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OCR A LEVEL PHYSICS A (H556): QUESTIONS BY TOPIC

Motion (3.1)

A Level Physics A (H556) · Module 3: Forces and motion

51 questions · 373 marks · Mark schemes included

OCR A Level Physics A (H556), June 2017 – June 2025

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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
3.1.1 KINEMATICS AND MOTION GRAPHS		17 Qs · 93 marks	4
1. Q2 <i>also 3.3 & 5.4</i>	H556/01 Modelling physics June 2018	1	5
2. Q12 <i>also 3.2</i>	H556/01 Modelling physics June 2018	1	6
3. Q14	H556/01 Modelling physics November 2020	1	7
4. Q1	H556/01 Modelling physics November 2021	1	8
5. Q11 <i>also 4.4</i>	H556/02 Exploring physics November 2021	1	9
6. Q1 <i>also 2.3 & 3.5 & 4.4 & 5.2</i>	H556/01 Modelling physics June 2022	1	10
7. Q3 <i>also 2.2 & 3.5 & 3.3 & 3.2</i>	H556/01 Modelling physics June 2022	1	11
8. Q11 <i>also 3.5 & 3.3 & 5.4 & 5.2</i>	H556/01 Modelling physics June 2022	1	12
9. Q1 <i>also 2.3 & 3.5 & 3.3 & 5.4</i>	H556/01 Modelling physics June 2023	1	13
10. Q3 <i>also 3.2</i>	H556/01 Modelling physics June 2023	1	14
11. Q17 <i>also 4.4</i>	H556/02 Exploring physics June 2019	5	15
12. Q16 <i>also 4.4</i>	H556/02 Exploring physics June 2022	10	16
13. Q17 <i>also 3.2</i>	H556/01 Modelling physics June 2019	11	18
14. Q20 <i>also 2.1 & 3.2 & 5.3</i>	H556/01 Modelling physics June 2022	12	20
15. Q18 <i>also 3.2 & 4.4 & 5.3</i>	H556/01 Modelling physics June 2019	14	22
16. Q16 <i>also 3.5 & 3.2</i>	H556/01 Modelling physics June 2025	14	26
17. Q21 <i>also 2.1 & 3.4 & 3.2 & 5.3</i>	H556/01 Modelling physics June 2023	17	30
3.1.2 LINEAR MOTION		27 Qs · 188 marks	34
18. Q8 <i>also 3.2</i>	H556/01 Modelling physics June 2017	1	35
19. Q4 <i>also 5.3</i>	H556/01 Modelling physics June 2018	1	36
20. Q9 <i>also 5.3</i>	H556/01 Modelling physics June 2018	1	37
21. Q10	H556/01 Modelling physics June 2018	1	38
22. Q3 <i>also 3.2</i>	H556/01 Modelling physics November 2020	1	39
23. Q3	H556/01 Modelling physics November 2021	1	40
24. Q14	H556/01 Modelling physics November 2021	1	41
25. Q4 <i>also 3.2</i>	H556/01 Modelling physics June 2022	1	42
26. Q4 <i>also 4.2</i>	H556/01 Modelling physics June 2024	1	43
27. Q7	H556/01 Modelling physics June 2024	1	44
28. Q11 <i>also 3.2</i>	H556/01 Modelling physics June 2024	1	45
29. Q18 <i>also 2.2 & 3.2</i>	H556/01 Modelling physics June 2023	6	46
30. Q20 <i>also 2.1 & 5.2</i>	H556/01 Modelling physics November 2020	7	48
31. Q1 <i>also 5.4</i>	H556/03 Unified physics June 2023	7	50



QUESTION	SOURCE	MARKS	PAGE
32. Q19	H556/01 Modelling physics June 2019	9	52
33. Q2 <i>also 5.3</i>	H556/03 Unified physics June 2018	10	54
34. Q22 <i>also 3.2 & 5.3</i>	H556/01 Modelling physics November 2020	10	56
35. Q21 <i>also 3.4 & 3.3 & 5.4 & 5.3</i>	H556/01 Modelling physics November 2021	11	59
36. Q6 <i>also 3.4 & 3.2 & 4.2 & 5.2</i>	H556/03 Unified physics June 2017	12	61
37. Q16 <i>also 2.1</i>	H556/01 Modelling physics November 2021	12	63
38. Q1 <i>also 2.1 & 3.2 & 5.4 & 5.2</i>	H556/03 Unified physics June 2022	12	65
39. Q2 <i>also 2.2 & 3.2</i>	H556/03 Unified physics June 2022	12	68
40. Q1 <i>also 3.2 & 5.1</i>	H556/03 Unified physics June 2019	13	71
41. Q4 <i>also 5.4 & 5.1</i>	H556/03 Unified physics November 2020	13	74
42. Q1	H556/03 Unified physics November 2021	13	77
43. Q19 <i>also 4.4 & 5.3</i>	H556/01 Modelling physics June 2017	15	80
44. Q4 <i>also 2.2</i>	H556/03 Unified physics June 2018	15	83
3.1.3 PROJECTILE MOTION	7 Qs · 92 marks		86
45. Q24 <i>also 6.4 & 6.3</i>	H556/02 Exploring physics November 2021	11	87
46. Q16 <i>also 3.3 & 4.2</i>	H556/01 Modelling physics June 2018	12	89
47. Q5 <i>also 4.4 & 5.3 & 6.2</i>	H556/03 Unified physics November 2020	12	92
48. Q17	H556/01 Modelling physics June 2025	13	95
49. Q1 <i>also 3.5 & 3.3 & 4.1 & 6.3 & 6.2</i>	H556/03 Unified physics June 2025	13	97
50. Q19 <i>also 3.3 & 4.5</i>	H556/02 Exploring physics June 2022	14	101
51. Q5 <i>also 3.2 & 4.4 & 4.1 & 5.3</i>	H556/03 Unified physics June 2022	17	103



QUESTIONS

51 questions · 373 marks · 3 sub-topics



SUB-TOPIC 3.1.1

KINEMATICS AND MOTION GRAPHS

Sub-topic 3.1.1 · 17 questions · 93 marks · lowest tariff first



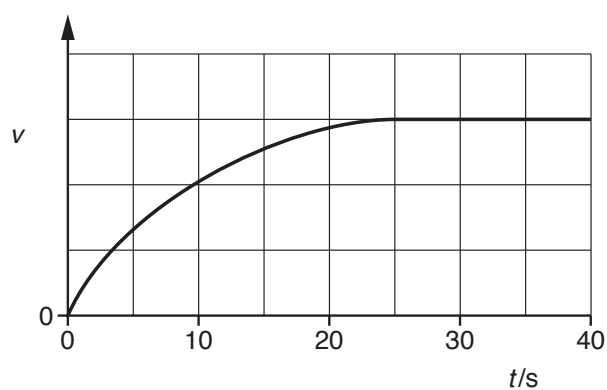
- 2 Which set of quantities are all scalar?
- A acceleration, displacement, velocity
 - B energy, mass, power
 - C extension, force, gravitational potential energy
 - D weight, kinetic energy, work done

Your answer

[1]



- 12 An object is dropped from rest at time $t = 0$. It falls vertically through the air. The variation of the velocity v with time t is shown below.



Which statement is correct about this object?

- A It has constant acceleration.
- B It experiences zero drag at $t = 30$ s.
- C It has an acceleration of 9.81 ms^{-2} at $t = 0$ s.
- D It travels the same distance in every successive 10 s.

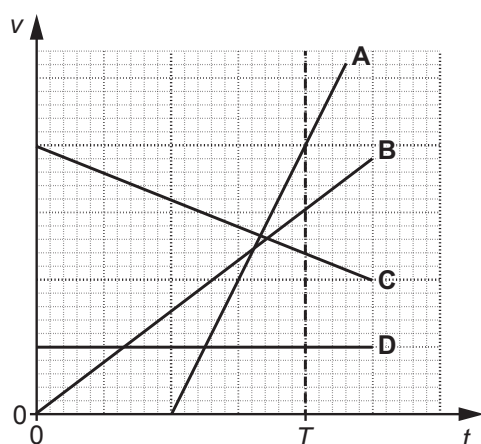
Your answer

[1]

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Turn over

14 The velocity v against time t graphs for four objects **A**, **B**, **C** and **D** are shown below.



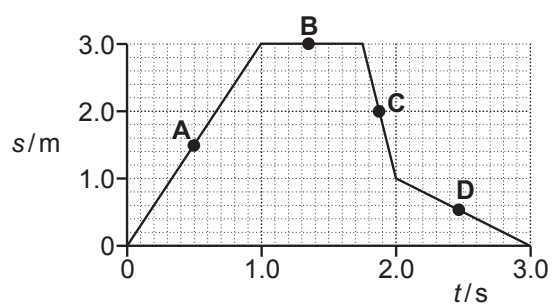
Which object travels the greatest distance between $t = 0$ and $t = T$?

Your answer

[1]

- 1 An object is moving in a straight line.

The displacement s against time t graph for this object is shown below.

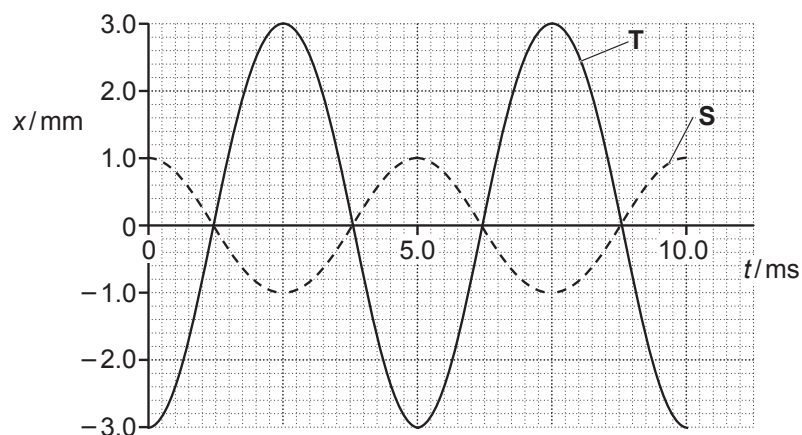


At which point **A**, **B**, **C** or **D**, does the object have the **greatest** speed?

Your answer

[1]

- 11 The diagram below shows the graphs of displacement x against time t for two waves **S** and **T**.



The waves meet at a point in space.
The superposition of these two waves produces a resultant wave.

What is the frequency f and the amplitude A of the resultant wave?

- A** $f = 100 \text{ Hz}$, $A = 2.0 \text{ mm}$
- B** $f = 100 \text{ Hz}$, $A = 4.0 \text{ mm}$
- C** $f = 200 \text{ Hz}$, $A = 2.0 \text{ mm}$
- D** $f = 200 \text{ Hz}$, $A = 4.0 \text{ mm}$

Your answer

[1]

- 1 A student has constructed the table below of possible scalar and vector quantities.

	Scalar	Vector
A	acceleration	momentum
B	displacement	amplitude
C	frequency	wavelength
D	mass	centripetal force

Which row is correct?

Your answer

[1]



- 3 A student has plotted a velocity against time graph for a trolley moving down a ramp.

Which of the following pair of quantities can be determined from the gradient of the graph and the area under the graph?

- A acceleration, displacement
- B acceleration, impulse
- C displacement, kinetic energy
- D force, work done

Your answer

[1]



11 Which pair of quantities do **not** have the same, or equivalent, units?

- A acceleration, gravitational field strength
- B angular frequency, angular velocity
- C gravitational potential, kinetic energy
- D impulse, momentum

Your answer

[1]

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Turn over



1 Which row contains **only** scalar quantities?

- A Absolute temperature, displacement, moment
- B Acceleration, force, momentum
- C Gravitational potential, kinetic energy, mass
- D Kinetic energy, mass, momentum

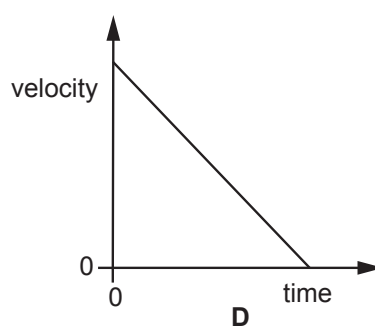
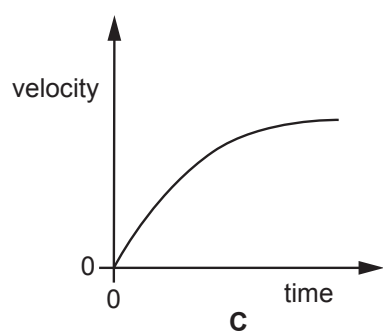
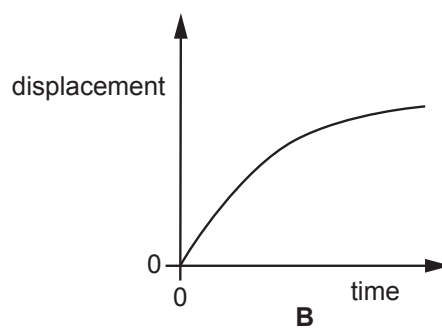
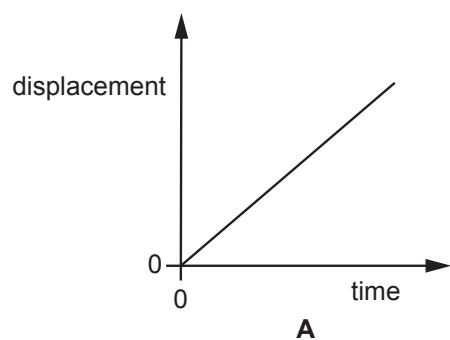
Your answer

[1]



- 3 The resultant force acting on a moving object is zero.

Which graph shows this?



Your answer

[1]

- 17 (a) Fig. 17.1 shows the variation with distance of the displacement of a **stationary** wave at time $t = 0$.

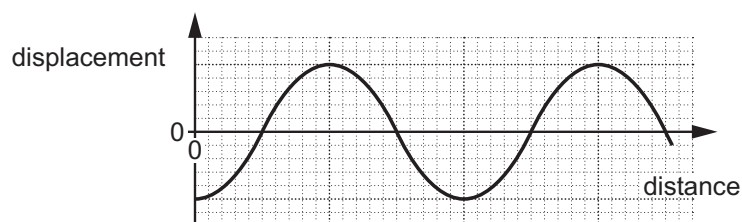


Fig. 17.1

The period of the wave is T .

- (i) On Fig. 17.1, sketch a graph to show the variation of the displacement at time $t = \frac{T}{2}$. [1]
- (ii) On Fig. 17.1, show the positions of **all** the nodes. Label each node **N**. [1]
- (b) Stationary sound waves are formed in a tube closed at one end.
Fig. 17.2 shows three stationary wave patterns formed in the air column of the tube.

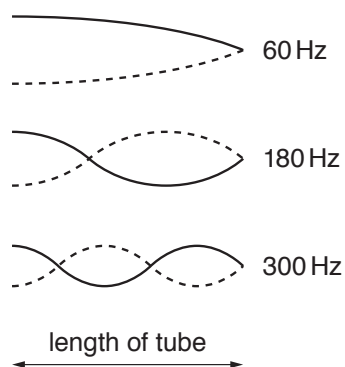


Fig. 17.2

The frequency f of the oscillations for each stationary wave is shown in Fig. 17.2.

Use Fig. 17.2 to explain how the frequency f of the sound wave depends on the wavelength λ .

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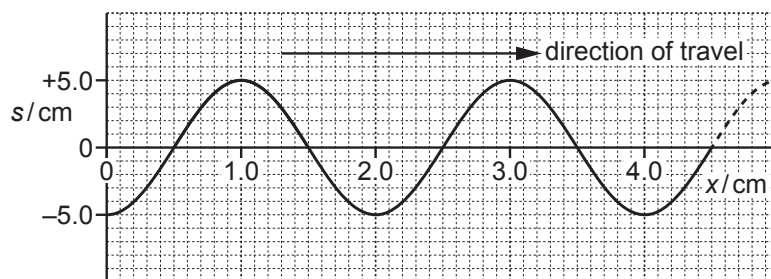
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..... [3]

- 16 (a) A graph of displacement s against distance x for a **progressive** wave at time $t = 0$ is shown below.



Determine:

- (i) the phase difference ϕ in radians between the points on the wave at $x = 1.5\text{ cm}$ and $x = 2.5\text{ cm}$

$$\phi = \dots\dots\dots \text{ rad [1]}$$

- (ii) the displacement s at time $t = \frac{3}{4}T$ at $x = 1.5\text{ cm}$, where T is the period of the oscillations of the wave.

$$s = \dots\dots\dots \text{ cm [1]}$$

- (b) A beam of coherent light of wavelength λ is incident normally at two parallel slits (double-slit). A series of bright and dark fringes are formed on a distant screen placed parallel to the line joining the slits.

The location of some of these fringes is shown in **Fig. 16.1**.

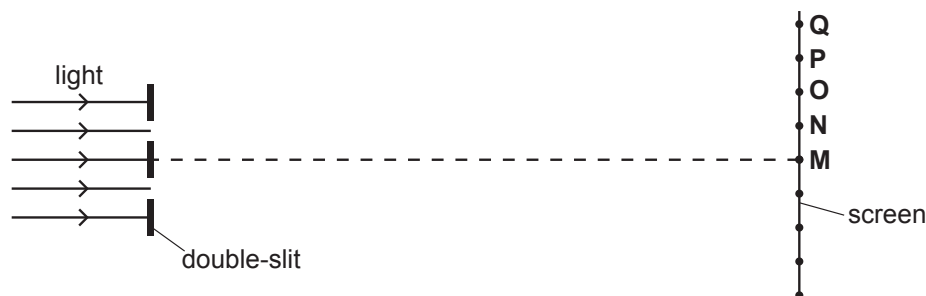


Fig. 16.1 (not to scale)

The bright fringes are seen at points **M**, **O** and **Q**. The dark fringes are seen at points **N** and **P**.

State the phase difference ϕ in degrees, and the path difference d in terms of wavelength λ , for the waves from the two slits meeting at point **P**.

$$\phi = \dots\dots\dots^\circ \text{ [1]}$$

$$d = \dots\dots\dots \lambda \text{ [1]}$$

- (c) A student is doing an experiment to determine the speed of sound in air by producing stationary waves inside a horizontal glass tube.

Fine powder is sprinkled inside the tube. A loudspeaker is placed close to the open end of the tube. The other end of the tube is closed. The loudspeaker is connected to a signal generator producing a frequency of 2.72 kHz.

The powder inside the tube forms piles at certain locations inside the tube, see **Fig. 16.2**.

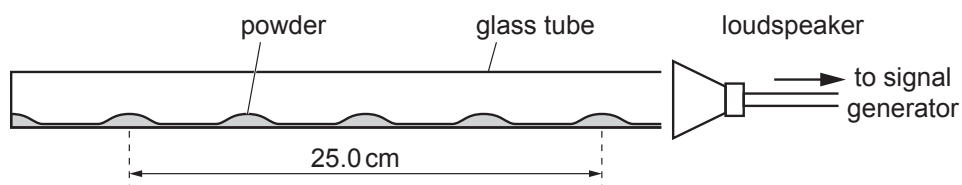


Fig. 16.2 (not to scale)

- (i) Suggest why the powder piles up at the nodes within the tube.

.....
 [1]

- (ii) Use **Fig. 16.2** to determine the speed of sound v .

$v = \dots\dots\dots \text{ms}^{-1}$ [3]

- (iii) Determine the fundamental (minimum) frequency f_0 of the stationary wave that can be formed within this tube.

$f_0 = \dots\dots\dots \text{Hz}$ [2]

- 17 A student uses a motion-sensor connected to a laptop to investigate the motion of a hollow ball of mass $1.2 \times 10^{-2} \text{ kg}$ falling through air.

The ball is dropped from rest. It reaches terminal velocity before it reaches the ground.

The upthrust on the ball is negligible.

Fig. 17 shows the variation with time t of the velocity v of the ball as it falls towards the ground.

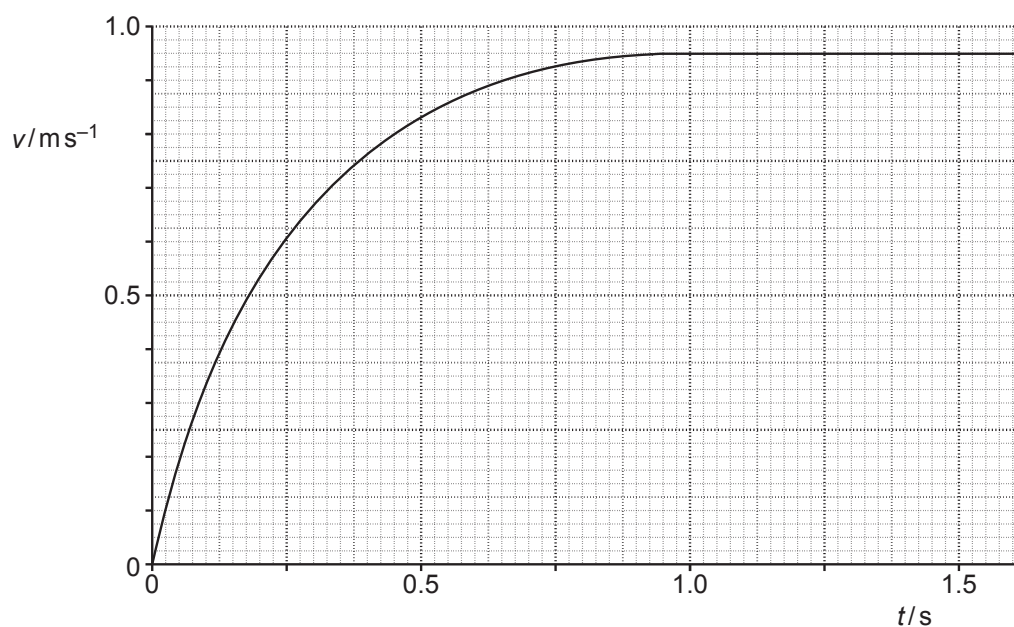


Fig. 17

- (a) Draw a tangent to the curve at $t = 0.25 \text{ s}$ and determine the acceleration of the ball.

acceleration = ... ms^{-2} [3]

- (b) Calculate the resultant force F acting on the ball at $t = 0.25$ s.

$F =$ N [1]

- (c) Use your answer in (b) to calculate the drag on the ball at time $t = 0.25$ s.

drag = ... N [3]

- (d) The student now adds a small amount of sand inside the hollow ball.
As before, the ball is dropped from rest and it also reaches terminal velocity before it reaches the ground.

- (i) Describe how the forces acting on the sand-filled ball at $v = 0.50 \text{ m s}^{-1}$ compare with the forces acting on the hollow ball at this speed.

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..... [2]

- (ii) Explain why the terminal velocity of the sand-filled ball will be greater than the terminal velocity of the hollow ball.

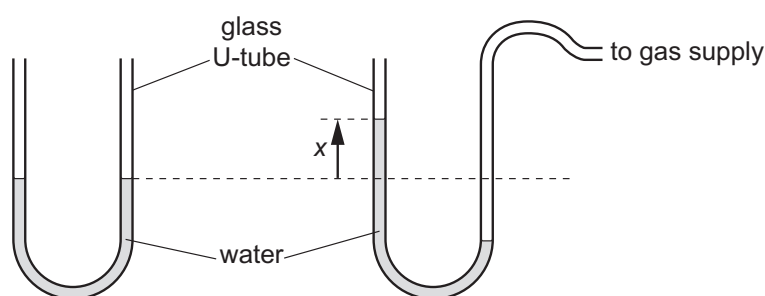
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..... [2]

- 20 (a) For a simple harmonic oscillator, the acceleration a is given by the equation $a = -\omega^2 x$, where ω is the angular frequency and x is the displacement.

Show that this equation is homogeneous by reducing both sides to S.I. base units.

[2]

- (b) The diagram shows a glass U-tube partially filled with a mass of water.



One end of the U-tube is connected to a gas supply of **constant** pressure and the other end is open to the atmosphere. The displacement of the water from its equilibrium position is x . The density ρ of water is 1000 kg m^{-3} .

- (i) The pressure from the gas supply raises the water in the U-tube. The vertical distance between the two levels of water in the two vertical sections of the U-tube is 10.0 cm ($x = 5.0 \text{ cm}$).

Δp is the difference between the gas pressure and atmospheric pressure. Calculate Δp .

$\Delta p = \dots\dots\dots \text{ Pa}$ [2]

- (ii) When the gas supply is disconnected, the water levels in the U-tube oscillates with simple harmonic motion. The acceleration a of the water level in the left-hand side of the U-tube is given by the equation

$$a = -\frac{2\rho g A}{m} x$$

where m is the mass of the water in the U-tube, A is the internal cross-sectional area of the U-tube, ρ is the density of water, g is the acceleration of free fall and x is the displacement of the water level in the left-hand side of the U-tube.

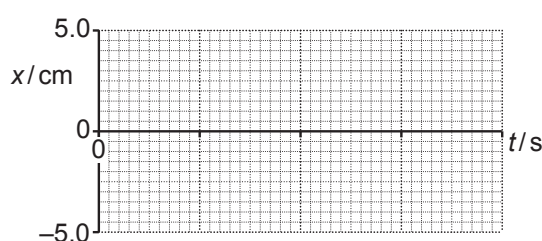
For this U-tube, $A = 1.0 \times 10^{-4} \text{ m}^2$ and $m = 0.052 \text{ kg}$.

- 1 Show that the period T of the oscillations is about 1 second.

[3]

- 2 The oscillations of the water level are slightly **damped**.
At time $t = 0$, $x = 5.0 \text{ cm}$.

Sketch a suitable graph of displacement x against time t for the oscillating water level. Add suitable values to the time t axis.



[3]

- 3 The U-tube is now connected to another gas supply where the pressure oscillates at a frequency of about 1 Hz.

Explain the effect this will have on the water in the U-tube.

.....

 [2]

- 18 A mass hanging from a vertical spring is pulled down. It is then released from rest at time $t = 0$. The mass oscillates vertically in a **vacuum** with simple harmonic motion about the equilibrium position. The spring is in tension at all times.

Fig. 18.1 shows the position of the mass at $t = 0$.

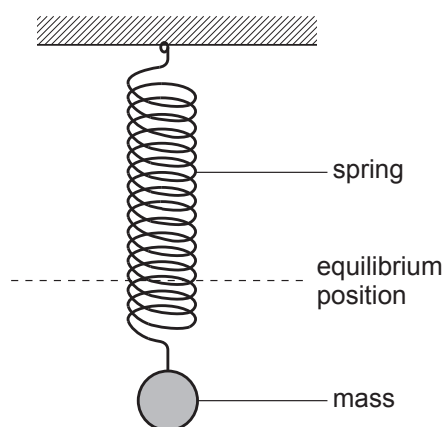


Fig. 18.1

At time $t = 6.5\text{ s}$ the magnitude of the acceleration a of the mass is 3.6 ms^{-2} and its displacement x is $4.6 \times 10^{-2}\text{ m}$.

- (a) (i) Use the defining equation for simple harmonic motion to show that the natural frequency f_0 of the mass-spring system is about 1.4 Hz .

[3]

(ii) Calculate the amplitude A of the oscillations.

$A = \dots\dots\dots$ m [2]

(b) The mass-spring system shown in Fig. 18.1 is now made to oscillate in **air**.

Different types of energy are involved in the oscillations of this mass-spring system.

Describe the energy changes that will take place as the mass moves from the lowest point in its motion through the equilibrium position to the highest point in its motion.

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..... [4]

Question 18 continues on page 16

- (c) Fig. 18.2 shows the mass and spring now attached to a mechanical vibrator, which can oscillate with variable frequency.

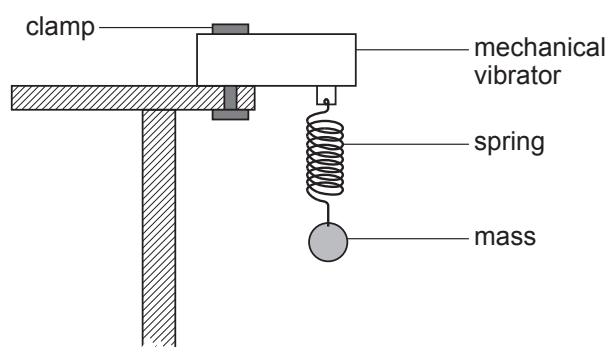


Fig. 18.2

The mass oscillates in air.

- (i) The vibrator frequency is varied from 0 Hz to 2.5 Hz.
On Fig. 18.3, sketch a graph to show the variation with vibrator frequency of the amplitude of the mass. Label your graph **K**.

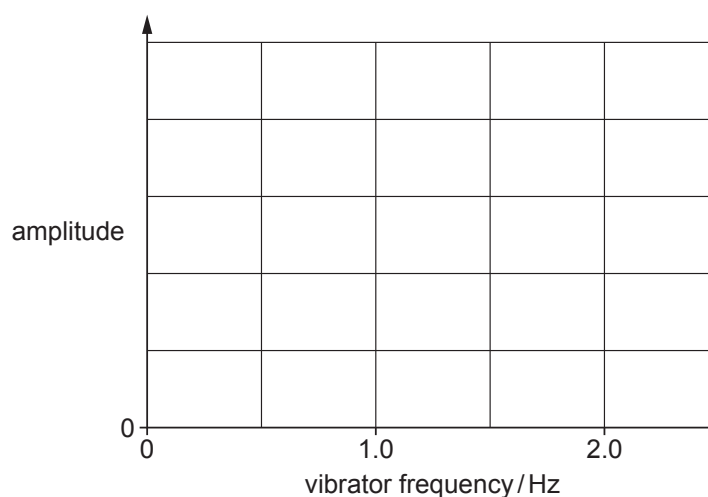


Fig. 18.3

[2]

- (ii) A light disc is now attached to the mass to increase the damping.
The vibrator frequency is again varied from 0 Hz to 2.5 Hz.
Sketch a second graph on Fig. 18.3 to show the new variation of the amplitude.
Label this graph **D**.

[1]

- (iii) Explain why the phenomenon demonstrated in this experiment can cause problems for engineers when designing suspended footbridges.

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..... [2]

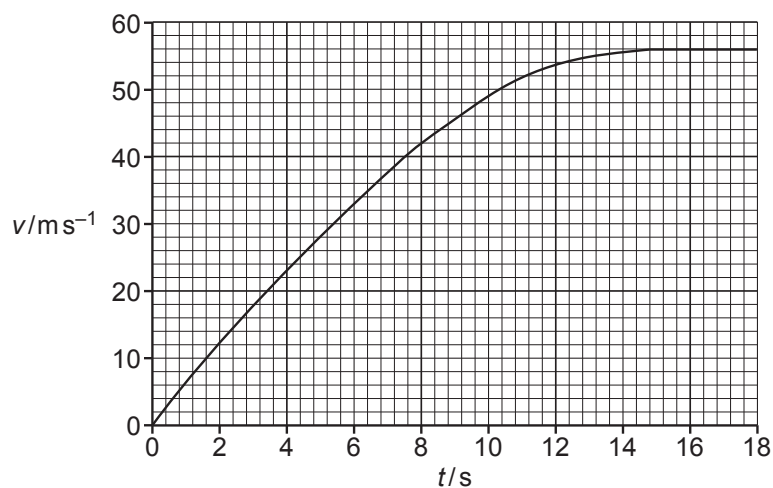


16 An electric car of mass 1700 kg is tested to measure its maximum speed.

Fig. 16.1 shows a graph of velocity v against time t for the first 18 seconds of the test.

During this time the force produced by the motor is constant.

Fig. 16.1



(a)

(i) Describe using **Fig. 16.1**, the method you would use to estimate the distance travelled in 18 s.

.....

 [2]

(ii) Use the graph in **Fig. 16.1** to show that the acceleration of the car at time $t = 12$ s is about 1.5 ms^{-2} .

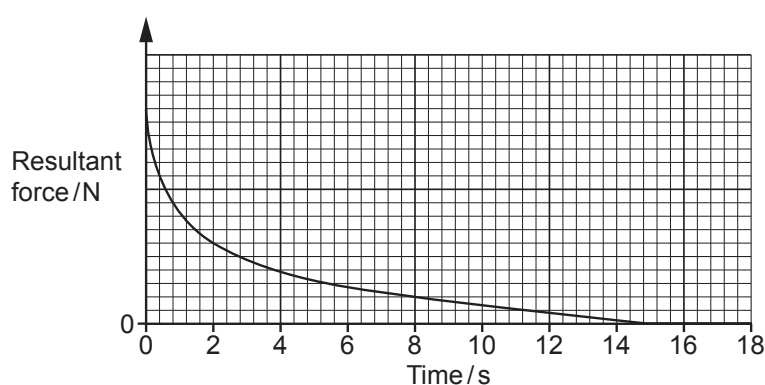
[2]

(iii) Use Fig. 16.1 to calculate the change of momentum of the car in 18 s.

= kg m s^{-1} [2]

(b) Fig. 16.2 shows a graph of **resultant** force against time during the test.

Fig. 16.2



(i) Explain, in terms of the forces acting on the car, the shape of the graph in Fig. 16.2.

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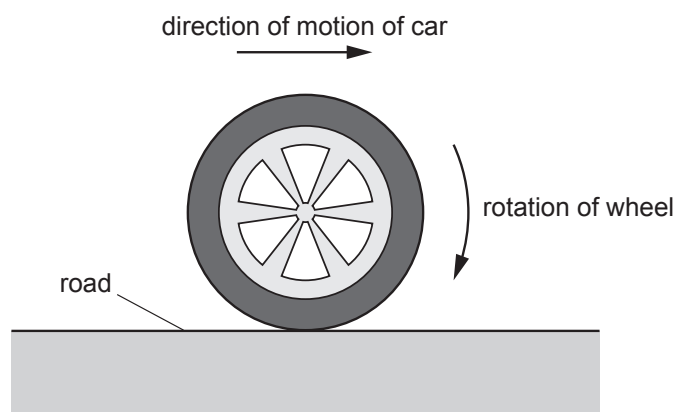
 [2]

(ii) Explain why the value you have calculated in (a)(iii) is the area under the graph in Fig. 16.2.

.....

 [1]

- (c) The diagram below shows one of the wheels of the car that is driven by the electric motor.



- (i) Use Newton's third law to explain how frictional forces cause the car to accelerate.

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..... [2]

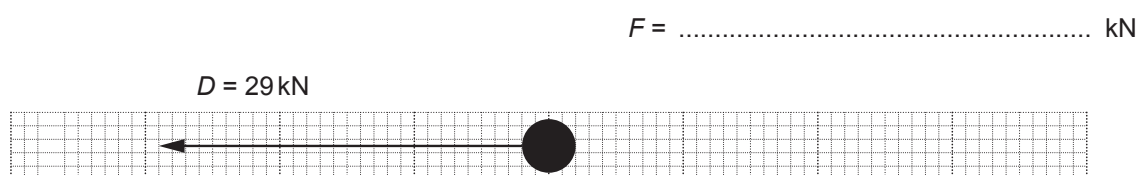
- (ii) Calculate the resultant force acting on the car at $t = 12\text{ s}$, using your answer to (a)(ii).

resultant force = ... N [1]

- (iii) The black dot in the diagram below represents the car at time $t = 12$ s. The total resistive forces acting on the car, D , are shown.

Calculate the constant **total** frictional force F from the powered wheels of the car which provides the thrust on the car.

Use your answer to draw an arrow on the diagram below to show the direction and magnitude of F .



[2]

21 (a) Fig. 21.1 shows a stationary glider of mass m on an air track.

The glider has identical springs with force constant k attached to each end which are secured to fixed posts.

The air track blower is turned on and the glider is displaced a small distance x_0 , as seen in Fig. 21.2. It is then released.

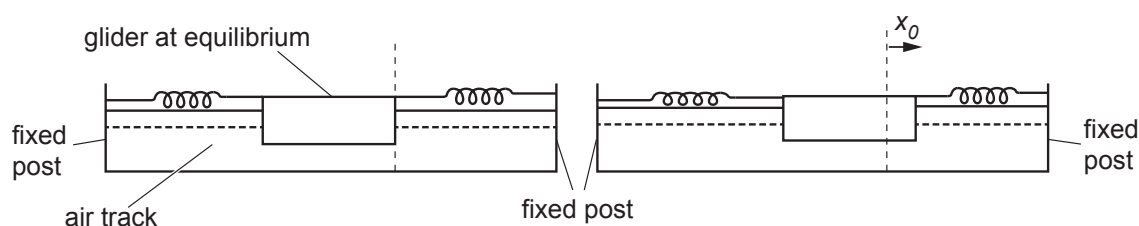
The glider moves horizontally in simple harmonic motion.

The springs remain in tension throughout the motion.

The time taken for 20 complete oscillations is measured, and the period T calculated.

Fig. 21.1

Fig. 21.2



The relationship between the period T , the mass of the glider m and the force constant k is described by the equation

$$T^2 = \frac{2\pi^2 m}{k}.$$

- (i) Show that the equation above is homogeneous by reducing the equation to SI base units.

[2]

- (ii) Explain why the magnitude of the resultant force F on the glider is given by $F = 2kx$ where x is the displacement at any time.

.....

.....

.....

..... [2]

- (iii) State and explain the effect, if any, of increasing the initial displacement on the period of the subsequent motion.

.....
 [2]

- (b) Masses are added to the glider, and the measurement of $20T$ repeated.

The results table is below.

m/kg	$20T/\text{s}$	T	T^2
0.200	12.2	0.61	0.372
0.300	13.6	0.68	0.462
0.400	15.6	0.78	0.608
0.500	17.6	0.88	0.774
0.600	18.9	0.945	0.893
0.700	20.0	1	1

- (i) Describe **two** different errors in the table.

1

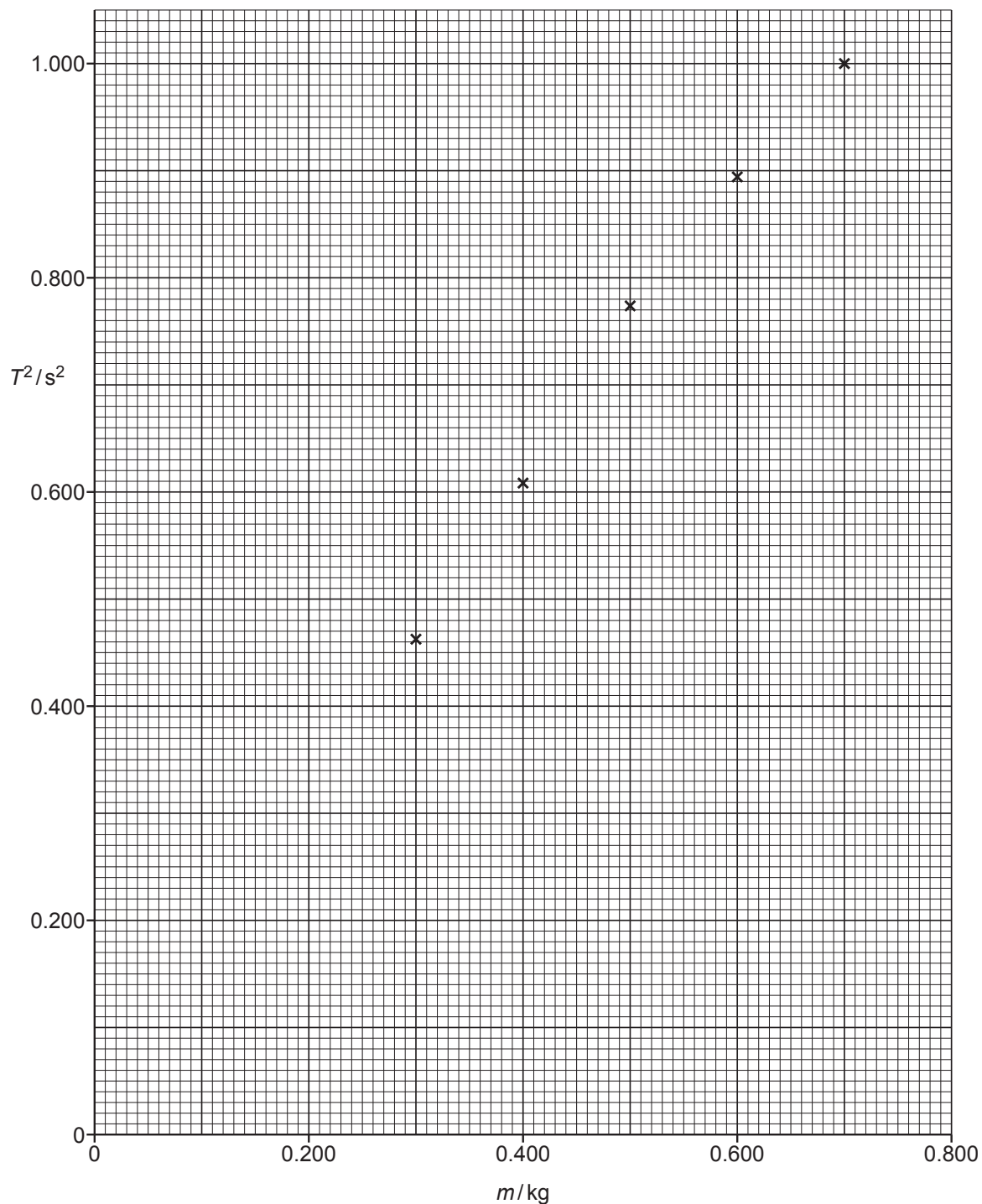
 2
 [2]

(ii) Plot the **first** data point from the table on the graph below.

The other points have all been plotted. The table of results is repeated on the opposite page.

Include on your graph a line of best fit.

[2]



m/kg	$20T/\text{s}$	T	T^2
0.200	12.2	0.61	0.372
0.300	13.6	0.68	0.462
0.400	15.6	0.78	0.608
0.500	17.6	0.88	0.774
0.600	18.9	0.945	0.893
0.700	20.0	1	1

(iii) Use the graph to determine the value of k .

$k = \text{..... } \text{Nm}^{-1}$ [3]

(c) When the initial displacement is increased, one spring increases its extension while the extension of the other spring decreases.

Explain why the **maximum** kinetic energy of the motion increases.

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..... [4]

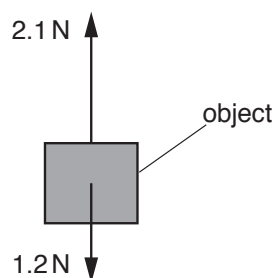
SUB-TOPIC 3.1.2

LINEAR MOTION

Sub-topic 3.1.2 · 27 questions · 188 marks · lowest tariff first



- 8 The diagram shows two opposite vertical forces of magnitude 1.2 N and 2.1 N acting on an object.



Which of the following statements could be correct?

- 1 The object is accelerating and moving up.
- 2 The object is decelerating and moving down.
- 3 The magnitude of the resultant force is 0.9 N.

- A** Only 3
- B** Only 1 and 3
- C** Only 2 and 3
- D** 1, 2 and 3

Your answer

[1]

- 4 The acceleration a of a simple harmonic oscillator is related to its displacement x by the equation

$$a = -25x.$$

What is the frequency of the oscillator?

- A 0.80 Hz
- B 1.3 Hz
- C 4.0 Hz
- D 5.0 Hz

Your answer

[1]

- 9 A pendulum is oscillating in air and experiences damping.

Which of the following statements is/are correct for the damping force acting on the pendulum?

- 1 It is always opposite in direction to acceleration.
- 2 It is always opposite in direction to velocity.
- 3 It is maximum when the displacement is zero.

A Only 1 and 2

B Only 2 and 3

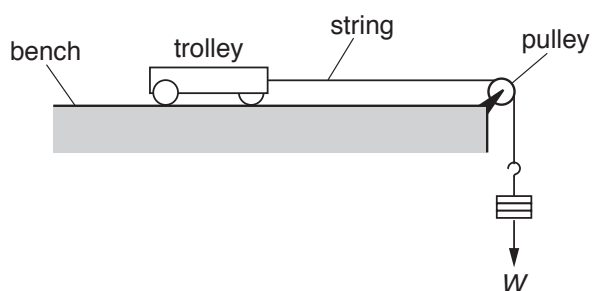
C Only 3

D 1, 2 and 3

Your answer

[1]

- 10 A trolley of mass M is pulled along a horizontal table by a force W provided by a mass hanging from the end of a string as shown.



Frictional forces are negligible. The acceleration of free fall is g .

What is the correct equation for the acceleration a of the trolley?

A $a = \frac{W}{M}$

B $a = g$

C $a = \frac{W}{2M}$

D $a = \frac{W}{M + \frac{W}{g}}$

Your answer

[1]

- 3 A tennis ball is hit with a racket. The force applied by the racket on the ball is F . The ball has a vertical path through the air.

Which statement is correct when the ball is at its **maximum** height?

- A The ball has a downward acceleration.
- B The force acting on the ball is F .
- C The ball experiences greatest drag.
- D The weight of the ball is equal to the drag.

Your answer

[1]

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- 3 The table shows some data for a car travelling on a straight road with an initial speed of 13 m s^{-1} .

Thinking distance / m	9.0
Braking distance / m	14
Stopping distance / m	23

The car has a constant deceleration when the brakes are applied.

What is the magnitude of the deceleration of the car during braking?

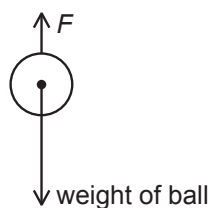
- A 0.46 m s^{-2}
B 3.7 m s^{-2}
C 6.0 m s^{-2}
D 9.4 m s^{-2}

Your answer

[1]



- 14 A ball of mass m is falling vertically through the air.



The total upward force acting on the ball is F . The force F is less than the weight of the object. The acceleration of free fall is g .

Which expression is correct for the acceleration a of the ball?

A $a = 0$

B $a = \frac{mg - F}{m}$

C $a = \frac{mg + F}{m}$

D $a = g$

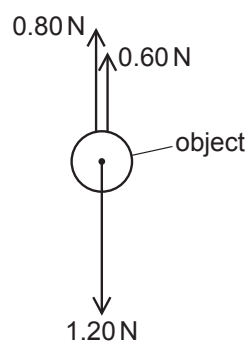
Your answer

[1]

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- 4 The diagram below shows the directions and magnitudes of the three forces acting on an object at a specific time as it moves through water.



The weight of the object is 1.20 N, the upthrust on the object is 0.80 N and the drag is 0.60 N.

Which statement is correct about this object at this specific time?

- A It has reached its terminal velocity.
- B It is accelerating.
- C It is decelerating.
- D It is moving upwards.

Your answer

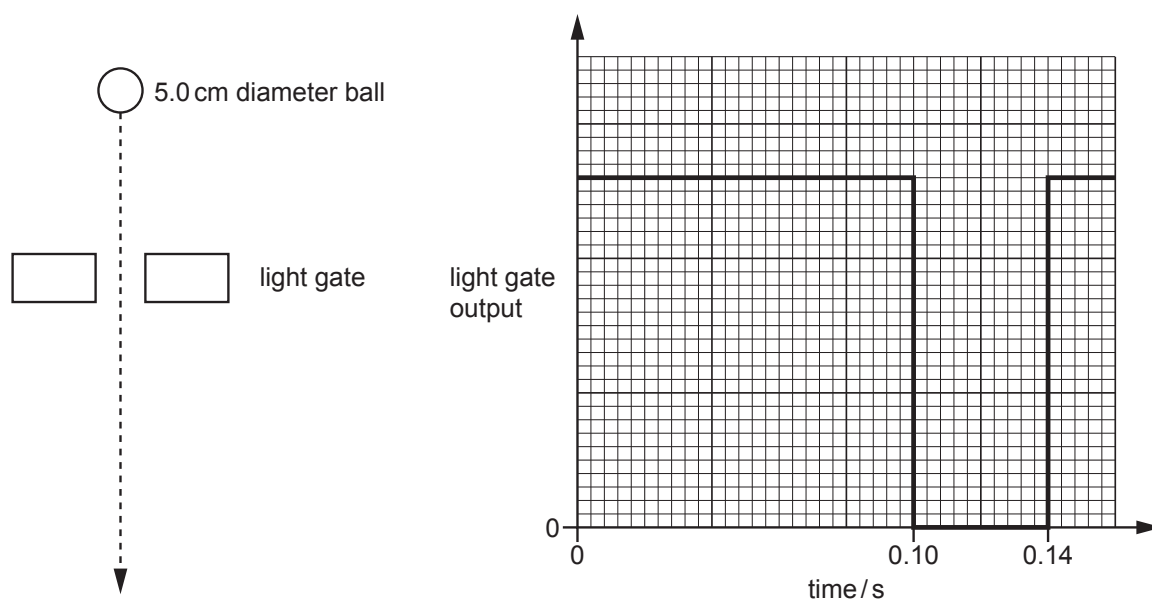
[1]

- 4 To determine the acceleration of free fall g , a ball is dropped from rest from a point vertically above a light gate.

The ball has a diameter of 5.0 cm. It is dropped at time $t = 0$.

The light gate output shows that the ball passes through the gate between times $t = 0.10$ s and $t = 0.14$ s.

The graph shows the output from the light gate.



Air resistance has negligible effect on the motion of the ball.

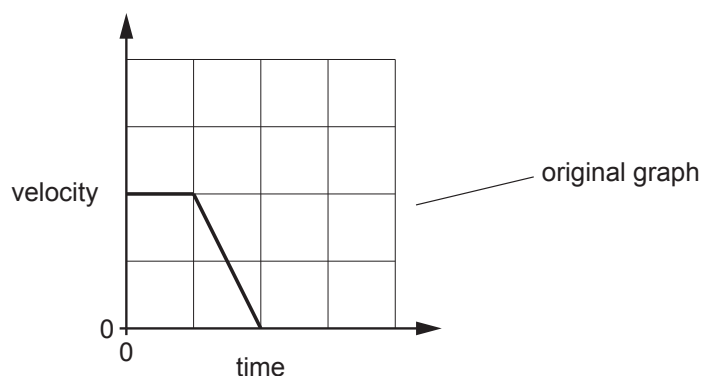
What is the value of g in ms^{-2} from these measurements?

- A 8.93
- B 9.81
- C 10.4
- D 12.5

Your answer

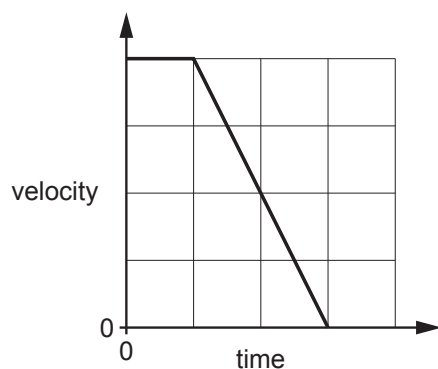
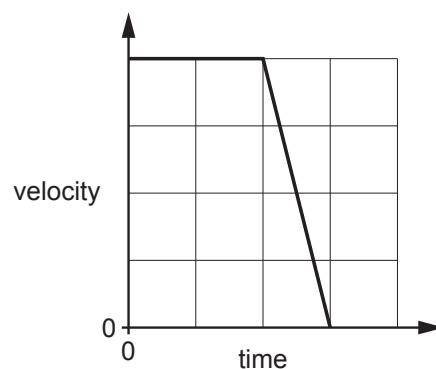
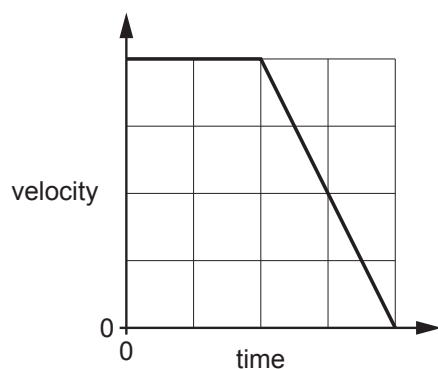
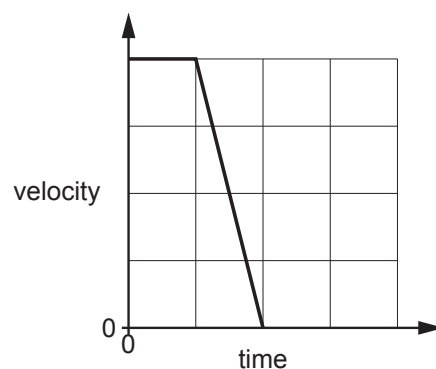
[1]

- 7 The graph shows a velocity-time graph for a vehicle. At time $t = 0$ the driver observes an obstruction in the road. A short time later the brakes are applied, and the vehicle stops. The braking force remains constant.



The situation is repeated. This time the vehicle starts with twice the original velocity. All other variables remain the same.

Which diagram shows the correct velocity-time graph for this new situation? The same scales are used on all graphs.

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

Your answer

[1]

- 11 A car drives over a bridge at speed v . The path of the car is part of a vertical circle of radius r . The mass of the driver is m .

At the top of the bridge the driver of the car experiences apparent weightlessness and no normal contact force from the car seat.

The acceleration of free fall is g .

Which statement is correct?

- A $mg = 0$
- B $v \geq gr$
- C $v^2 \geq gr$
- D $mv^2 \geq gr$

Your answer

[1]

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18* A student is attempting to determine the value of g , the acceleration due to gravity, by two different methods.

Method 1. Vertical drop method

Measuring the time of fall of a small dense ball being dropped from rest from different heights.

Method 2. Rolling ball method

Measuring the time it takes for the same ball to roll 1.900 m down a ramp, set at different angles.

Single sets of results are shown below. The times were measured using a standard stopwatch operated by the student.

Compare and discuss the uncertainties of the two values of g that could be obtained using these single measurements.

Describe how the student would analyse both sets of data when a full range of results has been taken.

Vertical drop method

Drop height/m	Time taken/s
1.20	0.50

Rolling ball method

Length of ramp/m	Angle/°	Time taken/s
1.900	30	0.90

[6]

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Additional space if required

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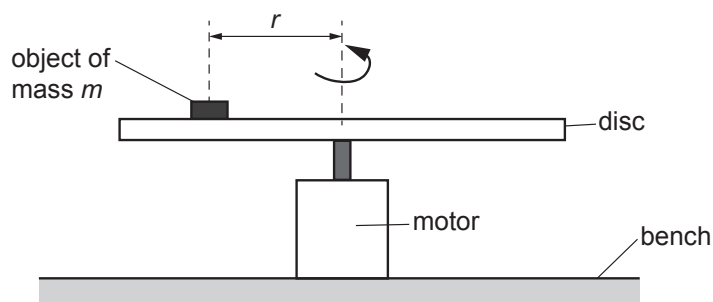
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- 20 A small object of mass m is placed on a rotating horizontal metal disc at a distance r from the centre of the disc.



The frequency of rotation is adjusted using a motor attached to the disc.

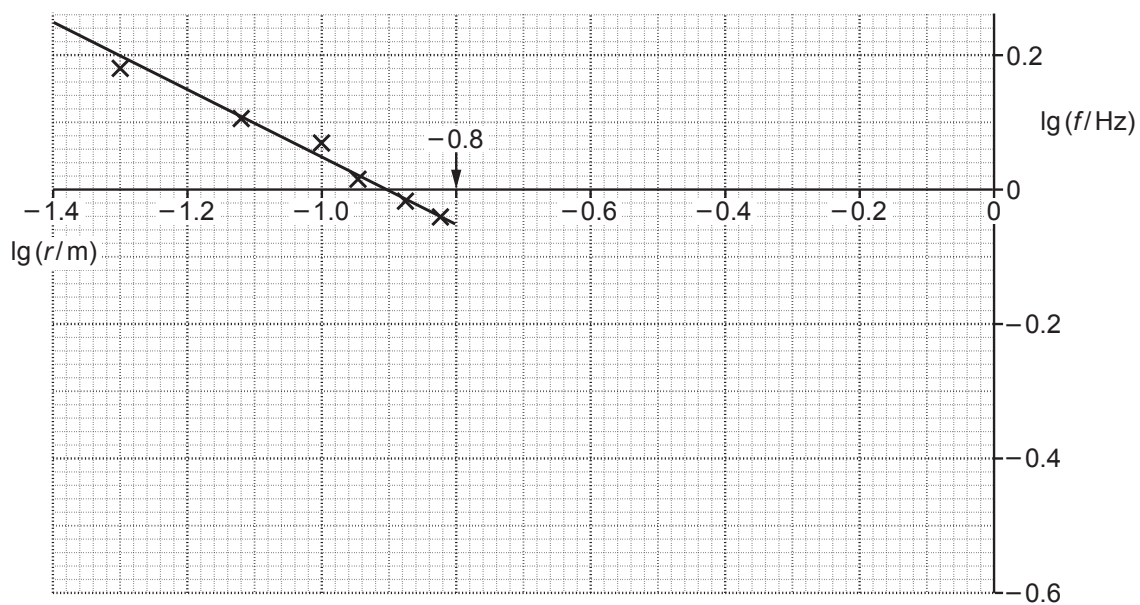
The frequency of rotation of the disc is slowly increased from zero, until the object slips off. At this point, the friction F acting on the object is equal to the centripetal force.

The friction F is given by the expression $F = kmg$, where k is a constant and g is the acceleration of free fall. The constant k has no units.

- (a) Show that the frequency f at which the object slips off is given by the equation $f^2 = \left(\frac{gk}{4\pi^2}\right) \times \frac{1}{r}$.

[3]

(b) A student plots a graph of $\lg(f/\text{Hz})$ against $\lg(r/\text{m})$.



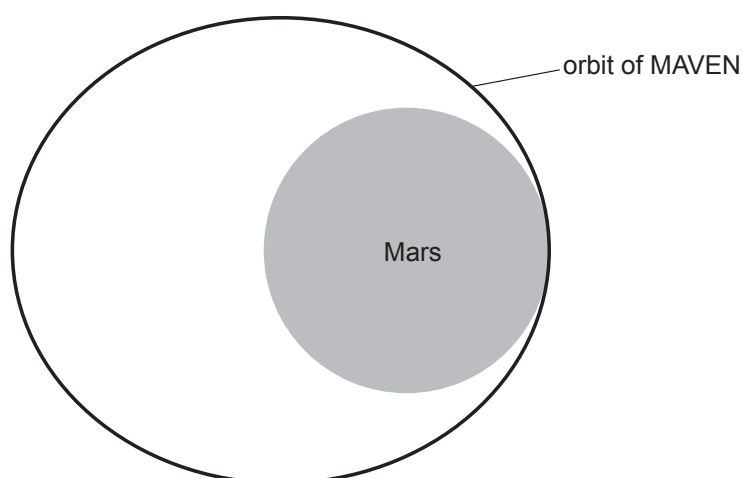
For this graph: $y\text{-intercept} = \frac{1}{2} \times \lg\left(\frac{gk}{4\pi^2}\right)$

Use the graph to determine the constant k . Write your answer to 2 significant figures.

$k = \dots\dots\dots$ [4]

1 The MAVEN spacecraft orbits Mars and studies its upper atmosphere.

(a) The diagram below shows the orbit of MAVEN around Mars.



(i) Mark an **X** on the diagram to show the point in the orbit where MAVEN has maximum acceleration. [1]

(ii) Explain how Kepler's 1st law applies to MAVEN's orbit around Mars.

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..... [2]

(b) The table shows data for four orbits around Mars.

Phobos and Deimos are moons of Mars.

An areostationary orbit for Mars is the equivalent of a geostationary orbit for Earth.

Orbit	Time period/hours	Average distance from centre of Mars/km
MAVEN	4.5	6 500
Phobos	7.7	9 400
Deimos	30	23 000
Areostationary	25	20 000

(i) Show that Kepler’s 3rd law applies to this data.

[2]

(ii) Suggest **two** reasons why MAVEN was **not** placed in an areostationary orbit.

1

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2

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[2]

- 19 (a) A car is travelling along a straight road at 18 ms^{-1} .
The driver sees an obstacle and after 0.50 s applies the brakes.
The **stopping** distance of the car is 38 m .

Calculate the magnitude of the deceleration of the car when the brakes are applied.

deceleration = ... ms^{-2} [3]

- (b)* A student rolls a marble at different speeds on a carpet to model the braking of a car.

The student wishes to investigate how the total distance x travelled before the marble stops (braking distance) depends on its initial speed v .

The speed v and distance x are related by the equation $\frac{1}{2}mv^2 = Fx$ where m is the mass of the marble and F is the constant frictional force acting on the marble.

- Describe how an experiment can be conducted in the laboratory to investigate the relationship between v and x .
- Explain how the data can be analysed to determine F . [6]

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Additional answer space if required.

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- 2 The 500 m tall Taipei 101 tower is shown in Fig. 2.1. The tower has a massive sphere suspended across five floors near the top of the building to dampen down movement of the tower in high winds and earthquakes. The sphere is connected to pistons (not shown) which drive oil through small holes providing damping. The vibration energy of the sphere is converted to thermal energy.

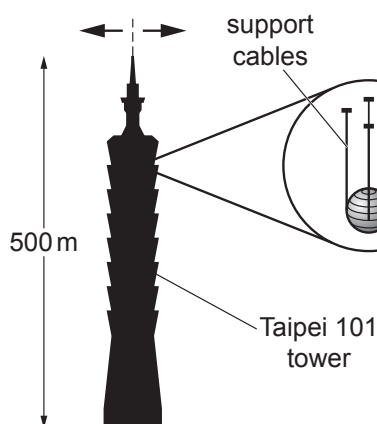


Fig. 2.1

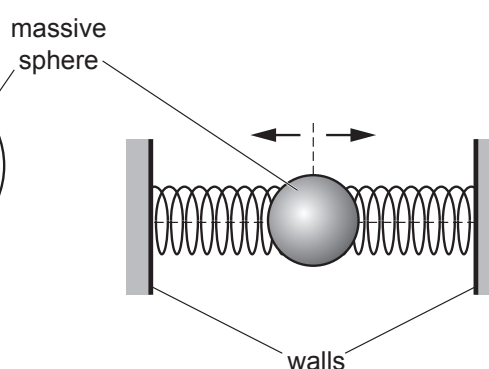


Fig. 2.2

Fig. 2.2 models the damper system as the sphere held between two springs. The movement of the walls of the tower forces the sphere to oscillate in **simple harmonic motion**.

In the strongest wind, the natural frequency of the oscillations of the tower is 0.15 Hz and the maximum acceleration of the sphere is 0.050 m s^{-2} .

- (a) Calculate the maximum displacement of the sphere in the strongest wind.

maximum displacement = ... m [3]

- (b) Explain why the natural frequency of the damper system must be about 0.15 Hz.

.....

 [2]

- (c) The acceleration a of the sphere is given by the equation

$$a = -\left(\frac{k}{m}\right)x$$

where k is the force constant of the spring combination, x is the displacement of the sphere and m is the mass of the sphere.

The mass of the sphere is $6.6 \times 10^5 \text{ kg}$. The natural frequency of the oscillations of the sphere is 0.15 Hz .

- (i) Show that the force constant k of the spring combination is about $6 \times 10^5 \text{ N m}^{-1}$.

[3]

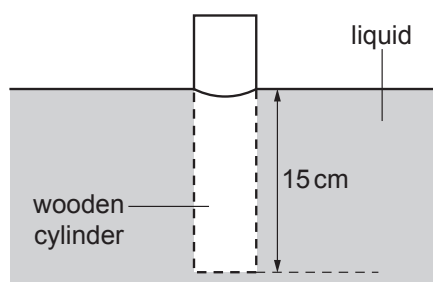
- (ii) The S-wave of an earthquake causes a sudden movement of the building displacing the sphere 0.71 m from its equilibrium position relative to the building.

Use your answer in (i) to calculate the energy transferred to the springs of the damper system.

energy transferred = ... J [2]



- 22 A long wooden cylinder is placed into a liquid and it floats as shown.



The length of the cylinder below the liquid level is 15 cm.

- (a) (i) State **Archimedes' principle**.

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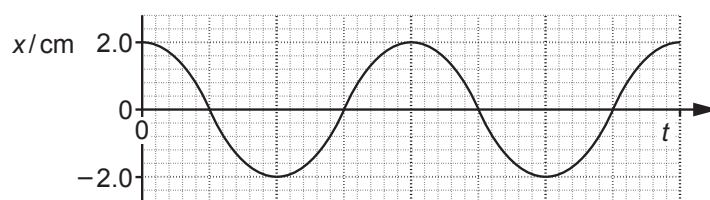
 [1]

- (ii) The pressure exerted by the liquid alone on the bottom of the cylinder is $1.9 \times 10^3 \text{ Pa}$.

Calculate the density ρ of the liquid.

$\rho = \dots\dots\dots \text{ kg m}^{-3}$ [2]

- (b) The cylinder is pushed down into the liquid and then allowed to oscillate freely. The graph of displacement x against time t is shown below.



The cylinder oscillates with simple harmonic motion with frequency of 1.4 Hz.

- (i) Calculate the displacement, in cm, at time $t = 0.60$ s.

displacement = ... cm [3]

- (ii) Calculate the maximum speed of the oscillating cylinder.

maximum speed = ... ms^{-1} [2]

- (iii) The cylinder is now pushed down further into the liquid before being released.
As before, the cylinder oscillates with simple harmonic motion.

State the effect this has on

- 1 the amplitude

.....

- 2 the period.

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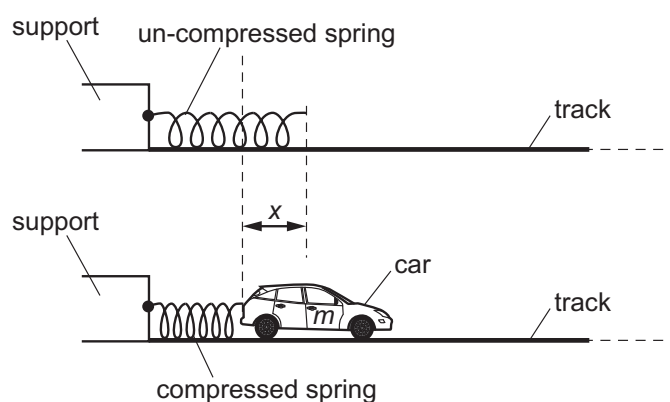
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- 21 (a) One end of a spring is fixed to a support. A toy car, which is on a smooth horizontal track, is pushed against the free end of the spring. The spring compresses. The car is then released. The car accelerates to the right until the spring returns back to its original length.



The car moves with **simple harmonic motion** as the spring returns to its original length.

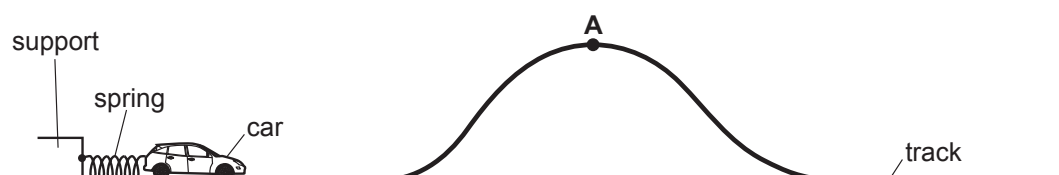
The acceleration of the car is given by the expression $a = -\left(\frac{k}{m}\right)x$, where m is the mass of the car, k is the force constant of the spring and x is the compression of the spring.

Use the data below to calculate the time t it takes for the spring to return to its original length after the car is released.

- mass of car $m = 80 \text{ g}$
- force constant k of the spring $= 60 \text{ N m}^{-1}$.

$t = \dots\dots\dots \text{ s}$ [4]

- (b) The arrangement in (a) is used to propel the toy car along a smooth track.



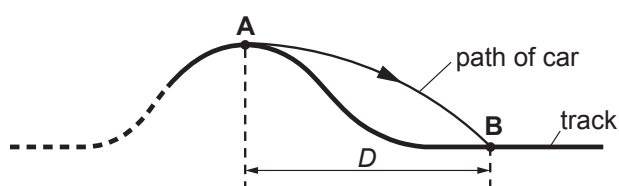
- (i) Point **A** is at the top of the track.
The launch speed of the car is now adjusted until the car just reaches **A** with zero speed.
The height of **A** is 0.20 m above the horizontal section of the track.

All the elastic potential energy of the spring is transferred to gravitational potential energy of the car.

Calculate the initial compression x of the spring.

$x = \dots\dots\dots$ m [3]

- (ii) At a specific speed, the car leaves point **A** horizontally and lands on the track at point **B**.
The horizontal distance between **A** and **B** is D .



Air resistance has negligible effect on the motion of the car between **A** and **B**.

- 1 Explain how the time of flight between **A** and **B** depends on the speed of the car at **A**.

.....

 [2]

- 2 Explain how the distance D depends on the speed of the car at **A**.

.....

 [2]

- 6 This question is about the motion of a ball suspended by an elastic string above a bench. The mass of the string is negligible compared to that of the ball. Ignore air resistance.

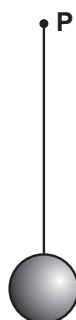


Fig. 6.1

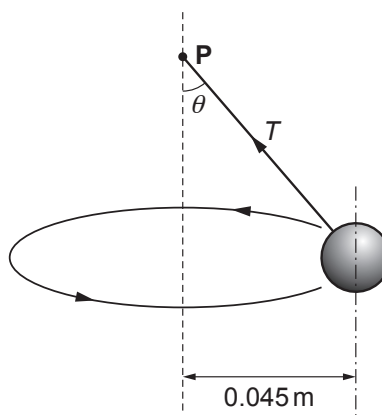


Fig. 6.2 (not to scale)

In Fig. 6.1 the ball of weight 1.2 N hangs vertically at rest from a point **P**. The extension of the string is 0.050 m. The string obeys Hooke's law.

In Fig. 6.2 the ball is moving in a horizontal circle of radius 0.045 m around a vertical axis through **P** with a period of 0.67 s. The string is at an angle θ to the vertical. The tension in the string is T .

- (a) On Fig. 6.2 draw and label one other force acting on the ball. [1]

- (b) (i) Resolve the tension T horizontally and vertically and show that the angle θ is 22° . [2]

- (ii) Calculate the extension x of the string shown in Fig. 6.2. [3]

$x = \dots\dots\dots$ m [3]

- (c) Whilst rotating in the horizontal plane the ball suddenly becomes detached from the string. The bottom of the ball is 0.18 m above the bench at this instant. The ball falls as a projectile towards the bench beneath. Fig. 6.3 shows the view from above.

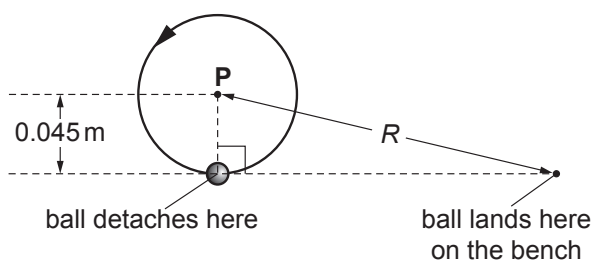


Fig. 6.3

Calculate the horizontal distance R from the point on the bench vertically below the point **P** to the point where the ball lands on the bench.

$R = \dots\dots\dots$ m [4]

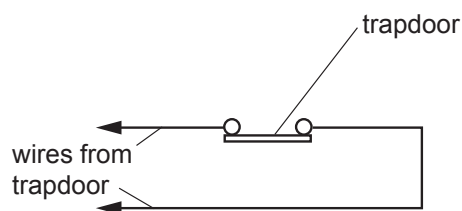
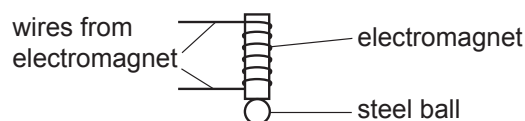
- (d) Returning to the situation shown in Fig. 6.2, state and explain what happens when the rate of rotation of the ball is increased.

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 [2]

16 A student wants to determine the value of the acceleration of freefall g .

(a) The diagram below shows part of the arrangement which the student used.



A steel ball is dropped from an electromagnet. The ball falls vertically. The ball hits a trapdoor and opens the trapdoor.

The ball travels a distance s from the bottom of the electromagnet to the trapdoor in a time t .

The student uses the equation $s = \frac{1}{2}gt^2$ to determine g .

(i) Show that the equation $s = \frac{1}{2}gt^2$ is homogeneous, with both sides of the equation having the same base units.

[2]

(ii) Describe how the student could use standard laboratory equipment to take accurate measurements of the distance s and the time t .

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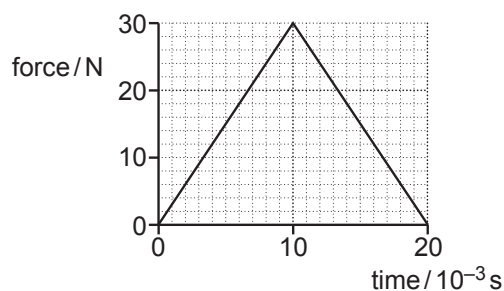
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[4]

- (b) The trapdoor falls downwards when the ball hits it.
The ball collides **elastically** with the trapdoor with a speed of 4.4 m s^{-1} .

The graph of force acting on the ball against time is shown below.



The mass of the ball is 0.050 kg .

- (i) Calculate the initial momentum p_1 of the ball just before it hits the trapdoor.

$$p_1 = \dots\dots\dots \text{ kg m s}^{-1} \text{ [1]}$$

- (ii) Use the graph to calculate the magnitude of the final momentum p_2 of the ball immediately after the collision.

$$p_2 = \dots\dots\dots \text{ kg m s}^{-1} \text{ [3]}$$

- (iii) The mass of the trapdoor is 100 g .

Calculate the final speed v of the trapdoor immediately after the collision.

$$v = \dots\dots\dots \text{ m s}^{-1} \text{ [2]}$$

Turn over

- 1 The table shows some data on the planet Venus.

Mass/kg	4.87×10^{24}
Radius/km	6050
Density of atmosphere at surface/kg m⁻³	65
Period of rotation about its axis/hours	5830

- (a) Calculate the magnitude of the gravitational field strength g at the surface of Venus.

Give your answer to **3** significant figures.

$$g = \dots\dots\dots \text{N kg}^{-1} \text{ [3]}$$

- (b) Two identical space probes, **A** and **B**, land on a flat surface on Venus.

Probe **A** lands at the north pole. Probe **B** lands on the equator.

Each probe has mass 760 kg and volume 1.7 m^3 .

- (i) Calculate the centripetal acceleration a of probe **B** at the equator due to the rotation of Venus about its axis.

$$a = \dots\dots\dots \text{ms}^{-2} \text{ [3]}$$

- (ii) The atmosphere exerts the same upthrust on each probe.

Using your answer to (a), calculate the upthrust acting on each probe.

upthrust = ... N [3]

- (iii) Explain which probe will experience the greater normal contact force from the surface of Venus.

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..... [3]

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- 2 A student investigates the oscillations of a uniform rod of length L which is pivoted at the top, as shown in **Fig. 2.1**.

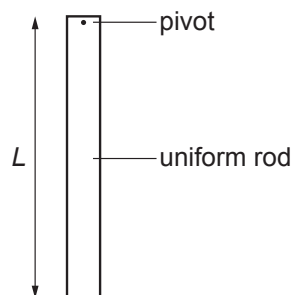


Fig. 2.1

- (a) Describe how to determine accurately the period T of oscillations of this rod.

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..... [2]

- (b) The relationship between the frequency f of the oscillations of the rod and its length L is

$$f = \frac{1}{2\pi} \sqrt{\frac{3g}{2L}},$$

where g is the acceleration of free fall.

The student varies the length L of the rod and determines the period T for each length.

The student plots a graph of T^2 against L , shown in **Fig. 2.2**. A line of best fit has already been drawn.

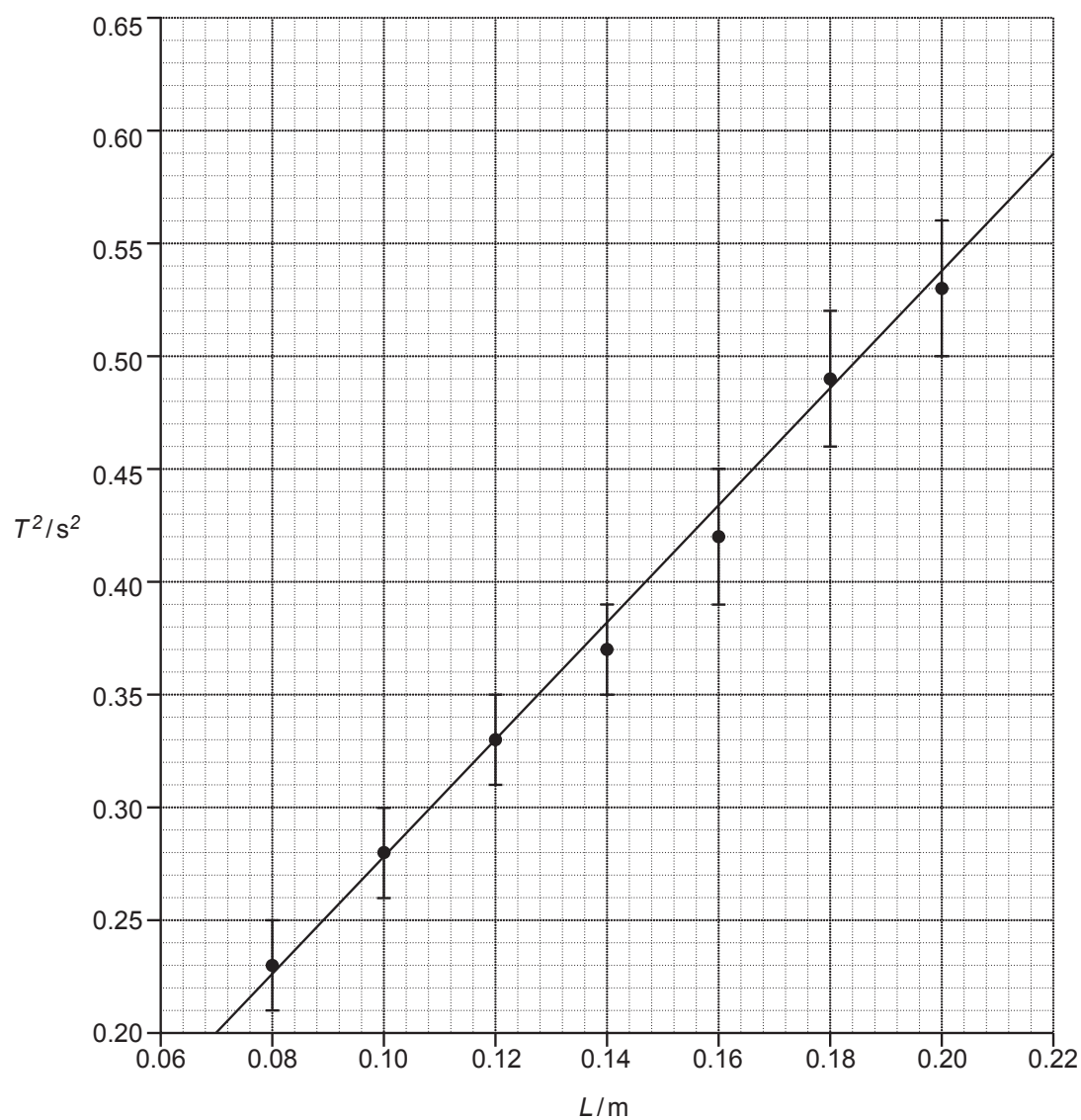


Fig. 2.2

- (i) Show that the gradient of the graph is given by the equation

$$\text{gradient} = \frac{8\pi^2}{3g}$$

[2]

- (ii) The gradient of the line of best fit on **Fig. 2.2** is $2.64 \text{ s}^2 \text{ m}^{-1}$.

Use this value to determine g .

$$g = \dots\dots\dots \text{ ms}^{-2} \text{ [2]}$$

- (iii) Draw a line of worst fit on **Fig. 2.2**.

[1]

- (iv) Use your line of worst fit to calculate the percentage uncertainty in g .

$$\text{percentage uncertainty} = \dots\dots\dots \% \text{ [3]}$$

- (v) Use the true value of g (9.81 ms^{-2}) to evaluate the accuracy of the student's value of g from this experiment. Include a calculation in your answer.

.....

 [2]

- 1 A toy rocket is made from a 1.5 litre plastic bottle with fins attached for stability.

The bottle initially contains 0.30 litres of water, leaving 1.2 litres of trapped air at a temperature of 17 °C.

A pump is used to increase the pressure of the air within the plastic bottle to $2.4 \times 10^5 \text{ Pa}$ at the start of lift-off.

Fig. 1.1 shows the rocket at the start of lift-off.

$$1 \text{ litre} = 10^{-3} \text{ m}^3$$

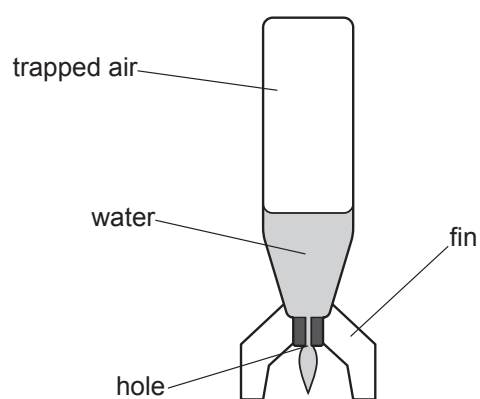


Fig. 1.1

- (a) Calculate, in moles, the amount of trapped air in the bottle at the start of lift-off.

amount of air = ... mol [2]

- (b) The trapped air pushes the water downwards out of the hole, causing the rocket to rise. The temperature of this air remains constant.

Calculate the final pressure of the trapped air just before all the water has been released.

final pressure = ... Pa [3]

- (c) Here is some data on the toy rocket.

mass of empty bottle and fins = 0.050 kg
area of cross-section of hole = $1.1 \times 10^{-4} \text{ m}^2$
initial pressure of trapped air = $2.4 \times 10^5 \text{ Pa}$
atmospheric pressure = $1.0 \times 10^5 \text{ Pa}$
density of water = $1.0 \times 10^3 \text{ kg m}^{-3}$

- (i) Use the data above to show that the **upwards** force on the rocket at the start of lift-off is about 15 N.

[2]



(ii) Hence calculate the initial vertical acceleration of the rocket.

initial acceleration = ... ms^{-2} [3]

(d) Discuss whether adding more water initially would enable the rocket to reach a greater height.

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..... [3]

- 4 The International Space Station (ISS) orbits the Earth at a height of $4.1 \times 10^5 \text{ m}$ **above** the Earth's surface.

The radius of the Earth is $6.37 \times 10^6 \text{ m}$. The gravitational field strength g_0 at the Earth's surface is 9.81 N kg^{-1} .

- (a) Both the ISS and the astronauts inside it are in free fall.

Explain why this makes the astronauts feel **weightless**.

.....

 [1]

- (b) (i) Calculate the value of the gravitational field strength g at the height of the ISS above the Earth.

$g = \dots\dots\dots \text{N kg}^{-1}$ [3]

- (ii) The speed of the ISS in its orbit is 7.7 km s^{-1} . Show that the period of the ISS in its orbit is about 90 minutes.

[2]

Question 4 continues on page 12

Turn over

(c) Use the information in (b)(ii) and the data below to show that the root mean square (r.m.s.) speed of the air molecules inside the ISS is approximately 15 times smaller than the orbital speed of the ISS.

- molar mass of air = $2.9 \times 10^{-2} \text{ kg mol}^{-1}$
- temperature of air inside the ISS = 20°C

[3]

- (d) The ISS has arrays of solar cells on its wings. These solar cells charge batteries which power the ISS. The wings always face the Sun.

Use the data below and your answer to (b)(ii) to calculate the **average** power delivered to the batteries.

- The total area of the cells facing the solar radiation is 2500 m^2 .
- 7% of the energy of the sunlight incident on the cells is stored in the batteries.
- The intensity of solar radiation at the orbit of the ISS is 1.4 kW m^{-2} outside of the Earth's shadow and zero inside it.
- The ISS passes through the Earth's shadow for 35 minutes during each orbit.

average power = ... W [4]

- 1 Fig. 1 shows a high-speed electric train.

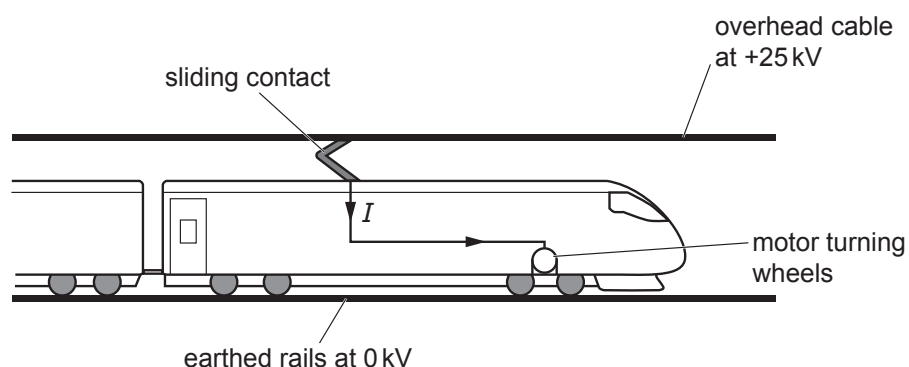


Fig. 1

The potential difference between the overhead cable and the rails on the ground is 25 kV. The sliding contact on the top of the train constantly touches the overhead cable. The overhead cable supplies a current I to the electric motor of the train. The motor turns the wheels. The train experiences a **resultant** forward force F .

The total mass of the train is $2.1 \times 10^5 \text{ kg}$.

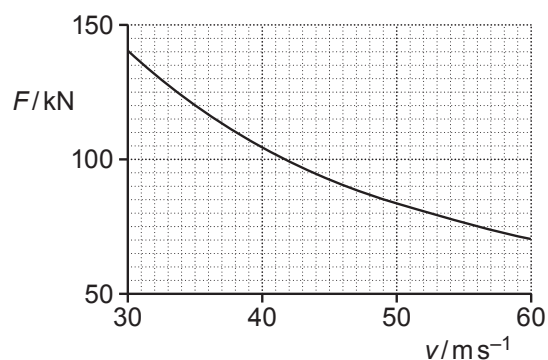
- (a) The train accelerates from rest. The value of F is 190 kN for speeds less than 6.0 ms^{-1} .
- (i) Show that the train's acceleration is about 1 ms^{-2} .

[1]

- (ii) Calculate the distance s that the train travels to reach a speed of 6.0 ms^{-1} .

$s = \dots\dots\dots \text{ m}$ [2]

- (iii) The speed of the train is v .
During one period of its journey, the train accelerates from $v = 30 \text{ m s}^{-1}$ to $v = 60 \text{ m s}^{-1}$.
The graph of F against v for this period is shown below.



- Use the graph to show that output power of the electric motor during this period is constant at about 4 MW.

[3]

- Calculate the current I in the electric motor when the train is travelling at 50 m s^{-1} .

$I = \dots\dots\dots \text{ A}$ [2]

Question 1 is continued on page 4

- (b) The overhead cable in **Fig. 1** must be tensioned.
It is constructed from several equal lengths of wire.

Some data for one length of this wire are shown below.

- length = 1500 m
- area of cross-section = $1.1 \times 10^{-4} \text{ m}^2$
- resistivity = $1.8 \times 10^{-8} \Omega \text{ m}$
- the Young modulus = $1.2 \times 10^{10} \text{ Pa}$
- strain = 1.3%

- (i) Calculate the resistance R of one length of wire.

$R = \dots\dots\dots \Omega$ [2]

- (ii) Calculate the tension T in one length of wire.

$T = \dots\dots\dots \text{ N}$ [3]

- 19** This question is about a simple pendulum made from a length of string attached to a mass (bob). For oscillations of small amplitude, the acceleration a of the pendulum bob is related to its displacement x by the expression

$$a = -\left(\frac{g}{L}\right)x$$

where g is the acceleration of free fall and L is the length of the pendulum. The pendulum bob oscillates with simple harmonic motion.

- (a) (i)** Show that the period T of the oscillations is given by the expression

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

[3]

- (ii)** A student notices that the amplitude of each oscillation decreases over time. Explain this observation and state what effect this may have on T .

.....

 [2]

(b)* Describe with the aid of a labelled diagram how an experiment can be conducted and how the data can be analysed to test the validity of the equation $T^2 = \frac{4\pi^2}{g}L$ for oscillations of small amplitude.

[6]

[6]

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Turn over



- (c) Another student conducts a similar experiment in the laboratory to investigate the small amplitude oscillations of a pendulum of a mechanical clock. Each 'tick' of the clock corresponds to **half** a period.

(i) Show that the length of the pendulum required for a tick of 1.0 s is about 1 m.

[2]

- (ii) If the pendulum clock were to be used on the Moon, explain whether this clock would run on time compared with an identical clock on the Earth.

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..... [2]

- 4 Fig. 4.1 shows an arrangement used by a student to determine the acceleration of free fall.

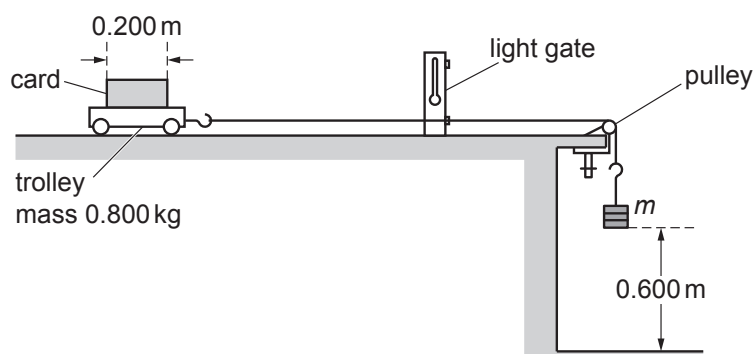


Fig. 4.1

A trolley is attached to a variable mass m by a string which passes over a pulley.

The mass m is released from rest and falls through a fixed height of 0.600 m accelerating the trolley of mass 0.800 kg. When the mass m hits the floor, the trolley then continues to move at a **constant** velocity v .

This constant velocity v is determined by measuring the time t for the card of length 0.200 m to pass fully through a light gate connected to a timer.

Frictional forces on the trolley and the falling mass m are negligible.

- (a) Show that the relationship between v and m is

$$v^2 = \frac{1.20mg}{(m + 0.800)}$$

where g is the acceleration of free fall.

[2]

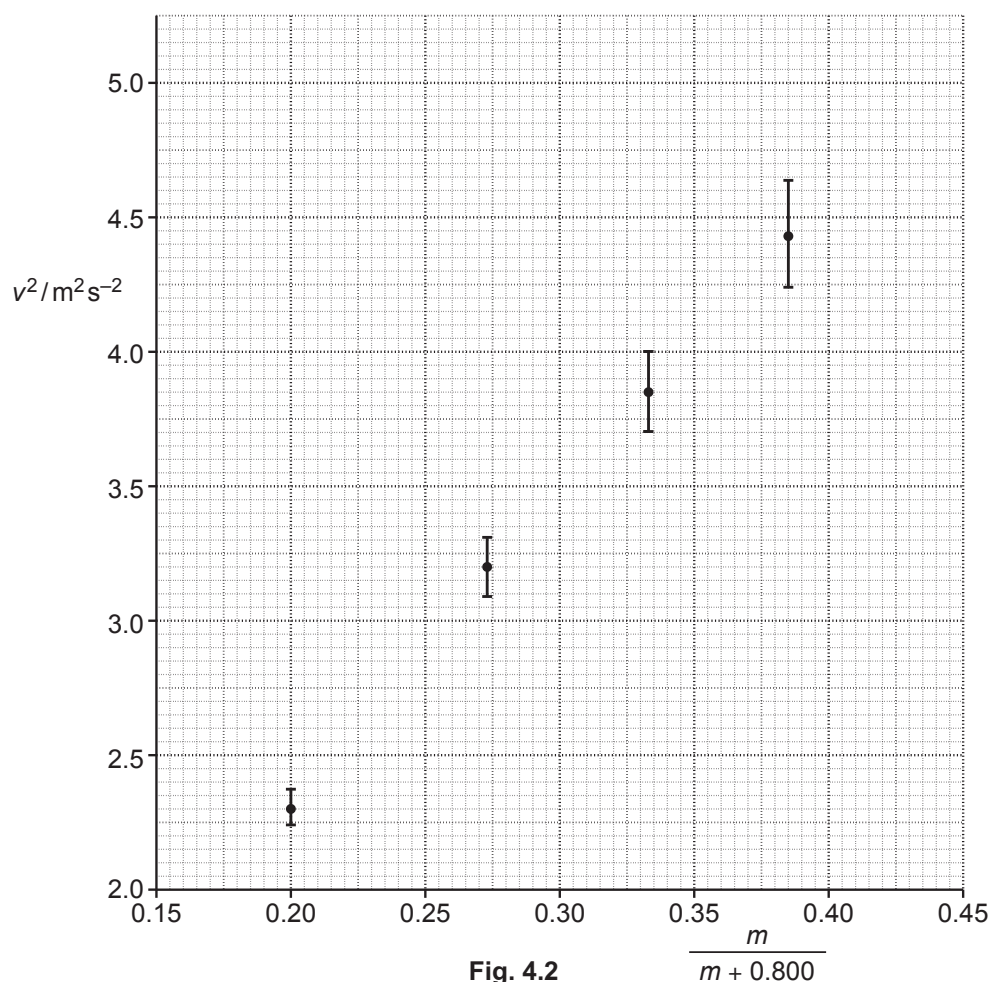
- (b) The student records the information from the experiment in a table. The column headings and just the last row for $m = 0.600$ kg from this table are shown below.

m/kg	$t/10^{-3}\text{s}$	$\frac{m}{(m + 0.800)}$	v/ms^{-1}	$v^2/\text{m}^2\text{s}^{-2}$
0.600	90 ± 2	0.429	2.22 ± 0.05	

- (i) Complete the missing value of v^2 in the table including the absolute uncertainty.

[2]

- (ii) Fig. 4.2 shows some of the data points plotted by the student. Plot the missing data for $m = 0.600 \text{ kg}$ on Fig. 4.2 and draw the straight line of best fit. [2]



- (c) (i) Use the equation given in (a) to show that the gradient of the graph of v^2 against $\frac{m}{(m + 0.800)}$ is equal to $1.20g$. [1]

- (ii) Assume that the best-fit straight line through the data points gives 9.5 m s^{-2} for the experimental value of g . Draw a worst-fit line through the data points on Fig. 4.2 and determine the absolute uncertainty in the value for g .

absolute uncertainty = $\pm$ m s^{-2} [4]

Question 4 is continued on page 12.

Turn over

- (d) It is suspected that the card on the trolley did not pass at right angles through the light beam.

Discuss, without doing any calculations, the effect this may have on the experimental value for the acceleration of free fall g .

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..... [4]

SUB-TOPIC 3.1.3

PROJECTILE MOTION

Sub-topic 3.1.3 · 7 questions · 92 marks · lowest tariff first



24 (a) Fig. 24 shows two horizontal metal plates in a vacuum.

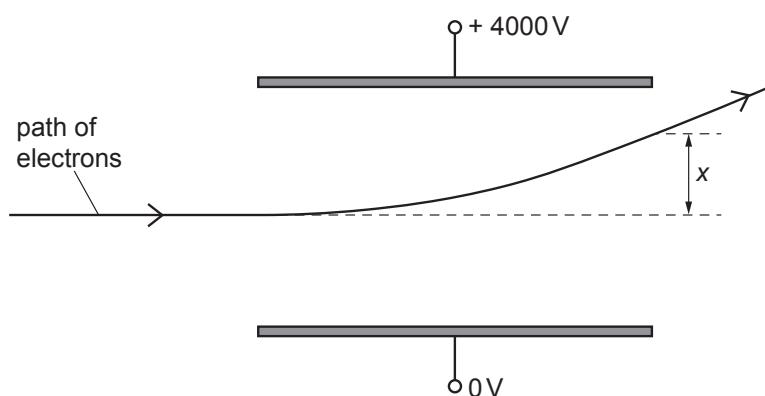


Fig. 24

The diagram is **not** drawn to scale.

Electrons travelling horizontally enter the space between the charged plates and are deflected vertically.

The potential difference between the plates is 4000 V.

The distance between the plates is 0.08 m.

The initial speed of the electrons is $6.0 \times 10^7 \text{ m s}^{-1}$.

The vertical deflection of the electrons at the far end of the plates is x .

(i) Show that the vertical acceleration a of an electron between the plates is $8.8 \times 10^{15} \text{ m s}^{-2}$.

[3]

(ii) The length of each plate is 0.12 m.

Show that the time t taken by the electron to travel this length is $2.0 \times 10^{-9} \text{ s}$.

[1]

- 16 (a)** A tennis ball is struck with a racket. The initial velocity v of the ball leaving the racket is 30.0 m s^{-1} and it makes an angle of 70° to the horizontal as shown in Fig. 16. Air resistance is negligible

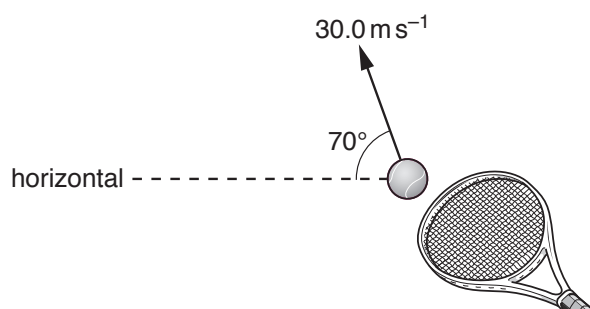


Fig. 16

- (i)** Calculate the vertical component of the initial velocity of the ball.

vertical component = ... m s^{-1} [1]

- (ii)** Use your answer in **(i)** to show that the ball reaches a maximum height h of about 40 m.

$h = \dots\dots\dots \text{m}$ [2]

Turn over

[6]

Turn over

- 5 This question is about investigations involving an electromagnetic wave.

A vertical transmitter aerial emits a **vertically polarised** electromagnetic wave which travels towards a vertical receiver aerial. The wavelength of the wave is 0.60 m.

Fig. 5.1 shows a short section of the oscillating electric field of the electromagnetic wave.

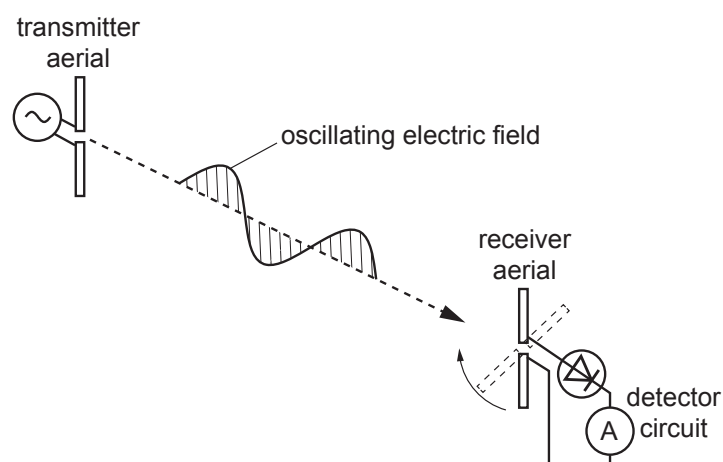


Fig. 5.1

- (a) Calculate the frequency f of the transmitted wave.

$$f = \dots\dots\dots \text{ Hz [2]}$$

- (b) The electromagnetic wave is caused by electrons oscillating in the transmitter aerial. Each electron oscillates with simple harmonic motion.

Calculate the maximum acceleration a_{max} of an electron which oscillates with an amplitude of $4.0 \times 10^{-6} \text{ m}$.

$$a_{\text{max}} = \dots\dots\dots \text{ ms}^{-2} [3]$$

- (c) Suggest why the diode in **Fig. 5.1** is necessary for an ammeter to detect a signal at the receiver aerial.

.....

 [1]

- *(d) A student carries out two investigations with these electromagnetic waves.

In **investigation 1**, the student rotates the receiver aerial about the horizontal axis joining the two aerals, as shown in **Fig. 5.1**.

In **investigation 2**, the student places a metal sheet behind the receiver aerial. The student moves the sheet backwards and forwards along the horizontal axis joining the two aerals, as shown in **Fig. 5.2**.

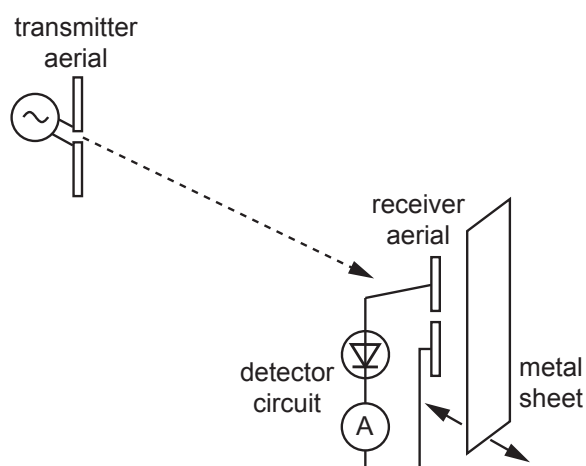


Fig. 5.2

For each of these two investigations:

- Explain why the ammeter sometimes gives a maximum reading and sometimes a zero (or near zero) reading.
- State the orientations of the receiver aerial in **investigation 1**, and the positions of the metal sheet in **investigation 2**, where these maximum and zero readings would occur.

[6]

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Additional answer space if required.

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- 17** An aircraft is flying horizontally at an altitude of 10 000 m and a constant speed of 220 m s^{-1} .

While maintaining this speed, the controls are adjusted so that the aircraft is in **projectile** motion until the altitude is 7500 m.

Throughout the projectile motion the passengers experience apparent weightlessness.

(a)

- (i)** A condition for projectile motion is constant vertical acceleration. State the other condition.

.....

..... **[1]**

- (ii)** Show that t , the time taken to reach the new altitude of 7500 m, is about 23 s.

[2]

- (iii)** Determine the magnitude and direction of the velocity of the aircraft at time t .

velocity = ... m s^{-1}

angle to the vertical ° **[4]**

(iv) Explain why the engines of the aircraft must provide thrust during the projectile motion.

.....

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..... [2]

(b)

(i) The average radius of the Earth is 6400 km.

Show that the ratio below is greater than 0.99.

$$\frac{\text{gravitational field strength at 10 000 m altitude}}{\text{gravitational field strength at the surface of the Earth}}$$

[2]

(ii) Explain why the passengers are described as 'weightless' during the projectile motion of the aircraft.

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..... [2]

- 1 The Earth's aurora is an atmospheric effect visible in the polar regions.

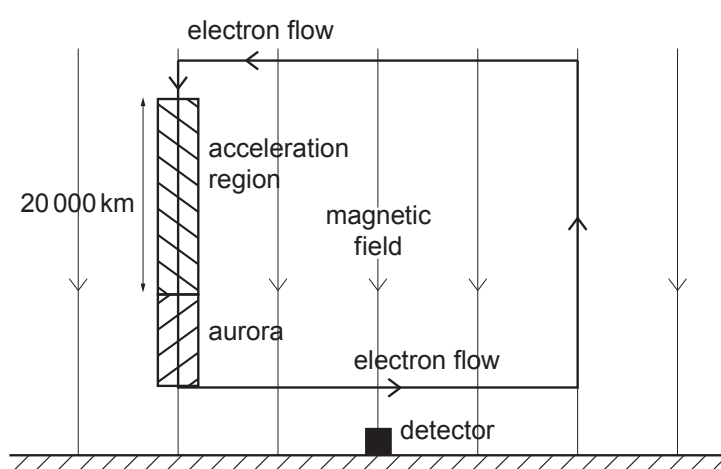
Electrons in the upper atmosphere initially move vertically downwards along one of the Earth's **magnetic** field lines. They are accelerated by an **electric** field.

These electrons collide with oxygen atoms causing atomic electrons to be excited to higher energy levels. The atomic electrons then return to lower energy levels, releasing photons of green light, red light and ultraviolet.

The accelerated electrons then travel horizontally through the atmosphere, before travelling vertically along a different magnetic field line, and then completing the circuit by travelling horizontally back to their starting point.

The situation is shown in **Fig. 1.1**.

Fig. 1.1



not to scale

- (a) The accelerated electrons are accelerated by electric fields parallel to the magnetic field lines.

The length of the acceleration region is 20 000 km and the electric field value is 0.2 mV/m . The electric field can be assumed to be uniform.

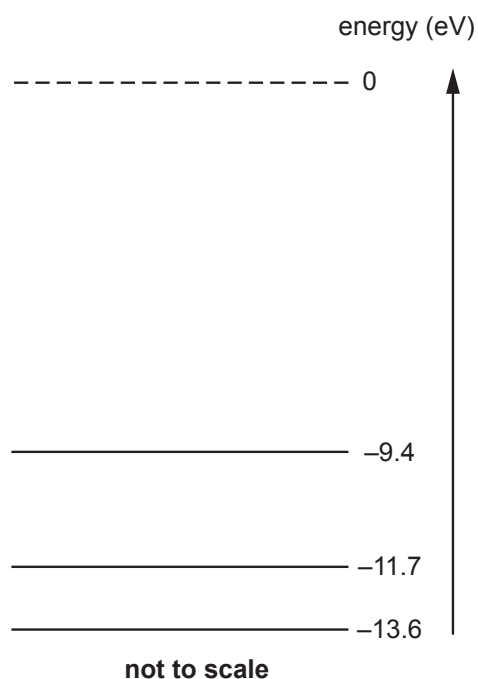
- (i) Calculate the kinetic energy gained by the electrons as they pass through the electric field, in joules.

kinetic energy = ...J [3]

- (ii) State and explain the direction of the electric field required to accelerate the electrons **downwards**.

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..... [2]

- (b) A simplified energy level diagram for atomic oxygen is shown below.



Determine the wavelength of the green light emitted.

Fully justify your answer.

wavelength = ... m [4]

- (c) The horizontal current closest to the Earth produces a magnetic field which can be detected at ground level.

With reference to **Fig. 1.1**, state and explain the direction of this magnetic field.

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..... [2]

- (d) Suggest **two** ways that the horizontal current may affect the atmosphere.

1

.....

2

..... [2]

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- 19 The diagram below shows two parallel plates, **E** and **C**, in an evacuated glass tube.

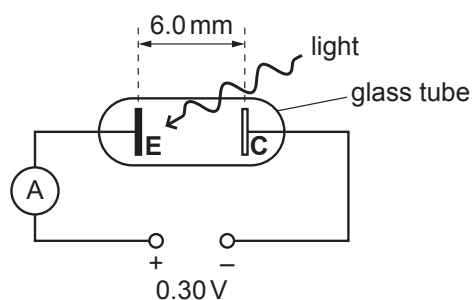


Plate **E** is made from potassium, which is sensitive to light. Plate **C** is not sensitive to light.

The separation between the plates is 6.0 mm and the potential difference between the plates is 0.30 V.

Light of frequency 6.3×10^{14} Hz is incident on plate **E**. The photoelectrons emitted from this plate have **maximum** kinetic energy 0.30 eV (4.8×10^{-20} J). The photoelectrons are repelled by the negative plate **C**. The ammeter reading is zero because these photoelectrons reach plate **C** with zero kinetic energy.

- (a) Calculate the work function of potassium in eV.

work function = ... eV [3]

- (b) This question is about a photoelectron emitted perpendicular to plate **E** and with an initial kinetic energy of 4.8×10^{-20} J.

- (i) Show that the magnitude of deceleration of this photoelectron is $8.8 \times 10^{12} \text{ ms}^{-2}$.

[3]

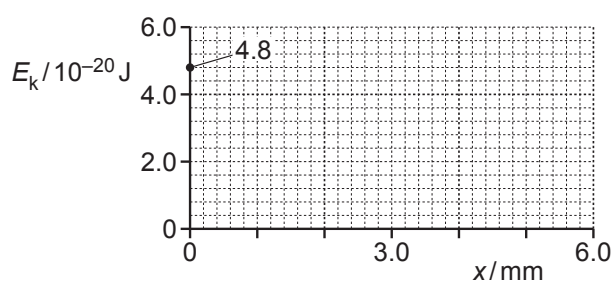
- (ii) Show that the initial speed of the photoelectron is about $3 \times 10^5 \text{ m s}^{-1}$.

[2]

- (iii) Calculate the time t taken by the photoelectron to travel from plate **E** to plate **C**.

$t = \dots\dots\dots \text{ s}$ [2]

- (iv) Using the axes shown below, sketch a graph of kinetic energy E_k against distance x from plate **E**.



[2]

- (c) Explain, in terms of photons, what happens to the ammeter reading when light of frequency greater than $6.3 \times 10^{14} \text{ Hz}$ is now incident on plate **E**.

.....

 [2]

- 5 A student experiments with microwaves emitted from a transmitter. The frequency f of the microwaves from the transmitter can be adjusted.

(a) The microwaves are produced by an alternating current in the transmitter.

In one experiment, f is 11 GHz. In a wire in the transmitter, the magnitude of the **maximum** alternating current is 20 mA. The wire has cross-sectional area $1.4 \times 10^{-8} \text{ m}^2$ and is made of a metal with free electron number density $8.0 \times 10^{28} \text{ m}^{-3}$.

- (i) Show that the maximum drift velocity of each free electron in the wire is about 0.1 mm s^{-1} .

[3]

- (ii) The student models the average motion of the free electrons in the wire as simple harmonic motion.

Use your answer to (i) to calculate the amplitude A of this motion.

$A = \dots\dots\dots \text{ m}$ [3]

- (iii) Without further calculation, explain how the maximum acceleration of a free electron varies as the frequency f is adjusted, provided that the maximum alternating current remains constant.

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 [2]

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Additional answer space if required

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- (ii) Transmitter **X** is rotated about the line **AB** and the experiment is repeated at different orientations until it has been rotated by 180° .

Describe and explain the observed patterns of maximum and minimum intensity.

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MARK SCHEMES

official mark schemes



2	B		1	
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12	C		1	
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14	C	1	
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17	(a)	(i)	'Inverted' graph	B1	Ignore amplitude
		(ii)	Nodes shown correctly	B1	Expect at least 2 nodes labelled N No mark if the labels N are omitted Note the nodes must be on the original graph and not that sketched in (a)(i)
	(b)		Correct relationship between length of tube and λ for at least two stationary waves speed / v is constant or $f\lambda = \text{constant}$ or $f \propto 1/\lambda$ Calculation comparing at least two stationary waves to show $f\lambda = \text{constant}$ or $f \propto 1/\lambda$	B1 B1 B1	Allow L for length of tube Example $L = \lambda/4$ at 60 Hz, $L = 3\lambda/4$ at 180 Hz $L = 5\lambda/4$ at 300 Hz Allow $\lambda/4$ linked to 60 (Hz) etc on diagram or in text Not just f increases λ decreases Note - calculation can also score the previous B1 mark E.g f increases by a factor of 5 (from 60 Hz to 300 Hz) and λ decreases by the same factor (of 5)
			Total	5	

16	(a)	(i)	π (rad)	B1	Allow 3.14 or 3.1 (rad) Do not allow answer in degrees
		(ii)	- 5.0 (cm)	B1	Allow 1 SF. Must see negative sign.
	(b)		540 ($^{\circ}$)	B1	Allow 180 $^{\circ}$ Do not allow answer in radians
			1.5 (λ)	B1	Allow 3/2
	(c)	(i)	Zero amplitude / displacement / oscillations / movement (at the nodes)	B1	Allow minimum or least for zero throughout Ignore references to pressure e.g. min/max pressure Allow correct answers in terms of pressure <u>gradients</u> Penalise incorrect answers in terms of antinodes Ignore correct answers in terms of antinodes
		(ii)	$2\lambda = 25$ (cm) / $\lambda = 12.5$ (cm) $v = 2720 \times 0.125$ $v = 340$ (m s $^{-1}$)	C1 C1 A1	Maximum one POT error in this question Special case: one mark only for bare 340 (m s $^{-1}$) with no working Allow 2 marks for 170 m s $^{-1}$ if calculated from $\lambda = 6.25$ (cm)
		(iii)	$11f_0 = 2.72$ ($\times 10^3$) or $11/4 \times 12.5 = \lambda_o/4$ or $\lambda_o = 1.375$ (m) $f_0 = (340 / 1.375) = 247$ (Hz)	C1 A1	Allow length of tube = 0.344 (m) Allow 250 (Hz) Allow ecf on v from (c)(ii).
			Total	10	



17	(a)		Tangent drawn correctly by eye Attempt made to determine the gradient of tangent acceleration = $1.3 \text{ (m s}^{-2}\text{)}$	B1 C1 A1	Allow answer in range 1.2 to 1.4 (m s^{-2})
	(b)		$F (= ma = 1.2 \times 10^{-2} \times 1.3) = 0.016 \text{ (N)}$	B1	Possible ECF from (a) ($1.2 \times 10^{-2} \times \text{their answer}$) Note answer to 3 SF is 0.0156 (N)
	(c)		$W = 1.2 \times 10^{-2} \times 9.81$ or 0.118 (N) $0.0156 = 0.118 - \text{drag}$ (Any subject) drag = 0.10 (N)	C1 C1 A1	Possible ECF from (b) Allow: use of 'g' for 9.81 Allow 0.1 (N)
	(d)	(i)	Drag is the same (at a certain velocity) weight is greater or <u>resultant</u> force is larger	B1 B1	Allow air resistance for drag
		(ii)	(TV requires) weight = drag and weight is greater Clear link to idea that greater speed gives greater drag (for same cross-sectional area)	B1 B1	
			Total	11	

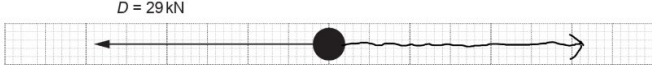
20	a			$\omega \rightarrow \text{s}^{-1}$ or $\omega^2 \rightarrow \text{s}^{-2}$ LHS = m s^{-2} and RHS = m s^{-2} clearly shown by unit algebra	M1 A1	Allow $\omega \rightarrow (\text{radians}) \text{s}^{-1}$ Allow $\omega^2 = (2\pi f)^2$ or $(2\pi/T)^2$ with some evidence of units afterwards e.g. RHS = $\text{m} \cdot (\text{s}^{-1})^2$
	b	i		$\Delta p = 0.10 \times 1000 \times 9.81$ $\Delta p = 980 \text{ (Pa)}$	C1 A1	Allow 1 mark for 490 Pa; 5.0 cm used
		ii	1	$\omega^2 = \frac{2\rho g A}{m}$ or $\omega^2 = 37.7 \text{ (rad}^2 \text{ s}^{-1})$ $\omega = 6.1$ $T = \frac{2\pi}{6.1}$ $T = 1.02 \text{ (s)}$	C1 C1 C1 A0	NOT $\omega = 37.7$ Alternative route: • Substitution of expression for omega • Re-arrangement to make T subject • Evidence of evaluation to $T = 1.02 \text{ (s)}$
			2	Oscillation is isochronous starting from (0,5) Correct value(s) on the horizontal axis At least 2 oscillations shown and amplitude is decreasing	B1 B1 B1	Period same by eye. Note scale must be linear and increasing Amplitude of 2nd oscillation smaller by eye.
			3	The (driving) frequency is close to the natural frequency (of the system) / resonance will occur (Level of) water will oscillate with large amplitude	B1 B1	Allow a description of consequence such as water leaving the tube or being unable to measure the height of liquid
				Total	12	

18	(a)	(i)	$a = -\omega^2 x$ seen Suitable linking $a = -\omega^2 x$ and either $\omega = 2\pi f$ or $\omega = 2\pi/T$ with substitution $f = 1.41$ (Hz)	B1 M1 A1	e.g. $4\pi^2 f^2 = 78.3$ or $f = \sqrt{3.6/4\pi^2 \times 4.6 \times 10^{-2}}$ or $f = 8.85/2\pi$ or $T = 0.71\dots$ Allow $f = 1.408\dots$ (Hz)
		(ii)	$A = \frac{x}{\cos \omega t}$ or $A = \frac{4.6 \times 10^{-2}}{\cos(2 \times \pi \times 1.4 \times 6.5)}$ (Any subject) $A = 0.057$ (m)	M1 A1	Not: sine for cosine. Note $A = 0.090(4)$ (m) if 1.41 used Note $A = 0.0796$ (m) if 1.408 used Allow 1 mark for cosine used with calculator in degrees

Question			Answer	Marks	Guidance
	(b)		EPE decreases (from bottom to top)	B1	Not EPE becomes 0 (or negative) Allow for the first two marking points: description that refers to total potential energy starts at maximum, is minimum at equilibrium point and max again at top, provided total potential energy is stated to be the sum of EPE and GPE Allow as alternative for first three marks: EPE to KE and GPE in bottom half EPE and KE to GPE in top half EPE at start to GPE at top
			GPE increases (from bottom to top)	B1	
			KE starts at zero, finishes at zero and max at equilibrium point.	B1	
			Air gains thermal energy / Total energy (of mass and spring) decreases over time	B1	
	(c)	(i)	(Smooth) curve showing amplitude increases and then decreases	B1	Not: more than 1 peak Allow: asymptote instead of peak
			maximum at 1.4 Hz by eye	B1	
		(ii)	Curve similar shape yet lower at all non-zero f points with peak shifted slightly to <u>left</u> (of 1.4 Hz)	B1	Allow: curve without shifted peak i.e. peak at 1.4 Hz ECF their K curve
		(iii)	Bridge close to <u>resonance</u> if frequency of driver is close to natural frequency of bridge	B1	Allow: footfall/people walking/wind for driver Allow: <u>resonance</u> (occurs) when frequency of driving force is at natural frequency of bridge
			(Close to resonance) giving larger amplitude which causes damage or other named consequence	B1	
			Total	14	

16	(a)	(i)	Reference to area (under the curve) Construct rectangle or square plus triangle/ trapezium	B1 B1	Allow: reference to counting squares. Accept: annotation on the graph such as shapes Ignore: reference to integration Accept for 2 marks: Attempt to calculate number of squares (under the curve) and multiply by area of one square (even if the candidate has got the area of one square wrong)
		(ii)	Tangent drawn at (12, 54) Change in y / change in x =1.4	M1 A1	Allow value that rounds to 2sf in the range 1.3 - 1.7 to 2sf
		(iii)	Change in velocity = 56 ms^{-1} Change of momentum = $56 \times 1700 = 95000$ (kg ms^{-1})	C1 A1	Answer is 95200 to 3sf
	(b)	(i)			Accept 'air resistance' or 'friction' for 'drag' throughout

Question			Answer	Mark	Guidance
			Any two from: Drag force is increasing (so resultant decreases) (Zero resultant when or towards end) drag = driving force/friction from wheels Idea that drag force is increasing at a decreasing rate (so resultant decreases at a decreasing rate)	B1 B1 B1	Accept reference to drag force function ($F = kv^2$)
		(ii)	(Area under graph =) impulse / related to the product of time and force / change in momentum	B1	
	(c)	(i)	Tyre (or wheel) exerts a force on the road backwards / to the left / opposite to direction of motion Road exerts (equal and) opposite force (of the same type) on the tyre / AW	M1 A1	Check diagram Allow “car” for “tyre” Accept alternatives such as “forward” or “to the right”
		(ii)	Candidate's gradient from 1(a)(ii) $\times 1700$ evaluated	B1	Allow 1.5 (from stem) $\times 1700 = 2600$ N NOTE: range in acceptable gradients for (a)(ii) gives force between 2210-2720
		(iii)	$F = \text{Resultant } (2400) + D = 31000(\text{N}) = 31 \text{ (kN)}$	B1	Ignore PoT on answer line

Question			Answer	Mark	Guidance
			Arrow drawn from the circle to the right to scale i.e. 	B1	Allow ECF for resultant from part (ii) and/or D If using 1.5 from stem, $F=32000$ to 2sf Allow +/- half a small square by eye i.e. 31-32 squares Allow candidate's arrow consistent with number on answer line
			Total	14	

21	(a)	(i)	newton in base units is kg m s^{-2}	C1	
			Substitution and cancelling of kg and m arriving at $\text{s}^2 \rightarrow \text{s}^2$	A1	
		(ii)	One force is increased by kx and one is reduced by kx /AW Some working to include $kx - (-kx)$	B1 B1	reject 2 springs in series or 2 springs in parallel idea XP. accept one extension is reduced by x and one is increased by x / AW
		(iii)	period is independent of <u>amplitude</u> / AW No effect	M1 A1	Allow isochronous
	(b)	(i)	Units omitted from T and T^2 Valid statement about significant figures	B1 B1	allow correct statement about individual data points or decimal place or "precision" e.g. sf of T does not match sf of $20T$ or sf of T not consistent throughout column or idea that 1 sf never enough
		(ii)	Correct plotting within half a small square Correct line of best fit	B1 B1	ECF for incorrect plotting. NB Same number of points above and below the line AND fair distribution of distances from line

		(iii)	Gradient between 1.22 and 1.44	C1	reject use of data table
			$k=2\pi^2 \div \text{gradient}$	C1	ECF use of candidate's line
			k between 13.7 and 16.2	A1	ECF use of candidate's gradient as per rubric
	(c)		maximum four from: EPE gain (in stretched spring) > EPE lost (in relaxed spring) EPE is dependent on x^2 Total energy increases (and so KE increases since EPE → KE) Max KE when the system has minimum EPE / at equilibrium position/when $x=0$ Minimum EPE is unchanged Omega is same, amplitude has increased $v_{\max}$ when $x=0$ so $v_{\max}$ has increased ($\omega^2 = \sqrt{A^2 - x^2}$) $v_{\max}$ increased so $KE_{\max}$ increased	4 x B1	Allow EPE max is dependent on A^2 NOT EPE dependent on x alone Allow EPE dependent on x and F which is dependent on x (EPE = $\frac{1}{2}Fx$ idea) KE = $\frac{1}{2}kx^2$ is XP
			TOTAL	17	

8	D		1	
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4	A		1	
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9	B		1	
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10	D		1	
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3	A	1	
---	---	---	--



3	C	1	
---	---	---	--



14	B	1	
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4	C		1	
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4	C		1	
---	---	--	---	--



7	A	1	
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11	C	1	
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18		Level 3 (5–6 marks) Detailed quantitative discussion and comparison of uncertainties, and clear description of graphical analysis <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some quantitative discussion of uncertainty for one method and clear description of graphical analysis Or Discussion, with some quantitative ideas and comparison of uncertainty for both methods with some graphical analysis <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Incomplete discussion of uncertainty with no comparison Or Description of analysis <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i>	B1 x 6	Use level of response annotations in RM Assessor Indicative scientific points may include: Discussion of uncertainty • No repeat makes experiment inherently uncertain • Height +/- 1cm • Ramp length +/- 1mm • Resolution/"precision" of stopclock is 0.01s, but reaction time is much greater • Times +/- 0.1 s (or more) • Calculation of g will use time squared so double the percentage uncertainty in t • Angle likely to be +/- 1 or 2 degrees • Ramp calculation uses sine of angle, so difficult to quantify the uncertainty as a percentage to combine with other variables Comparison • Ramp method has greater time and length both greater so smaller percentage uncertainties • Frictional effects ramp method more • More difficult to measure times for drop • Uncertainty for height and ramp different Analysis • Ignore references to comparisons of the value of g found from both methods • Find g from $s = \frac{1}{2} a t^2$ for multiple values of s and average
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Question			Answer	Mark	Guidance
			0 marks <i>No response or no response worthy of credit.</i>		• Appropriate graphs plotted i.e. plotting t^2 on y-axis and s on x-axis, following some analysis/comparison with “$y=mx+c$” • Significance of gradient (e.g. t^2 against 2s gives gradient $1/g$ for drop method) • Determine uncertainty graphically using best/worst line method
			TOTAL	6	

20	(a)	$F = m\omega^2 r$ and $\omega = 2\pi f$ $kmg = m\omega^2 r$ Clear algebra leading to $f^2 = \left(\frac{gk}{4\pi^2}\right) \times \frac{1}{r}$	M1 M1 A1	Allow $F = mv^2/r$ and $v = 2\pi fr$ Allow this mark for $kmg = mv^2/r$
	(b)	y-intercept = - 0.45 $\frac{1}{2} \lg\left(\frac{gk}{4\pi^2}\right) = -0.45$ $\left(\frac{gk}{4\pi^2}\right) = 10^{-0.9}$ $k = \frac{0.126 \times 4 \times \pi^2}{9.81}$ $k = 0.51$	C1 C1 C1 A1	Allow ± 0.05 Allow attempt at calculating y-intercept using gradient and a point on the line. Not $e^{-0.9}$ wrong physics Allow k in range 0.48 to 0.63 Note Answer must be to 2 SF
		Total	7	

1	(a)	(i)	X marked on orbit at closest point to Mars	B1	Horizontal line through centre of X must pass through or touch the label 'Mars' Allow a single dot/circle marked on the orbit																														
		(ii)	orbits in an <u>ellipse</u> / orbit is <u>elliptical</u> with (COG of) Mars at one focus	B1 B1	Allow a general statement even if not applied to MAVEN eg (all) orbits are elliptical Ignore references to Sun or other planets Not the Sun at one focus																														
	(b)	(i)	$T^2 \propto r^3$ Correct calculations involving at least two sets of data which lead to a (reasonably) constant value	C1 A1	Not $T^2 = r^3$ Allow $T^2/r^3 = (\text{any}) \text{ constant}$ or $T^2 = (\text{any}) \text{ constant} \times r^3$ Allow $T_1^2 / T_2^2 = r_1^3 / r_2^3$ May be inferred from a subsequent calculation For example, T^2/r^3 (or r^3/T^2) calculated correctly at least twice: Allow a constant value calculated for one set of data and then applied to at least one other object Calculations do not need corresponding names of objects Ignore number of sf; ignore any incorrect calculations Ignore statements about whether or not Kepler's 3 rd Law applies Values below are for benefit of markers, POTs removed <table><tr><th>Object</th><th colspan="2">T^2/r^3</th><th colspan="2">r^3/T^2</th></tr><tr><td></td><td>$T(\text{hr})$</td><td>$T(\text{s})$</td><td>$T(\text{hr})$</td><td>$T(\text{s})$</td></tr><tr><td>MAVEN</td><td>7.4</td><td>9.6</td><td>1.4</td><td>10.5</td></tr><tr><td>Phobos</td><td>7.1</td><td>9.3</td><td>1.4</td><td>10.8</td></tr><tr><td>Deimos</td><td>7.4</td><td>9.6</td><td>1.4</td><td>10.4</td></tr><tr><td>Areostationary</td><td>7.8</td><td>10.1</td><td>1.3</td><td>9.9</td></tr></table>	Object	T^2/r^3		r^3/T^2			$T(\text{hr})$	$T(\text{s})$	$T(\text{hr})$	$T(\text{s})$	MAVEN	7.4	9.6	1.4	10.5	Phobos	7.1	9.3	1.4	10.8	Deimos	7.4	9.6	1.4	10.4	Areostationary	7.8	10.1	1.3	9.9
Object	T^2/r^3		r^3/T^2																																
	$T(\text{hr})$	$T(\text{s})$	$T(\text{hr})$	$T(\text{s})$																															
MAVEN	7.4	9.6	1.4	10.5																															
Phobos	7.1	9.3	1.4	10.8																															
Deimos	7.4	9.6	1.4	10.4																															
Areostationary	7.8	10.1	1.3	9.9																															

Question			Answer	Mark	Guidance
1	b	(ii)	(MAVEN needs) to see the whole planet / atmosphere or not just part of the planet / atmosphere (MAVEN needs) to be in / near to the atmosphere	B1 B1	Ignore comments about potential collisions / mass / orbital period / speed / direction Allow (if placed in an areostationary orbit, then) MAVEN would always orbit above the same place / it could only see one location / it could not see multiple locations / it could not see (atmosphere at) the poles / it could only see part of the (atmosphere of) Mars Allow (if placed in an areostationary orbit, MAVEN's orbital radius would be large that) it would not pass through the atmosphere / it could not analyse the atmosphere Not MAVEN is too close to see the atmosphere properly Note: Atmosphere does not need to be seen to award first B1 Atmosphere must be mentioned somewhere in the response to award second B1
			Total	7	

19	a	18×0.5 or $9(.0) \text{ m}$ $(a = \frac{v^2 - u^2}{2s}); \quad (a =) \frac{18^2}{2 \times 29} \quad (\text{Any subject})$ Deceleration = $5.6 \text{ (m s}^{-2}\text{)}$	C1 C1 A1	Allow 1 mark max for 4.26 or 4.3; (38 m used instead of 29 m) Allow 1 mark max for 3.4 or 3.45; (47 m used instead of 29 m) Ignore minus sign
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Question		Answer	Marks	Guidance
	b*	Level 3 (5–6 marks) Clear description of experiment and clear analysis. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some description of experiment and some analysis. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited description of experiment or limited analysis <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit.	B1 × 6	Use level of response annotation in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks etc. Indicative scientific points may include: Description • Ruler used to determine x • Balance used to determine mass of marble • x recorded for various v • Average readings to determine x • Suitable instrument used to determine v (light-gate / motion sensor / video techniques) or suitable description of inference of v from other measurements such as energy released from spring of known k and x, double average speed • Suitable method for consistent v or varying v e.g. ○ Released from same point on a track or ramp ○ Ejected from a spring with different compressions Analysis • Plot a graph of x against v^2 or graph consistent with suggested relationship e.g. v^2 against x; v against $\sqrt{x}$; $\frac{1}{2}mv^2$ against x • If relationship is correct, then a straight line through the origin. • Determination of gradient • F determined by $F = m/2$ divided by (gradient of x against v^2 graph) or other relationship with F as the subject consistent with candidate's proposed graph.
		Total	9	



Question	Answer	Mark	Guidance
2 (a)	$\omega = (2\pi f) = 2\pi \times 0.15$ or $0.3\pi (= 0.942 \text{ rad s}^{-1})$ $a_{\max} = (-\omega^2 A) = 4\pi^2 f^2 A = 0.050$ $A = 0.05/(2\pi \times 0.15)^2$ $A = 5.6 \times 10^{-2} \text{ (m)}$	C1 C1 A1	ω mark can be implicit in calculation $\omega^2 = 0.88$ or 0.89 using 0.942 or 0.94 allow 0.057 (m) ; N.B. answer is 0.053 if use ω instead of ω^2 mark as a TE max 2/3
(b)	Maximum energy is transferred between tower (driver) and sphere when sphere (driven) is at/close to the natural frequency <u>of the tower</u> or in this forced oscillation/resonance situation	B1 B1	allow causes maximum damping <u>of the tower</u> or maximum amplitude <u>of the sphere</u> /AW allow AW e.g. sphere must be driven close to/at the natural/resonance frequency <u>of the tower</u>
(c) (i)	$\omega^2 = k/m$ or $(2\pi f)^2 = k/m$ or $kA = ma_{\max}$ $k = (m4\pi^2 f^2) = 6.6 \times 10^5 \times (2\pi \times 0.15)^2$ or $(k = ma_{\max}/A) = 6.6 \times 10^5 \times 0.05/0.056$ $k = 5.9 \times 10^5 \text{ (N m}^{-1}\text{)}$	C1 M1 A1	allow ω or $\omega^2 = 0.88$ or 0.89 quoted from (a) ecf value of A from (a) as this is a 'show that' question some definite evidence of working must be shown. not $k = 6 \times 10^5$ allow answer to 2 or more SF.
(c) (ii)	$E = \frac{1}{2}kA^2 = 0.5 \times 5.9 \times 10^5 \times 0.71^2$ $E = 1.5 \times 10^5 \text{ (J)}$	C1 A1	allow value from (c)(i) or 6; or $a = (k/m)A$, $F = ma$, $E = \frac{1}{2}FA$ accept 1.48 to 1.51 or value from ecf special case: give $1/2$ for $E = 3(.0) \times 10^5 \text{ (J)}$ where it is clear that $2k$ has been used as the spring constant
	Total	10	



22	(a)	(i)	The upthrust (on an object in a fluid) is equal to the <u>weight</u> of fluid (it displaces)	B1	Note 'fluid' or 'liquid' must be mentioned at least once. Allow a named fluid, e.g. water
		(ii)	$(p = h\rho g)$ $1.9 \times 10^3 = 0.15 \times \rho \times 9.81$ $\rho = 1.3 \times 10^3 \text{ (kg m}^{-3}\text{)}$	C1 A1	
	(b)	(i)	$x = A \cos(\omega t)$ or $x = A \cos(2\pi ft)$ $x = 2.0 \cos(2\pi \times 1.4 \times 0.60)$ displacement = 1.1 (cm)	C1 C1 A1	Note: Treat use of sine as TE Note answer is 1.07 (cm) to 3SF Note answer if calculator left in degrees of 1.99cm scores 2 marks.
		(ii)	$(v_{\max} =) 2\pi \times 1.4 \times 0.02$ maximum speed = 0.18 (m s ⁻¹)	C1 A1	
		(iii)	1 Larger (amplitude) 2 Same (period)	B1 B1	
			Total	10	

Question	Answer	Marks	Guidance
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21	(a)		$\omega^2 = k/m$ or 60/0.080 or $\omega^2 = 750$ $T = 2\pi/27.39$ or $T = 0.2295$ (s) $t = \frac{1}{4} \times 0.2295$ $t = 0.057$ (s)	C1 C1 C1 A1	Allow correct algebraic expression for T Allow incorrect value for omega Allow incorrect value of T
	(b)	(i)	$E = \frac{1}{2}kx^2$ or $E = mgh$ or $0.080 \times 9.81 \times 0.20$ or $\frac{1}{2} \times 60 \times x^2$ $0.080 \times 9.81 \times 0.20 = \frac{1}{2} \times 60 \times x^2$ $x = 0.072$ (m)	C1 C1 A1	
		(ii)1	Time of flight is independent of speed/AW Because distance of fall is the same and initial velocity vertically is zero / velocity is horizontal at X	B1 B1	Allow algebraic answers that assume initial vertical velocity is zero/velocity is horizontal at X.
		(ii)2	D increases as speed at X increases because the time of flight is constant/AW D is directly proportional to speed at X	M1 A1	Allow $d = vt$ idea “ D is directly proportional to speed at X because the time of flight is constant” scores 2.
			Total	11	

Question	Answer	Marks	Guidance
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Question	Answer	Mark	Guidance
6	arrow down through centre of ball labelled weight or W or mg or 1.2 N	B1	zero if any other arrows or forces present
(b) (i)	(horizontally) mv^2/r (or $mr\omega^2$) = $T \sin \theta$ and (vertically) W or mg = $T \cos \theta$ ($\tan \theta = v^2/rg$ or $r\omega^2/g$) $\tan \theta = 0.045 \times 4 \times 9.87 \times 2.2/9.81$ or $0.48/1.2$ (= 0.40) $\theta = 22^\circ$	M1 A1 A0	accept figures in place of algebra, $r = 0.045$ m $v = 0.42$ m s ⁻¹ $\omega = 3\pi$ rad s ⁻¹ ; $r\omega^2 = 4.0$ m s ⁻² ; $W = 1.2$ N and $m = 0.12$ kg and $mr\omega^2 = 0.48$ N accept labelled triangle of forces diagram N.B. this is a <i>show that</i> Q; sufficient calculation must be present to indicate that the candidate has not worked back from the answer
(ii)	$k = (mg/x_0 = 1.2 / 0.050) = 24$ (N m ⁻¹) ($T = mg / \cos \theta = kx$ giving) $x = 1.2 / 24 \cos 22$ $x = 0.054$ (m)	C1 C1 A1	or solution by ratios
(c)	($y = \frac{1}{2}gt^2 \Rightarrow 0.18 = 0.5 \times 9.81 \times t^2$ giving $t = 0.19$ (s) ($x = vt \Rightarrow 0.42 \times 0.19 = 0.08$ (m) distance = $\sqrt{r^2 + x^2} = \sqrt{0.0020 + 0.0064} = 0.092$ (m)	C1 C1 C1 A1	alt: projectile motion: $x = vt$, $y = \frac{1}{2}gt^2$ $y = \frac{1}{2}g(x/v)^2$ ecf (b)i for v ; $x^2 = 2yv^2/g = 2 \times 0.18 \times 0.42^2/9.81$
(d)	T increases or string stretches or angle θ increases to provide/create a larger centripetal force	M1 A1	allow mv^2/r or $mr\omega^2$ in place of <i>centripetal force</i> causality must be implied to gain the A mark
	Total	12	



16	(a)	(i)	$(g \rightarrow) [\text{m s}^{-2}]$ and $(t \rightarrow) [\text{s}]$ or $(gt^2 \rightarrow) [\text{m s}^{-2} \times \text{s}^2]$ Clear evidence of working leading to m on both sides	M1 A1	
		(ii)	s / distance measured with a ruler / tape measure Timer mentioned for measuring t / time Measure distance from bottom of ball to (top of) trapdoor Any <u>one</u> from: - Take repeated readings (for t for same s) to determine average t - Avoid parallax error when using the ruler	B1 B1 B1 B1	
	(b)	(i)	$(p_1 = 4.4 \times 0.050) = 0.22 \text{ (kg m s}^{-1}\text{)}$	B1	
		(ii)	$(\text{impulse} =) \frac{1}{2} \times 30 \times 0.02$ or $0.30 \text{ (kg m s}^{-1}\text{)}$ $-0.30 = p_2 - 0.22$ $p_2 = (-) 0.08 \text{ (kg m s}^{-1}\text{)}$	C1 C1 A1	Allow any correct re-arrangement Possible ECF from (b)(i) Ignore sign Allow 0.52 for 2 marks
		(iii)	$(\text{momentum of trapdoor} =) 0.30 \text{ (kg m s}^{-1}\text{)}$ $v = 3.0 \text{ (m s}^{-1}\text{)}$	C1 A1	Allow $(KE_{\text{trapdoor}} =) \frac{1}{2} \times 0.05 \times (4.4^2 - 1.6^2)$ or 0.42 (J) Possible ECF from (b)(ii) Allow 1 SF answer here Allow alternate methods involving CoE (giving 2.9) and e(giving 2.8)
			Total	12	

1	(a)		$g = GM/r^2$ $g = \frac{6.67 \times 10^{-11} \times 4.87 \times 10^{24}}{(6\,050 \times 10^3)^2}$ $g = 8.87 \text{ (N kg}^{-1}\text{)}$	C1 Allow m for M Allow d or D or x or X or R for r C1 Full substitution needed Allow $r = 6\,050$ for this C1 mark A1 Allow a negative answer Answer must be to exactly 3sf for the A1 mark. Do not use the SF penalty for the paper here
	(b)	(i)	$a = \omega^2 r$ and $\omega = 2\pi / T$ or $a = v^2 / r$ and $v = 2\pi r / T$ Either $\omega = \frac{2\pi}{5830 \times 3600}$ or $v = \frac{2\pi \times 6050 \times 10^3}{5830 \times 3600}$ or $a = \frac{4\pi^2}{(5830 \times 3600)^2} \times 6050 \times 10^3$ $a = 5.42 \times 10^{-7} \text{ (m s}^{-2}\text{)}$	C1 Allow use of $T^2 = 4\pi^2 r^3 / (GM)$ and $v = 2\pi r / T$ C1 $\omega = 2.99 \times 10^{-7} \text{ (rad s}^{-1}\text{)}$ $v = 1.81 \text{ (m s}^{-1}\text{)}$ $a = \omega^2 r = (2.99 \times 10^{-7})^2 \times 6050 \times 10^3$ $a = v^2 / r = 1.81^2 / (6050 \times 10^3)$ Do not allow incorrect or omitted conversion of T A1 Allow answer given to 2sf Allow any answer which rounds to 5.4×10^{-7} Do not penalise incorrect km conversion (giving $a = 5.42 \times 10^{-10}$) if already penalised in (a)

[illegible]

2	(a)		use of stopclock (or stopwatch or timer) time n oscillations and divide by n	B1 B1	If n is specified then $n \geq 5$
	(b)	(i)	$f = 1/T$ working shown to give $T^2 = \left(\frac{8\pi^2}{3g}\right)L$	B1 B1	Allow $T = 2\pi \left(\frac{2L}{3g}\right)^{\frac{1}{2}}$ or $f^2 = 1/T^2$ Subject must be T^2 Allow $T^2/L = 8\pi^2/3g$
		(ii)	$g = \left(\frac{8\pi^2}{3 \times 2.64}\right)$ $g = 9.97 \text{ (m s}^{-2}\text{)}$	C1 A1	Answer must be given to at least 3sf
		(iii)	line of worst fit drawn	B1	Steepest or shallowest possible line that passes through all the error bars (allow $\pm\frac{1}{2}$ small square tolerance vertically) If two lines are drawn then they must both be correct
		(iv)	gradient of worst line calculated with large triangle working to find percentage uncertainty in g answer consistent with candidate's worst line	B1 M1 A1	$\Delta L \geq 0.06\text{m}$ Shallowest gradient $\approx 2.1(\text{s}^2 \text{ m}^{-1})$ and steepest $\approx 2.9 (\text{s}^2 \text{ m}^{-1})$ $\frac{\text{worst value of } g - 9.97}{9.97} (\times 100\%)$ Allow % uncertainty in gradient = $\frac{\text{gradient of wfl} - 2.64}{2.64} (\times 100\%)$ Expect answer $\approx 10\%$ (steepest wfl) and $\approx 27\%$ (shallowest wfl) Allow a negative answer
		(v)	percentage difference = $\frac{9.97 - 9.81}{9.81} \times 100\% = 1.6\%$ or absolute difference = $9.97 - 9.81 = 0.16$ or absolute uncertainty = $(9.97 - \text{value of } g \text{ from wfl})$ conclusion consistent with candidate's answer to (b)(iv)	M1 A1	Possible ECF from (b)(ii) Value for g is accurate if % uncertainty > % difference or if absolute uncertainty > absolute difference or if 9.81 lies within the uncertainty range for g
			Total	12	

1	(a)	$n (= pV/RT) = 2.4 \times 10^5 \times 1.2 \times 10^{-3} / 8.31 \times \underline{290}$ $n = 0.12 \text{ (mol)}$	C1 A1	Allow any correct rearrangement of the equation Allow use of $pV = NkT$ and $n = Nk/R$ or $n = N/N_A$ $(n = 0.1195)$
	(b)	$pV = \text{constant (or } p_1V_1 = p_2V_2)$ $p_{\text{final}} = 2.4 \times 10^5 \times 1.2/1.5$ $= 1.9(2) \times 10^5 \text{ (Pa)}$	C1 C1 A1	<u>Alternative method:</u> $p = nRT/V$ (p must be the subject) Allow use of $p = NkT/V$ (with $N = 7.2 \times 10^{22}$ and $k = 1.38 \times 10^{-23}$) Substitute $p = 0.12 \times 8.31 \times 290 / 1.5 \times 10^{-3}$ ECF from 1a for incorrect n and/or T $p = 1.9(3) \times 10^5 \text{ (Pa)}$
	(c)	(i) $\Delta p = (2.4 - 1.0) \times 10^5 = 1.4 \times 10^5 \text{ (Pa)}$ upwards force ($= \Delta pA$) $= (2.4 - 1.0) \times 10^5 \times 1.1 \times 10^{-4}$ $= 15 \text{ (N)}$	C1 C1 A0	<u>Alternative method:</u> Downwards force (from trapped air) $= pA = 2.4 \times 10^5 \times 1.1 \times 10^{-4}$ $= 26.4 \text{ (N)}$ and upwards force (from atmosphere) $= pA = 1.0 \times 10^5 \times 1.1 \times 10^{-4} = 11.0 \text{ (N)}$ So total upwards force $= 26.4 - 11.0$ $= 15.4 \text{ (N)}$ Ignore any attempt to calculate weight Special case: Allow 1/2 for the use of $\Delta p = 2.4 \times 10^5 \text{ (Pa)}$ giving upwards force $= 26.4 \text{ (N)}$

H556/03			Mark Scheme		June 2019
Question			Answer	Marks	Guidance
		(ii)	$m = 0.3 + 0.05 (= 0.35) \text{ (kg)}$ (Resultant force = upwards force – $W = ma$) $15.4 - (0.35 \times 9.81) = 0.35a$ or $a = 12/0.35$ $a = 34 \text{ (m s}^{-2}\text{)}$	C1 C1 A1	$0.050 + (10^3 \times 0.3 \times 10^{-3})$ <u>Alternative approach:</u> $a = (15.4/m) - g$ ECF for incorrect value of m No ECF ci (since we are told that upwards force = $15(.4)(N)$) Upwards force = 15 (N) gives $a = 33 \text{ (m s}^{-2}\text{)}$
		(d)	• (initial) upward force unchanged • (initial) downwards force/weight increases • (initial) resultant force decreases • (initial) acceleration decreases • (initial) <u>rate of</u> change in momentum of rocket decreases • time taken to expel water increases • valid conclusion that the maximum height depends on more than one factor	B1 x 3	Maximum 3 marks from 7 marking points: Ignore comments which assume an increase in pressure Ignore heavier Allow net or unbalanced or total for resultant Allow fuel for water e.g. the height depends on the bottle's velocity and its height when all the water has been expelled / the height depends on both the acceleration and the time taken to expel the water
			Total	13	

H556/03		Mark Scheme		June 2019
Question	Answer	Marks	Guidance	



4	(a)		There is no contact force between the astronaut and the (floor of the) space station (so no method of measuring / experiencing weight)	B1	Allow astronaut and the space station have same acceleration (towards Earth) / floor is falling (beneath astronaut)
	(b)	(i)	$M = 5.97 \times 10^{24}(\text{kg})$ or ISS orbital radius $R = 6.78 \times 10^6(\text{m})$ or $g \propto 1/r^2$ $(gr^2 = \text{constant so}) g \times (6.78 \times 10^6)^2 = 9.81 \times (6.37 \times 10^6)^2$ $g = 8.66 (\text{N kg}^{-1})$	C1 C1 A1	 or $g (= GM/R^2) = 6.67 \times 10^{-11} \times 5.97 \times 10^{24} / (6.78 \times 10^6)^2$ Allow rounding of final answer to 2 SF i.e. 8.7 (N kg ⁻¹)
		(ii)	$2\pi r/T = v$ or $T = 2 \times 3.14 \times 6.78 \times 10^6 / 7.7 \times 10^3$ $T = 5.5 \times 10^3 \text{ s } (= 92 \text{ min})$	M1 A1	ECF incorrect value of R from b(i)
	(c)		$\frac{1}{2}Mc^2 (\frac{1}{2}N_A mc^2) = \frac{3}{2}RT$ $c^2 = 3 \times 8.31 \times 293 / 2.9 \times 10^{-2} = 2.52 \times 10^5$ $\sqrt{c^2} = 500 (\text{m s}^{-1})$ $(= 7.7 \times 10^3 / 15)$	C1 C1 A1 A0	or $\frac{1}{2}mc^2 = \frac{3}{2}kT$ or $c^2 = 3kT/m$ or $c^2 = 3 \times 1.38 \times 10^{-23} \times 6.02 \times 10^{23} \times 293 / 2.9 \times 10^{-2} = 2.52 \times 10^5$ not $(7.7 \times 10^3 / 15) = 510 (\text{m s}^{-1})$
	(d)		power reaching cells $(= IA) = 1.4 \times 10^3 \times 2500 = 3.5 \times 10^6 \text{ W}$ power absorbed $= 0.07 \times 3.5 \times 10^6 = 2.45 \times 10^5 \text{ W}$ cells in Sun for $(92 - 35 =) 57$ minutes average power $= 57/92 \times 2.45 \times 10^5 = 1.5 \times 10^5 (\text{W})$	C1 C1 C1 A1	 mark given for multiplication by 0.07 at any stage of calculation $(90 - 35 =) 55$ minutes using $T = 90$ minutes ECF value of T from b(ii) $55/90 \times 2.45 \times 10^5 = 1.5 \times 10^5 (\text{W})$ using $T = 90$ minutes
			Total	13	

H556/03**Mark Scheme****November 2020**

Question	Answer	Marks	Guidance
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1	(a)	(i)	$(F = ma =) 190 \times 10^3 = 2.1 \times 10^5 \text{ N}$ $a = 0.90 \text{ (m s}^{-2}\text{)}$	M1 A0	$a = 0.905 \text{ to } 3 \text{ SF}$
		(ii)	$(v^2 = u^2 + 2as \text{ gives}) 36 = 2 \times 0.90 \times s$ $s = 20 \text{ (m)}$	C1 A1	Allow any valid <i>suvat</i> approach; allow ECF from (a)(i) Note using $a = 1$ gives $s = 18\text{(m)}$
		(iii)1	$P = Fv$ One correct calculation e.g. $F = 100 \times 10^3$ and $v = 42$ gives $P = 4.2 \times 10^6 \text{ (W)}$ $Fv = \text{constant}$	B1 B1 B1	Equation must be seen (not inferred from working) Allow any corresponding values of F and v ; working must be shown. No credit for finding area below curve Allow F is proportional to $1/v$ or graph is hyperbolic or correct calculation of Fv at <u>two</u> points (or more)
		(iii)2	$(P = VI = 4.2\text{MW so}) 4.2 \times 10^6 = 25 \times 10^3 \times I$ $I = 170 \text{ (A)}$	C1 A1	Allow $P = 4\text{MW}$ or ECF from (iii)1 Expect answers between 160 - 170 (A)
	(b)	(i)	$R (= \rho L/A) = 1.8 \times 10^{-8} \times 1500/1.1 \times 10^{-4}$ $R = 0.25 \text{ (}\Omega\text{)}$	C1 A1	
		(ii)	$E = \sigma/\epsilon = T/A\epsilon \text{ (so } T = EA\epsilon\text{)}$ $T = 1.2 \times 10^{10} \times 1.1 \times 10^{-4} \times 0.013$ $T = 1.7 \times 10^4 \text{ (N) or } 17 \text{ (kN)}$	C1 C1 A1	or calculation of $\sigma = 1.56 \times 10^8 \text{ (Nm}^{-2}\text{)}$ or $T = 1.56 \times 10^8 \times 1.1 \times 10^{-4}$
			Total	13	

4

H556/03

Mark Scheme

October 2021

Question	Answer	Marks	Guidance
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Question	Part	Sub-part	Answer	Mark	Comments
19	(a)	(i)	$\omega^2 = g/L$ $\omega = \frac{2\pi}{T}$ Correct substitution $\frac{4\pi^2}{T^2} = \frac{g}{L}$ and rearranging to give correct expression	M1 M1 A1	Note: Both M1 marks are required to score this A1 mark
		(ii)	Transfer of energy to air / retort stand (because of air resistance / friction) No effect on T (as T is independent of amplitude in SHM for small amplitude oscillations of pendulum)	B1 B1	Allow 'loss of energy from pendulum (due to friction)' Allow 'work done' for 'energy' Allow 'isochronous'

Question	Answer	Marks	Guidance
(b)*	Level 3 (5–6 marks) Clear description including steps to obtain high quality data and analysis <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Clear description and some analysis <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited description and analysis Or limited description <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	B1 × 6	Indicative scientific points may include: Experiment Description • Pendulum string clamped / fixed (can be shown on diagram) • Use a stopwatch to determine time period T • Time multiple oscillations to determine T • Use a ruler to measure L • Vary length L and determine T Quality of Data • Method used to ensure small oscillations • Small angles i.e. <10 degrees • Idea of fiducial mark • Start/stop timing at the centre of the oscillation • Measure from the fixed point to the centre of the bob Analysis • Correct plotting of graph, e.g. T^2 against L or T against $\sqrt{L}$ or $\lg T$ against $\lg L$ • Analysis of data table showing $T^2/L = \text{constant}$

Question			Answer	Marks	Guidance
					- Expect a straight line through the <u>origin</u> - Correct gradient of the line e.g. $4\pi^2/g$ Use only L1, L2 and L3 in RM Assessor.
	(c)	(i)	Correct substitution of $T = 2(.0 \text{ s})$ into $T^2 = \frac{4\pi^2}{g} L$ length = 0.99 (m)	C1 A1	Note: 1 (m) here cannot score this A1 mark
		(ii)	Lower g / gravitational field strength / acceleration (of free fall) on Moon. T is longer (on Moon) and justified by $T^2 = \frac{4\pi^2}{g} L$ or $T^2 \propto 1/g$ or $\frac{4\pi^2}{g}$ is larger	B1 B1	Accept 'g is a sixth of g on Earth' AW Not gravity (is less)
			Total	15	



Question	Answer	Mark	Comments
4 (a)	(change in) KE = (change in) GPE /AW $\frac{1}{2}(m + 0.8)v^2 = 0.6 mg$ (and hence equation as shown on QP)	M1 A1	allow $mgh = \frac{1}{2}Mv^2$ as long as it is clear that m and M are different, i.e. NOT $mgh = \frac{1}{2}mv^2$ allow linear motion equation $v^2 = u^2 + 2as$ <u>and</u> $F = Ma$ (W =) $mg = (m + 0.8)a$; $u = 0$ and $s = 0.6$
(b) (i)	(v^2 =) 4.93 ($\pm$) 0.22	B1 B1	allow 4.9 ($\pm$) 0.2 (same number of decimal places)
(ii)	Point (and error bar) plotted correctly Line of best-fit drawn through all points shown (use protractor tool at 49°)	B1 B1	tolerance $\pm\frac{1}{2}$ small square; possible ecf from (b)(i) allow ecf from point plotted incorrectly or point omitted
(c) (i)	$v^2 = \frac{1.20mg}{(m + 0.800)}$ compared with $y = mx + c$	B1	allow minimum of gradient = $v^2/[m/(m + 0.8)] = 1.2 g$ or expect $y = v^2$ <u>and</u> $x = m/(m + 0.800)$ so gradient = $1.20g$
(ii)	one acceptable worst-fit line drawn large triangle used to determine gradient Gradient (used to determine 'worst' g) absolute uncertainty given to one decimal place	B1 B1 B1 B1	roughly between extremes of top and bottom error bars or by eye; consequential ecfs for rest of (ii) $\Delta x > 0.13$; expect steepest 12.5 ± 0.2 or shallowest 10.3 ± 0.2 if point from bii not plotted steepest line is 12.9 answer from ± 0.8 to $1.1(m s^{-2})$; allow ecf from gradient value
(d)	card appears shorter or time measured shorter calculated speed of trolley larger gradient of graph steeper or $v^2 \propto g$ /AW so calculated g is greater	B1 B1 B1 B1	N.B. each B mark is consequential on the previous statement; e.g. ecf max of 3 marks for correct consequences of stating card appears longer or time longer
	Total	15	



24	(a)	(i)	$(E =) \frac{4000}{0.080}$ $(F =) \frac{4000}{0.080} \times 1.6 \times 10^{-19}$ $(a =) \frac{8.0 \times 10^{-15}}{9.11 \times 10^{-31}} \quad \text{or} \quad 8.78 \times 10^{15}$ $a = 8.8 \times 10^{15}$	C1 C1 C1 A0	$E = 5.0 \times 10^4 \text{ (V m}^{-1}\text{)}$ $F = 8.0 \times 10^{-15} \text{ (N)}$ Allow this mark if the working is shown. If only value is given, then the answer must be 3SF or more
		(ii)	$(t =) \frac{0.12}{6.0 \times 10^7}$ $(t = 2.0 \times 10^{-9} \text{ s})$	M1 A0	
		(iii)	$(x =) \frac{1}{2} \times 8.78 \times 10^{15} \times (2.0 \times 10^{-9})^2$ $x = 1.8 \times 10^{-2} \text{ (m)}$	C1 A1	Allow $a = 8.8 \times 10^{15}$
	(b)		Downward curved path Same x	B1 B1	Ignore any line outside of the plates Expect same x by eye
	(c)		Apply a magnetic field at right angles to electric field electric force = magnetic force No resultant vertical force, so only beta-particles with a specific speed will travel horizontally	B1 B1 B1	Note this mark is for the idea that E and B are <u>perpendicular</u> even if direction of B is incorrect Allow 'apply horizontal magnetic field' Allow $Eq = Bqv$ Allow $v = E/B$ in this arrangement
			Total	11	

16	(a)	(i)	vertical component = $30.0 \sin(70^\circ)$ or $30.0 \cos(20^\circ)$ vertical component = $28.2 \text{ (m s}^{-1}\text{)}$	A1	Allow 2 SF answer of 28
		(ii)	Evidence of $v^2 = u^2 + 2as$ and $v = 0$ or $gh = \frac{1}{2} u^2$ $h = \frac{28.2^2}{2 \times 9.81}$ (Any subject) $h = 40.5 \text{ (m)}$	C1 M1 A0	Allow v and u interchanged; a and g interchanged Allow use of candidate's answer for (a)(i) at this point Ignore sign Allow $h = \frac{28^2}{2 \times 9.81}$ or $(30 \sin(70)) / (2 \times 9.81)$ No ECF from (a)(i) for the second mark
		(iii)	The ball has horizontal motion / velocity (AW)	B1	Allow idea of horizontal e.g. sideways, forwards Not: 'moving' unqualified
		(iv)	(horizontal velocity =) $30.0 \cos 70^\circ$ or $10.2 \text{ (m s}^{-1}\text{)}$ or $30.0 \sin 20^\circ$. $E_k = \frac{1}{2} \times 0.057 \times 10.26^2$ $E_k = 3.0 \text{ (J)}$	C1 A1	Allow 1 SF answer Not 22 (J), $v = 28$ used Not 23 (J), $v = 28.2$ used Not 140 (J), $v = 70$ used



Question	Answer	Marks	Guidance
(b)*	Level 3 (5–6 marks) Clear description and analysis. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some description and some analysis. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited description and limited analysis or limited description or limited analysis <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response (NR) or no response worthy of credit (0).	B1× 6	Indicative scientific points may include: Description • Ruler used to determine x • Average readings to determine x • x recorded for various v • Suitable method for consistent v or varying v e.g. • Released from same point on a track • Ejected from a spring device with different compressions • Suitable method of determining point of impact e.g. • trial run to get eye in approximate correct position • carbon paper so that ball makes a mark on paper • scale in frame of video recording • tray of sand to catch ball • Suitable instrument used to determine v (light-gate / motion sensor / video techniques) or suitable description of inference of v from other measurements such as energy released from spring of known k and x • Ensuring the initial velocity of ball is horizontal Analysis • Horizontal velocity is constant • Time of fall is independent of v/horizontal velocity • Suggested relationship: e.g. $x \propto v$, x d.p. to v^2, etc • Plot a graph of x against v or graph consistent with candidate's suggested relationship • If relationship is correct, then a straight line through the origin. • Suggested relationship supported by correct physics or algebra. • Correct relationship supported by physics. Note: L1 is used to show 2 marks awarded and L1^ is used to show 1 mark awarded.
	Total	12	



5	(a)	$c = f\lambda$ or $f = 3.0 \times 10^8 / 0.60$ $f = 5.0 \times 10^8$ (Hz)	C1	Allow $v = f\lambda$
			A1	Allow 5×10^8
	(b)	$a_{\max} = -\omega^2 A$ or $a_{\max} = -(2\pi f)^2 A$ $\omega = 2 \times \pi \times 5.0 \times 10^8 = 3.1(4) \times 10^9$ (rad s ⁻¹) or $10^9 \pi$ $a_{\max} (= \pi^2 \times 10^{18} \times 4.0 \times 10^{-6}) = 3.9 \times 10^{13}$ (m s ⁻²)	C1	Allow without the minus sign
			C1	ECF from (a)
			A1	Not $4.0 \times 10^{12} \pi^2$
	(c)	the current (induced in the aerial) is alternating (5×10^8 times per second) (so the meter would register zero) / AW or the diode (half-)rectifies the current / changes the current (from a.c.) to d.c. / AW	B1	Allow 'a diode only lets current pass through in one direction' AW
	(d)	see next page	B1 x 6	
		Total	12	

H556/03

Mark Scheme

November 2020

Question			Answer	Marks	Guidance
5	(d)	*	Level 3 (5 - 6 marks) Response shows clear distinction between investigations; clear and correct reasoning is given for the situations which give maximum/minimum readings in <u>both</u> cases, including correct numerical values <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3 – 4 marks) Response refers to both investigations; some reasoning is given for the situations which give maximum/minimum readings in <u>both</u> investigations, including some numerical values <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1 – 2 marks) Limited reasons are given for the situations which give maximum/minimum readings in <u>either</u> investigation <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	B1 x 6	Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks, etc. Indicative scientific points may include: explanation 1 - receiver aerial vertical – electrons are driven (maximum distance) up and down along the length of the aerial because the oscillations (of the electric field) are vertical, causing maximum (a.c.) current - receiver aerial horizontal – electrons are driven (minimum distance) across the aerial because the oscillations (of the electric field) are only in the vertical plane (no oscillation along the aerial to cause current), so zero / minimum current - rotation of receiver aerial by $\pm 90^\circ$ (or 90° and 270°) from vertical leads to zero current explanation 2 - reflected wave superposes with incident wave at receiver aerial - coherent waves as from same source - constructive interference/waves in phase gives max current - reflected wave has travelled $n\lambda$ further, $n = 0, 1$, etc - so max current when plate is at $\lambda/2$, $2\lambda/2$, etc from receiver aerial, i.e. 30, 60 cm - destructive interference/waves 180° (π rad) out of phase gives zero current - reflected wave has travelled $(2n + 1)\lambda/2$ further, $n = 0, 1$, etc - so zero current when plate is at $\lambda/4$, $3\lambda/4$, etc from receiver aerial, i.e. 15, 45 cm - reflected signal will be weaker the further it has to travel so no longer complete cancellation (ammeter reads close to zero) Note: Give full credit to candidates who take the 180° (π rad) phase change on reflection into account, which gives max current at 15, 45 cm etc and zero current at 30, 60 cm etc.



H556/03

Mark Scheme

November 2020

Question	Answer	Marks	Guidance
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17	(a)	(i)	Constant horizontal speed/ Constant horizontal (component of) velocity/ Zero horizontal force (however expressed)/ Zero horizontal acceleration	A1	Allow any alternate wording
		(ii)	Use of $s = \frac{1}{2}at^2$ with $s=2500$ and with $a=9.8(1)$ or $a=g$ Consistent algebra that arrives at $t^2 = 2 \times 2500 / g$ and evaluation of t as a decimal e.g. $t = 22.6(\dots)$	M1 A1	Allow alternate using $v^2 = u^2 + 2as$ and then $v = u + at$ NOT $s = \frac{1}{2}vt$ with $v = 220$ found by $v = u + at$ (i.e. use of $t = 23$ to find v) Allow $t^2 = 509.6\dots$ for $t^2 = 2 \times 2500/g$ Allow $t = \sqrt{(2 \times 2500/g)}$ for $t^2 = 2 \times 2500/g$ Allow $9.8(1)$ for g Responses with $u = 220$ are XP

Question			Answer	Mark	Guidance
		(iii)	Vertical $v = gt = 220 \text{ ms}^{-1}$ $v = (220^2 + 220^2)^{0.5}$ $v = 310 \text{ (ms}^{-1}\text{)}$ Angle = 45°	C1 C1 A1 A1	ECF for their value of t ECF for their value of vertical v Allow answer that rounds to 3sf to be in range 310-315 (m s⁻¹) Allow '220' for 'maintaining this speed' NOT left as a surd NOT left as a trigonometric expression Allow answer in range 44-45 Allow answer in range 135-136 NOT left as a trigonometric expression NOT left as a surd ECF for their vertical velocity and use of trigonometry NOTE acute answer above 45.0 is incorrect
		(iv)	Reference to drag or air resistance or friction Thrust required for zero horizontal net force / thrust = drag	B1 B1	Accept reference to work done against resistive forces (either named or unnamed) Accept thrust allow to keep constant: vertical acceleration / horizontal velocity / horizontal speed Accept AW for "thrust" e.g. driving force

Question			Answer	Mark	Guidance
	(b)	(i)	g is proportional to $1/r^2$ $(6400 / 6410)^2 > 0.991$	M1 A1	Allow $g=GM/r^2$ Accept calculation of value of g at altitude Accept calculation of g at altitude divided by g at ground to give a number greater than 0.991 NOTE: 6400/6410 giving 0.9984 is XP NOTE: ratios that use the same value of r is XP
		(ii)	Aircraft and passengers have the same acceleration(g) No contact force(s on passenger from seat/body of the aircraft)	B1 B1	Accept passenger is (also) moving as a projectile Accept relative acceleration between aircraft and passenger is zero Accept reaction for contact NOT: idea that there no forces on passenger
			Total	13	

1	(a)	(i)	$V (= Ed) = 0.2 \times 10^{-3} \times 20,000 \times 10^3$ or $V = 4000 \text{ (V)}$ $W (= QV) = 1.6 \times 10^{-19} \times 4000$ $6.4 \times 10^{-16} \text{ (J)}$	C1 C1 A1	Allow $F (= QE) = 1.6 \times 10^{-19} \times 0.2 \times 10^{-3}$ or $F = 3.2 \times 10^{-23} \text{ (N)}$ Allow $W (= Fd) = 3.2 \times 10^{-23} \times 20,000 \times 10^3$
1	(a)	(ii)	electrons move in opposite direction to (electric) field/conventional current (so electric field is) upwards	M1 A1	Allow electrons are negatively charged
1	(b)		$11.7 - 9.4 (= 2.3 \text{ eV})$ $\lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{2.3 \times 1.6 \times 10^{-19}}$ $5.4 \times 10^{-7} \text{ (m)}$ Correct reasoning to select 540 nm - the middle wavelength (from red, green, UV) - the middle frequency - the middle photon energy - the middle-sized electron transition	C1 C1 A1 B1	Allow $13.6 - 11.7 (= 1.9 \text{ eV})$ or $13.6 - 9.4 (= 4.2 \text{ eV})$ Allow a <u>full</u> substitution with an energy level change of 9.4, 11.7 or 13.6 eV for this C1 mark only Allow an answer consistent with 1.9 eV or 4.2 eV (i.e. 296 nm or 654 nm gains 3 marks) Allow up to 4 marks for working backwards from stating wavelength of green light is ~550 nm i.e. $E = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{550 \times 10^{-9} \times 1.6 \times 10^{-19}}$ $E = 2.3 \text{ eV}$ $11.7 - 9.4 (= 2.3 \text{ eV})$

Question			Answer	Mark	Guidance
1	(c)		(conventional) current opposite to electron flow or (right) to left (magnetic field) out of the page	B1 B1	Allow annotation of figure to show circular magnetic field lines around current or arrow labelled current towards left on Fig 1.1
1	(d)		heating effect ionisation of atoms / lightning strikes	B1 B1	 Allow (ionisation causes) horizontal force / acceleration of gas (due to $F = BIL$ / motor effect)
			Total	13	

19	(a)	$(hf = \phi + KE_{\max}) = 6.63 \times 10^{-34} \times 6.3 \times 10^{14} = \phi + 4.8 \times 10^{-20}$ $\phi = 3.6969 \times 10^{-19} \text{ (J)}$ $\phi = 2.3 \text{ (eV)}$	C1 C1 A1	OR (in eV) $hf = 6.63 \times 10^{-34} \times 6.3 \times 10^{14} / 1.6 \times 10^{-19}$ $\phi = 2.6 - 0.30 \text{ (eV)}$ $\phi = 2.3 \text{ (eV)}$
	(b)	(i) $a = \frac{VQ}{dm}$ OR $a = \frac{EQ}{m}$ OR $KE = \frac{1}{2}mv^2$ and $v^2 = u^2 + 2as$ OR $KE = F \times d$ and $F = m \times a$ $a = \frac{0.30 \times 1.6 \times 10^{-19}}{6.0 \times 10^{-3} \times 9.11 \times 10^{-31}}$ / $a = \frac{50 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}$ / (Use of $KE = \frac{1}{2}mv^2$) $= 4.8 \times 10^{-20} = \frac{1}{2} \times 9.11 \times 10^{-31} \times v^2$ and (use of $v^2 = u^2 + 2as$) $\Rightarrow v^2 = (1.05 \times 10^{11}) = 2 \times a \times 6 \times 10^{-3} (\pm 0^2)$ / (Use of $KE = F \times d$) $= 4.8 \times 10^{-20} = F \times 6 \times 10^{-3}$ and (use of $F = m \times a$) $F = (8.0 \times 10^{-18}) = 9.11 \times 10^{-31} \times a$ $a = 8.78 \times 10^{12} \text{ (m s}^{-2}\text{)}$	C1 M1 A1	Allow u and v interchangeably throughout Allow calculation of $E = (0.30 / 6 \times 10^{-3}) = 50 \text{ (V m}^{-1}\text{)}$ or $v = 3.2 \times 10^5 \text{ (m s}^{-1}\text{)}$ or $v^2 = 1.05 \times 10^{11} \text{ (m s}^{-1}\text{)}^2$ or $F = 8.0 \times 10^{-18} \text{ (N)}$ for C1 mark Substitution mark – in any arrangement. Expect full substitutions including numerical value of m_e if appropriate Method 1: direct calculation of a Method 2: using $KE = \frac{1}{2}mv^2$ and $v^2 = u^2 + 2as$ Method 3: using $KE = F \times d$ and $F = m \times a$ Note must be more than 2 SF (not paper SF penalty) Ignore negative sign
		(ii) (Use of $KE = \frac{1}{2}mv^2$) $= 4.8 \times 10^{-20} = \frac{1}{2} \times m \times v^2$ OR $(u^2 = v^2 - 2as) = 0^2 - [2 \times (-) 8.8 \times 10^{12} \times s]$ Full substitution leading to $v = 3.2 \times 10^5 \text{ (m s}^{-1}\text{)}$	C1 A1	Allow u and v interchangeably Numerical value of m_e must be used if using KE method Note must be more than 1 SF (not paper SF penalty) Note 3.25 is acceptable for A1, but not 3.3

Question			Answer	Marks	Guidance
		(iii)	$t = \frac{3.2 \times 10^5}{8.8 \times 10^{12}}$ $t = 3.6 \times 10^{-8} \text{ (s)}$	C1 A1	Allow correct full substitution into any suvat equation Allow 3×10^5 for v Ignore signs of substituted values Expect values between 3.4×10^{-8} and 3.8×10^{-8} (s) No ecf from (b)(i) or (b)(ii)
		(iv)	Any line with negative slope starting from 0, 4.8×10^{-20} A straight line finishing at 6.0,0	M1 A1	$\frac{1}{2}$ square tolerance. ALLOW a curve with negative gradient. ALLOW a region of zero gradient, but not whole line $\frac{1}{2}$ square tolerance on axis intercepted
	(c)		Energy of photon increases (max) kinetic energy / speed (of electrons) increases / (some) electrons (now) reach C and there is a current or reading (on ammeter)	B1 B1	Do not allow increased <u>kinetic</u> energy of photons Do not allow explanation in terms of increased number of emitted electrons (per second) Allow photoelectrons for electrons
			Total	14	

5	(a)	(i)	$I_{\max} = nAv_{\max}e$ $v_{\max} = \frac{20 \times 10^{-3}}{8 \times 10^{28} \times 1.6 \times 10^{-19} \times 1.4 \times 10^{-8}}$ $v_{\max} = 1.1 \times 10^{-4} \text{ (m s}^{-1}\text{)}$	B1 Allow v for $v_{\max}$ throughout M1 Allow I for $I_{\max}$ Allow q or Q for e/a for A/V for v but not N for n A1 Substitution must be shown in full Answer must be given initially to 2 or more sf (but may later be rounded to 1sf)
		(ii)	$\omega = 2\pi f$ $A (= v_{\max}/\omega) = \frac{1.1 \times 10^{-4}}{2\pi \times 11 \times 10^9}$ or $A (= v_{\max}/\omega) = \frac{1.1 \times 10^{-4}}{6.9 \times 10^{10}}$ $A = 1.6 \times 10^{-15} \text{ (m)}$	C1 May be inferred from working $\omega = 2\pi \times 11 \times 10^9 = 6.9 \times 10^{10} \text{ (rad s}^{-1}\text{)}$ C1 Allow use of $v_{\max} = 1 \times 10^{-4} \text{ (m s}^{-1}\text{)}$ Allow $v_{\max}$ from (a)(i) given to more than 2sf but not ECF from any value which does not round to $1 \times 10^{-4} \text{ (m s}^{-1}\text{)}$ A1 Allow use of $v_{\max} = 1 \times 10^{-4} \text{ (m s}^{-1}\text{)}^1$ giving $A = 1.4 \times 10^{-15} \text{ (m)}$ to 2sf or $1.45 \times 10^{-15} \text{ (m)}$ to 3sf Special case: Allow $A = 1 \times 10^{-15} \text{ (m)}$ to 1 sf if $v_{\max} = 1 \times 10^{-4} \text{ (m s}^{-1}\text{)}$ is used
		(iii)	$(a_{\max} = \omega^2 A \text{ and } v_{\max} = \omega A)$ $a_{\max} = 2\pi f v_{\max}$ Since $v_{\max}$ is constant, $a_{\max} \propto f$	M1 Allow $a_{\max} = \omega v_{\max}$ Allow a for $a_{\max}$ and v for $v_{\max}$ A1

Question			Answer	Marks	Guidance
5	(b)*	(i)	Level 3 (5–6 marks) Clear explanation and clear description <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Clear explanation or clear description (but not both) or Some explanation and some description <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited explanation or Limited description <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	B1x 6	Use level of response annotations in RM Assessor Indicative scientific points may include: Explanation of pattern • Interference / superposition occurs • Path difference a whole number of wavelengths • means waves are (exactly) in phase (or $\Delta\phi = 0$) • giving (maximum) constructive interference • which leads to maximum intensity • Path difference an odd number of half wavelengths (or $\Delta\phi = \pi$ radians) • means waves are in antiphase • giving (maximum) destructive interference • which leads to minimum intensity Description of relationship between f and x • $\lambda = ax/D$ and $c = f\lambda \rightarrow x = cD/af$ • so $x \propto 1/f$ (provided a and D remain constant) • Use ruler along QP to measure x (or $10x/10$, say) • Connect oscilloscope to transmitter or detector to measure f • Vary f (keeping a and D constant) and measure corresponding x • Calculate fx which should remain constant • Or plot graph of $1/x$ against f (or x against $1/f$) • Should give straight line <u>through the origin</u>

Question			Answer	Marks	Guidance
5	(b)	(ii)	At 90° rotation, (interference) pattern disappears At 180° rotation, intensities are the same as at 0° but the maximum/minimum positions are switched / reversed Waves with polarisations at 90° to each other do not interfere / only waves with same polarisation interfere / only waves with a component in the same plane interfere	B1 B1 B1	Allow constant intensity along PQ Not zero intensity along PQ Allow <u>from 0 to 90°</u> the intensities of the maxima decrease (and the minimum intensities increase) Allow <u>from 90° to 180°</u> the intensities of the maxima increase (and the minimum intensities decrease) but the maximum/minimum positions are switched / reversed from between 0 and 90° Allow waves must <u>oscillate</u> in same plane to interfere Ignore at 90° rotation, only waves from Y are detected at D because D can only detect vertical polarised waves
			Total	17	

