, and speed record) OR Calculates unknown speed ✓ Answer that rounds to $4.73\ (\text{s})$ ✓	Expect to see $342\ \text{m s}^{-1}$ (341.7) Expect to see $4.69\ \text{s}$ Expect to see $9.42\ \text{s}$ Expect to see $340.3\ \text{m s}^{-1}$ Do not accept 2sf for final answer.	2	AO1 AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	speed from graph: $450\ \text{m s}^{-1}$ ✓ Use of their speed and KE equation to give consistent answer ✓	Accept 445 – 455 m s^{-1} Expect to see 6.6×10^{8} (J)	2	AO3 AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	**MAX three** from: ✓✓✓ • Use of graph to determine gradient • Uses (their) speed and (their) gradient to give acceleration • Use of $F = m \times$ (their a) to give resultant force • Use of $P =$ (their F) $\times$ (their speed) Final answer between 16% and 17%✓	Expect to see $450\ \text{m s}^{-1}$ for their speed Evidence for gradient may be on figure Allow ECF from **02.2** • $\frac{450}{5600} = 0.080(4)$ • Expect to see $450 \times 0.08 = 36(.2)\ \text{m s}^{-2}$ • Expect to see $2.35 \times 10^5\ \text{N}$ • Expect to see $450 \times 2.35 \times 10^5 = 106\ \text{MW}$ Reject power that is calculated assuming a constant speed.	4	AO1 AO2 2× AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	Identifies distance decelerating **AND** max velocity = (470 ± 5) m s^{-1} ✓ Uses *suvat* equation(s) to get $a = (-)\ 15$ m s^{-2} which is less than $3g$ (so yes). ✓	allow 7000 m to 7600 m allow answer consistent with their distance that rounds to 15 or 16 give full credit to calculations that show that an acceleration of $3g$ would stop the car in a (much) shorter distance, with a statement that this means that the actual acceleration must be (much) less than $3g$. For MP2 allow calculation of gradient × average speed to give $a = (-)\ 15$ m s^{-2} which is less than $3g$ (so yes)	2	AO3
Total			**10**	

Question	Answers	Additional comments/Guidelines	Mark	AO

D

C

23	C	G F

20	D	$4d$	AO2

05.1	horizontal velocity = $20\cos 40° = 15.3$ ✓(m s^{-1}) horizontal velocity (is constant) / minimum when vertical velocity = 0 ✓	Needs minimum 3 sf For MP1 it must be clear that the horizontal velocity has been determined.	2	AO2 L2 Maths 1

Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	(vertical velocity) $v = 20\sin 40°$ $(= 12.9)$ ✓ (m s^{-1}) $s = ut + \frac{1}{2}at^2$ $-3 = -12.9t + \frac{1}{2} \times 9.81t^2$ or $3 = 12.9t - \frac{1}{2} \times 9.81t^2$✓ $(4.91t^2 - 12.9t + 3.00 = 0)$	For second mark both suvat equation and substitution must be shown. Equation may be rearranged before substitution	2	AO1 AO2 L2 Maths 2

Question	Answers	Additional comments/Guidelines	Mark	AO
05.3	Use of quadratic formulae with +, − or ± ✓ 0.258 s and 2.37 s✓ Time to reach 3 m once on the way up and once on the way down (OWTTE)✓ Larger value ✓	eg $t = \frac{12.9 \pm \sqrt{(-12.9)^2 - 4 \times 4.91 \times 3.00}}{2 \times 4.91}$ Two correct answers alone scores first 2 marks. ecf available for last 2 marks	4	AO1 AO1 L2 Maths 2 AO2 AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
05.4	$s = vt = 20 \cos 40° \times 2.37 = 36.3$ m so no✓	ecf from **05.3** Calculation must be seen	1	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
05.5	Gradient is the acceleration **AND** area under graph = <u>vertical</u> distance travelled✓$_1$ Without air resistance: comment about gradient✓$_2$ comment about area✓$_3$ With air resistance comment about gradient✓$_4$ comment about area✓$_5$	For each comment on the graph a reason must be given not just a description. e.g for ✓$_2$ • constant gradient = g or $9.81\ \text{m s}^{-1}$ e.g. for ✓$_4$ • initially steeper gradient since air resistance in same direction as weight (so $a > g$) • when line crosses time axis, gradient = g /9.81 / gradient without air resistance as air resistance = 0 when $v = 0$ / • After crossing time axis, gradient decreases as air resistance increases with speed E.g. for ✓$_3$ or ✓$_5$ • total area under graph = 0 since ball starts and finishes on ground • area between graph and axis is max height/**vertical** distance • without air resistance reaches a higher height as area greater statement referring to area under both graphs gains ✓$_3$ and ✓$_5$	5	AO1 AO2 AO2 AO3 AO3
Total			**14**	

Question	Answers	Additional comments/Guidelines	Mark	AO

C

C

B

24	B (AO2)	4100 N	

25	C (AO1)	the gravitational force of the parachutist on the Earth

23	A	$\frac{mg}{k}$	

24	C	The acceleration is unchanged.

23	D	931 N	AO2

21	B	The drag force when her velocity is v_2 is equal to the drag force when her velocity is v_1.	AO2

B

D

25	C	250 J
		$Q \quad E$

19	D		force	mass × displacement

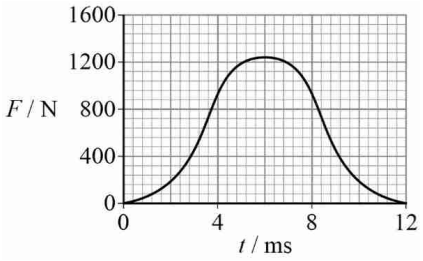
24	D	4700 kg	AO2

06.2	$16\,000 \times 2.8 - 12\,000 \times 3.1 = 28\,000\,v$ ✓ $v = 0.27(1)$ (m s^{-1}) ✓	Must see substitution Correct equation (watch signs) gets first and second marks	1 1
06.3	Impulse = $16\,000(2.8 - 0.271)$ or $12\,000(3.1 + 0.271) = 4.0(5) \times 10^4$ ✓ N s or kg m s^{-1} ✓	If 0.3 m s^{-1} used then impulse will be 4.0×10^4 or $4.08(4.1) \times 10^4$	1 1
06.4	Trucks move in opposite directions/rebound ✓ velocity of **B** is greater than that of **A** because total momentum is to the right OR **B** has lower mass ✓ or Momentum of **B** after collision is same as that of **A** before the collision (and vice versa)		1 1
Total			**8**

20

	Keys to Objective Test Questions (each correct answer is worth 1 mark)												
Q	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
A	B	B	C	C	A	B	B	A	C	D	B	D	D
Q	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	
A	D	D	C	C	D	C	B	D	C	D	A	D	

06.1	Max 1 from: Calculation of Δv Calculation of E_k using their Δv 1✓ 52(.3) J 2✓	For 1✓ expect to see $Ft = m\Delta v$ and $u = 0$ $v = \frac{6.55}{0.410} = 15.9756 \text{ m s}^{-1}$ Condone POT error in 1✓ $E_k = \frac{1}{2}pv = \frac{1}{2} \times 6.55 \times 15.9756$ $= 52.320$ (J) Do not allow rounding error. If no other mark given, award **max 1** for a combination of ke and momentum equations seen in numbers or symbols $Ek = \frac{1}{2}\frac{(mv)^2}{m}$	2	1 × AO1 1 × AO2

Question	Answers	Additional comments/Guidance	Mark	AO
06.2	Area under graph = 8.5 large squares OR 212 small squares $_1$✓ uses area of graph = impulse $_2$✓ judges that the interval is 400 N AND annotates y-axis with 400 N intervals $_3$✓	Allow 8 to 9 or (small □) 200 to 225 Accept attempt to calculate area using y-axis interval as unknown quantity Area = 6.55 N s on its own is insufficent for $_2$✓ Allow evaluation of impulse ÷ their number of squares One square = $F \times 2 \times 10^{-3} = \frac{6.55}{\text{their number of squares}}$ And F = their area of one square ÷ 2×10^{-3} s  $_3$✓: minimum 3, non-zero, major grid lines labelled	3	1 × AO2 2 × AO3

Question	Answers	Additional comments/Guidance	Mark	AO
06.3	Any **two** from: $_1\checkmark_2\checkmark$ • resolve $18\ \text{m s}^{-1}$ vertically (to obtain u) • use of SUVAT with their u eg $s = (\text{their } u) \times t + \frac{1}{2}at^2$ • evidence of consistent sign for s, u and a $t = 2.87$ (s) $_3\checkmark$	$18\sin 48$ seen or inferred from use of $(-)13.37(7)$ use of $v = u + at$ with $v = 0$ and $s = ut + \frac{1}{2}at^2$ with $u = 0$ $-2.0 = (18\sin 48)t + \frac{1}{2}(-9.8)t^2$ OR $2.0 = (-18\sin 48)t + \frac{1}{2}(9.8)t^2$ Do not award MP3 if negative solution quoted. Allow 2.86 or 2.9 Allow any correct alternative route	3	1 × AO1 2 × AO2
Total			**8**	

20

Question	Answers	Additional comments/Guidance	Mark	AO
	1			

05.1	(= $7(.2) \times 10^5$)	Expect answer to be calculated correctly and to 2+ sf. Accept 700 kJ as 2 sf	2
05.2	Component of velocity = $31 \times \cos(20)$ **OR** evidence of using momentum = mass × velocity (eg 1.5×10^3 x a velocity) ✓ $= 4.4 \times 10^4$ ✓ For unit <u>only</u> accept kg m s^{-1} **OR** N s ✓	Allow ecf for speed from 05.1 Accept 4.65×10^4 kg m s^{-1} for max 2 Use of 30.6 m s^{-1} gives 43 kN s	3
05.3	(KE before collision = 700 kJ) Speed (parallel to barrier) after (= $31 \times \cos 20$) = 28.7 m s^{-1} ✓ KE after(= ½ × $1.5 \times 10^3 \times 28.7^2$) = 618 kJ ✓ Change = 700 – 618 ✓ (= 82 kJ) **OR**	Allow ecf for speed from 05.1 Use of KE = $p^2/2m$ can gain full credit. Allow ecf for momentum in 05.2 Final answer depends on extent to which candidate has rounded in earlier parts. Allow correctly evaluated solutions for full credit.	3

	~~Speed (perpendicular to barrier) after = $31 \times \sin 20$ (= $10.5\ m\ s^{-1}$)~~✓ Loss of KE (= ½ × $1.5 \times 10^3 \times 10.5^2$) = 82 kJ ✓ Justification that total KE = KE due to speed parallel to barrier + KE due to speed perpendicular to barrier ✓	~~In this question, do not insist~~ on final answer to 2+ sf. If there is a suggestion that KE is a vector or can be resolved, do not award MP3.	

05.4	Evidence of work done = force × distance Eg Force = 82 000 / 1.5 **OR** *their value for 05.3*÷1.5✓ = 5.5×10^4 N✓ This is less than braking force – so yes. ✓ **OR** energy approach • work done by barrier = 60 kN x 1.5 m✓ • 90 kJ ✓ • which is > E_k of vehicle, so yes ✓ **OR** impulse argument • evaluate time taken to stop, 0.26 s ✓ • impulse value leading to distance or force✓ • conclusion consistent with correct method of calculation ✓ **OR** use of *F=ma* and *suvat* : • F= ma leading to *a* = (-)40 m s^{-2}✓ • *suvat* leads to 1.37 m✓ • which is <1.5 m, so yes ✓	Allow 80 kJ for energy General scheme for alternatives and reverse arguments is: • first step calculation • subsequent calculation(s) leading to comparative value. Allow ecf for error in first step. • conclusion consistent with correct method of calculation Alternative suvat method: • uses suvat to get a = 36.5 m s^{-2} • uses F=ma • which is <60 kN, so yes	3

05.5	~~(Steel barrier is better because)~~ Increase time of contact as material deforms ✓ Reference to impulse (= change in momentum = Ft) implies smaller force (on dummy) ✓ **OR** Increasing stopping distance as material deforms ✓ Reference to work done (= Fs) implies smaller force (on dummy) ✓	Allow correct discussion leading to concrete barrier is worse. Alternative second mark for either alternative can be awarded for correct reference to F=ma	2

Total			**13**

Question	Answers	Additional Comments/Guidelines	Mark
	1.5 (ms) ✓		

C

C

06	C

23	A

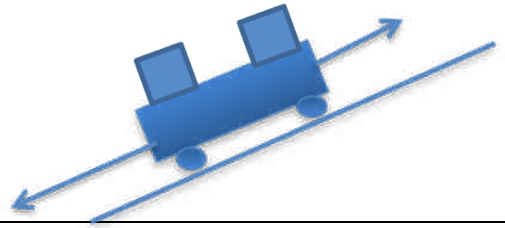
07	C (AO1)	work done and the moment of a couple

09	B (AO1)	10^6 J

26	D (AO2)	0.614 N s	

8	C	60 kg	

11	A		1 mN	1 km		AO1

06.1	arrow parallel to slope labelled (M+2m)gsin35 and label parallel to slope labelled tension OR T✓ 	Ignore arrows not parallel to ground e.g. weight Ignore friction W not acceptable for (M +2m)g	1

06.2	T – Mgsin35 = Ma AND (M+2m)gsin35 – T = (M+2m)a ✓ add two equations (M + 2m)gsin35 – Mg sin35 = Ma + (M +2m)a ✓ HENCE (a= mgsin35/(M+m)) OR (M +2m)gsin35 – Mgsin35✓ (= (2M+2m)a) a = 2mgsin35 /(2M +2m) ✓ HENCE (a= mgsin35/(M+m))		1 1

06.3	SECOND MARK CONDITIONAL ON FIRST mass/impulse/acceleration (of trollies) is the same✓	SECOND MARK CONDITIONAL ON FIRST both have same speed / magnitude of velocity but different	1

	momenta (trolley A and B) the same	masses✓ (hence)momentum of A is greater/momenta in opposite directions✓	1

06.4	acceleration = $\frac{1}{4} \times \frac{30 \times 9.81 \times \sin 35^{o}}{(30+95)} = 0.338$ ✓ (use of $v^2 = 2as$) $v = \sqrt{(2 \times 0.338 \times 9.0)} = 2.47$ ✓ $t = \frac{2.47}{0.338} = 7.3$ s ✓ OR (use of $s = 1/2at^2$) $9 = ½ \times 0.338 \times t^2$ ✓ $t = 7.3$ s ✓	CE from acceleration calculation If used g for acceleration then no marks awarded	1 1 1

06.5	number of journeys = (1800/(12 + 7.3) = 93 or 94✓ number of blocks = 2 × 93 = 186 or 2 × 94 = 188✓	Allow CE from 06.4 Allow between 93 to 94 Allow CE from incorrect number of journeys Allow 186 to 188	1 1

Total			**10**

Question	Answers	Additional Comments/Guidelines	Mark

01.1	(correct Δv and Δt) and answer in range (-)2.5 to (-)2.9 (m s^{-2}) ✓ Use of $F = ma$ using their a with answer i.e Force =1. 8 x 10^4 x their a from an attempt at a tangent or trying to use *suvat* equation✓	$-15/5.5 = 2.7$ (3) m s^{-2} Allow if answer rounds to these values answers from best attempts at tangent in range 4.7 to 4.9 x 10^4 N	
01.2	Attempt to estimate area under the graph. ✓ Correct square count 21 to 23 10 mm squares (525-575 small squares) **OR** distance per square = 2.5 m or 0.1 m✓ Value in range 50 m to 60 m **and conclusion** that escape lane would be long enough✓	Use of *suvat* equation = 0 For attempt to find area using trapezium rule expect use of 1 s intervals for this mark.	1 1 1

7

01.3	KE of lorry : to KE of gravel (as it is pushed aside/moved)✓ OR PE of gravel (as it may be ejected upwards)✓ transfer to thermal energy /internal energy/heating of gravel /ground/lorry **OR** work done on the gravel/vehicle increasing internal energy/raising temperature✓	Ignore losses due to friction Not KE of the ground Must refer to what is heated	Max 2 1 1

1.4	Appreciates that KE converted into PE or May be stated or by attempt to use of $mgh = ½ mv^2$ or Calculates initial KE of lorry $\frac{1}{2}1.8 \times 10^4 \times 17.5^2 = 2.76 \times 10^6$ (J) ✓ Height needed in escape lane $= 2.76 \times 10^6/(1.8 \times 10^4 \times 9.81) = 15.6$ m or Length of lane required $=15.6/\sin 25 = 37$ m **(**compare with 85 m) or vertical height of ramp = 35.9 m (compare with height needed 15.6 m) or maximum change in PE possible = 85 sin 25 x 9.81 x 1,8 x 10^4= 6.3 x 10^6 (J) (compare with initial KE) ✓ **Comparison and conclusion** that escape lane would be long enough.This must follow from correct working✓ Deceleration produced by slope = 9.8(1) sin 25 or 4.15 (4.1 or 4.2) m s^{-2} seen✓ Distance to stop from $v^2 = 2as$ give s = 37 m (compare with 85 m)✓ Or Minimum deceleration needed = $17.5^2/2$ x 85 = 1.8 m s^{-2} (compare with 4.15 m s^{-2})	Allow max 2 if height = 85 tan 25 or length of lane = 15.6/tan 25 i.e allow these incorrect values when drawing conclusion Arriving at 37 m gets first two marks	1 1 1

	Comparison and conclusion that escape lane would be long enough This must follow from correct working✓		

01.5	The straight road of uniform gradient because: The deceleration (condone acceleration) is uniform ✓ with the gravel the initial deceleration is larger/may vary ✓ Travelling through gravel could make the vehicle unstable/bounce erratically(owtte) ✓ Gravel because: On the ramp the lorry would roll backwards after stopping (as it has no brakes)	Do not allow deceleration less when on gravel(It is greater initially) Do not allow answers that (average) force using gravel lane is less than decelerating force on the ramp (due to increased stopping distance or stopping time) Or because stopping time is longer	Max 1
Total			**12**

	Clear indication of correct process two correct values for λv from working plus conclusion (7.35; 7.25; 7.35)✓	Condone no or misuse of powers of 10 Allow use of v alue of *h* as the constant to show that v values in table are consistent with the λ values	1 1

04.1	moment (of weight of the box) ✓ Links pivot position to a consideration of moments ✓	Award 2 for 1.25 x weight of beam = 1.5 x weight of empty box Confusion of moments with eg work done/forces = max 1	2
04.2	Clockwise moment = $610 \times 9.81 \times 1.5$ (= 8976 N m) ✓ Anticlockwise moment = $250 \times 4 + T \sin 50 \times 4.0$ (N m)✓ Use of clockwise = anticlockwise✓ Use of T sin 50° seen / relates vertical component to tension✓ T (= 1994/sin 50°) = 2600 (N)✓	Credit any evidence to work out a moment with one mark Condone cos 50 in MP2. Allow ecf for clockwise moment Allow ecf for anticlockwise moment Use of g = 10 N kg^{-1} gives 2990 N Omission of 4.0 m (g = 9.8) gives 10410 N. Use of cos 50 (g = 9.8) gives 3100 N	5

12

		Allow max 4 for use of g = 10 N kg^{-1}.	

13

04.3	$7.5 = ½\ g\ t^2$ ✓ (t = 1.2 s) (calculate distance) s (= ut = 18 × 1.2) = 22 (m)✓	Allow ecf from incorrect t for MP2	2

04.4	**(Range will be greater:)** component of velocity upwards ✓ rock will spend longer in the air ✓ greater *t* ✓ ***therefore*** the range is greater ✓ **OR** **(Range will be smaller)** Counterweight will fall less far before projectile released ✓ Less energy transferred to rock ✓ Initial speed of rock less/horizontal velocity reduced ✓ ***therefore*** the range is smaller ✓ **OR** (balanced arguments) ***therefore*** the range is unchanged / answer is indeterminate✓	Candidates can argue from both lists to reach a balanced view suggesting that there is no change. Full credit can be obtained from 2 deductions from one list ✓✓+ consistent conclusion✓ 1 deduction from each list ✓✓+ consistent conclusion ✓ Do not allow an unsupported conclusion. Conclusion must be consistent with **correct** statements. Treat incorrect statements as neutral. Do not reward arguments based on a longer time of flight.	Max 3
Total			12

Question	Answers	Additional Comments/Guidelines	Mark
	Conversion of 110 km h^{-1} to 31 m s^{-1} ✓ = ½ × 1.5 × 10^3 × *their conversion*^{2} with a consistent answer✓	Allow ecf for incorrect or failure to carry out speed conversion Expect answer to be calculated correctly and to 2+	

B

C

D

26	D

26	C	$\frac{\rho}{A}$ $\frac{E}{A}$	

27	D (AO1)	$9E$	

28	C (AO3)	The strain of Q is double the strain of P.

26	D		

25	C	$3E$	AO2
		$k(\Delta L)^2$	

26	C	$\frac{\pi(\quad)}{2t}$	AO2

31	A	190 g	AO2

04.1	Idea that YM = $\frac{\text{(tensile) stress}}{\text{(tensile) strain}}$ and (tensile) strain has no units ✓		1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
04.2	Evidence of determination of volume of one wire $_1$✓ Uses relationship between density of **X** OR the density of the wire used in MP1 and their volume to determine their mass $_2$✓ Answer between £4800 and £4900 $_3$✓	When X is used in MP1, condone the use of diameter for radius of X. Expect $V = 3.3 \times 10^{-6}\ \text{m}^3$ Condone PoT error Expect $M = 64\ \text{g}$ or $65\ \text{g}$ Condone PoT error 75×64 or 75×65	3	AO3

Question	Answers	Additional comments/Guidance	Mark	AO
04.3	**W** and **Z**, as their densities are the same (and density is the only one that is a property of the material) ✓	Allow suggestion that the Young modulus is the same provided there is evidence of its determination for both.	1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
04.4	Draws best-fit line $_1$✓ Uses pair of values of stress and strain from point on line more than halfway along the line OR uses a difference in two pairs that is more than half the line $_2$✓ Evidence of attempt to use equation(s) to determine E, k, l, A or d from graph OR for **W** (for use in a comparison). $_3$✓ Compares E for **W** with value from **Figure 5** OR compares k, l, A or d for **Figure 5** with value for **W** With answer yes $_4$✓	For $_1$✓ look for an equal scatter of points either side of the line. Allow half square tolerance on graph read-offs. Condone PoT error Copy of W data from table 1 eg cross-sectional area of **W** $= 2.27 \times 10^{-6}$ m^2 Condone PoT error $E = 6.8 \times 10^{10}$ (N m^{-2}) Accept answers that round in the range 6.7×10^{10} to 6.9×10^{10} for E from graph.	4	AO3

Wire	Length / m	Diameter / mm	Stiffness / N m^{-1}	Density / kg m^{-3}
W	3.10	1.7	4.90×10^4	2.71×10^3

Total			9

Question	Answers	Additional comments/Guidance	Mark	AO

05.1	Evidence of appropriate use of Figure 11 e.g. $105 \times 10^{6} \div 7.5 \times 10^{-4}$ leading to an answer in the range 1.38 to 1.42×10^{11} Pa ✓	Some evidence that Figure 11 is used: calculation based on a point on line between 75 MPa and 125 MPa OR calculation from point on straight line extended OR Use of triangle from more than half of the linear section. Allow 2 sf answer 1.4×10^{11} (Pa).	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	Idea that wire undergoes only (very) small (increase in) strain beyond the linear section before fracture ✓	Reject idea that there is **no** increase in strain. Condone ‘extension’ or ‘(plastic) deformation’ for ‘strain’. Condone ‘shortly after’ for ‘beyond’ Accept: does not show 'necking' before fracture Accept: fracture occurs very near the limit of proportionality (condone ‘elastic limit’). Accept references to a particular value of strain e.g. 9×10^{-4} to 12.7×10^{-4}	1	AO1 × 1

Question	Answers	Additional comments/Guidelines	Mark	AO
05.3	Evidence of determination of total load or load on one wire ✓ (halves load) Use of $E = \frac{(\text{their } F) \times L}{A \times \Delta L}$ ✓ $\Delta L = 1.1(4) \times 10^{-3}$ (m) ✓	Total load $= (4.4 + 16.0) \times 9.8(1) = 200(.1)$ N Allow 'g' for 9.8(1) Expect to see F =100 N and $A = 5.03 \times 10^{-7}$ m^2. Condone use of d in calculation of cross-sectional area A in MP2. Or separate calculations using $\sigma = F \div A$, $E = \sigma \div$strain, strain $= \Delta L \div L$ Condone POT error in MP2.	3	AO1× 1 AO2× 2

Question	Answers	Additional comments/Guidelines	Mark	AO
05.4	Evidence of extension/strain in each wire is the same $_1$✓ Substitutes data leading to $F_a = 1.33\ F_s$ $_2$✓ Calculates F_s or F_a $_3$✓ Evidence of an attempt at a moment equation $_4$✓ Distance = 1.18 m ✓$_5$	$\Delta L = \{FL \div AE\}$ steel = $\{FL \div AE\}$ aluminium $\{F \div d^2E\}$ steel = $\{F \div d^2E\}$ aluminium $_1$✓ $\frac{F_s}{0.8^2 \times 210} = \frac{F_a}{1.6^2 \times 70}$ $F_a = 1.33\ F_s$ OR $F_s = 0.752\ F_a$ $_2$✓ $1.33\ F_s + F_s = 200$ N $F_s = 86$ N, $F_a = 114$ N $_3$✓ Attempt to take moments about A or B or other suitable point, expect to see $16.0gx = 228 - 4.4g$ ✓$_4$ Note that an answer of 1.14 m comes from not taking into account the weight of the beam Award **max 4** for this approach. ECF for MP2 and MP3 in MP4	5	AO3× 5
Total			**10**	

22

Question	Answers	Additional comments/Guidelines	Mark	AO

C

D

D

A

C

C

B

C

B

A

D

A

D

B

B

B

D

A

A

C

D

C

C

D

C

D

B

D

A

C

C

C

08	B

12	D

13	A

25	C

C

A

C

16	B	muon electron

17	D	The frequency is 0.17 Hz.

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

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

12	B	$4g$

13	A	7.2 J

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

22

25	B	200 0.45

26	A	Its rate of change of momentum is at a minimum.

31	C	2.55×10^{-13} J

14	B (AO2)	maximum kinetic energy of a photoelectron

19	A (AO1)	first

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

13	D (AO2)	the orbital period of the satellite	

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

22	B (AO2)	3.9×10^{-2} T	

13	A		decreasing the kinetic energy of the electrons

14	C		1.2	0.17

31	B	the kinetic energy of the mass

19	C	4.0×10^{-14} m

20	B	6.0×10^{-3} T	

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

23	D	600 μV

24	D	395 V

27	C	0.174 A

31

09	A		/ /	

10	A		increases	decreases	AO2

29	B	$2\pi^2 mf^2 r^2$	AO1

24

8	B	doubling the volume at constant pressure

12	B	decreasing the frequency of the ac input voltage

15	A	doubling the transmission voltage of the cable
		Be

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

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 $1\ \mathrm{m}^2$

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 $1\ \mathrm{V}$

10	A	energy is conserved.	AO1

14	A	$\frac{1}{\text{diameter of the wire}}$	AO1

25	B		maximum	minimum		AO1	

30	D	$\frac{q}{r}$	AO1

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

20	D	$4I$	AO2

21	A	0	AO2

22	D	6.25 μV	AO2

23	A	80%	AO2

28	C	4.7 MeV	AO2

04.1	Either appreciation of mass of $\mathrm{He} = 4 \times$ mass of neutron OR idea that n and He have equal (and opposite) momenta ✓ Combination of momentum and KE equations (to give idea that KE is inversely proportional to m with same p) and therefore KE of neutron $= 4 \times$ KE of He ✓	Expect to see KE $= \frac{p^2}{2m}$	2	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	calculates KE of neutron OR uses mass of neutron from data booklet with *their calculated KE* in a KE equation✓ $v = 5.2 \times 10^7$ m s^{-1} ✓	$80\% \times 2.82 \times 10^{-12} = 2.26 \times 10^{-12}$ (J) Do not allow use of 2.82×10^{-12} as *their calculated KE.* $m_n = 1.67(5) \times 10^{-27}$ kg Accept answers of 5.18×10^7 or 5.19×10^7 m s^{-1} Calculator values: 5.1823878×10^7; (using 1.68) 5.1901169×10^7; (using 1.675) 5.1978807×10^7 (using 1.67)	2	AO2
Total			**4**	

Question	Answers	Additional comments/Guidelines	Mark	AO

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

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

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

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

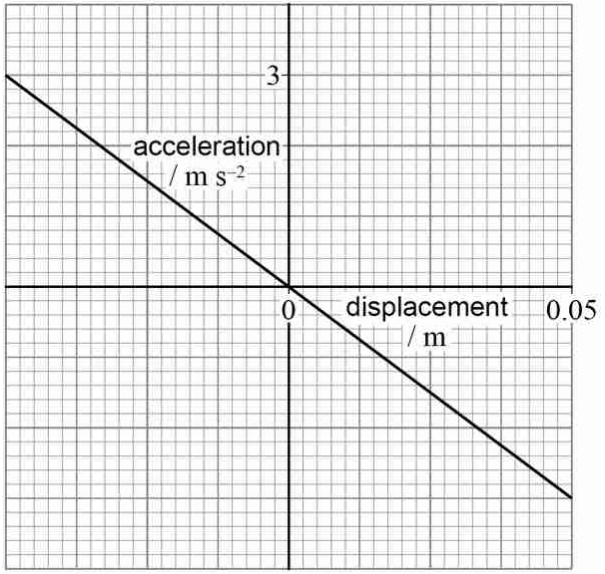
Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	(the speed before and after a collision is the same in the elastic collision) $\Delta p\ (= p_f - p_i) = -mc - mc = -2mc$ ✓	Use of subscripts i and f or before and after do not need explanation. Δ will be assumed to mean (final – initial).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

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

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

8

Question	Answers	Additional comments/Guidelines	Mark	AO

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

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

Question	Answers	Additional comments/Guidance	Mark	AO

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

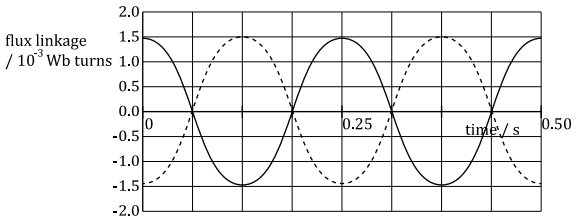
03.2	$B Q v = m v^2 / r$ ✓ $t_{\text{semi-circle}}$ (= distance / speed) = $\pi r / v$ Or use of t_{circle} (= distance / speed) = $2 \pi r / v$ ✓(this mark can only be awarded if it follows an attempt to answer the first mark) combining gives ($t_{\text{circle}} = 2\pi m / B Q$ so) $t_{\text{semi-circle}}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

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

Total			**6**

11

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

05.1	AB 2.5×10 $\times 5.0 \times 10$ 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-

02.1	EITHER calculate value for constant using two calculations✓ calculate value for constant using three calculations <u>and</u> make a comment that they have same value✓ OR calculate ratio between masses and √T for one pair of values✓ calculate ratio between masses and √T for two pair of values <u>and</u> make comment about same value✓ OR work out constant and use to predict one other frequency or mass✓ work out constant and use to predict two other frequencies or mass✓	need to see table to look for any working e.g. 0.5/0.8 = √110/√140 no comment needed with this alternative	2
02.2	$\mu = \rho A = 1150 \times \pi(5.0 \times 10^{-4}/2)^2$ $\mu = 2.258 \times 10^{-4}$ (kg m^{-1})✓ use of consistent *m* and *f* Substituted in $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ including g but condone powers of 10 error✓ 0.67 m✓	 Award second mark if *T* and *f* substituted correctly (ignore μ) If used diameter for radius incorrectly then lose first mark but can get third mark (answer 0.335 m)	3
02.3	appreciation of reducing diameter when string is stretched.✓		2

	lower mass per unit length so (constant of proportionality and hence) frequency is higher (than would be predicted)✓		
Total			**7**

Question	Answers	Additional Comments/Guidelines	Mark

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

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

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

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

02.1	place mirror behind ruler $_1$✓	give credit for any relevant annotation to Figure 6 or in additional sketch for $_1$✓ do not insist on contact between mirror and ruler	1	2 x AO3
	adjust position (of eye / head) until pin hides / lines up with its own reflection / image $_2$✓	condone use of (non-hypotenuse) edge of set-square to define horizontal plane $_1$✓ adjust position until horizontal edge of set square meets/is touching pin or wtte $_2$✓ if no other mark given award $_{12}$✓= 1 max for 'read value at eye level' OR move (clamped) ruler closer to pin	1	

Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	valid strategy using apparatus in **Figure 5**: y (as the dependent variable) measured (or wtte) for different values of <u>one</u> independent variable (only L or m are acceptable) $_1$✓	for $_1$✓ must refer to variables only using the symbols and/or terms given on page 8; accept 'weight' / mg as independent variable condone mock table as intent / y = 'extension'	1	2 x AO1
	identifies the correct control variable (besides w and t) $_2$✓	for $_2$✓ L = control variable if m = independent variable OR m = control variable if L = independent variable; if L is being varied and $m = 250$ g is stated, this can be taken as m = control variable and therefore known; take a similar approach if m is being varied but in this case L must have a **quoted value** that is ≤ 30 cm; for more than one independent variable, eg variation of both m and L $_{12}$✗✗ but allow ECF for $_4$✓ as long as plot is valid, eg y against mL^3	1	
	suitable measuring instruments for L OR w OR t $_3$✓	ANY ONE of the following (for more than one response mark as LIST) for L: use ruler; for w: use (any type of vernier) callipers; accept micrometer (screw gauge); for t: use micrometer (screw gauge); accept digital / electronic (vernier) callipers	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
02.2 continued	analysis: suggests valid plot $_4$✓ identifies correctly how E can be found from a valid plot $_5$✓	for $_4$✓ plot must involve y [by itself or combined with another factor] on one axis and their independent variable [by itself or combined with another factor] on the other axis; do not insist on y as ordinate for $_5$✓ E must be the subject; some examples include:	1 1	2 x AO3

ordinate	abscissa	E =
y	m	$\frac{4\times L^3\times g}{w\times t^3\times \text{gradient}}$
mg	y	$\frac{4\times L^3\times \text{gradient}}{w\times t^3}$
y	L^3	$\frac{4\times m\times g}{w\times t^3\times \text{gradient}}$
y	$\frac{4\times L^3}{w\times t^3}$	$\frac{m\times g}{\text{gradient}}$
$\log y$	$\log m$	$\frac{4\times g\times L^3}{w\times t^3\times 10^{\text{intercept}}}$
$\log y$	$\log L$	$\frac{4\times m\times g}{w\times t^3\times 10^{\text{intercept}}}$

Total			7

10

Question	Answers	Additional comments/Guidelines	Mark	AO

03.1	Max 2 from one route ✓✓ **Alternative 1** • $\Phi = BA\cos\theta = 4.9 \times 10^{-5} \times (2 \times 8.0) \times \cos 68° = 2.9(4) \times 10^{-4}$ (Wb) OR $\Phi = BA = 4.9 \times 10^{-5} \times (2 \times 8.0) = 7.84 \times 10^{-4}$ (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 $\varepsilon = 2.3 \times 10^{-4}$ ✓ (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 $t = \left(\frac{2s}{a}\right)^{\frac{1}{2}} = \left(\frac{2\times 8.0}{9.81}\right)^{\frac{1}{2}} = 1.28$ 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

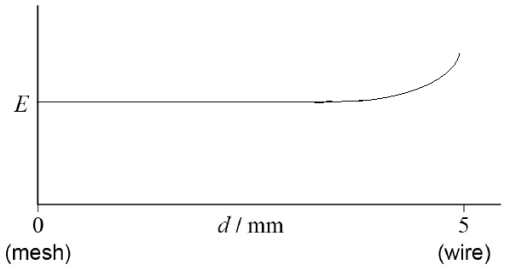
Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	(As the coil moves) there is a rate of change of flux through the coil ✓$_1$ (owtte) The induced emf is proportional to the rate of change of flux (linkage) so the (magnitude) of the emf decreases ✓$_2$ (owtte)	✓$_1$ The first part ie the induced 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	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

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

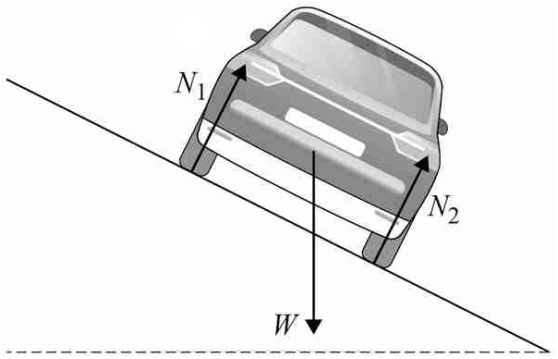
Question	Answers	Additional comments/Guidelines	Mark	AO
05.3	Idea that the force from the Moon is in the opposite direction to the force from the Earth ✓1 **An expression of why S_2 can't orbit Earth at this ω and r without the moon.** Idea that the Earth's gravitational force is too great or that it 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

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

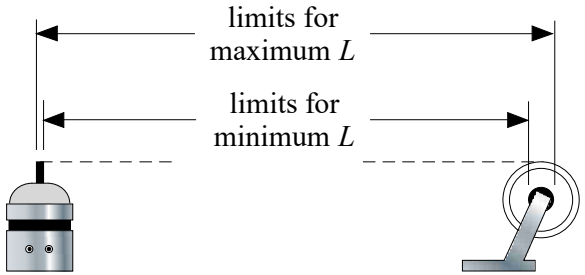
Question	Answers	Additional comments/Guidance	Mark	AO
07.2	$v = 58.7$ (m s^{-1}) ✓	Calculator value: 58.73670062 Accept 59 Do not accept rounding error.	1	AO2

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

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

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

Question	Answers	Additional comments/Guidance	Mark	AO
	1			

01.1	mass per unit length **of string** OWTTE $_1$✓ length (of string) between vibration generator and pulley $_2$✓ acceptable limits for defining L in **Figure 1**:  	**quantitative properties only** answers may be in either order for $_1$✓ condone minor slip 'wire'; condone 'μ' **of string**; 'type of string' / 'same string' are neutral for $_2$✓ accept 'distance between vibration generator and pulley' / 'length of horizontal (part of) string; allow clear annotation to **Figure 1** to **correctly** identify dimension (correct by eye): allow use of a symbol, eg L condone 'amplitude of supply output voltage' / 'output voltage' or WTTE 'ac frequency' (or WTTE) / 'total (suspended) mass' / 'length of vibrating section (of string)' / 'diameter of string' (or WTTE) / 'amount of string between generator and pulley'/ 'temperature of string' / 'positions of generator etc' are neutral	2	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
01.2	m has a maximum range of 170 g. ✓	CAO	1	AO3

Question	Answers	Additional comments/Guidance	Mark	AO
01.3	V_{peak} in range 18(.0) to 19(.0) (V) OR calculates V_{rms} using $\frac{\text{their } V_{peak}}{\sqrt{2}}$ 1✓ V_{rms} in range 13.0 to 13.2 (V) 2✓	for 1✓ allow $V_{rms} = 0.71 \times$ their V_{peak} etc; allow $V_{peak\ to\ peak}$ in range 36(.0) to 38(.0) (V) OR $V_{rms} = \frac{\text{their } V_{peak\ to\ peak}}{2\sqrt{2}}$ allow V_{rms} **correct** in cm, ie $\frac{3.7 \pm 0.1}{\sqrt{2}}$ OR $\frac{7.4 \pm 0.2}{2\sqrt{2}}$ for 2✓ max 4 sf; condone 4 sf rounding to 3 sf in range do not accept 2 sf 13 (V)	2	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
01.4	T_{100} in range 104 to 107 (ms) ✓	period must be expressed in units of time; allow 0.104 to 0.107 **s** if answer line amended	1	AO3

Question	Answers	Additional comments/Guidance	Mark	AO
01.5	determines T_{200} OR f_{200} AND attempts to compare T_{200} with T_{100} (their **01.4**) OR attempts to compare f_{200} with f_{100} (based on their **01.4**) 1✓ expected pairs of values: $T_{100} = 105.4$ ms; $T_{200} = 74.5$ ms $f_{100} = 9.49$ Hz; $f_{200} = 13.4$ Hz $T_{100} = 5.30$ cm; $T_{200} = 3.73$ cm compares $\frac{\text{their } T_{100}}{\text{their } T_{200}}$ OR $\frac{\text{their } f_{200}}{\text{their } f_{100}}$ to $\sqrt{2}$ OWTTE AND makes a reasoned judgement (to show if their evidence is consistent with doubling m) 2✓	for 1✓ their T_{200} in range 73.5 to 75.6 ms OR f_{200} in range 13.2 to 13.6 Hz; condone use of T_{100} and T_{200} in cm OR in div; ignore POT but must be consistent between values for $T_{100/200}$ or $f_{100/200}$; allow **any** quantitative comparison; condone a qualitative comparison award 2✓ as follows: states **Figure 2** is the expected result with $\frac{\text{their } T_{100}}{\text{their } T_{200}} \geq 1.34$ AND ≤ 1.48 (OR 1.4) etc OR states **Figure 2** is **not** the expected result with $\frac{\text{their } T_{100}}{\text{their } T_{200}} < 1.13$ OR > 1.69 ; otherwise accept either conclusion OR 'cannot tell'	2	AO3
Total			**8**	

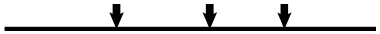
8

Question	Answers	Additional comments/Guidance	Mark	AO

04.1	emf is the intercept on the pd/y axis✓ gradient of the graph is –r /internal resistance is <u>minus</u> the gradient of the graph/modulus of gradient is r/absolute value of gradient is r/magnitude of gradient is r✓		1 1
04.2	figure 5 circuit supplies 50 mA ✓ figure 6 circuit has emf of 1.4 V ✓ and internal resistance of 12 Ω ✓ hence current of 78 mA which is >75 mA ✓ OR calculate required pd is 0.45 V (0.075 × 6.0)✓ show pd for cell in fig. 5 is 0.1 V ✓ show pd across parallel cells in fig. 6 is 0.4 V✓ show total pd in fig 6 is 0.5 V which is greater than 0.45 V✓ OR calculate emf needed for 75 mA in fig 5 (1.05)✓ calculate emf needed in fig 6 (1.35)✓ comment on emf needed in fig. 5 is larger than cell provides✓ comment on emf in fig. 6 being close to what is required✓	Can use different routes independently for fig 5 and fig 6 If candidates calculated current is not 50 mA or 75 mA allow CE for correct conclusion relating to 75 mA Must explain which circuit <u>is</u> suitable. If their calculation shows neither circuit suitable must explain why <u>both</u> circuits not suitable from graph for current for current of 75 mA from graph for current of ½ of 75 mA i.er. 37.5 mA i.e. 0.1 V from single cell and 0.4 V from parallel cells	4
04.3	useful power dissipated = $(75 \times 10^{-3})^2 \times 6$✓ (= 0.03375 (W)) input power (at the cells) = 0.03375/.04 = (W)✓ solar power =0.8437 /(32×10^{-4})=260 (263.7 or 264) W m^{-2}✓	Condone use of 78 mA gives answer of 285 W If use resistance of 18 Ω then lose first mark but CE to give answer of 791 W CE from power calculation but not from % calculation if incorrect % calculation at any stage only qualify for useful power mark	1 1 1

Total			**9**

Question	Answers	Additional Comments/Guidelines	Mark

05.1	(using mass defect = $\Delta m = Z\, m_p + N\, m_n - M_{Co}$) $\Delta m = 27 \times 1.00728 + 32 \times 1.00867 - 58.93320$ (u) ✓ $\Delta m = 0.5408$ (u) ✓ Binding Energy = $0.5408 \times 931.5 = 503.8$ (MeV) ✓ (CE this mark stands alone for the correct energy conversion even if more circular routes are followed.	Look at use of first equation and if electrons are used or mass of proton and neutron confused score = 0. If subtraction is the wrong way round lose 1 mark. Data may come from rest mass eg m_n =939.551 MeV or 1.675×10^{-27} kg or 1.00867 u. So if kg route used $\Delta m = 8.83 \times 10^{-28}$ kg BE = 7.95×10^{-28} J and 497 Mev. Conversion mark (2nd) may come from a wrong value worked through. 0.47(5)	3
05.2	$(2.52 - 1.76) \times 10^{-13} = 7.6 \times 10^{-14}$ J ✓ $7.6 \times 10^{-14} / 1.60 \times 10^{-13} = 0.47$ or 0.48 MeV ✓(0.475 MeV)	Correct answer scores both marks.	2
05.3	6 (specific wavelengths)		1
05.4	(longest wavelength = lowest frequency = smallest energy) $(2.29 \times 10^{-13} - 2.06 \times 10^{-13}) = 2.3 \times 10^{-14}$ (J) ✓ $\lambda\ (= h\, c / E) = 6.63 \times 10^{-34} \times 3.00 \times 10^{8} / 2.3 \times 10^{-14}$ ✓ $\lambda = 8.6 - 8.7 \times 10^{-12}$ (m) ✓ (8.6478×10^{-12} m)	Allow a CE in the second mark only if the energy corresponds to an energy gap including those to the ground state. The allowed energy gaps for CE are: 2.29, 2.06, 1.76, 0.53, 0.30 all x 10^{-13}J Note substitution rather than calculation gains mark. The final mark must be as shown here and not from a CE above.	3
Total			**9**

Question	Answers	Additional Comments/Guidelines	Mark

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.		

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

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

Total			**9**	

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

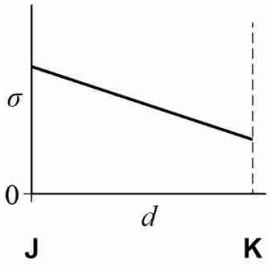
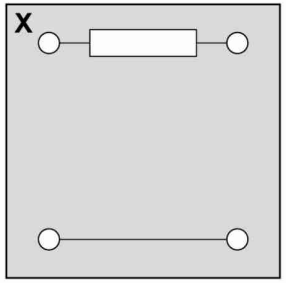
06.1	Equates resultant force to ma and shows a proportional to y, as $A\rho mg$ are all constant✓ Minus sign included and explained: (restoring) force/acceleration directed to centre of oscillation ✓ (hence SHM)	In MP1: Condone upthrust/buoyancy force for resultant force $F = ma = -A\rho yg$ $a = -\frac{A\rho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

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

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

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

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

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

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

02.1	All four rows correct $_1$✓$_2$✓ Any two rows correct $_1$✓	<table><tr><th>Particle</th><th>Baryon</th><th>Hadron</th><th>Lepton</th><th>Meson</th></tr><tr><td>π^+</td><td></td><td>✓</td><td></td><td>✓</td></tr><tr><td>n</td><td>✓</td><td>✓</td><td></td><td></td></tr><tr><td>K^+</td><td></td><td>✓</td><td></td><td>✓</td></tr><tr><td>Σ^0</td><td>✓</td><td>✓</td><td></td><td></td></tr></table> Accept any reasonable notation for ✓	2	1 × AO1 1 × AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	Identifies strangeness as the consideration as interaction would be strong/not weak ✓ K^- and Σ^0 have same strangeness of -1✓ Demonstration that LHS and RHS strangeness not equal AND that the LHS is zero ✓	Do not award MP1 for suggestion that any other quantum number is not conserved. Evidence for MP2 and MP3 can be seen in a correct use of strangeness values e.g. 0 + 0 → -1 -1	3	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	clear assignment of each particle to its correct rest mass including the photon ✓ idea that LHS mass > RHS mass✓	Electron AND positron rest energy = 0.510999 MeV π^0 rest energy = 134.972 MeV Gamma/photon rest mass = 0 Allow rounded values for rest mass.	2	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	annihilation of the positron with an electron ✓	Do not allow answers such as ‘elimination’	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
02.5	Idea that international collaboration/co-operation/verification is required OR (investment in) expensive equipment/hardware/ infrastructure is required ✓	Accept idea that (people with) particular/specialist talents/technology/infrastructure must be in place. Ignore references to peer review or vague statements such as 'it takes a long time' or 'it/the research is expensive'.	1	AO1
Total			9	

Question	Answers	Additional comments/Guidelines	Mark	AO

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

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

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

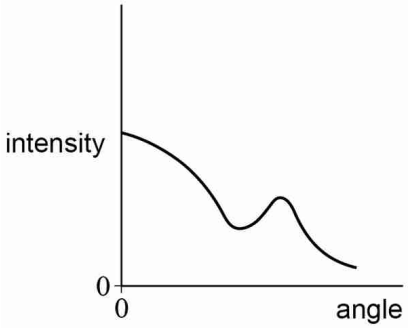
Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	$T = 4 \times 293$ or 4 times the starting temperature in K ✓ change in temperature = 879 (K) ✓ (correct answer gains both marks) **Alternative** $T = \frac{m(2c_{rms})^2}{3k}$ correctly calculated for their m, c_{rms} ✓ Their calculated $T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

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

Question	Answers	Additional comments/Guidelines	Mark	AO

01.1	Any **one** from: ✓ • $(\Delta)E_k = (\Delta)E_P$ seen • $E_k = 1.60 \times 10^{-19} \times 5.59 \times 10^{6}$ or 8.94×10^{-13} seen • $Q_\alpha = 2e$ and $Q_{Au} = 79e$ An energy $= \frac{Q_\alpha Q_{Au}}{4\pi\varepsilon_0 r}$ seen in any form ✓ $r\left(= \frac{2 \times 1.60 \times 10^{-19} \times 79 \times 1.6 \times 10^{-19}}{4\pi \times 8.85 \times 10^{-12} \times 5.59 \times 10^{6} \times 1.60 \times 10^{-19}}\right)$ (<) 4.1×10^{-14} (m) ✓ (allow 1 sf) cao	MP1 may be seen in substitution for r Condone PoT error in MP1 and MP2. In MP2: Allow use of $E = QV$ **and** $V = \frac{Q}{4\pi\varepsilon_0 r}$ with Q_α and Q_{Au} in either order. Condone use of k for $\frac{1}{4\pi\varepsilon_0}$ unless contradicted by use of 1.38×10^{-23} Condone use of E_k in MeV. Condone 10^{-14} if supported by some correct substitution. Correct answer to at least 1 SF gains all 3 marks.	3	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
01.2	Any **two** from: ✓✓ • Idea that alpha particles give an upper limit on size of the nucleus / estimate is larger than nuclear radius • Idea that (distance of closest approach) depends on the energy of the alpha particle • Idea that recoil of nucleus is ignored • Idea that alpha particle has finite size	Ignore references to shape of nucleus. bullet 1: condone idea that it does not hit the nucleus. Referencing the distance of closest approach is not enough. bullet 2: is for the idea that the closest approach method does not give a single value • Condone does not take into account neutrons / only considers charge / only considers number of protons. If no other mark awarded allow **max 1** for reference to not taking into account the effect of the strong nuclear force.	2	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
01.3	When angle = 0 there is a maximum **and** first minimum is not zero **and** at least one subsequent smaller maximum ✓	 Allow subsequent peaks Condone the line meeting the intensity axis at non-zero but negative gradient. Do **not** allow double slit (even superposed with single slit) or diffraction grating (light-like) patterns.	2	AO1
	Idea that nuclear radius is determined from (first diffraction) minimum ✓	Allow suitable annotation of diagram for answer Ignore any equation given.		

Question	Answers	Additional comments/Guidance	Mark	AO
01.4	Any **one** of: ✓ • volume of a nucleus is (approximately) spherical • $V = \frac{4}{3}\pi R^3$ or $V = \frac{4}{3}\pi R_0^3 A$ • volume is proportional to A • mass $= A \times$ mass of nucleon • mass (/kg) $= A \times 1.661 \times 10^{-27}$ • mass is proportional to A Density $\left(=\frac{m}{V}\right) = \frac{Am_{(n)}}{\frac{4}{3}\pi {R_0}^3 A} = \frac{m_{(n)}}{\frac{4}{3}\pi {R_0}^3}$ **AND** where all are constants / equation is independent of A. **OR** Combining of two proportional statements and cancelling of A ✓	Do **NOT** accept bullets 3, 4,5 or 6 when A is referred to as area, activity or any other incorrect quantity. $R \propto A^{\frac{1}{3}}$ or $R^3 \propto A$ is not enough. Accept alternative values or u in bullet 5	2	AO1
Total			**9**	

Question	Answers	Additional comments/Guidance	Mark	AO
		Any suggestion that particles do not follow		

07.1	*(use of* $v = 2\pi f\sqrt{a^2 - x^2}$*)* v_{max}=2π×2.0×2.5×10^{-2} v_{max}= 0.314 m s^{-1}✓ (use of E_k = ½mv^2) 54 × 10^{-3}= ½m × $(0.314)^2$ *m*= 1.1 (kg) ✓ $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$	Can	1 1

	$2.0 \times 2\pi = \sqrt{(k/1.1)}$ ✓ $(k = (4\pi)^2 \times 1.1)$ $k = 173\ (172.8)$ ✓(N m^{-1}) OR $5.4 \times 10^{-3} = ½\ k\ (2.5 \times 10^{-2})^2$✓ k= 173 (172.8) N m^{-1}✓ OR $54 \times 10^{-3} = ½\ F \times 2.5 \times 10^{-2}$ $F = 4.32$ $4.32 = k \times 2.5 \times 10^{-2}$ k = 173 (N m^{-1})	If use either these method can then find mass from frequency formula or from kinetic energy Accept 170 and172.8 to 174	1 1
07.2	(use of $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$) same mass so $f \propto \sqrt{k}$ thus frequency = $2.0 \times \sqrt{3}$✓ frequency = 3.5 (3.46) (Hz) ✓	Allow CE from 07.1 for k or m	1 1
07.3	Two from: (resonance) peak/maximum amplitude is at a higher frequency✓ due to higher spring constant✓ (resonant) peak would be broader ✓ due to damping✓ amplitude would be lower (at all frequencies)✓ due to energy losses from the system✓	First mark in each case for effect Second mark for reason 2 marks max for effects 2 marks max for reason Cannot award from sketch graph unless explained First mark in each pair stand alone Second mark conditional on first in each pair	 1 1 1 1

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	B	C	C	C	A	A	B	C
Q	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	
A	D	B	B	B	C	B	B	C	B	D	D	D	

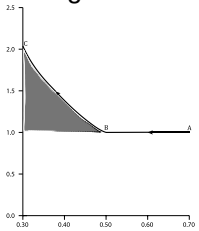
01.1	The volume/size of the gas molecules is negligible/point mass or point molecule Or molecules are <u>point</u> masses Or small <u>compared</u> to the volume/size occupied by of the gas ✓ owtte	No mark for all the same size or spherical. Without the comparison the word used must suggest extremely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

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

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

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

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

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

Question	Answers	Additional Comments/Guidelines	Mark

03.1	creates nodes and antinodes bland ✓ In some positions the waves always cancel /interfere destructively to give zero amplitude/no vibration/nodes) **OR** interfere constructively to produce positions of maximum amplitude/maximum vibration/antinodes ✓		1
03.2	Use of $f=\frac{1}{2l}\sqrt{\frac{T}{\mu}}$ ✓ 4.2 (4.19)× 10^{-4} (kg) ✓	Either rearranges for μ without substitution or substitutes correctly in the formula	1 1
03.3	240 (244) (m s^{-1})		1

03.4	1 rotation of the peg = 22 mm ✓ extra extension = 22 × 75/360 = 4.6 mm (ecf for incorrect circumference)✓ Total extension = 11 + 4.6 (15.6 mm) so tension 35 - 36N ✓ Calculates frequency **for their tension**	Or Reads increase in tension produced by the extra extension (about 10 N) from graph and adds to 25 πd x 75/360 not evaluated =1 Inspect their length and their tension in the substitution T must <u>be greater than</u> the original 25N Condone adding or subtracting <u>extra</u> extension to 0.33 m If 4.0 × 10^{-4} kg used then answer will be in range 448 Hz to 455 Hz If 4.19 x 10^{-4} used 438 to 444 Hz	1 1 1 1
Total			**10**

	Length of resistance wire = 50 × 2 × 3.14 × 4 × 10^{-3} = 1.26 m✓ Substitution of data in resistance formula	or 50 × 3.14 × 8 × 10^{-3} ecf for incorrect length from attempt at a calculation	1 1

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

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

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

Total			10

8

Question	Answers	Additional comments/Guidelines	Mark	AO

05.1	Electromagnetic ✓	Reject electrostatic as it is not one of the fundamental forces.	1	AO1.1a
05.2	Arrow drawn at X in a direction radially away from the centre of the gold nucleus ✓		1	AO1.1b
05.3	Answer number 5 or 6 plus one consistent justification ✓ One more consistent justification ✓ List of justifications: Cannot be 1, 2, or 3 as these s alpha's deflect up Or must be 5 to 9 as these all alpha's deflect down. Cannot be 4 as this would backscatter or is scattered at 180° Cannot be 7, 8 or 9 as the deflection would be too small Or must be 2, 3, 5, 6 as these have a greater deflection than alpha1.	First mark must come with at least one justification. The second mark is possible to obtain with two consistent justifications even if the first mark is missed. E.g. if an answer 7 is given then quoting the first two justifications gains a mark.	2	AO1.1b AO3.1b

Question	Answers	Additional comments/Guidelines	Mark	AO
05.4	(Using of potential energy $= \frac{Qq}{4\pi\varepsilon_o r}$) Substituting the values of the two charges multiplied together into an equation $(2 \times 1.6 \times 10^{-19})(79 \times 1.6 \times 10^{-19})$✓1 PE = $\frac{2\times79\times\left(1.6\times10^{-19}\right)^2}{4\pi\times8.9\times10^{-12}\times5.5\times10^{-14}}$ or 6.58×10^{-13} (J) ✓2 (loss of KE = $\frac{1}{2}mv^2$ = gain in PE} $\left(v = \left(\frac{2 \times 6.58 \times 10^{-13}}{6.8 \times 10^{-27}}\right)^{1/2}\right)$ $v = 1.4 \times 10^7$ (m s^{-1})✓3	2 The substitution may be inferred at the next stage of the calculation that uses KE = $\frac{1}{2}mv^2$ = PE	3	AO1.1b AO2.1h ×2 M2 ×2

05.5	Using by substitution or rearrangement $R = r_o A^{1/3}$ ✓ $R_{Ag} = 5.7 \times 10^{-15}$ (m) ✓	$\left(R_{Ag} = R_{Au} \times \left(\frac{A_{Au}}{A_{Ag}}\right)^{1/3}\right)$ $\left(R_{Ag} = 6.98 \times 10^{-15} \times \left(\frac{107}{197}\right)^{1/3}\right)$ The use of the equation must involve both nuclei.	2	AO1.1b ×2 M2 ×2
05.6	Nucleons are incompressible / Nucleons have a constant separation / Neutrons and protons have similar masses / Neutrons and protons have similar volumes ✓	A mark can be given for 'nucleons touch' but it must be implied that this is with all 12 neighbours'.	1	AO3.1a
Total			**10**	

Question	Answers	Additional comments/Guidelines	Mark	AO	

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

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

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

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

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

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

05.1	Force due to uniform magnetic field (is constant and always) at 90° 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**	

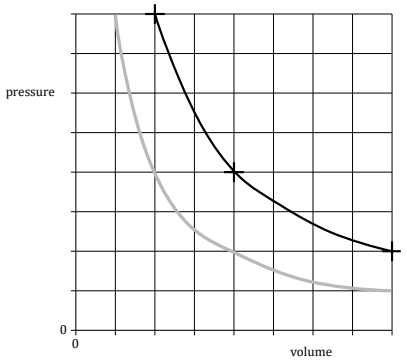
Question	Answers	Additional comments/Guidelines	Mark	AO

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

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

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

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

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

Question	Answers	Additional comments/Guidelines	Mark	AO

03.1	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

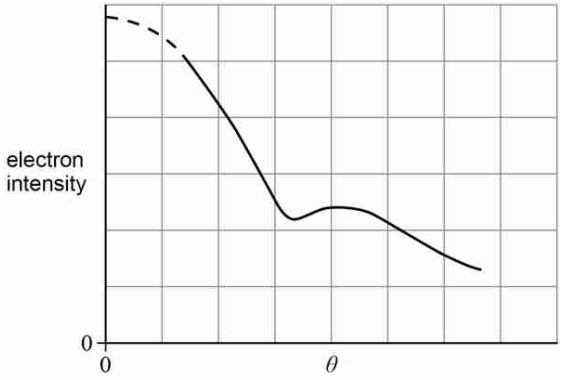
Question	Answers	Additional comments/Guidelines	Mark	AO
03.5	change in kinetic energy or kinetic energy per unit mass formulated ✓1 allow 2 sf	✓1 $\frac{1}{2}m\left(v^2_B - v^2_A\right)$ **OR** 1.18×10^{10} (J) **OR** $\frac{\Delta E_k}{m} = \frac{1}{2}\left(v^2_B - v^2_A\right)$ **OR** $m \times 2.40 \times 10^5$ 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

14

Question	Answers	Additional comments/Guidelines	Mark	AO

06.1	Any **two** from: ✓✓ • using electrons gives greater resolution (as the wavelength can be made very small) • electrons can get closer to the nuclei (as there is no electrostatic repulsion) • electrons have less recoil (as their mass is small compared to the nucleus) • free electrons are easier to accelerate **OR** give energy to (as charge-to-mass ratio is higher) • electrons are easier to produce • scattering distributions are easier to interpret **OR** strong nuclear interaction is not involved • using alpha particles only gives the distance of closest approach/upper limit to the radius.	OWTTE on each advantage Allow reverse arguments	2	AO1 AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
06.2	A curved line showing an decrease in intensity with increase in θ.✓ There is a single **non-zero** minimum. ✓	Do not allow U-shaped graphs. The initial part of the curve may be absent. Award MAX 1 for a line that covers less than half the θ axis.  	2	AO1 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
06.3	Density (= mass÷volume) = $\frac{Am_{\text{nucleon}}}{\frac{4}{3}\pi R^3}$ ✓1 (substituting density = $\frac{Am_{\text{nucleon}}}{\frac{4}{3}\pi\left(R_0 A^{\frac{1}{3}}\right)^3}$) Density = $\frac{3m_{\text{nucleon}}}{4\pi(R_0)^3}$ (in which) all (terms are) constant **OR** the expression does not depend on *A* ✓2	✓1 Do not accept *M* unlabelled. Accept *m* (ie lowercase) unlabelled. Condone m_{n} (mass of neutron in Data sheet) for m_{nucleon}. Accept only 1.67×10^{-27} (kg) for mass of nucleon (ie to 3 sf). Allow ecf to MP2 for any misrepresentation of *m* provided it is clear that it signifies mass of a single nucleon. ✓2 If the constants are identified the equation may be converted into a ratio. The equation may be rearranged to have R_0 as the subject with work to show that this is a constant *when the density is constant*.	2	AO1 AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
06.4	Any **one** of: ✓ The mass of the nucleus is not exactly $A \times m_{\text{nucleon}}$ (because this ignores the binding energy) **OR** The volume equation assumes that the nucleus is a perfect sphere (which is not true) OWTTE **OR** The density equation that uses the nuclear radius formula implies that the density is uniform within a nucleus which is not true. OWTTE **OR** Protons have a slightly different mass to a neutron	Do not accept "density of individual nucleons can be different from each other". It is not allowed as it does not occur in the working equation.	1	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
06.5	$R_0 = \left(\frac{R}{A^{\frac{1}{3}}} = \frac{4.02\times10^{-15}}{(35)^{\frac{1}{3}}} \right) = 1.2(3)\times10^{-15}\,(\text{m})$ ✓1 Substitutes values into density equation ✓2 Density = $2.1 \times 10^{17}\,(\text{kg m}^{-3})$ ✓3	✓2 e.g. Density=$\left(\frac{\text{mass}}{\text{volume}} = \frac{Am}{\frac{4}{3}\pi R^3} \right) =$ $\frac{35 \times 1.67 \times 10^{-27}}{\frac{4}{3}\pi\left(4.02 \times 10^{-15}\right)^3}$ ✓3 Evidence of a calculation must be given to gain this mark Accept 2.15 but not 2.2	3	AO2 ×3
Total			**10**	

Question	Answers	Additional comments/Guidelines	Mark	AO

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

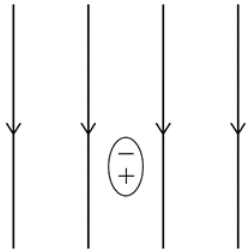
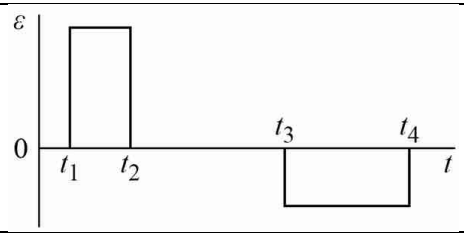
Question	Answers	Additional comments/Guidelines	Mark	AO
07.2	Any **two** points from: ✓✓ • U-235/Uranium fuel will (be more likely to) absorb the neutron • slow neutrons are less damaging **OR** cause less fatigue to the structure of the reactor/shielding/etc • slow neutrons (spend longer within the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

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

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

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

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

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

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

04.1	(moderator) - the neutron undergoes an elastic collision/bounces off with less speed/kinetic energy ✓ (Any reference to absorption loses the mark)	Must have the idea that the neutron slow because of collisions	1

04.2	(control rod) – the neutron is absorbed ✓	'stopped' will not get the mark. If alternatives are given all must be correct to gain mark.	1

04.3	the neutron is absorbed/U-236 is formed ✓ (causing) the nucleus (of fuel/uranium) to split into (two smaller) daughter nuclei / nuclei / fragments✓ releasing (several fast-moving) neutrons ✓	1st mark can use words like absorbed/takes in/ 2nd mark: alternative words for nuclei are **not** acceptable (eg daughter ~~products~~) 3rd mark 'neutrons' must be plural.	3

04.4	**Descriptor**	**(Bullet point headings are detailed at the bottom end of the table)**	**Mark**
	High Level – Good to Excellent All three bullet points must be addressed. The source must be identified and two stages in the treatment sequence must be given. Finally three problems encountered in the treatment of waste and how the problems are overcome should be stated. (Note discussion of a problem will often cover a stage of the treatment). *The information presented as a whole should be well organised using appropriate specialist vocabulary. There should only be one or two spelling or grammatical errors for this mark.*	6 marks = At least 6 points made coming from all three of the bullet point headings. (note some written points may count as answers to bullet point headings 2 and 3) 5 marks = 5 points made coming from all three of the bullet point headings. To be in this top band communication skills must be good and the ideas easy to follow.	5–6

	Intermediate Level – Modest to Adequate All three bullet points must be addressed. The source must be identified as well a stage in the treatment along with a problem encountered in the treatment of waste and how it is dealt with. One additional piece of information must be made from any of the bullet points listed below to be at the top of this band. *The grammar and spelling may have a few shortcomings but the ideas must be clear.*	4 marks = 4 points made coming from at least 2 bullet point headings. 3 marks = 3 points made coming from at least 2 bullet point headings. To be in this moderate band communication skills must good enough to understand the ideas easily even if the order is a little unclear.	3–4
	Low Level – Poor to Limited To be at the top of this band two bullet points must be addressed which must include a problem encountered in the treatment of waste and how it is dealt with. A single mark is awarded if any of the information given in the bullet points listed below is given. *There may be many grammatical and spelling errors and the information may be poorly organised.*	2 marks = Two points made from any bullet point heading. 1 mark = any point made coming from any bullet point heading. Or the script as a whole shows some basic understanding of the issues.	1–2
	The description expected in a competent answer should include: **1st bullet point** The (highly radioactive/ most dangerous) waste are the fission fragments from the fission of uranium-235 or from (spent) fuel rods. **2nd bullet point** The waste is initially placed in cooling ponds/water (close to the reactor for a number of years)		

	plutonium/uranium is separated to be recycled high level waste is vitrified/made solid into (pyrex) glass then placed in (stainless) steel/lead/concrete cylinders/containers/bunkers to be stored **deep** underground (simply stating buried/underground is not enough) **3rd bullet point** (the problem and its solution must both be given, some examples are given below) the waste is (initially) is very hot/generates heat so has to be placed in water/cooling ponds (to remove the heat) the waste (initially) is highly radioactive and needs to be screened in water/cooling ponds (to absorb the radiation) the waste (initially) is highly radioactive and needs to be remotely handled (to avoid human contact with the waste). In liquid form the (high level) waste may leak hence the need to vitrify (and barrel in steel) The waste will be radioactive for hundreds/thousands of years so storage needs to be stable in a container hence the need to vitrify (and barrel in stainless steel) The waste will be radioactive for hundreds/thousands of years so long term storage needs to be in geologically stable areas (deep underground). Transporting waste presents a potential danger to the public so waste is transported enclosed in impact/crash resistant/extra thick and strong casings Or processed onsite or nearby.		

Total			**11**

Question	Answers	Additional Comments/Guidelines	Mark

06.1	Or To allow the neutron to be absorbed by the fuel/U-235 ✓	alternative. Reject inaccurate descriptions for example ones that imply the neutrons are undergoing fission.	1	AO2-1a-1
06.2	$E_{final} = (1 - 0.63)\ E_{incident}$ or $E_{final} = 0.37\ E_{incident}$ ✓1 (continuing this idea, $E_1 = (1 - 0.63)\ E_0$ $E_2 = (1 - 0.63)\ E_1$ so $E_2 = (1 - 0.63)^2\ E_0$ and $E_5 = (1 - 0.63)^5\ E_0$ $E_5 = (1 - 0.63)^5 \times 2.0 \times 10^6$)) $= 1.4 \times 10^4$ eV ✓2 (1.39×10^4 eV)	If no marks are scored a single mark can be given: if the final answer that has a power of 10 error possibly by not using the M in the eV. OR using 0.63 rather than (1 – 0.63) in the calculation giving the answer $2(.0) \times 10^5$ (eV) ✓2 A correct final answer gains full marks	2	AO2-1b-1 AO2-1f-1 Math2-2
06.3	A link made between the change in kinetic energy or	✓1 Ref. to mass is needed. {Essence of marking point: The mass	2	AO2-1g-1

	momentum to the masses of the (two) particles involved in the collision. ✓1 A consistent argument that results in a statement 'as nucleon number/number of nucleons in the nucleus increases more collisions are required. ✓2	determines how much KE/momentum is lost} ✓2 Ref to nucleon number or equivalent needed but mass is not. {Essence of marking point: If N is high then not much KE is lost so more collisions are needed} An example of an argument could be: More (kinetic) energy is lost when the mass of the moderator atom/nucleus is closer to the mass of the neutron So the number of collisions needed increases with nucleon number		AO3-1a-1

Question	Answers	Additional Comments/Guidance	Mark	ID details
06.4	Mass difference = (mass$_U$ + mass$_n$) – (mass$_{Xe}$ + mass$_{Sr}$ + 4 mass$_n$) = (235.044 + 1.0087) – (141.930 + 89.908 + 4 × 1.0087) ✓$_1$ = 0.180 u ✓$_2$ {if no unit present take u as the default unit} (= 0.180 × 931.5) = 168 (MeV) ✓$_3$	✓$_1$ Mark for word equation or substitution, one neutron may be cancelled from both parts of the subtraction. Condone any simple slip in transferring the numbers. Also the mark can be awarded for giving or comparing the mass on the LHS with the RHS. ✓$_2$ Only allow correct answer. ✓$_3$ This mark can stand alone for the conversion of any number of u converted to MeV. 2 sig figs is acceptable. The conversion mark can come from any part of this question not just the final line. {1 kg = 6.02 x 10^{26}} A correct answer gains all 3 marks.	3	AO2-1f-3 Math2-1
06.5	1. (Small amounts of fossil fuel used) so <u>little</u> greenhouse gas emissions/less global warming/less CO_2/less climate change. {not <u>no</u> greenhouse gas} 2. (Less fossil fuel used) so cleaner air. 3. Small amounts of fuel consumed to get the same/large amount of power/energy. 4. Nuclear power can be produced continuously{condone use of constant} (whereas renewables are dependent on sunlight/wind etc). 5. Some (but not all) nuclear power stations can adjust their output quickly. 6. Benefit of producing medical isotopes.	Just one of the examples may be from the following: At present nuclear fuel is obtained from stable allied countries (as opposed to oil/gas). Facilitates nuclear weapon production. (Less fuel used) so less transportation needed. Examples of rejected ideas because they are incomplete or wrong: Produces more energy. There is more uranium than fossil fuel. Damages the environment less. Provides jobs. More efficient than others.	3	AO1-1a-1 AO3-1a-2

	✓✓✓any three points	Reference to cost. It's a renewable source.		

Total			**11**

	Keys to Objective Test Questions (each correct answer is worth 1 mark)												
Qu	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
Ans	**C**	**B**	**B**	**C**	**D**	**C**	**A**	**B**	**D**	**D**	**D**	**D**	**A**
Qu	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	
Ans	**C**	**C**	**B**	**B**	**C**	**C**	**D**	**A**	**B**	**D**	**B**	**C**	

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

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

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

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

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

Question	Answers	Additional comments/Guidelines	Mark	AO

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

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

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

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

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

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

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

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

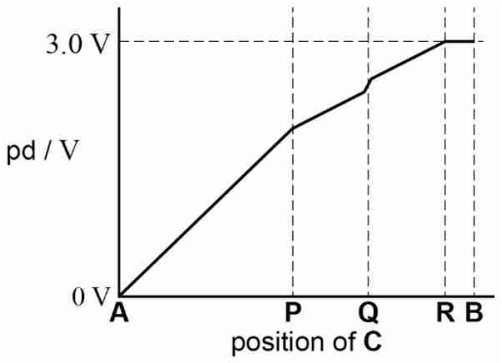
Question	Answers	Additional comments/Guidelines	Mark	AO
05.4	Correct use of efficiency $\eta = \frac{\text{power}_{out}}{\text{power}_{in}}$ once ✓1 Correct use of $I = P/V$ with their values once at any point ✓2 I = 3200 (A) (correct answer only, no ecf) ✓3	✓1 examples could be: power at 132 kV = 72 / 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

03.1	(1 C of) the charge gains ε J on passing through cell OR energy transferred (by 1 C) in R_1 is V_1 (J) OR energy transferred (by 1 C) in R_2 is V_2 (J) OR energy transferred (by 1 C) in r is Ir (J) ✓ (for conservation of energy) $\varepsilon = IR_1 + IR_2 + Ir$ ✓	If no other mark awarded, allow one mark for definition of emf in terms of energy transfer. accept: 'dissipated' accept 'lost volts' for Ir but reject 'voltage across r' accept 'work done' for 'energy transferred' Alternative for MP2 $\varepsilon = V_1 + V_2 + Ir$ provided that MP1 is awarded.	2	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	Equates emf to $Ir + 2.89$ in some form ✓1 Calculates I from $2.89 \div 125$ (=0.02312 A) ✓2 Giving $r = 4.76\ (\Omega)$ ✓3	If no other mark awarded, award one mark for use of emf value in MP2. Allow in MP1 (their current/A) ×125Ω for 2.89 V Allow alternative routes for ✓1 and ✓2. E.g. 'Lost volts'= 0.11 V ✓1 Applies potential-divider equation e.g. $0.11 \div 2.89 = r \div 125$ ✓2 OR $3 \div (125 + r) = 2.89 \div 125$ ✓1✓2 Must see at least 3 sf answer Answer must round to 4.76(Ω)	3	AO2 × 3

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	(Resistance splits $25\ \Omega$ and $104.8\ \Omega$) Applies potential divider formula eg $\frac{V}{3.00}=\frac{25}{129.8}$ ✓ $V = 0.58$ (V) ✓	Accept other routes for MP1 e.g. using $V = IR$, with $25\ \Omega$ and their current, for example from • $I = 0.023$ A (from Q03.2) • $I = \frac{\text{emf}}{\text{total resistance}} = \frac{3}{125+r}$ • $I = \frac{terminal\ pd}{125}$ **OR** using $V = \frac{2.89}{5}$ with an identification of 2.89 V as the terminal pd. If no other mark awarded, allow one mark for using $29.8\ \Omega$ instead of $129.8\ \Omega$ for total resistance giving $2.5(2)$ V.	2	AO2× 2

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	Any **four** from: Straight line 0 V **A** to **P** 1✓ Less steep non-zero gradient from **P** to **Q** 2✓ Short steep increase at **Q** 3✓ **Q** to **R** about same non-zero gradient as **P** to **Q** 4✓ Horizontal line from **R** to **B** at 3.0 V 5✓	 For 3✓ allow range no greater than width of "**Q**" label on horizontal axis. If graph sketched from 3 V (at **A**) to 0V (at **B**) award **max 2** (based on 2✓ and 4✓). If a single diagonal straight line from 0 V (at A) to B, award 1✓only. If a single diagonal straight line from 0 V (at A) to R and then horizontal to B, award only 1✓ **and** 5✓ if scored (**ie max 2**).	Max 4	AO3 × 4
Total			**11**	

15

Question	Answers	Additional comments/Guidelines	Mark	AO
	Uses			

06.1	Appropriate use of $V = IR$ ✓ Variable resistor resistance = $190\ (\Omega)$ ✓	e.g. for MP1: • determines total circuit resistance • determines pd across thermistor • use of $= I(R_{XY}+R_{YZ})$✓ Condone POT error in MP1 Expect to see total circuit resistance of $542\ (\Omega)$ Expect to see pd across resistor of 2.3 V. Condone POT error in MP1 Calculator value: 191.67 Ω	2	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
06.2	Evidence of 22 °C converted to K ✓ Determines R OR $\frac{3.2}{12}$ OR $\frac{3.2}{12\times10^{-3}}$ ✓ Evidence of use of $\ln(\frac{R}{R_0})$ with their values✓ $B = 1110$ ✓ K ✓	Allow ecf from MP1. Expect 295 K Expect to see $267\ \Omega$ Condone use of $R_0 = 190\ \Omega$ in MP3 Accept 1100 Accept answers that round to 1110 or 1120 Allow ecf only from temperature conversion. Do not accept k for K	5	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
06.3	Current causes thermistor temperature to change ✓ Thermistor resistance decreases as temperature increases✓	Allow a clear description of thermal runaway for both marks.	2	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
06.4	Uses ammeter(s) (in series) to show current at X = current at Y = current at Z OR Uses voltmeter(s) to show that emf/terminal pd / 6.5 V = pd across XY + pd across YZ✓ Links current readings to (conservation of) charge AND Links pd readings to (conservation of) energy✓	Do not allow ‘currents across’. Do not accept ‘battery pd’ unless it is clearly being measured. If points XYZ are not referred it must be clear where the meters are attached.	2	AO1
Total			11	

Question	Answers	Additional comments/Guidelines	Mark	AO

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

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

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

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

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

Question	Answers	Additional comments/Guidance	Mark	AO

03.1	$238 \times 1.661 \times 10^{-27}$ or 3.953×10^{-25} seen OR their mass $\times 3.23 \times 10^{24}$ ✓ 1.28 (kg) ✓ **Alternative method`** $n = \frac{3.23 \times 10^{24}}{6.02 \times 10^{23}}$ or 5.37 mol seen OR their number of moles × 238 ✓ 1.28 (kg) ✓	Allow use of 1.67×10^{-27} kg Allow inclusion of electron masses. Allow use of 1.673×10^{-27} and 1.675×10^{-27} leading to 1.29	2	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
03.2	$A_0\ (=\lambda N) = 8.11 \times 10^{14}$ (Bq) ✓ Any **three** from: ✓✓✓ • dividing an output power / A / N / m by 0.0458 or multiplying an input power / α energy / A_0 / N_0 / m_0 by 0.0458 • Use of $A = \frac{\text{any power}}{8.94\times10^{-13}}$ or $\frac{\text{any power}}{8.94\times10^{-13}\times0.0458}$ to calculate P or A • use of $t = \frac{\ln\left(\frac{A}{A_0}\right)}{-\lambda}$ or $t = \frac{\ln\left(\frac{N}{N_0}\right)}{-\lambda}$ or $t = \frac{\ln\left(\frac{m}{m_0}\right)}{-\lambda}$ or $t = \frac{\ln\left(\frac{P}{P_0}\right)}{-\lambda}$ • convert time to years (divide a time by $365 \times 24 \times 60 \times 60$) or decay constant to yr^{-1}. Time = 14.5 (Earth years) ✓	Condone small rounding errors. $\frac{29.6}{0.0458} = 646$ W $\frac{646}{8.94\times10^{-13}} = 7.23\times10^{14}$ Bq $t = \frac{\ln\frac{7.23}{8.11}}{-2.51\times10^{-10}} = 4.58\times10^{8}$ s Allow use of $0.5^{\frac{t}{t_{0.5}}}$ **and** $t_{0.5} = \frac{\ln 2}{\lambda}$ instead of $e^{-\lambda t}$. Allow conversion of half-life to years. Allow ecf for their A_0 Accept answers that round to 14 or 15 years based on working seen. Missing efficiency results in 404 y.	5	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
03.3	Any **three** from: ✓✓✓ • valid $Q = mc\Delta\theta$ substitution or answer • valid $Q = mL$ substitution or answer • 3 valid Q calculations • energy provided by laser between charges $(= 1000 \times 3) = 3000$ (J) OR a valid power calculation for their Q Total energy required $= 2900$ (J) < 3000 (J) so yes ✓	Ignore PoT in bullet points Heat ice to 0.0 °C: $10^{-3} \times 2100 \times 25 = 52.5$ J Melt ice at 0.0 °C: $10^{-3} \times 334 \times 10^{3} = 334$ J Vaporise water at 0.0 °C: $10^{-3} \times 2500 \times 10^{3} = 2500$ J Allow $(L_f + L_v)$ in $Q = mL$ as two calculations. Allow any correct comparison for MP4 e.g. Energy required 2887 < 3000 J Powers 962 < 1000 W Mass of ice 0.00104 > 0.001 kg time 2.8865 < 3 s Δθ 79.0 > 25 K Allow other valid comparisons.	4	AO3
Total			**11**	

Question	Answers	Additional comments/Guidance	Mark	AO

01.1	MP1 is for evidence of determining the charge on the nucleus. ✓ MP2 is for evidence of determining either the number of protons OR the number of nucleons. ✓ MP3 is for determining number of neutrons. ✓	Charge = $4.39 \times 10^{7} \times 8.02 \times 10^{-26}$ kg $(= 3.52 \times 10^{-18}$ C) Number of protons = charge/1.6×10^{-19} (= 22) OR Number of nucleons $= 8.02 \times 10^{-26} / 1.67 \times 10^{-27}$ (= 48) Number of neutrons = 48 – 22 = 26 Note use of 1.7 gives 27 neutrons and loses MP3	3	3×AO2.1f

Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	Evidence of conversion of MeV to J ✓ Substitution into KE equation ✓ Correct final answer ✓	Energy = $2.15 \times 10^{8} \times 1.6 \times 10^{-19}$ ($= 3.44 \times 10^{-11}$ J) - allow POT error in MP1 $v^2 = 2E/m = 8.58 \times 10^{14}$ $v = 2.9(3) \times 10^{7}$ m s^{-1}	3	1×AO1.1b 2×AO2.1f

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	π^+ $e^+ + \nu_e$ OR charge: $1 = 1 + 0$✓ B: $0 = 0 + 0$ AND L: $0 = -1 + 1$✓ (S: $0 = 0 + 0$)		2	2×AO1.1b

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	(K^+ $\mu^+ + \nu_\mu$) Correct strangeness $+1 = 0 + 0$ ✓ Weak interaction so strangeness can change (by 0, +1 or –1) ✓		2	2×AO1.1b

Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	Decay consistent with Q B L conservation✓ Equation involving pions ✓	 e.g. $K^+ \quad \pi^+ + \pi^+ + \pi^-$ $K^+ \quad \pi^+ + \pi^0$	2	1×AO1.1a 1×AO1.1b
Total			**12**	

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

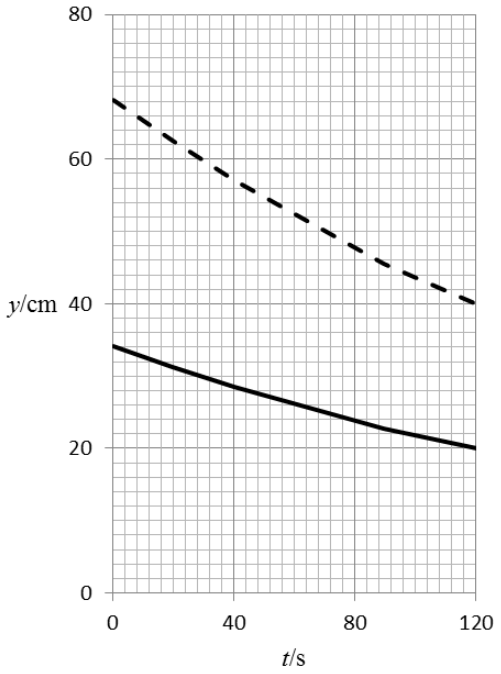
02.1		reject 'weigh'/ weighed	
	method to reduce uncertainty in volume $_3$✓	read water level at <u>bottom of the meniscus</u> (or wtte or allow sketch); don't penalise further use of 'beaker' treat as neutral: 'dry cylinder before use' OR procedure to avoid systematic error in determining mass, eg tare / 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 $_2$✓		

<table>
<tr><td>02.6</td><td>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 ✓</td><td>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}</td><td>AO3-1a = 1</td></tr>
<tr><td>02.7</td><td>(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:
<table><tr><th rowspan="2">t/s</th><th colspan="2">y/cm</th></tr><tr><th>min</th><th>max</th></tr><tr><td>0</td><td>33</td><td>35</td></tr></table>
AND through EITHER of
<table><tr><th rowspan="2">t/s</th><th colspan="2">y/cm</th></tr><tr><th>min</th><th>max</th></tr><tr><td>60</td><td>24</td><td>28</td></tr><tr><td>120</td><td>17</td><td>23</td></tr></table>₂✓</td><td> 
</td><td>AO2-1d = 2</td></tr>
<tr><td>Total</td><td></td><td></td><td>13</td></tr>
</table>

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 =

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

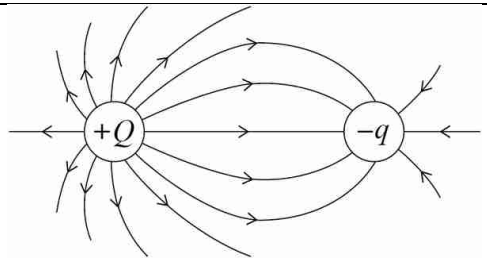
Question	Answers	Additional comments/Guidance	Mark	AO
06.2	Arrow starting at dot, pointing vertically down the page ✓	Condone a downwards vertical arrow where the line of action passes through the point. The line of action of the arrow must travel through the plasma torus near to the ion. Ignore arrows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

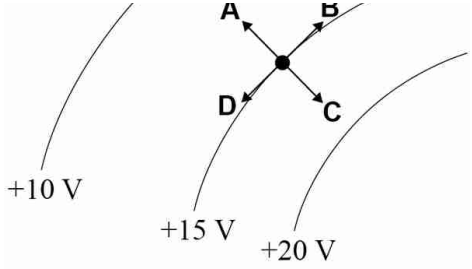
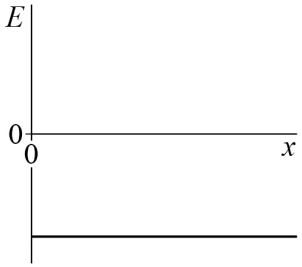
Question	Answers	Additional comments/Guidance	Mark	AO
06.3	$BQv = \frac{mv^2}{r}$ ✓	Evidence for MP1 can come from substitution of candidates centripetal force as their magnetic force in second equation. Do **not** accept e for Q in MP1 when correct answer not seen. Allow ecf for use of their centripetal 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.		

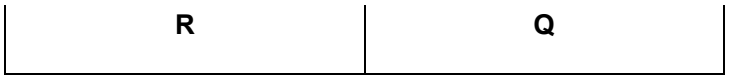
Question	Answers	Additional comments/Guidance	Mark	AO
06.4	Use of $F = ma$ / $a = \frac{v^2}{r}$ **OR** use of $F = QE$ ✓ $a\left(=\frac{QE}{m}\right)=\frac{3.2\times10^{-19}\times371\times10^{-6}}{5.31\times10^{-26}}$ ✓ 2.24×10^3 (m s^{-2}) ✓	Ignore PoT in MP1 and MP2 Condone in MP1 **and** MP2 the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

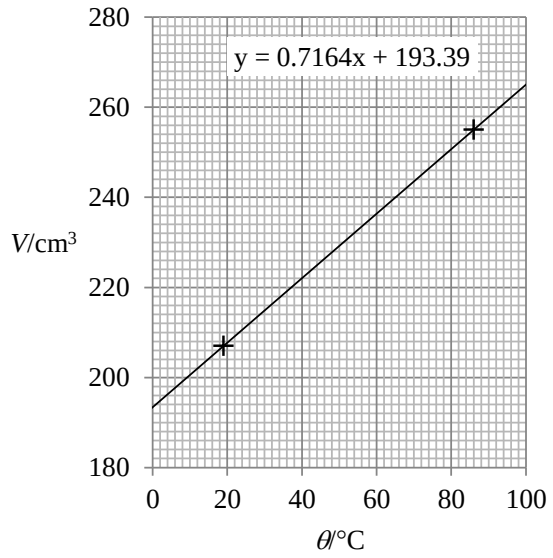
14	C		AO1
15	D		AO2
16	D		AO1
17	C	600 μF	AO2
18	C	233 Ω	AO2

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

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

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

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

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

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

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

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

	Alternative 2 $(E_k)_{average} = \frac{3kT}{2} = \frac{3 \times 1.38 \times 10^{-23} \times 310}{2} = 6.42 \times 10^{-21}$ (J) OR $(E_k)_{total} = (E_k)_{average} \times N_A = 6.42 \times 10^{-21} \times 6.02 \times 10^{23}$ $(E_k)_{total} = 3.86 \times 10^3$ (J) ✓1Alt2 $c_{rms} = \left(\frac{2 \times (their\ energy)}{\text{molar mass}}\right)^{1/2} = \left(\frac{2 \times (E_k)_{total}}{\text{molar mass}}\right)^{1/2}$ $= \left(\frac{2 \times 3.86 \times 10^3}{4.0 \times 10^{-2}}\right)^{1/2}$ ✓2Alt2 = 439 (m s^{-1}) ✓3Alt2	from the second mark. A correct answer gains all three marks {On most occasions answer 5.7×10^{-10} m s^{-1} yields 2 marks as the wrong mass has been used} ✓1Alt2 The mark can be given for evaluating either the average or the total kinetic energy. ✓2Alt2 Give a mark for this rearrangement and substitution even if the energy is incorrect. c_{rms} must be the only unknown in the equation, data and constants to be shown. ✓3Alt2 Only allow a correct answer so no ecf from the second mark. A correct answer gains all three marks {On most occasions answer 5.7×10^{-10} m s^{-1} yields 2 marks as the wrong mass has been used} Note the slightly different answers for the third mark which depends on the route taken.		
02.4	(In equilibrium at the same temperature) both gases have the same <u>mean or average</u> kinetic energy ✓	Allow 'they are the same' as a bold statement. However if this is not an opening statement following the question then 'mean or average' must be used.	1	AO2-1d-1 Math2-1
02.5	Particles/atoms/molecules collide with the piston/walls and change momentum ✓1 (The piston provides the) force = <u>rate of change</u> of momentum	✓1 Ignore any reference to particles colliding with each other.	3	AO1-1b-2 AO2-1b-1

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

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

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

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

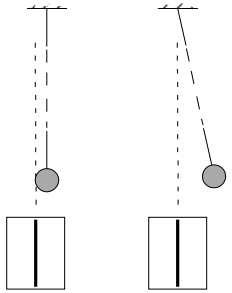
Question	Answers	Additional Comments/Guidance	Mark	ID details
04.4	Using distance = 80 mm (mark given even in a wrong formula) Or Stating that the charge can be considered to be in the centre of each sphere ✓1 $F\ (=\frac{Q_1Q_2}{4\pi\varepsilon_o r^2}) = \frac{\left(52\times10^{-9}\right)^2}{4\pi\varepsilon_o(0.080)^2}$ ✓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

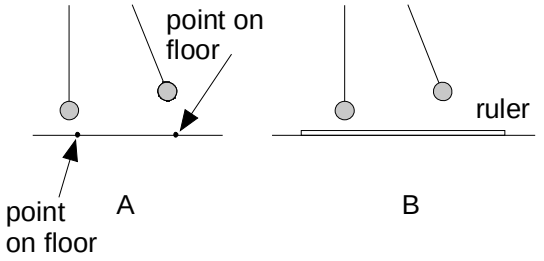
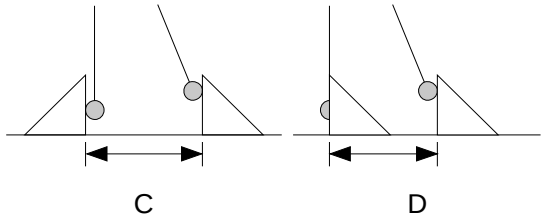
		of the tension. ✓2Alt A second calculation of the tension which is stated to be consistent with the first.		

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

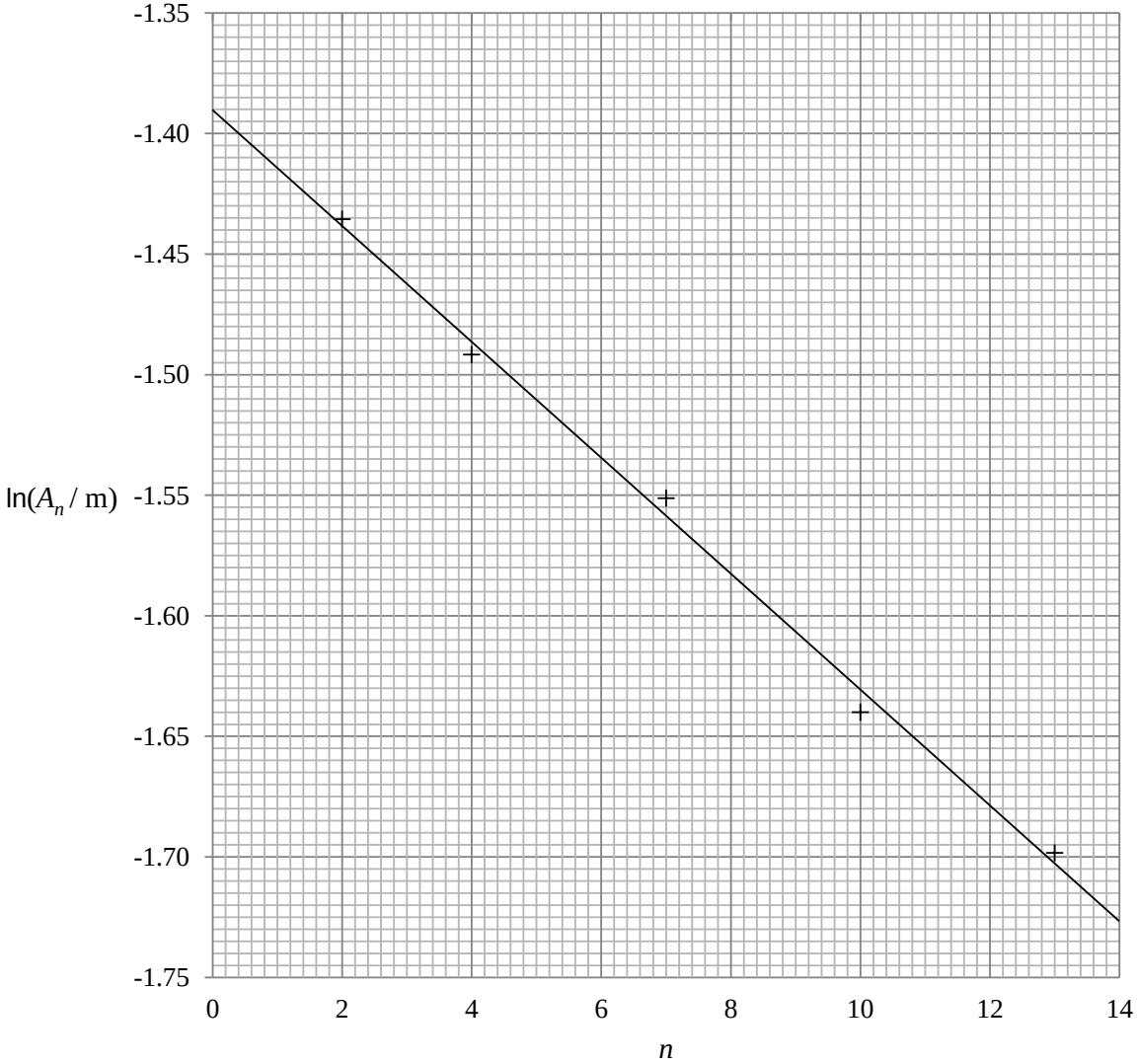
Question	Answers	Additional Comments/Guidance	Mark	ID details
	$N = \frac{\Phi}{AB}$ Or $N = \frac{1.5 \times 10^{-3}}{2.5 \times 10^{-2} \times 5.0 \times 10^{-4}}$ ✓1	✓1 *N* must be the subject of the equation for the mark. ✓2 A correct answer gains both marks.		AO1-1a-1

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

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

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	extrapolation of curve to (at least) $x = 0.70$ m $_1$✓ consistently-recorded min 3 dp values for $T_{0.35}$ and $T_{0.70}$ $_2$✓ evidence of valid calculation (check denominator correct); percentage increase in range 1.4(0) % to 1.8(0) % $_3$✓	for $_1$✓extrapolation must be continuous and smooth; allow (ruled) straight line; reject hairy, thick or dashed lines for $_2$✓allow values seen in working; $T_{0.35}$ must round to 2.322; condone $T_{0.70}$ by eye don't insist on horizontal or vertical lines between curve and vertical axis on **Figure 3** for $_3$✓expected answer is 1.51%	1 2	AO3.1a AO2.1h
01.4	rejects anomalous 0.247; average $A_5 \geq$ 3 sf (that rounds to) 0.22$\underline{1}$ (s) $_1$✓ correct uncertainty calculation or 0.004(0) (s) seen $_2$✓ **or** does not reject 0.247; average A_5 = (rounds to) 0.22$\underline{6}$ (s); correct uncertainty calculation or 0.01$\underline{5}$ (s) seen $_{12}$✓ correct % uncertainty from $\frac{their\ half\ \ range}{their\ average} \times 100 \geq$ 2 sf $_3$✓	0.221 and 1.8 % on answer lines earn $_{123}$✓✓✓ $_1$✓ (0.247 rejected) full answer 0.2214 (s) $_2$✓ from half range; can be inferred from working $_3$✓ if $_{12}$✓✓full answer 1.81 %; allow 1.8 % or 1 sf 2 % when 0.247 is not rejected $_{12}$✓full answer 0.2257 (s) $_3$✓ full answer 6.647 %; allow 6.6$\underline{4}$ / 6.6$\underline{5}$ % or 2 sf 6.6 / 6.7 % for $_3$✓ allow ECF only if uncertainty is from half range	3	AO2.1h

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



10

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

Question	Answers	Additional comments/Guidelines	Mark	AO

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 $F \downarrow$ 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 $I \rightarrow$ 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 $\text{T (OR } B) \equiv \frac{\text{N}}{\text{A m}} \equiv \frac{\text{N s}}{\text{C m}}$ for B✓ allow $\text{TA (OR } B\ I) \equiv \frac{\text{N}}{\text{m}}$ for AB✓✓ allow $k \equiv \text{kg}\ \frac{(\text{A})\text{m}}{\text{N}}(\text{A}^{-1})$ for BC✓✓ allow $\text{T (OR } B) \equiv \frac{\text{kg (m) s}^{-2}}{\text{A (m)}} \equiv \frac{\text{kg}}{\text{C s}}$ for BC✓✓ allow $\text{TA (OR } B\ I) \equiv \frac{\text{kg (m) s}^{-2}}{\text{(m)}}$	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		

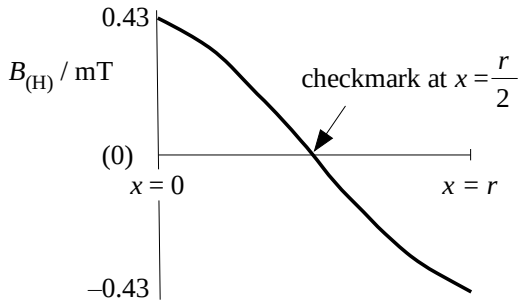
Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	use of $1 - \cos 25(°)$ or $1 - \sin 65(°)$ in a calculation of percentage change $_1$✓	for $_1$✓ expect either ≥ 3 sf rounding to $1 - 0.906$ OR $1 - 0.91$ seen in working OR $100 - 90.6$ or $100 - 91$ seen in working;	2	AO2-1h
	$(-)\ 9.4$ (%) 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		

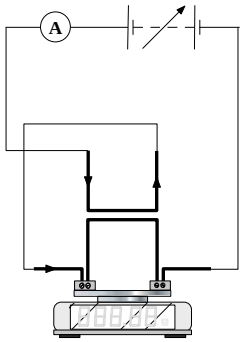
Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	r in range 67 to 69 mm OR $x_{0.5}$ in range 50 to 55 mm 1 ✓ $\frac{x_{0.5}}{r}$ in range 0.73 to 0.81 2 ✓	$\frac{x_{0.5}}{r}$ in range gets both marks for 1 ✓ either value can be seen in working OR on (along horizontal axis in) **Figure 13** 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 = $\frac{\text{their gradient} \times 9.81(\times 10^{-3})}{15(\times 10^{-2})}$; 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	