AQA A-LEVEL PHYSICS · 7408

PHYSICS



EXAM QUESTION PACK

3.4.1 FORCE, ENERGY AND MOMENTUM · PACK 1

SCORE	PERCENTAGE
/217	%

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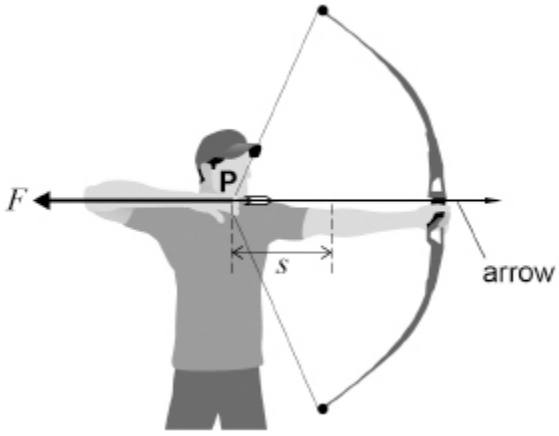
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1. **Figure 1** shows an archer using a bow in a competition.

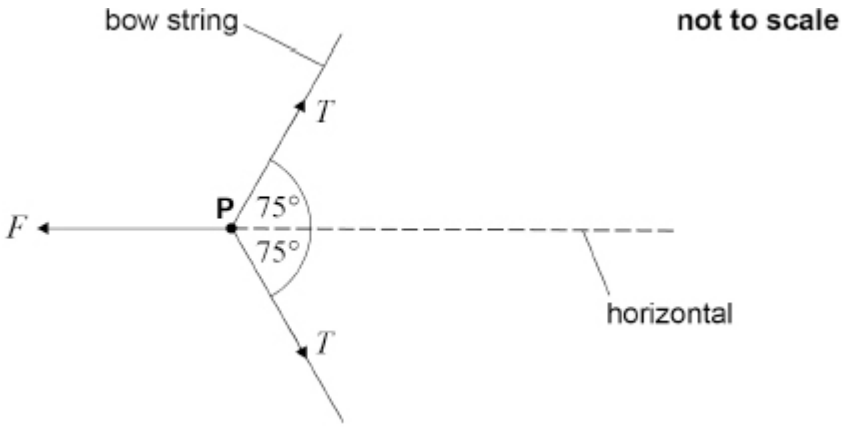
Figure 1



The archer exerts a force F to pull point **P** on the string back through a distance s.

(a) **Figure 2** is a simplified diagram of the bow string showing the forces acting on **P**.
The tension in the string is T and the string makes an angle of 75° to the horizontal.

Figure 2



In **Figure 2**, F is 160 N and **P** is in equilibrium.

Calculate T.

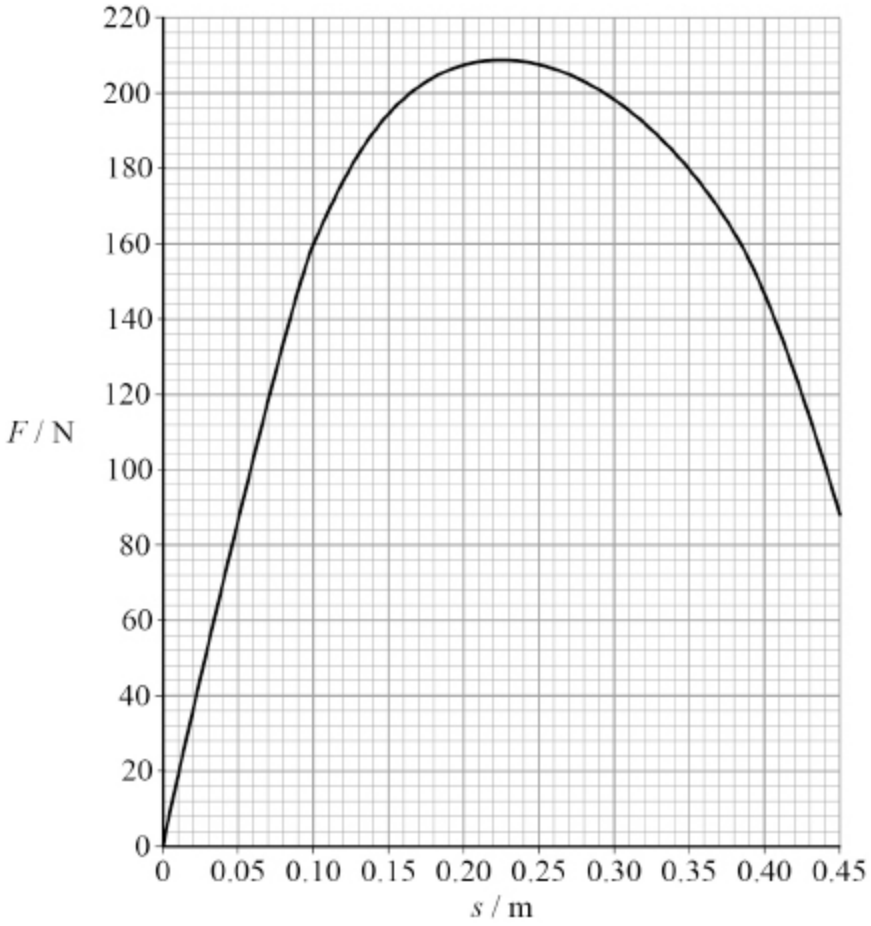
T = _____ N

(2)

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The bow is designed so that F varies with s as shown in **Figure 3**.

Figure 3



(b) An arrow of mass 21 g is placed in the bow.

The archer pulls **P** back by a distance s of 0.22 m and then releases the arrow in a horizontal direction.

Assume that there are no resistive forces acting on the arrow as it is released.

Determine the initial horizontal acceleration of the arrow.

initial horizontal acceleration = _____ $\mathrm{m\ s^{-2}}$

(2)

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The arrow is replaced with a different arrow of mass m.
The archer pulls **P** back by a distance sr so that the energy stored in the bow is 64 J and F is 160 N.

(c) Deduce s_r.

_____

_____

_____

_____

s_r = _____ m

(2)

(d) The bow has an efficiency of 0.82

The arrow leaves the bow in a horizontal direction with a velocity of 190 km h^{-1}.

Calculate m.

m = _____ kg

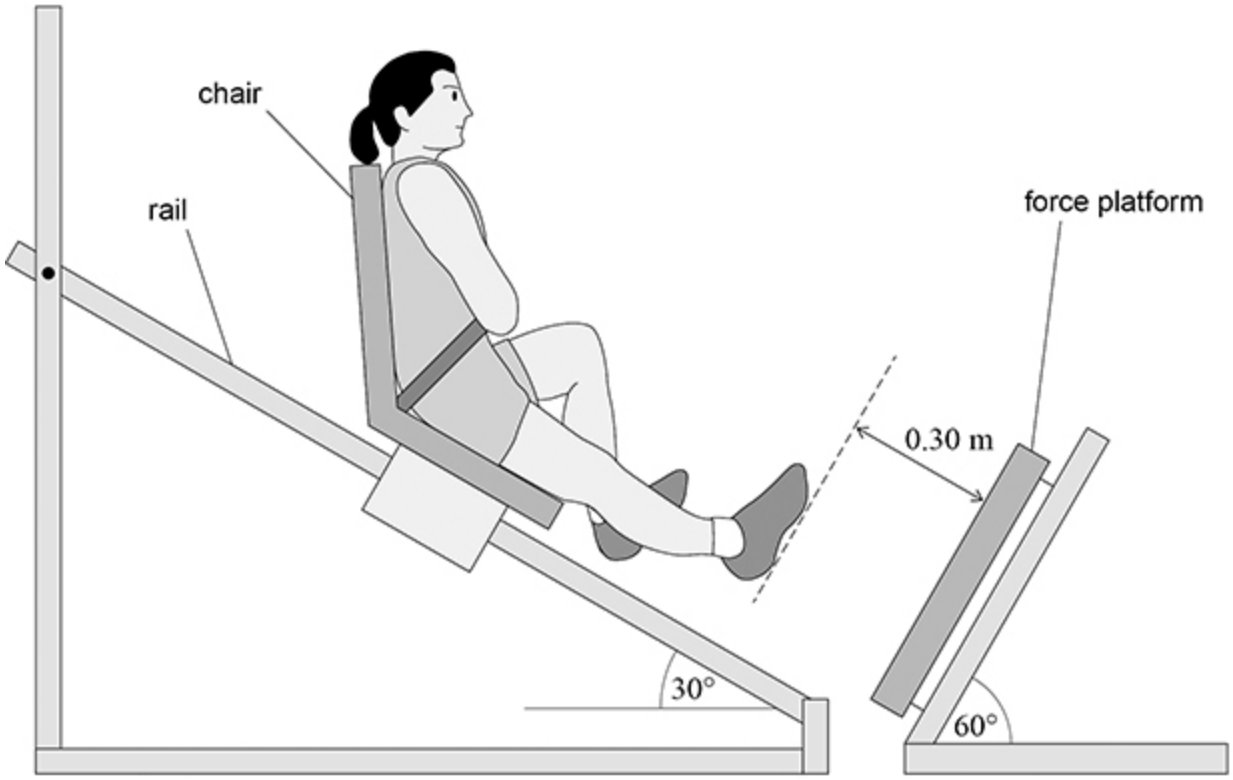
(3)

(Total 9 marks)

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2. **Figure 1** shows apparatus used to measure the force exerted by an athlete during a single-leg jump.

Figure 1



In **Figure 1**, the athlete is strapped into a chair and held at rest halfway along a rail. The chair is then released to slide down the rail. The athlete keeps her right leg extended until her right foot makes contact with a force platform.
Friction between the rail and the chair is negligible.

initial distance between right foot and platform = $0.30\ \text{m}$
angle between rail and floor = $30°$
angle between platform and floor = $60°$

(a) Show that the athlete and chair accelerate towards the platform at approximately $5\ \text{m s}^{-2}$.

(1)

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(b) Calculate the speed of the athlete when her right foot makes initial contact with the platform.

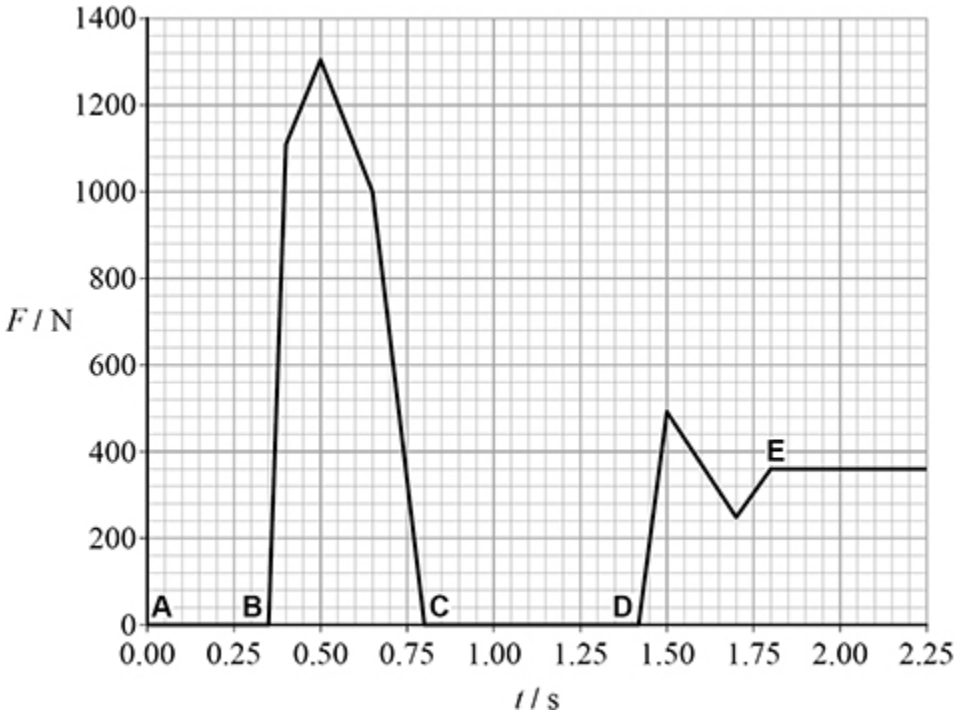
speed = _____ $\mathrm{m\ s^{-1}}$

(2)

After her right foot makes contact with the platform, she uses her right leg to stop moving and then push herself back up the rail. She slides down the rail again, lands on the platform with both feet and comes to rest.

Figure 2 shows the variation of force *F* on the platform with time *t* during the full motion.

Figure 2



The sequence below describes what happens at the five instances **A**, **B**, **C**, **D** and **E** shown in **Figure 2**.

A: athlete and chair are released at $t = 0.00$ s
B: right foot of athlete contacts the platform with leg fully extended
C: right foot loses contact with the platform
D: athlete lands on the platform with both feet
E: athlete and chair come to rest

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(c) Determine the impulse provided by the force platform between **B** and **C**.

impulse = _____ N s

(2)

(d) Determine the distance travelled by the athlete between **C** and **D**.

distance travelled = _____ m

(3)

(e) Determine, using **Figure 2**, the combined mass of the athlete and chair.

mass = _____ kg

(2)

(Total 10 marks)

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

What is the maximum speed of the particle?

A 8.6 mm s^{-1} ⬭

B 27 mm s^{-1} ⬭

C 54 mm s^{-1} ⬭

D 110 mm s^{-1} ⬭

(Total 1 mark)

4. **Figure 1** shows a conveyor used to raise concrete blocks on a building site. The blocks do not slip on the belt at any time.

Figure 1

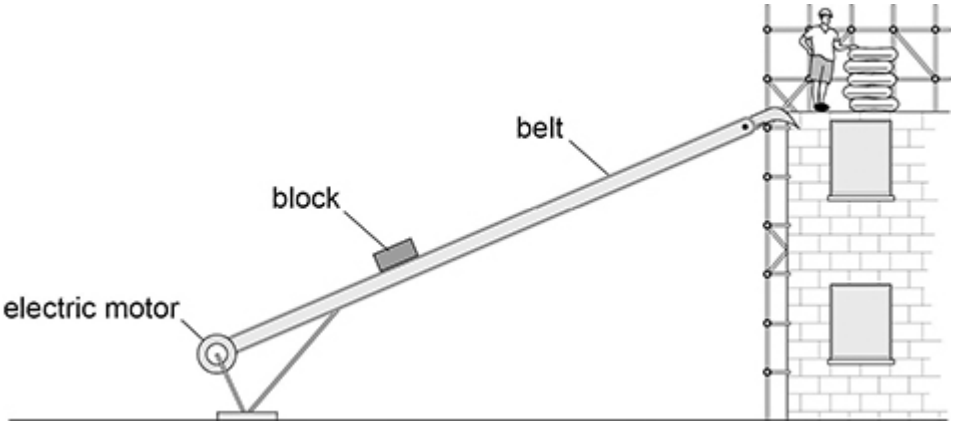
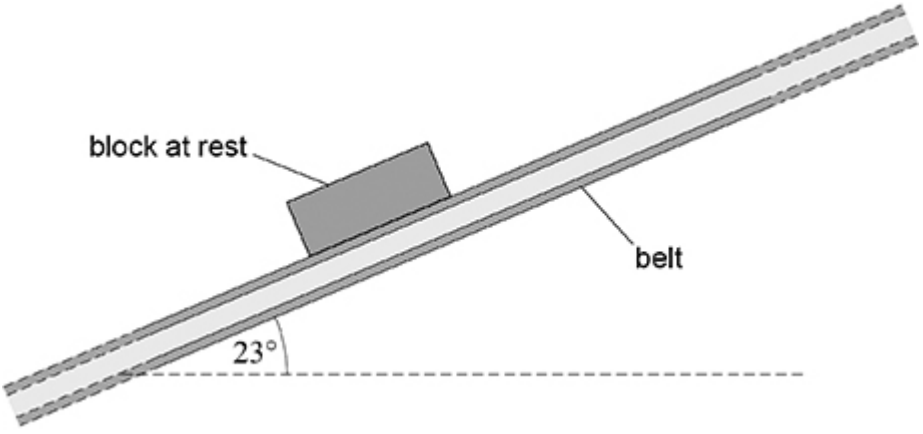


Figure 2 shows an enlarged view of one block on the belt. The belt is inclined at 23° to the horizontal. The mass of the block is 19 kg.

Figure 2



The belt exerts a frictional force F on the block when the block is at rest.

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(a) Draw an arrow on **Figure 2** to show the line of action of F.

(1)

(b) Show that the magnitude of F is approximately 70 N.

(1)

(c) The belt is driven by an electric motor. When the motor is switched on, the belt and the block accelerate uniformly from rest to a speed of 0.32 m s^{-1} in a time of 0.50 s.

Calculate the magnitude of the frictional force of the belt on the block during this acceleration.

frictional force = _____ N

(3)

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(d) The motor is connected to a 110 V dc supply that has negligible internal resistance. The maximum operating current in the motor is 5.0 A.

The efficiency of the motor and drive system of the conveyor is 28%. The belt travels at 0.32 m s^{-1} and is 8.0 m long.

Deduce the maximum number of blocks that can be moved on the belt at one time.

maximum number of blocks = _____

(4)

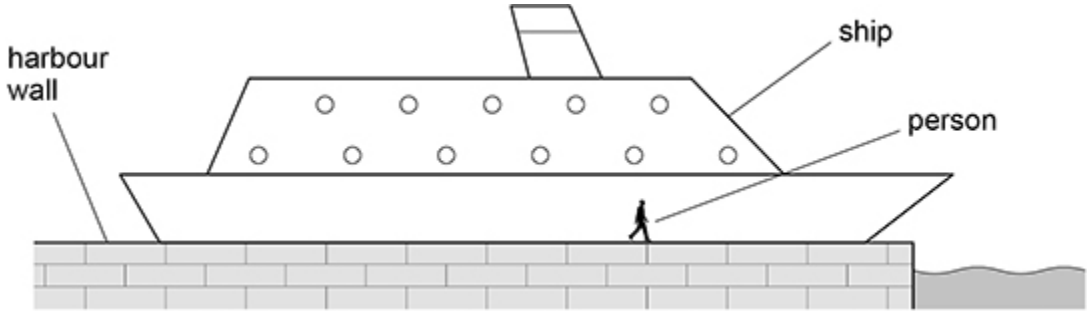
(Total 9 marks)

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5. (a) **Figure 1** shows a ship leaving a harbour at a constant velocity.

The ship moves at the same velocity as a person walking on the harbour wall alongside the ship.

Figure 1



The momentum of the ship is approximately 1×10^7 N s.

Estimate the mass of the ship.

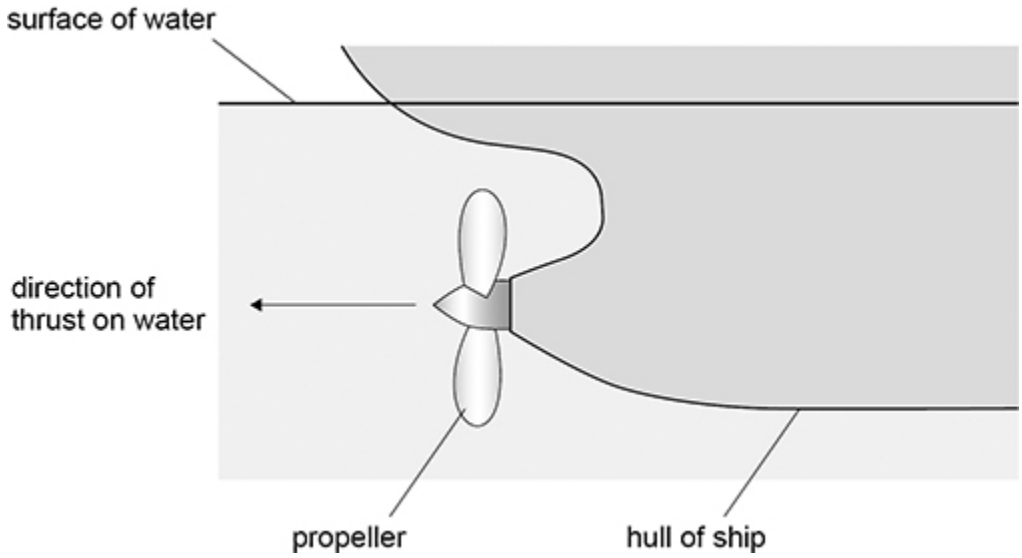
mass of ship = _____ kg

(2)

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(b) **Figure 2** shows the direction of the thrust exerted by the ship's propeller as the propeller rotates. The ship's engine makes the propeller rotate. When more water is accelerated, more work is done by the engine.

Figure 2



Explain, using Newton's laws of motion, how the thrust of the propeller on the water enables the ship to maintain a constant momentum.

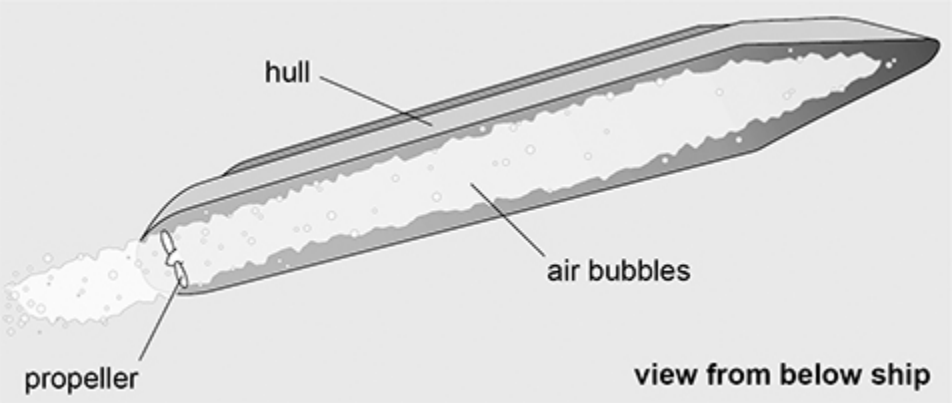
(4)

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(c) **Figure 3** shows the bottom of the hull with a drag reduction system in operation.
Air bubbles are introduced into the water below the hull. This reduces the work done per second against the drag on the hull at any given speed.

However, when the air bubbles reach the propeller they decrease the mass of water being accelerated by the propeller every second. This decreases the thrust produced by the propeller at a given speed of rotation.

Figure 3



The system enables the ship to save fuel while maintaining the same momentum.

Explain why the system delivers this fuel saving.
In your answer, consider the effects of the introduction of the system on

- the thrust
- the drag on the hull.

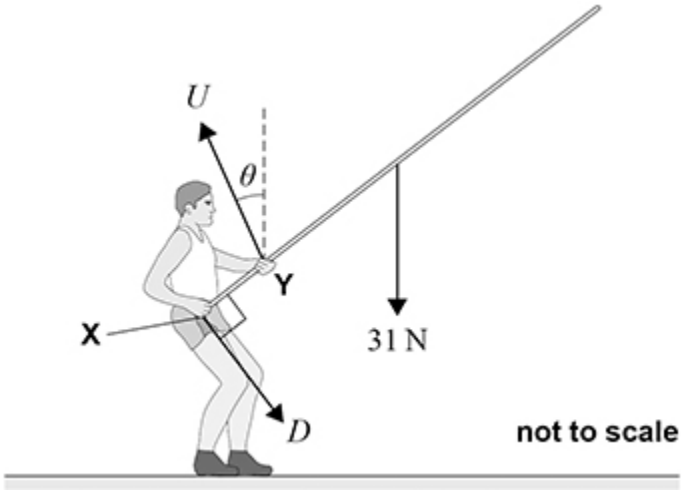
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(Total 9 marks)

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6. **Figure 1** shows an athlete holding a vaulting pole at an angle of 40° to the horizontal.

Figure 1

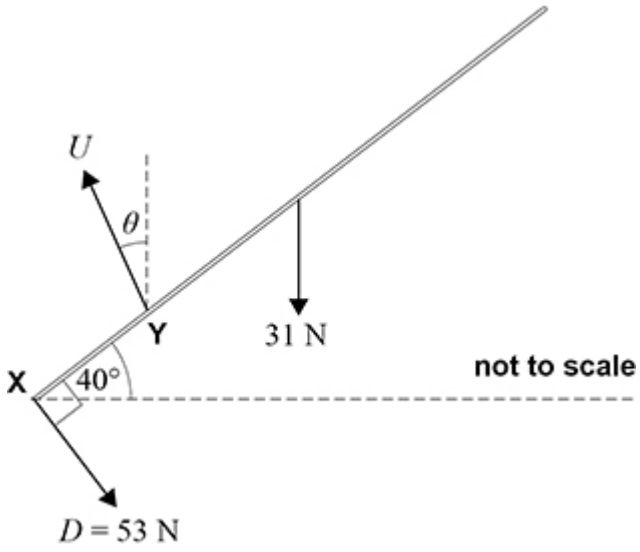


Forces D and U are exerted on the pole by the athlete's right and left hands respectively.
U is applied at point **Y** at an angle θ to the vertical.
The magnitude of D is 53 N and is applied at 90° to the pole at **X**.

The uniform pole is in equilibrium. It has a weight of 31 N.

Figure 2 shows the forces acting on the pole.

Figure 2



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(a) Determine, using a scale Figure, θ and the magnitude of U.

θ = _____ °

magnitude of U = _____ N

(4)

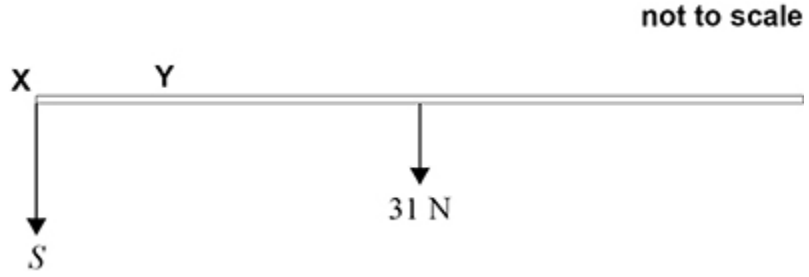
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(b) The athlete now moves the pole to a horizontal position. The pole is held stationary in this position.

The athlete's right hand applies a force S vertically downwards at **X** as shown in **Figure 3**.

The athlete's left hand applies a force V at **Y**.

Figure 3



Discuss the differences between the magnitudes and directions of force U in **Figure 1** and force V applied at **Y** in **Figure 3**.

_____

_____

_____

_____

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_____

_____

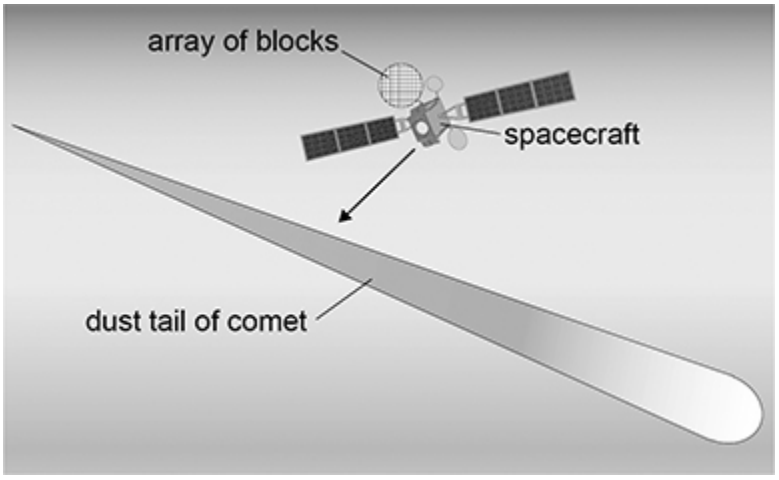
(3)

(Total 7 marks)

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7. **Figure 1** shows a spacecraft travelling towards a comet.
The spacecraft has an array of blocks designed to capture small dust particles from the comet's tail.

Figure 1



To test the blocks before launch, a spherical dust particle **P** is fired at a right angle to the surface of a fixed, stationary block.
P has a mass of 1.1×10^{-9} kg. It has a speed of 5.9×10^{3} m s^{-1} when it hits the surface of the block.
P comes to rest inside the block.

(a) Calculate the work done in bringing **P** to rest.

work done = _____ J

(1)

(b) **P** travels a distance of 2.9 cm in a straight line inside the block before coming to rest. The resultant force on **P** varies as it penetrates the block.

Calculate the average force acting on **P** as it is brought to rest.

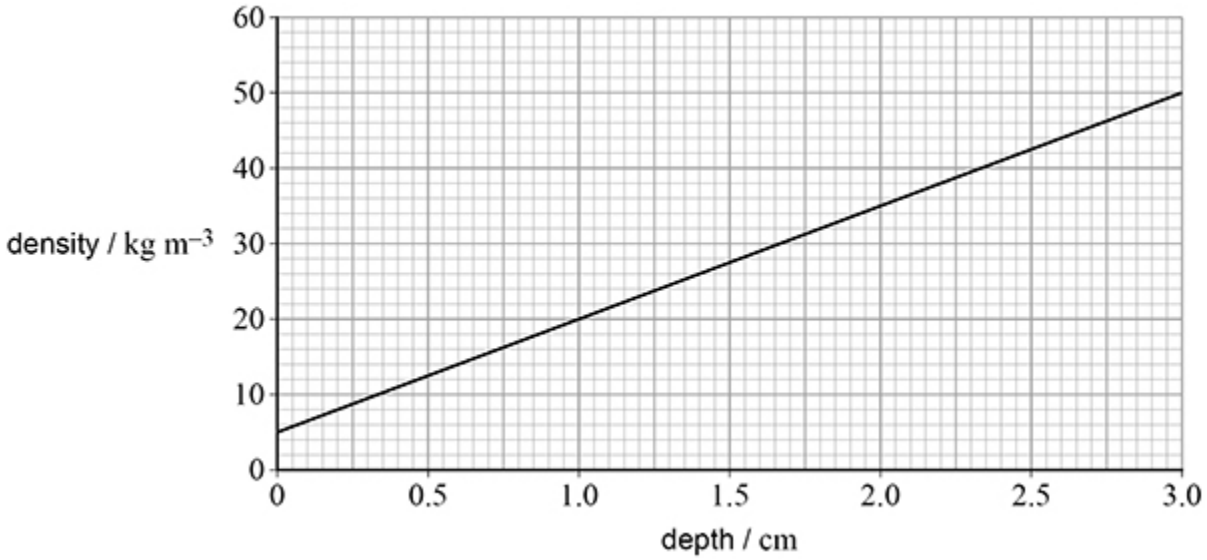
average force = _____ N

(2)

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(c) The block is rectangular with an area of cross-section of 8.0 cm^2 and a thickness of 3.0 cm. **Figure 2** shows how the density of the block varies with depth up to its maximum thickness.

Figure 2



Calculate the mass of the block.

mass = _____ kg

(4)

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(d) In another test, a spherical particle **Q** is fired at a right angle to the surface of an identical block.

Q has the same mass as **P** and is travelling at the same speed as **P** when it strikes the surface of the block.
Q is made from a less dense material than **P**.

Compare the distance travelled by **Q** with that travelled by **P** as they are brought to rest.

_____

_____

_____

_____

_____

_____

(3)

(Total 10 marks)

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

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

A $2E$ ⬭

B $3E$ ⬭

C $4E$ ⬭

D $9E$ ⬭

(Total 1 mark)

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9. A ball is thrown vertically upwards and returns to its original position 2.4 s later. The effect of air resistance is negligible.

What is the total distance travelled by the ball?

A 5.9 m ⬭

B 7.1 m ⬭

C 14 m ⬭

D 28 m ⬭

(Total 1 mark)

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



What is the tension in the tow rope?

A 3000 N ⬭

B 4100 N ⬭

C 7800 N ⬭

D 8900 N ⬭

(Total 1 mark)

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11. A tennis ball has a mass of $58\ \text{g}$.
The ball is dropped from rest from a height of $1.8\ \text{m}$ above the ground and falls vertically.
The ball rebounds vertically to a height of $1.1\ \text{m}$.
The effect of air resistance is negligible.

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

A $0.040\ \text{N s}$ ⬭

B $0.075\ \text{N s}$ ⬭

C $0.215\ \text{N s}$ ⬭

D $0.614\ \text{N s}$ ⬭

(Total 1 mark)

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



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

A the drag force on the parachutist from the air ⬭

B the tension in the strings of the parachute ⬭

C the gravitational force of the parachutist on the Earth ⬭

D the lift force on the parachute from the air ⬭

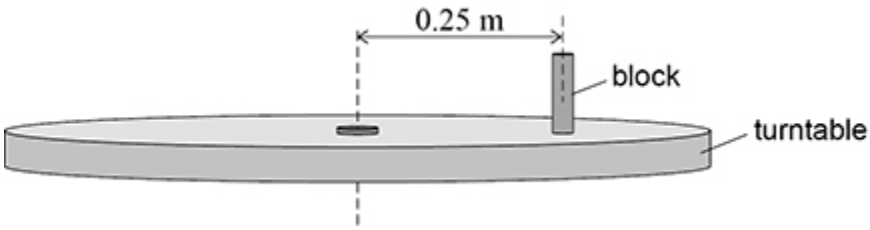
(Total 1 mark)

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13. A teacher sets up a demonstration to show the relationship between circular motion and simple harmonic motion (SHM).

She places a block on a turntable at a point $0.25\ \text{m}$ from its centre, as shown in **Figure 1**.

Figure 1



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

(a) Calculate the time taken for the turntable to complete one revolution.

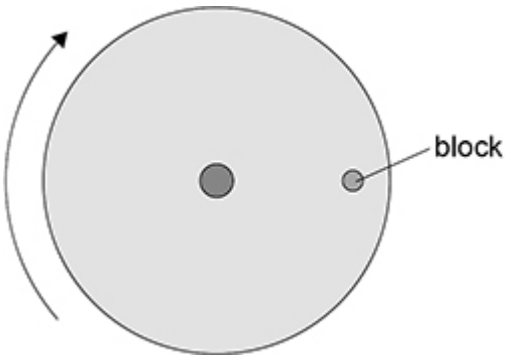
time = _____ s

(2)

(b) **Figure 2** shows a plan view of the turntable and block.
The turntable rotates in a clockwise direction.

Draw an arrow on **Figure 2** to show the direction of the resultant force on the block.

Figure 2



(1)

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(c) The mass of the block is $0.12\ \text{kg}$.

Calculate the magnitude of the resultant force on the block.

magnitude of force = _____ N

(2)

(d) Describe, with reference to one of Newton's laws of motion, the evidence that a resultant force is acting on the block.

_____

_____

_____

_____

_____

(2)

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

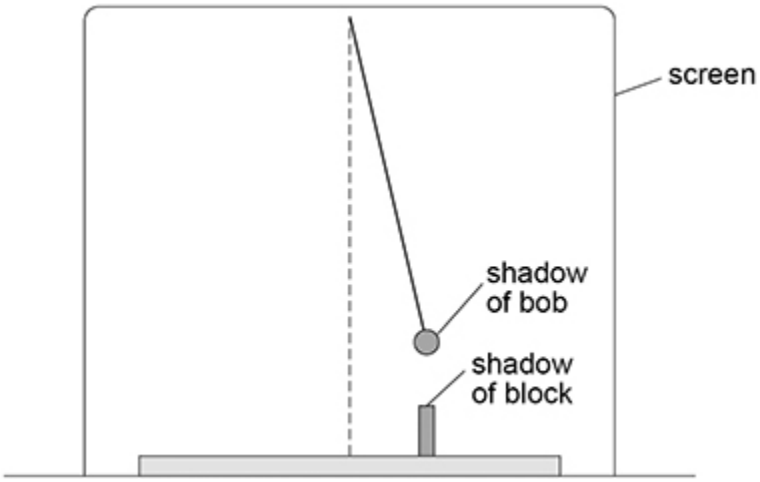
Calculate the length of the simple pendulum.

length = _____ m

(2)

(f) A lamp is used to project shadow images of the block and pendulum bob on a screen.
Both shadows appear to move with SHM across the screen.
Figure 3 shows the images on the screen at one instant.

Figure 3



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Initially the shadows move in phase with the same amplitude.

Air resistance affects the motion of the pendulum.

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

amplitude _____

_____

_____

phase _____

_____

_____

(2)

(Total 11 marks)

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

What is an estimate of its kinetic energy?

A 10^4 J ⬭

B 10^6 J ⬭

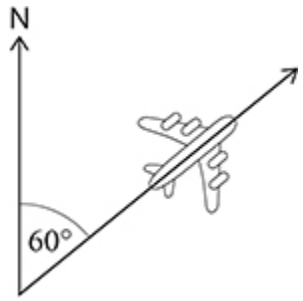
C 10^8 J ⬭

D 10^{10} J ⬭

(Total 1 mark)

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15. An aeroplane flies horizontally at $150\ \text{m s}^{-1}$ along a bearing $60°$ east of north.



How far north from its starting position is the aeroplane after one hour?

A 270 km ⬭

B 470 km ⬭

C 510 km ⬭

D 540 km ⬭

(Total 1 mark)

16. Which two quantities have the base unit $\text{kg m}^2\ \text{s}^{-2}$?

A kinetic energy and momentum ⬭

B kinetic energy and Young modulus ⬭

C work done and the moment of a couple ⬭

D work done and pressure ⬭

(Total 1 mark)

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17. Object **P** has a mass of $7500\ \text{kg}$ and travels at $12\ \text{m s}^{-1}$.
Object **Q** has a mass of $2500\ \text{kg}$ and travels at $20\ \text{m s}^{-1}$ in the same direction as **P**.
P and **Q** collide and remain together after the collision.

What is the total kinetic energy of **P** and **Q** immediately after the collision?

A 70 kJ ⬭

B 140 kJ ⬭

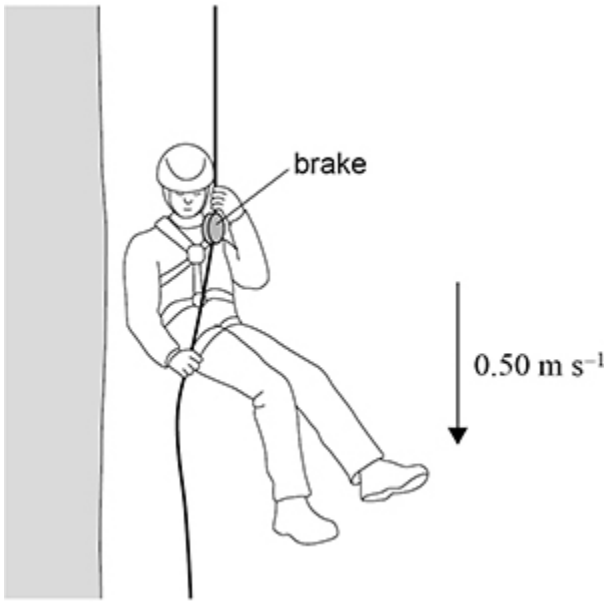
C 980 kJ ⬭

D 2.0 MJ ⬭

(Total 1 mark)

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18. A climber wears a harness attached to a rope. The rope passes through a brake. There is friction between the rope and the brake.



The climber uses the brake to descend at a steady speed of $0.50\ \text{m s}^{-1}$.
The combined mass of the climber, the harness and the brake is $60\ \text{kg}$.

What is the rate of energy transfer to the brake and rope?

A 15 W ⬭

B 29 W ⬭

C 150 W ⬭

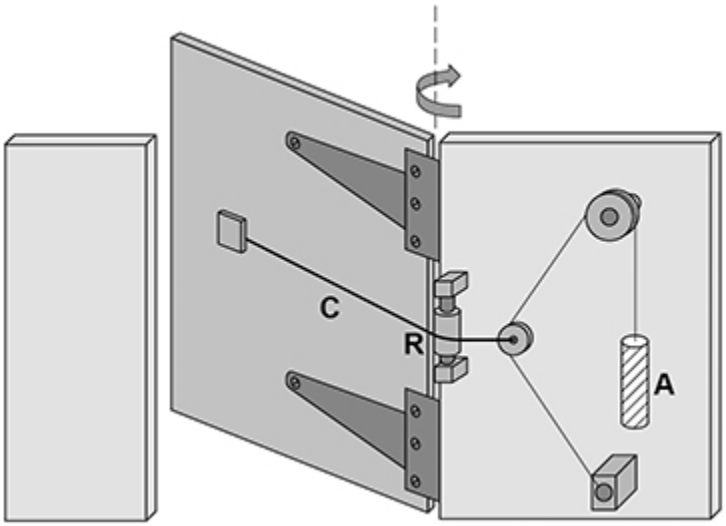
D 290 W ⬭

(Total 1 mark)

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19. **Figure 1** shows a garden gate with a pulley system designed to close the gate.

Figure 1



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

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

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

The table below gives the density of three available materials.

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

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(a) Deduce which **one** of the three materials is used for **A**.

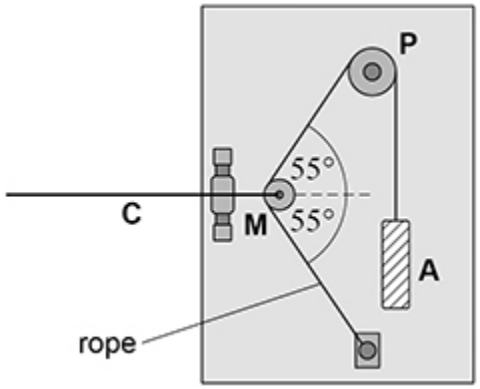
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(3)

Figure 2 shows the pulley arrangement when the gate is closed.

Figure 2



Pulleys **P** and **M** are frictionless so that the tension in the rope attached to **A** is equal to the weight of **A**.

A weighs $35\ \mathrm{N}$ and the weight of moveable pulley **M** is negligible.

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(b) Calculate the tension in the horizontal cable **C** when the gate is closed.

tension = _____ N

(2)

(c) Pulley **M** is pulled to the left as the gate is opened.

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

_____

_____

_____

_____

_____

(2)

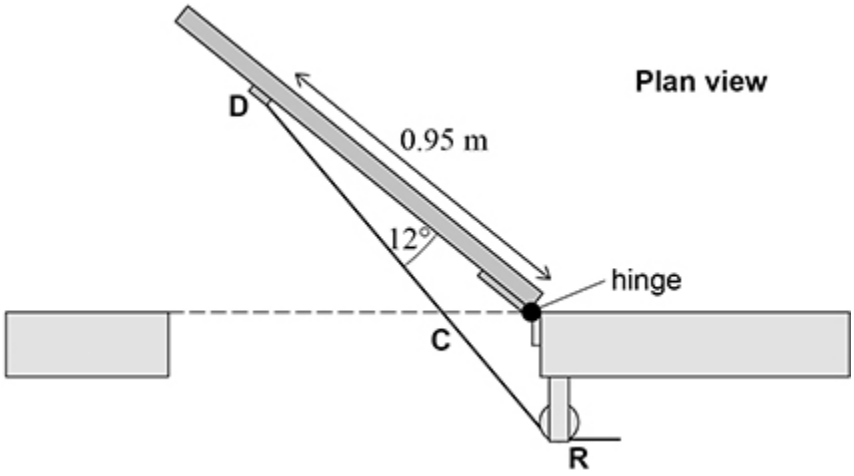
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(d) **Figure 3** shows a plan view with the gate open. The horizontal cable **C** passes over pulley **R** and is attached to the door at **D**.

The angle between the door and the horizontal cable **C** is $12°$.

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

Figure 3



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

Calculate the moment of the tension about the hinge.

moment = _____ N m

(2)

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(e) The same system is attached to an identical gate with stiffer hinges. Now the system does not supply a sufficiently large moment to close the gate.

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

1 _____

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2 _____

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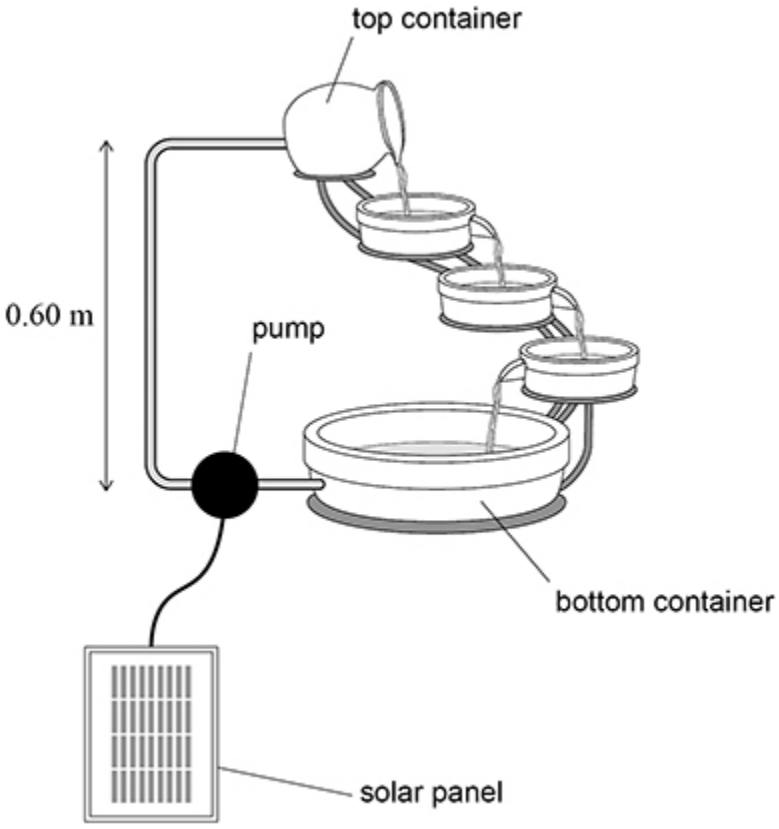
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(4)

(Total 13 marks)

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20. A solar panel powers a pump for a water feature.



Solar energy is incident on the solar panel at a rate of $1.5\ \text{W}$.
Water from the bottom container is continually pumped through a vertical height of $0.60\ \text{m}$ to the top container.

The overall efficiency of the solar panel and the pump is 20%.

What mass of water can be pumped into the top container each second?

A $5\ \text{g}$ ⬭

B $50\ \text{g}$ ⬭

C $100\ \text{g}$ ⬭

D $250\ \text{g}$ ⬭

(Total 1 mark)

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21. Which row only contains SI fundamental base units?

A A, kg, N, s ⬭

B A, K, mol, s ⬭

C C, kg, m, mol ⬭

D J, K, m, s ⬭

(Total 1 mark)

22. Which description of a couple and its unit is correct?

	Description	Unit	
A	consists of two equal parallel forces	$N\ m^{-1}$	⬭
B	produces translational motion	$N\ m$	⬭
C	consists of two equal and opposite forces	$N\ m$	⬭
D	produces rotational motion	$N\ m^{-1}$	⬭

(Total 1 mark)

23. A firework rocket moves vertically upwards.
The rocket's fuel burns at a steady rate to produce a constant thrust.
The mass of the rocket decreases with time.

Ignore the effects of air resistance on the rocket.

Which row shows the acceleration of the rocket before, and the acceleration immediately after, the fuel has been used up?

	Acceleration before	Acceleration immediately after	
A	increasing upwards	constant downwards	⬭
B	increasing upwards	decreasing upwards	⬭
C	constant upwards	constant downwards	⬭
D	decreasing upwards	constant downwards	⬭

(Total 1 mark)

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24. **P** and **Q** are two balls of the same diameter. **P** has a greater mass than **Q**.

Both balls are projected at the same time from the top of a tall building that stands on horizontal ground.
Both balls are projected with the same horizontal velocity.
P reaches the ground after time t_P and at a horizontal distance d_P from the building.
Q reaches the ground after time t_Q and at a horizontal distance d_Q from the building.

The air is still and air resistance is **not** negligible.

Which row is correct?

	Time	Horizontal distance	
A	$t_P = t_Q$	$d_P = d_Q$	⬭
B	$t_P = t_Q$	$d_P > d_Q$	⬭
C	$t_P < t_Q$	$d_P = d_Q$	⬭
D	$t_P < t_Q$	$d_P > d_Q$	⬭

(Total 1 mark)

25. A mass **M** hangs in equilibrium from a vertical spring that obeys Hooke's law.
M is pulled down by $10\ \text{cm}$ and then released to oscillate about the equilibrium position.
M returns to the equilibrium position for the first time $0.50\ \text{s}$ after release.

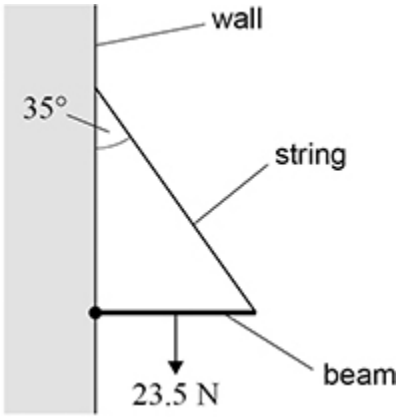
Which row gives the amplitude and the period of the oscillations?

	Amplitude / cm	Period / s	
A	10	1.0	⬭
B	10	2.0	⬭
C	20	2.0	⬭
D	20	1.0	⬭

(Total 1 mark)

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26. A uniform beam of weight $23.5\ \text{N}$ is attached by a hinge to a vertical wall and supported by a string.
The string makes an angle of $35°$ to the wall.



What is the tension in the string?

A $14\ \text{N}$ ⬭

B $21\ \text{N}$ ⬭

C $29\ \text{N}$ ⬭

D $41\ \text{N}$ ⬭

(Total 1 mark)

27. Which is a scalar quantity?

A force ⬭

B kinetic energy ⬭

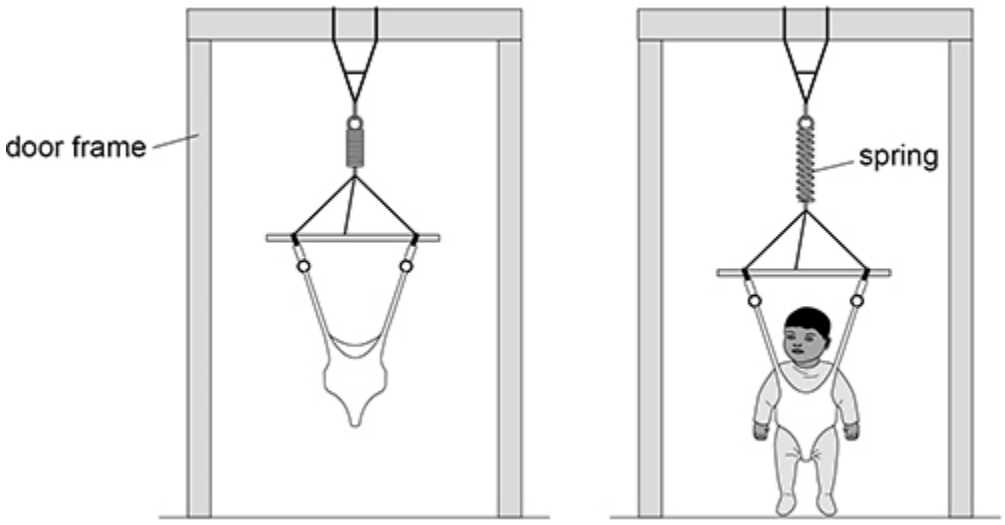
C momentum ⬭

D velocity ⬭

(Total 1 mark)

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28. A baby bouncer consists of an inextensible harness attached to a spring.



The stiffness of the spring is in the range:

A 1–10 N m^{-1} ⬭

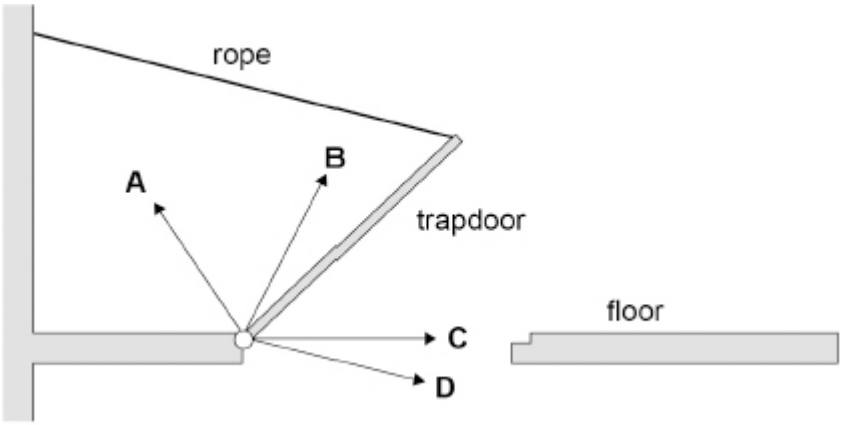
B 10–100 N m^{-1} ⬭

C 100–1000 N m^{-1} ⬭

D 1000–10 000 N m^{-1} ⬭

(Total 1 mark)

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



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

A ⬭

B ⬭

C ⬭

D ⬭

(Total 1 mark)

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

What is the terminal speed of the sphere?

A $\frac{mg}{k}$ ⬭

B $\frac{km}{g}$ ⬭

C kmg ⬭

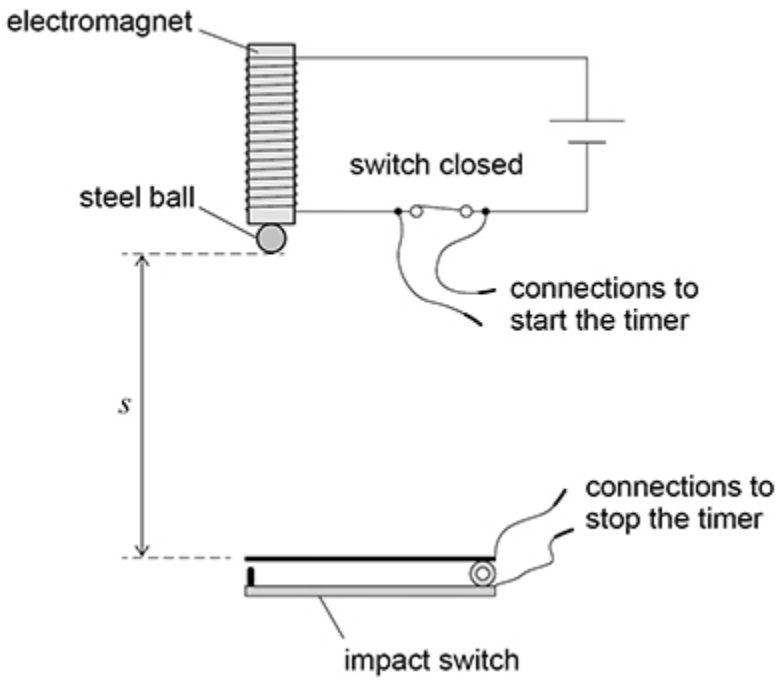
D $\frac{k}{mg}$ ⬭

(Total 1 mark)

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31. **Figure 1** shows apparatus used to determine the acceleration g due to gravity by a free-fall method.

Figure 1



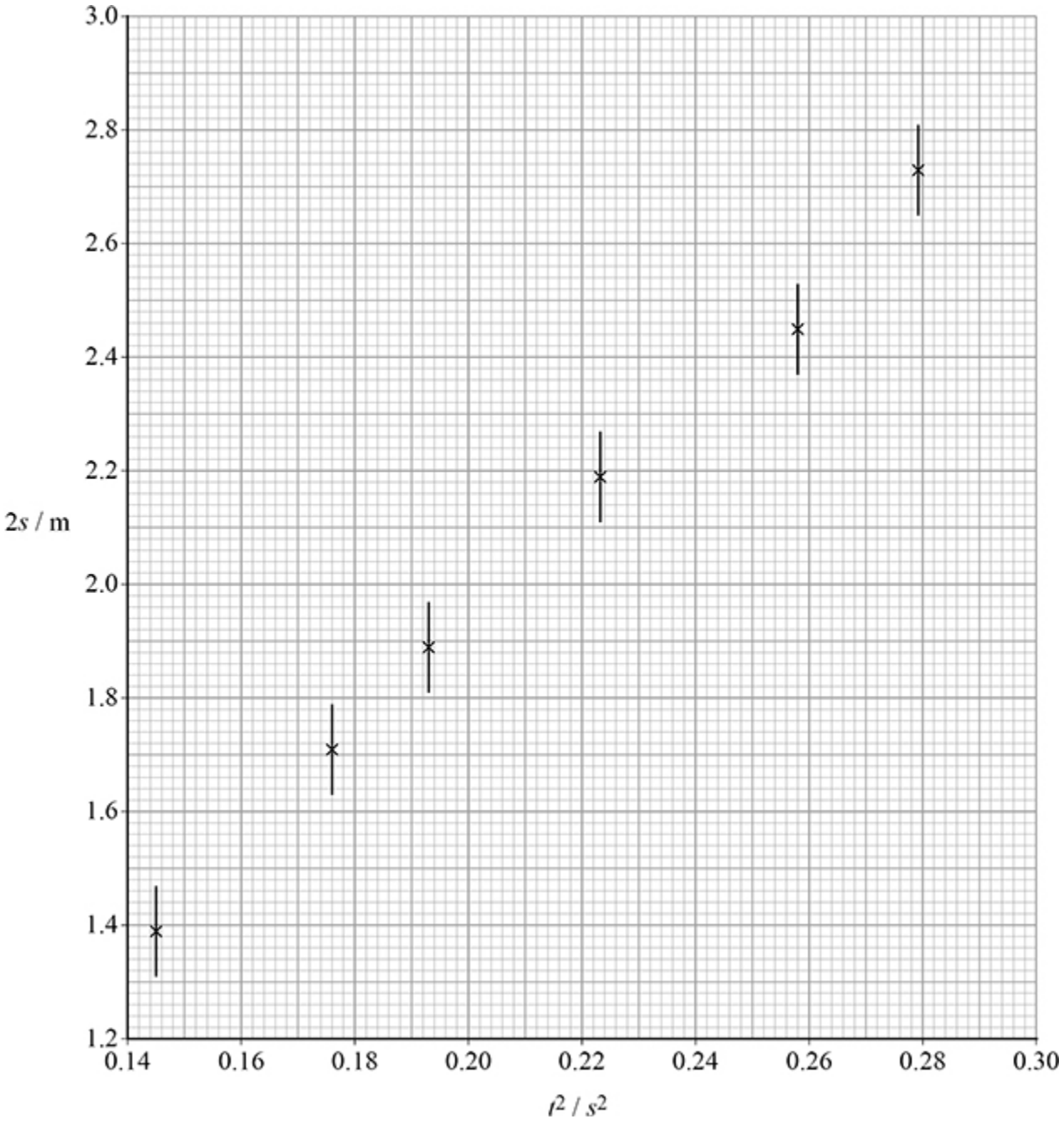
When the switch is opened a timer starts and a steel ball is released from rest.
The ball falls vertically onto an impact switch and this stops the timer.
The timer displays the time t for the ball to fall through the vertical distance s shown in **Figure 1**.

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A student obtains values of t for different values of s.

The student plots the graph of $2s$ against t^2 shown in **Figure 2**.

Figure 2



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(a) The student has used an absolute uncertainty in s to draw the vertical error bars in **Figure 2**.

Deduce the student's absolute uncertainty in s.

absolute uncertainty in s = _____ m

(1)

(b) Determine

- the maximum gradient G_{max} of a straight line that passes through all the error bars
- the minimum gradient G_{min} of a straight line that passes through all the error bars.

G_{max} = _____

G_{min} = _____

(3)

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(c) It can be shown that $2s = gt^2$.

Determine a value for g using G_{max} and G_{min}.

g = _____ m s^{-2}

(2)

(d) Determine the percentage uncertainty in your value for g.

percentage uncertainty = _____ %

(2)

A fault develops in the apparatus.
When the switch is opened there is now a 30 m s delay before the ball is released.

(e) State the type of error produced by this fault.

_____

(1)

(f) A graph of $2s$ against t^2 is produced using results from the faulty apparatus.

Describe how this graph is different from the graph in **Figure 2**.

_____

_____

_____

(1)

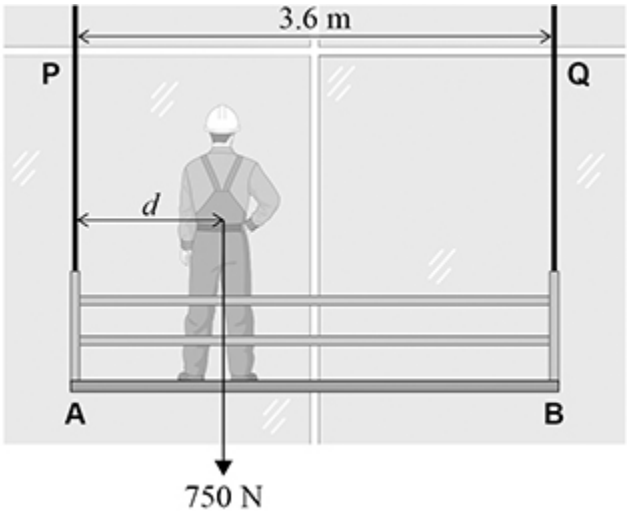
(Total 10 marks)

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32. **Figure 1** shows a worker of weight $750\ \text{N}$ on a uniform platform. The weight of the worker is acting at a horizontal distance d from end **A**.

Throughout this question, assume that the platform is horizontal and that all cables obey Hooke's law.

Figure 1



The platform weighs $1800\ \text{N}$ and is suspended by vertical cables **P** and **Q**.
Each cable has an unstretched length of $3.0\ \text{m}$.
The horizontal distance between **P** and **Q** is $3.6\ \text{m}$.

(a) The worker moves to a position where the tension in the left-hand cable **P** is $1150\ \text{N}$.

Calculate d for this position.

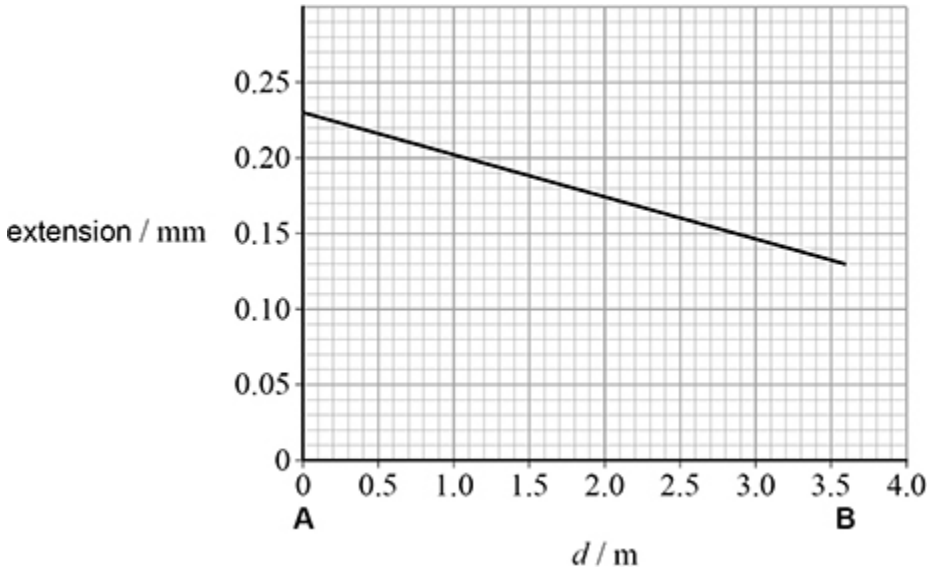
d = _____ m

(3)

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Figure 2 shows how the extension of **P** varies with d as the worker walks slowly along the platform from **A** to **B**.

Figure 2



The worker moves to a position **X** where the strain in **P** is 6.0×10^{-5}.

(b) Determine d for position **X**.

d = _____ m

(2)

(c) The cable material has a Young modulus of 1.9×10^{11} N m^{-2}.

Calculate the tensile stress in **P** when the worker is at **X**.

tensile stress = _____ N m^{-2}

(1)

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(d) The original cables **P** and **Q** are replaced.

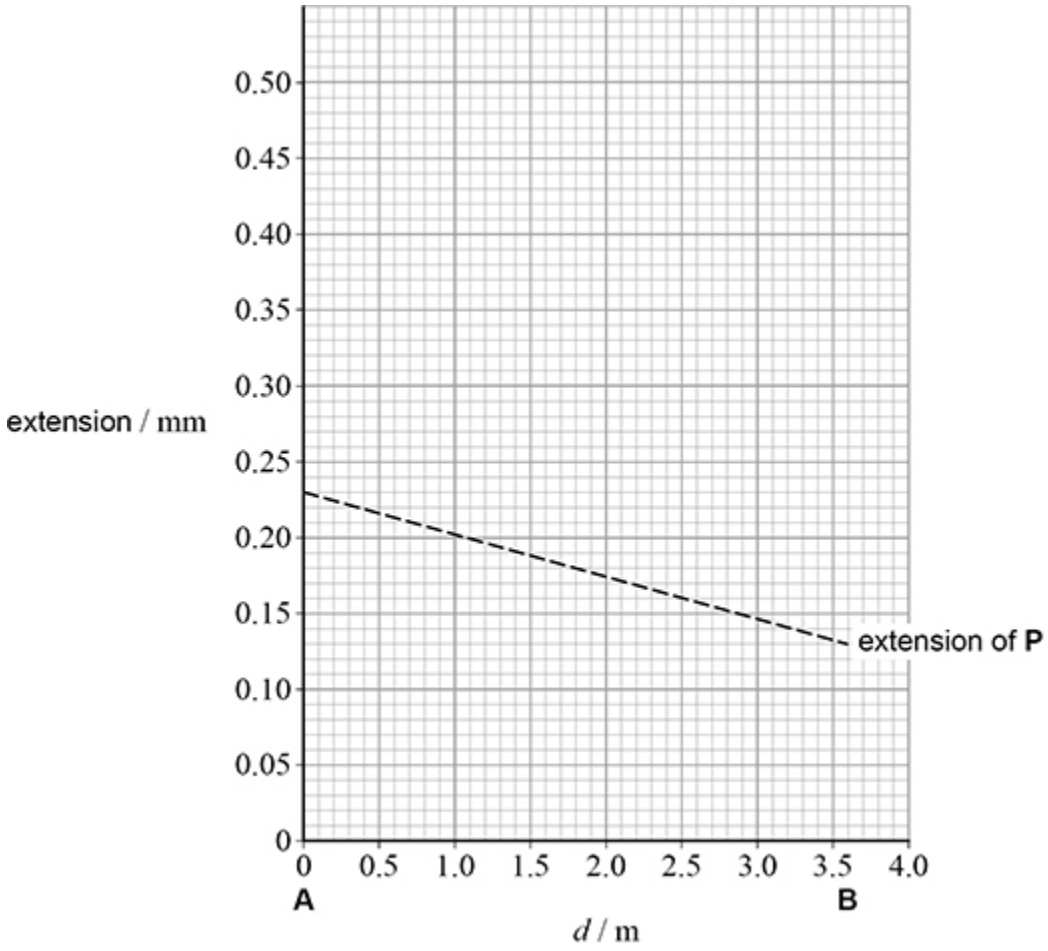
The table below shows how the properties of the original cables compare with the replacement cables.

	Unstretched length	**Radius**	**Young modulus of cable material**
Original cables	L	r	E
Replacement cables	L	$\frac{r}{2}$	$2E$

After the cables have been replaced, the worker walks slowly from **A** to **B**.

Draw on **Figure 3** a line to show the variation of the extension of the replacement left-hand cable with d.
The original line from **Figure 2** is shown on **Figure 3** as a dashed line to help you.

Figure 3



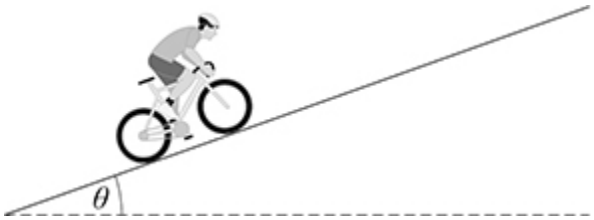
(3)

(Total 9 marks)

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33. (a) **Figure 1** shows a cyclist going up a hill.

Figure 1



not to scale

The angle θ of the slope of the hill is constant.
The total mass m of the cyclist and bicycle is $65\ \text{kg}$.

Write an expression for the component of the total weight parallel to the slope.

_____

(1)

(b) The useful power output of the cyclist is $310\ \text{W}$.
The cyclist has a steady speed of $1.63\ \text{m s}^{-1}$.

Assume that air resistance is negligible at this speed.

Calculate θ.

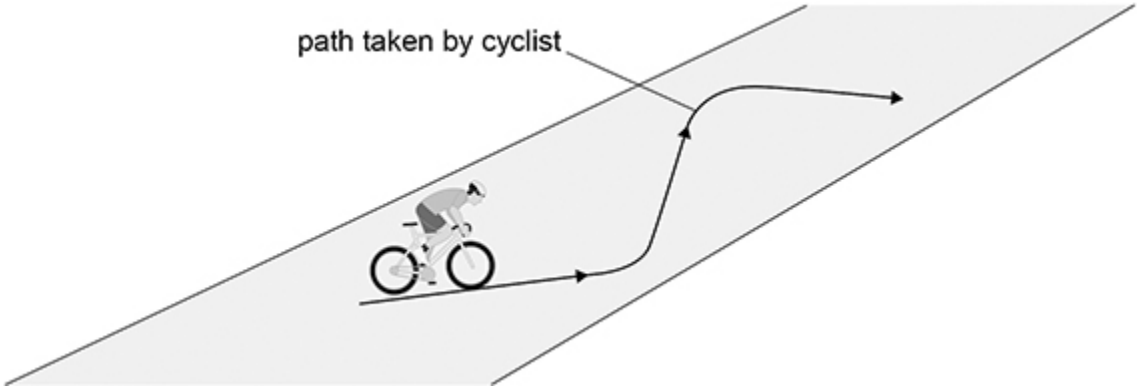
θ = _____ °

(2)

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Figure 2 shows an alternative 'zig-zag' path taken by the cyclist up the same hill. She maintains a steady speed of $1.63\ \text{m s}^{-1}$.

Figure 2



(c) Discuss how her useful power output when taking the path in **Figure 2** compares with her useful power output in part (b).

_____

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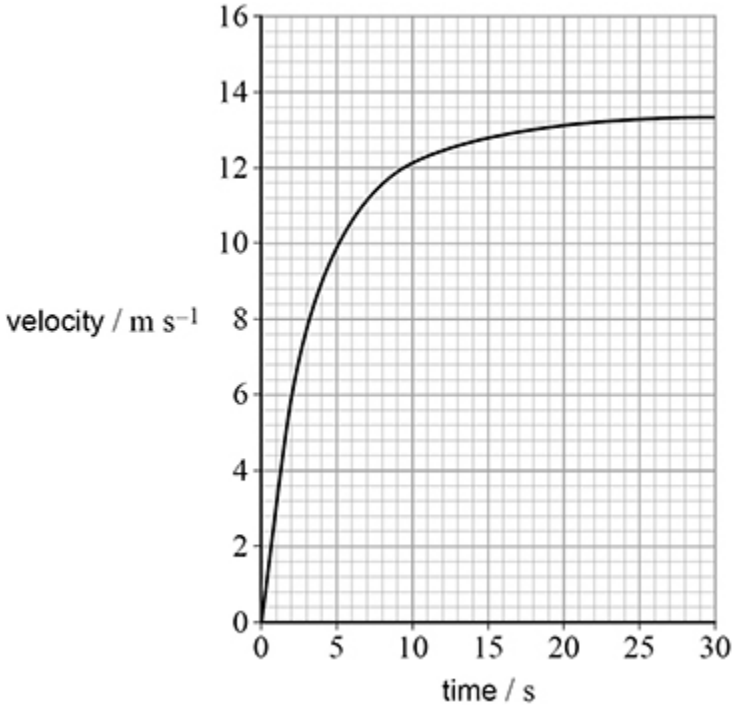
(3)

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The cyclist reaches the top of the hill. She then travels back down the hill in a straight line. The bicycle rolls freely without the cyclist pushing the pedals or applying the brakes.

Figure 3 shows the variation of her velocity with time as she goes down the hill.

Figure 3



(d) Determine the acceleration of the cyclist $10.0\ \text{s}$ after she begins to go down the hill.

acceleration = _____ m s^{-2}

(3)

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(e) Energy transfers occur as the cyclist travels down the hill.

Outline how these energy transfers explain the shape of the graph in **Figure 3**.

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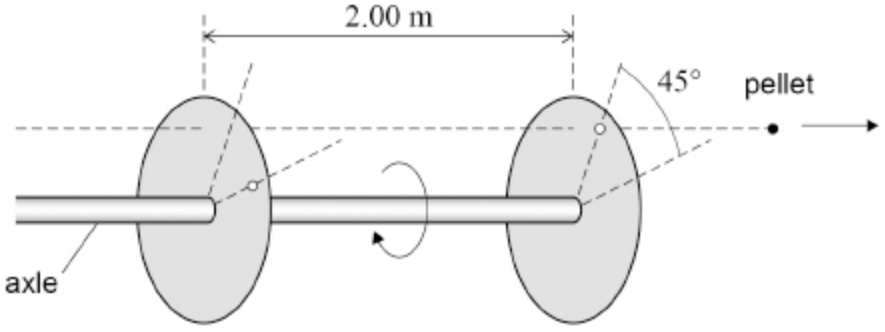
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(4)

(Total 13 marks)

34. Two circular discs made of card rotate at constant speed on a common axle.



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The discs are 2.00 m apart.

An air-gun pellet is fired parallel to the axle. The pellet makes holes in the discs.
The holes are separated by an angle of 45°.
The speed of the pellet between the discs is 300 $\mathrm{m\ s^{-1}}$.

How many revolutions does each disc complete in one second?

A 19 ⬭

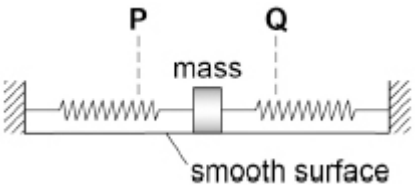
B 118 ⬭

C 740 ⬭

D 1074 ⬭

(Total 1 mark)

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



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

A the acceleration of the mass ⬭

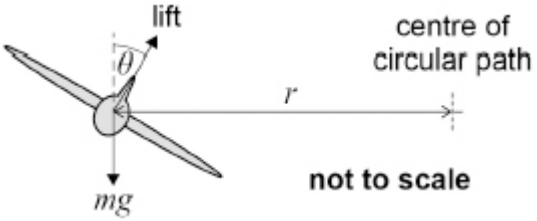
B the kinetic energy of the mass ⬭

C the potential energy of the mass–spring system ⬭

D the resultant force of the springs on the mass ⬭

(Total 1 mark)

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



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

What is tan θ?

A $\frac{gv^2}{r}$ ⬭

B $\frac{rv^2}{g}$ ⬭

C $\frac{rg}{v^2}$ ⬭

D $\frac{v^2}{rg}$ ⬭

(Total 1 mark)

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

Which is correct?

A The accelerating force is unchanged. ⬭

B The accelerating force is halved. ⬭

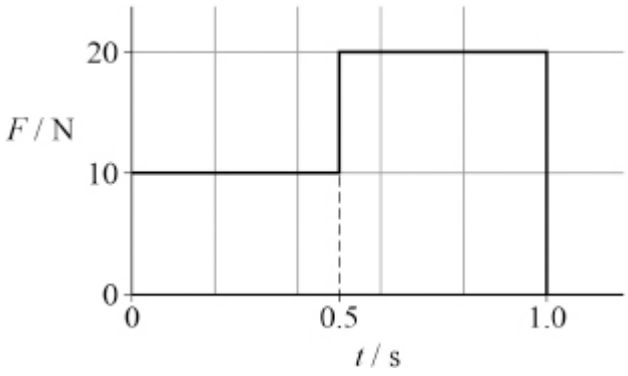
C The acceleration is unchanged. ⬭

D The acceleration is halved. ⬭

(Total 1 mark)

38. A variable force F acts on an object of mass 2.0 kg. The object is at rest at time $t = 0$

The graph shows the variation of F with t.



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What is the speed of the object when $t = 1.0$ s?

A 3.75 m s^{-1} ⬭

B 5.00 m s^{-1} ⬭

C 7.50 m s^{-1} ⬭

D 15.0 m s^{-1} ⬭

(Total 1 mark)

39. **Figure 1** shows a robotic helicopter that is used on Mars. The helicopter is powered by a battery. Before each flight, the battery is charged by a solar panel.

Figure 1

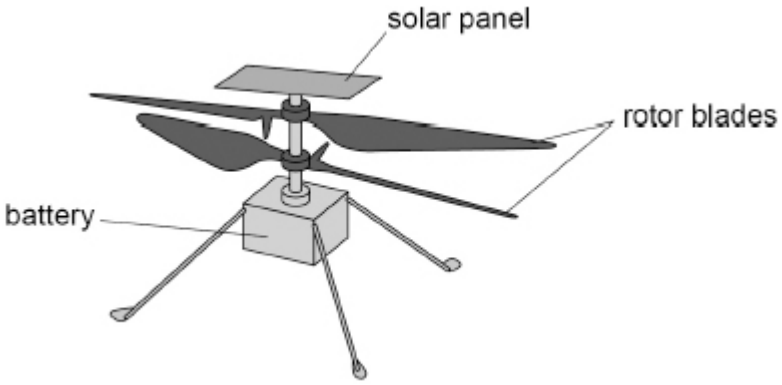
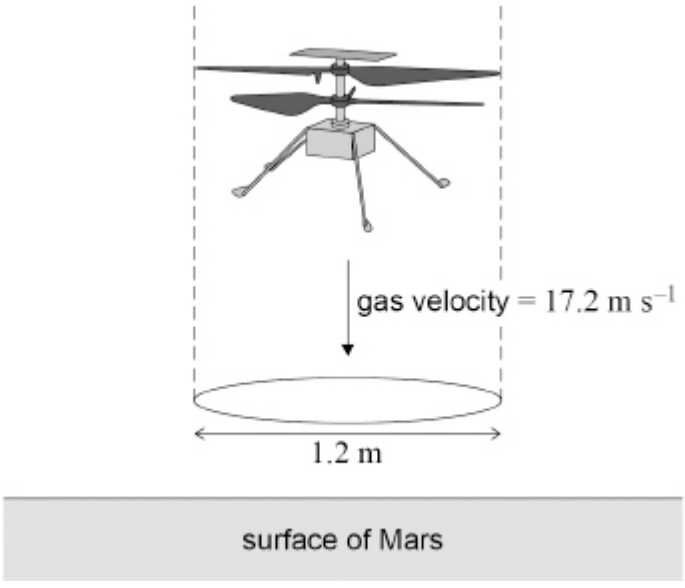


Figure 2 shows the helicopter hovering at a constant height above the surface of Mars. The rotor blades move a column of atmospheric gas vertically downwards at a velocity of 17.2 m s^{-1}. The diameter of this column is 1.2 m.

Figure 2



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(a) The gas moved by the rotor blades has a density of 0.020 $\mathrm{kg\ m^{-3}}$.

Show that the helicopter moves approximately 0.4 kg of gas every second.

(3)

The movement of the gas creates an upward force on the helicopter. This upward force enables the helicopter to hover at a constant height.

The gravitational field strength on Mars is 3.72 $\mathrm{N\ kg^{-1}}$.

(b) Calculate the mass of the helicopter.

mass = _____ kg

(3)

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(c) The battery stores 0.035 kW h of energy before a flight.
The flight lasts for 39 s.
The battery has a power output of 340 W during the flight.

Determine the percentage of the initial energy stored in the battery that is transferred during the flight.

percentage = _____ %

(2)

(d) The helicopter has a maximum flight time of a few minutes due to the limited amount of energy stored in the battery. The battery accounts for about 15% of the helicopter's mass.

A student suggests that adding another identical battery that doubles the energy available to the helicopter would double its flight time.

Deduce without calculation whether the student's suggestion is correct.

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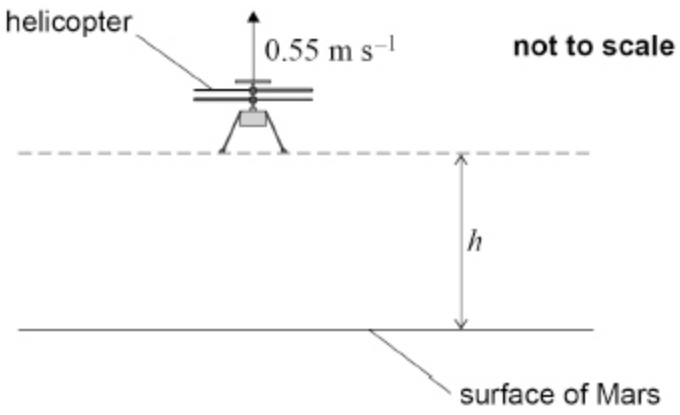
_____

(3)

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Figure 3 shows a simplified side view of the helicopter moving vertically upwards with a speed of $0.55\ \text{m s}^{-1}$.
At the instant shown, the helicopter is at a height h and the blades stop rotating.

Figure 3



The gravitational field strength on Mars is $3.72\ \text{N kg}^{-1}$.

The weight of the helicopter is the only force acting on it when the blades stop rotating. Drag forces on the helicopter are negligible as it rises to a maximum height and then falls back to the surface.

(e) Calculate the time taken for the helicopter to reach its maximum height from the instant the blades stop rotating.

time = _____ s

(2)

(f) When the helicopter makes contact with the surface it has a velocity of $2.2\ \text{m s}^{-1}$.

Calculate h.

h = _____ m

(2)

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(g) A student suggests that the acceleration of the helicopter is constant from the instant the blades stop rotating until the helicopter makes contact with the surface.

Discuss this suggestion with reference to an appropriate Newton's law of motion.

_____

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(2)

(Total 17 marks)

40. Which is a pair of vectors?

A weight and work ⬭

B force and energy ⬭

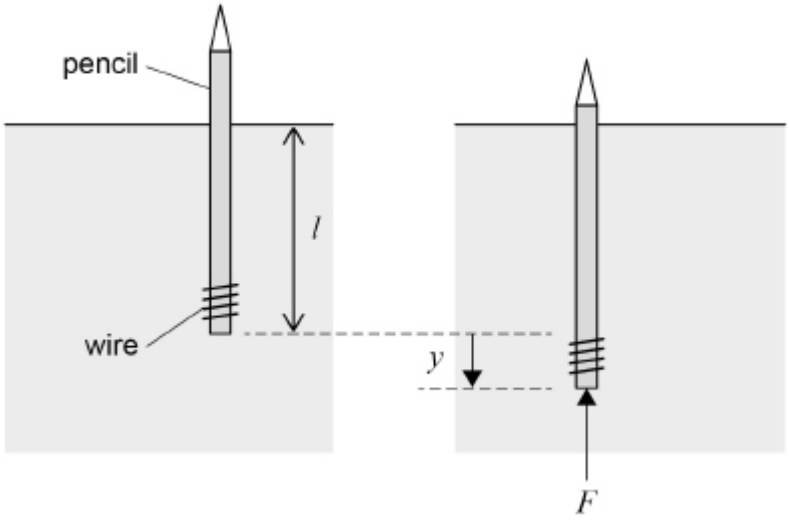
C displacement and momentum ⬭

D acceleration and power ⬭

(Total 1 mark)

41. A pencil is weighted with a thin coil of wire. The volume of the wire is negligible. **Figure 1** shows the pencil and wire floating in equilibrium in water.

Figure 1 **Figure 2**



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In **Figure 1** the combined weight of the pencil and wire is equal to an upwards force called the buoyancy force. The length of the pencil that is submerged is l.
A student pushes the pencil down through a displacement y as shown in **Figure 2**.
The buoyancy force is now greater than the weight.
There is a resultant upward force F acting on the pencil when the student releases it.
The magnitude of F for any value of y is given by

$$F = A\rho gy$$

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

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

(a) Show that the pencil moves with simple harmonic motion.

_____

_____

_____

_____

(2)

(b) The time period T of the vertical oscillations is given by

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

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The measured value of l in **Figure 2** is 85 mm.
The pencil is pushed down 5.0 mm and released.

Calculate the maximum acceleration of the pencil.

maximum acceleration = _____ $\mathrm{m\ s^{-2}}$

(2)

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

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

(c) Explain what is meant by resonance.

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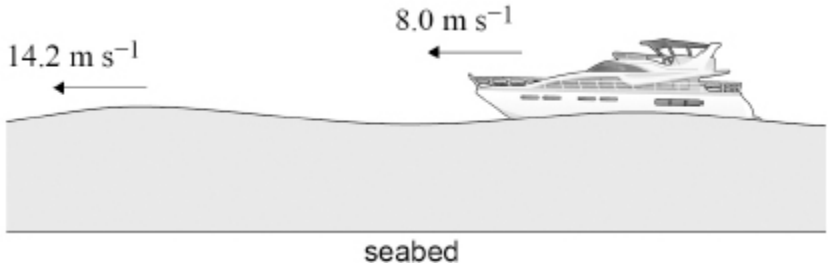
(2)

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(d) **Figure 3** shows a ship moving through continuous waves of wavelength 118 m and velocity 14.2 $\mathrm{m\ s^{-1}}$.

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

Figure 3



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The natural frequency of heave oscillations of the ship is 0.13 Hz.

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

There are two options:

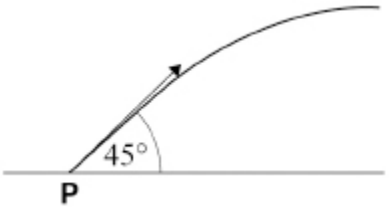
- stop the ship's motors and loosely anchor the ship to the seabed
- continue to sail the ship at 8.0 m s^{-1} in the same direction.

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

(3)

(Total 9 marks)

42. A ball is kicked from point **P** on level ground. The ball initially travels at 45° to the horizontal. The ball reaches its maximum height after a time of 2.0 s.
Air resistance can be ignored.



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What is the displacement of the ball from **P** when at its maximum height?

A 20 m ⬭

B 40 m ⬭

C 45 m ⬭

D 60 m ⬭

(Total 1 mark)

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

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

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

(Total 1 mark)

44. A person jumps as high as she can from a standing position.

What is a reasonable estimate of her speed just after she leaves the ground?

A 2 m s^{-1} ⬭

B 4 m s^{-1} ⬭

C 8 m s^{-1} ⬭

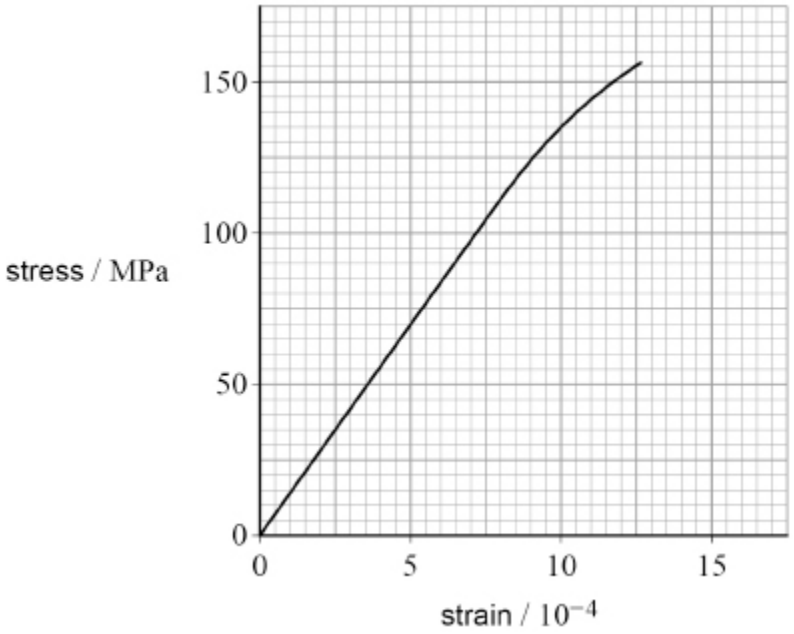
D 10 m s^{-1} ⬭

(Total 1 mark)

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45. **Figure 1** shows the stress–strain graph for a metal in tension up to the point at which it fractures.

Figure 1



(a) Determine, using **Figure 1**, the Young modulus of the metal.

Young modulus = _____ Pa

(1)

(b) Explain how the graph shows that this metal is brittle.

_____

_____

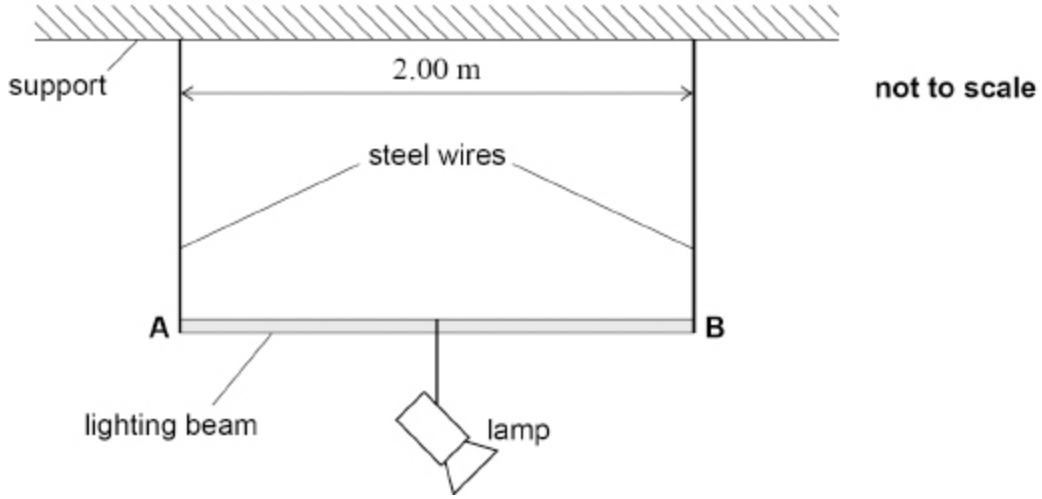
_____

(1)

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Figure 2 shows a uniform rigid lighting beam **AB** suspended from a fixed horizontal support by two identical vertical steel wires. A lamp is attached to the midpoint of **AB**.

Figure 2



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

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

(c) Calculate the extension of each wire.

extension = _____ m

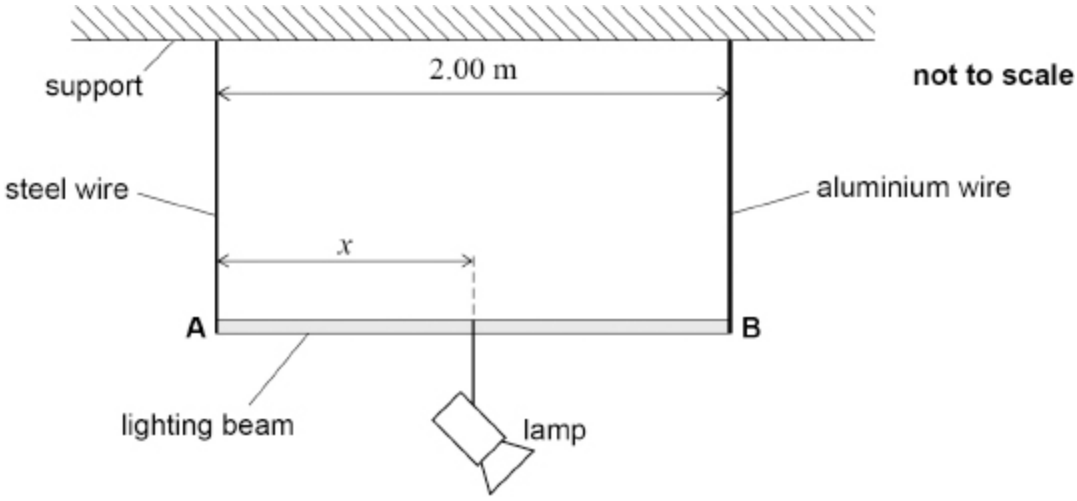
(3)

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(d) The right-hand steel wire is removed and replaced with an aluminium wire of diameter 1.60 mm. The unloaded length of the aluminium wire is the same as that of the original steel wire.

When the lamp is at the midpoint of **AB**, one of the wires extends more than the other so that **AB** is not horizontal. To make **AB** horizontal the lamp has to be moved to a distance x from **A**. **Figure 3** shows the new arrangement.

Figure 3



The Young modulus of aluminium is 7.00×10^{10} Pa.

Deduce distance x.

x = _____ m

(5)

(Total 10 marks)

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46. Which combination of an object's speed and journey time gives a distance travelled of 1 mm?

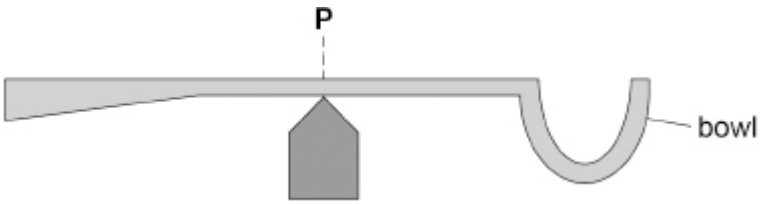
	Speed	Journey time	
A	$10\ \mu\text{m s}^{-1}$	$100\ \text{s}$	⬭
B	$10\ \text{km s}^{-1}$	$0.01\ \mu\text{s}$	⬭
C	$1\ \text{nm s}^{-1}$	$1\ \text{Gs}$	⬭
D	$0.1\ \text{Mm s}^{-1}$	$100\ \text{ns}$	⬭

(Total 1 mark)

47. **Figure 1** shows a spoon used to measure the mass of food.

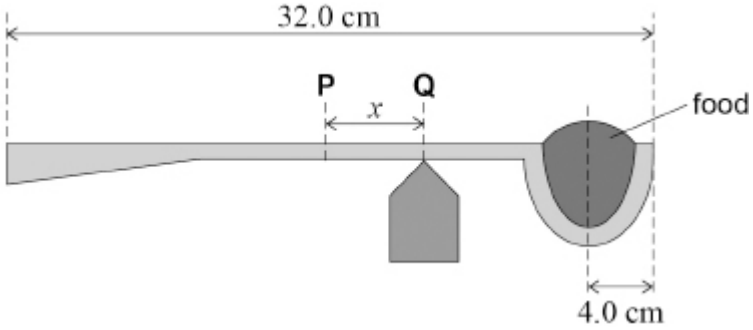
The empty spoon balances when a pivot is placed under a point **P** halfway along the spoon.

Figure 1



The spoon tilts when food of mass M is placed in the bowl. The spoon is rebalanced by moving the pivot a distance x to the right of **P**. The new position of the pivot is under point **Q** in **Figure 2**.

Figure 2



The total length of the spoon is 32.0 cm. The weight of the food acts through a line at a distance of 4.0 cm from the right-hand edge of the spoon.

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(a) Explain why the spoon in **Figure 2** is balanced when the pivot is at **Q**.

_____

_____

_____

_____

(2)

(b) The empty spoon has mass m .

Show that, for the arrangement in **Figure 2**,

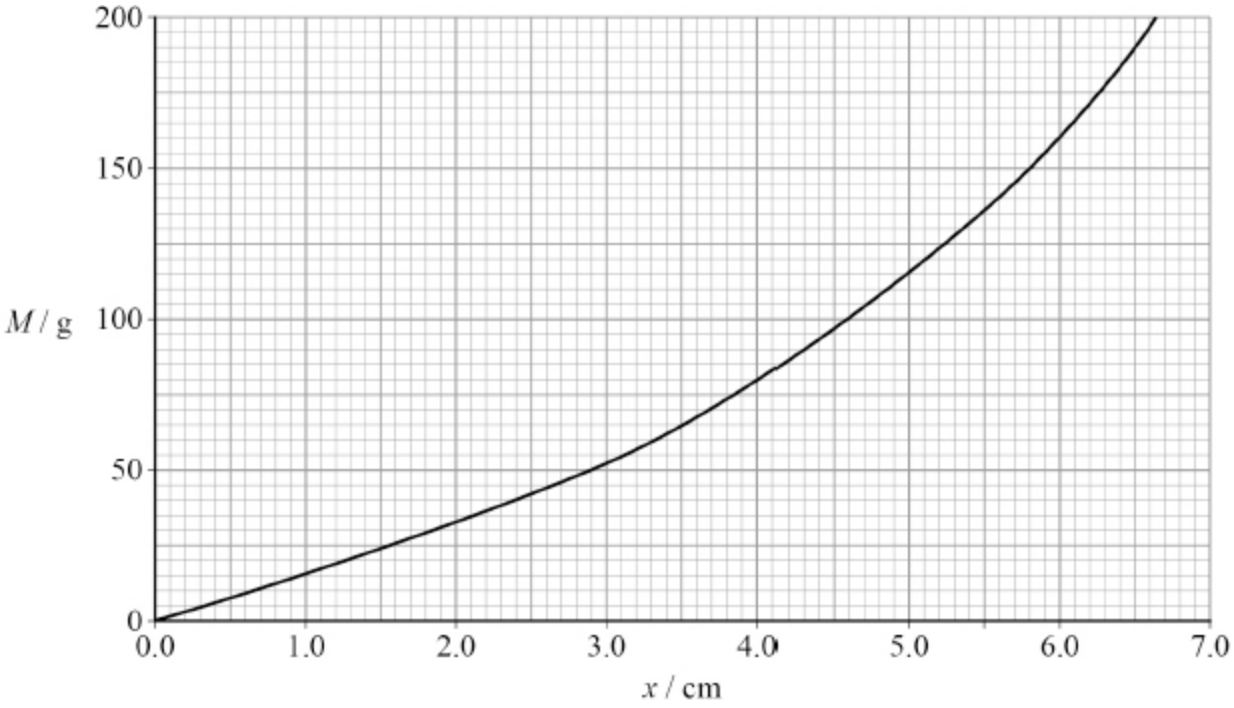
$$\frac{m}{M} = \frac{(12.0 - x)}{x}$$

(2)

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(c) **Figure 3** shows how x varies with M .

Figure 3



Determine, using **Figure 3**, the weight of the empty spoon.

weight = _____ N

(3)

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(d) A scale, in grams, is marked on the spoon between **P** and the bowl. **Figure 3** is used to calibrate this scale in intervals of 25 g.

M can be measured by balancing the spoon. The value is read from the point of the scale directly above the pivot.

State and explain how the uncertainty in the value read from the scale changes as M increases.

_____

_____

_____

_____

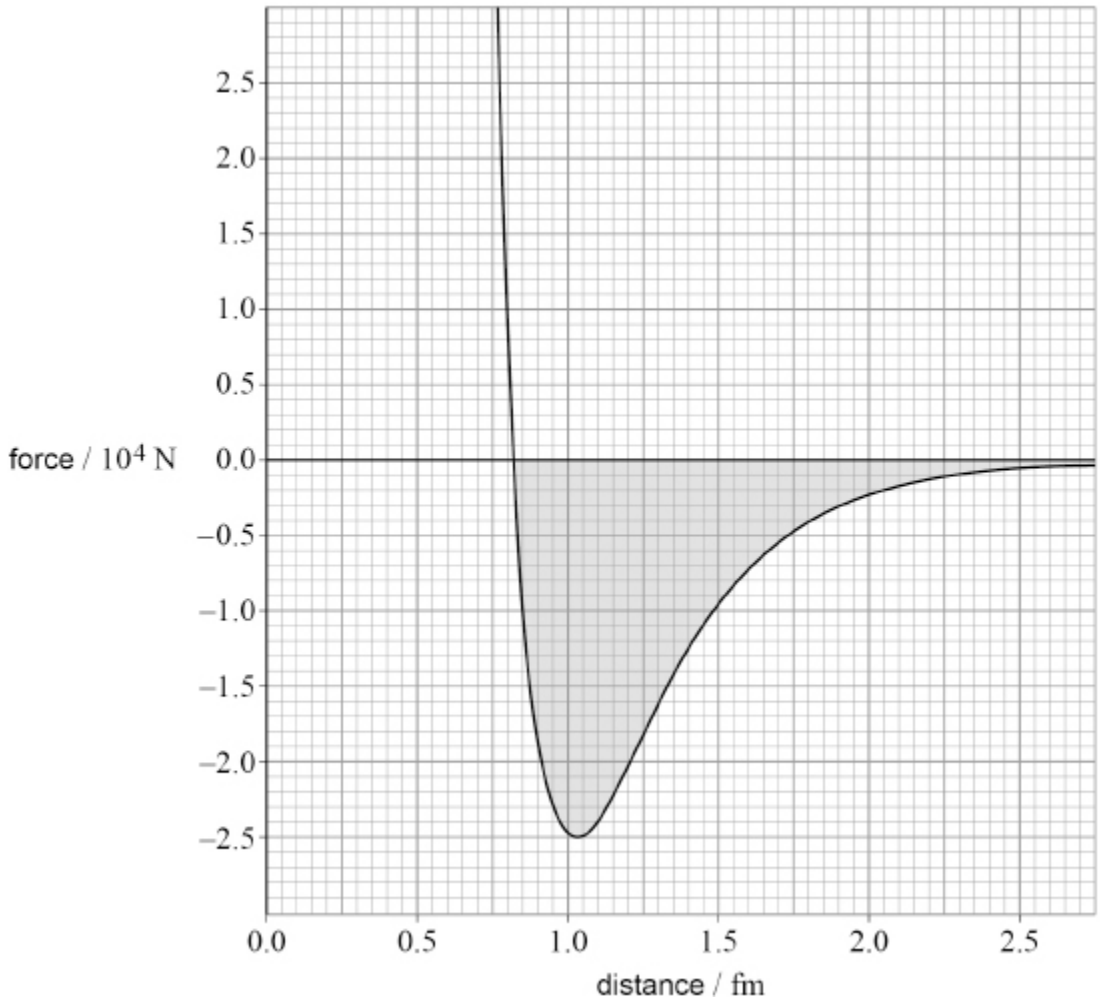
_____

_____

(3)

(Total 10 marks)

48. The graph shows the variation of force with distance between a proton and a neutron.



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The shaded area represents

A acceleration. ⬭

B impulse. ⬭

C rate of change of kinetic energy. ⬭

D work done. ⬭

(Total 1 mark)

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

(a) The average speed for one of these runs was 343 $\mathrm{m\ s^{-1}}$.

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

time = _____ s

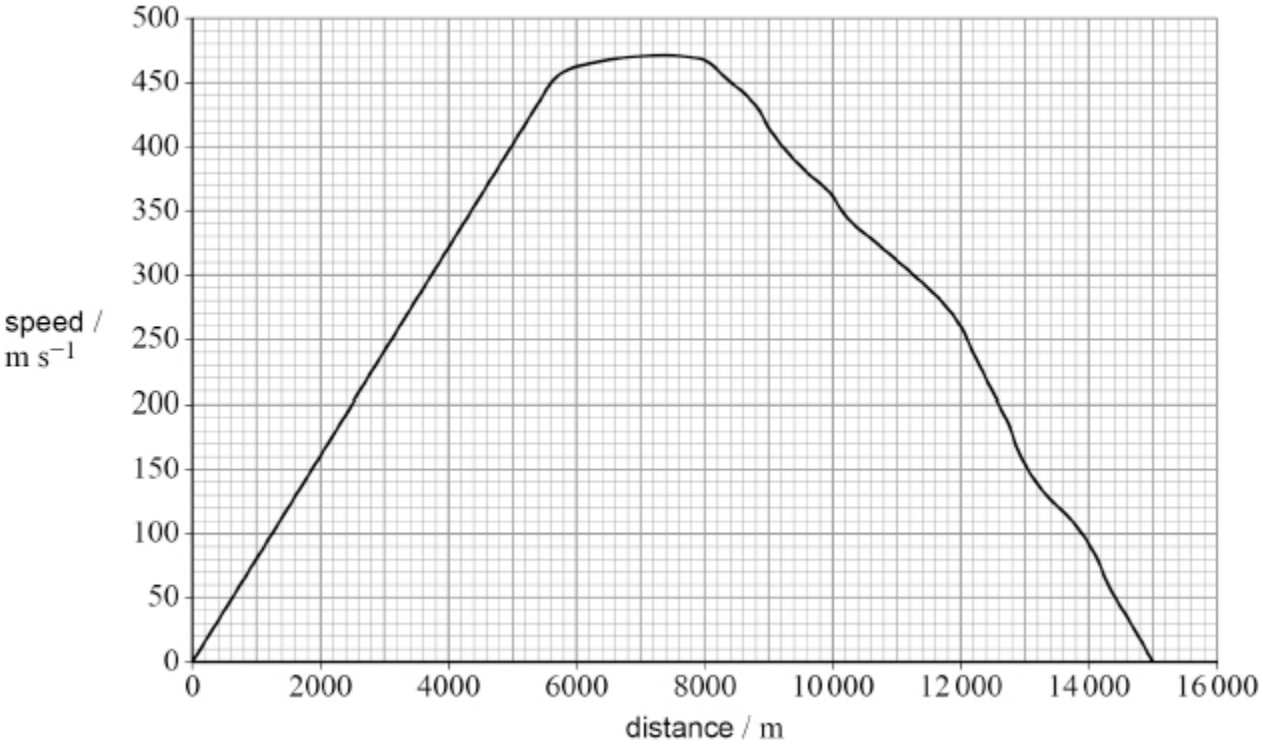
(2)

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(b) Engineers are designing a new jet-powered car to break this record.

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

Figure 1



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

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

kinetic energy = _____ J

(2)

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(c) At any point on the graph in **Figure 1**, the acceleration is given by:

acceleration = speed × gradient of line

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

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

percentage of input power = _____ %

(4)

(d) Scientists recommend that the average deceleration of the driver of the car should be less than $3g$.

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

_____

_____

(2)

(Total 10 marks)

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50. A pellet of mass 25 g travelling horizontally at 40 $\mathrm{m\ s^{-1}}$ enters a fixed wooden block. The pellet stops after travelling a horizontal distance of 2.5 cm in the block.

What is the average resistive force acting on the pellet?

A 20 N ⬭

B 800 N ⬭

C 1600 N ⬭

D 8000 N ⬭

(Total 1 mark)

51. An object of mass 0.20 kg moves with an initial velocity u. It collides with a stationary object of mass 0.30 kg.

The objects stick together when they collide.
No external forces act on the objects.

What is the final velocity of the two objects after the collision?

A 0.40u ⬭

B 0.67u ⬭

C 1.5u ⬭

D 2.5u ⬭

(Total 1 mark)

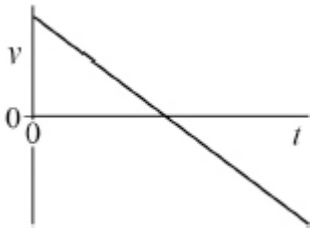
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52. A girl kicks a football vertically upwards at time $t = 0$

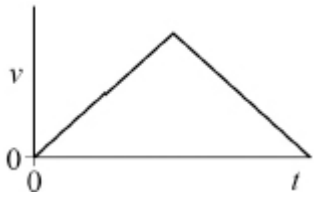
Air resistance is negligible.

What is the variation of the vertical component of velocity v of the football with t until it reaches the ground?

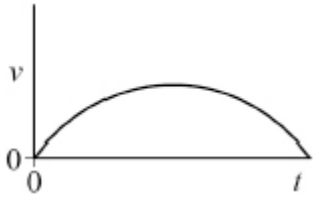
A



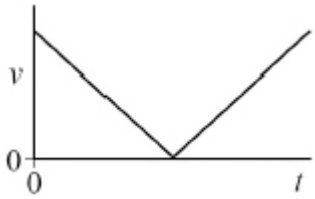
B



C



D



(Total 1 mark)

53. A ball is dropped from a height h. The ball hits the ground with a velocity v.

The ball is now dropped from a height of $2h$.
Air resistance is negligible.

What is the velocity at which the ball hits the ground?

A v

B $\sqrt{2v}$

C $v\sqrt{2}$

D $2v$

(Total 1 mark)

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54. **P** and **Q** represent displacements.



What is the resultant displacement when **P** and **Q** are added?

A  ⬭

B  ⬭

C  ⬭

D  ⬭

(Total 1 mark)

55. A stroboscope emits bright flashes of white light.
The duration of each flash and the frequency of the flashes can be varied.

The table below shows information about the stroboscope.

	Minimum	**Maximum**
Duration of each flash / μs	60	300
Frequency of flashes / Hz	1	150

The duration of each flash is T_1.
The time from the start of a flash to the start of the next flash is T_2.

The duty cycle of a stroboscope is defined as $\frac{T_1}{T_2}$.

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(a) What is the maximum duty cycle of the stroboscope?

Tick ✓ **one** box.

6.0×10^{-5} ☐

3.0×10^{-4} ☐

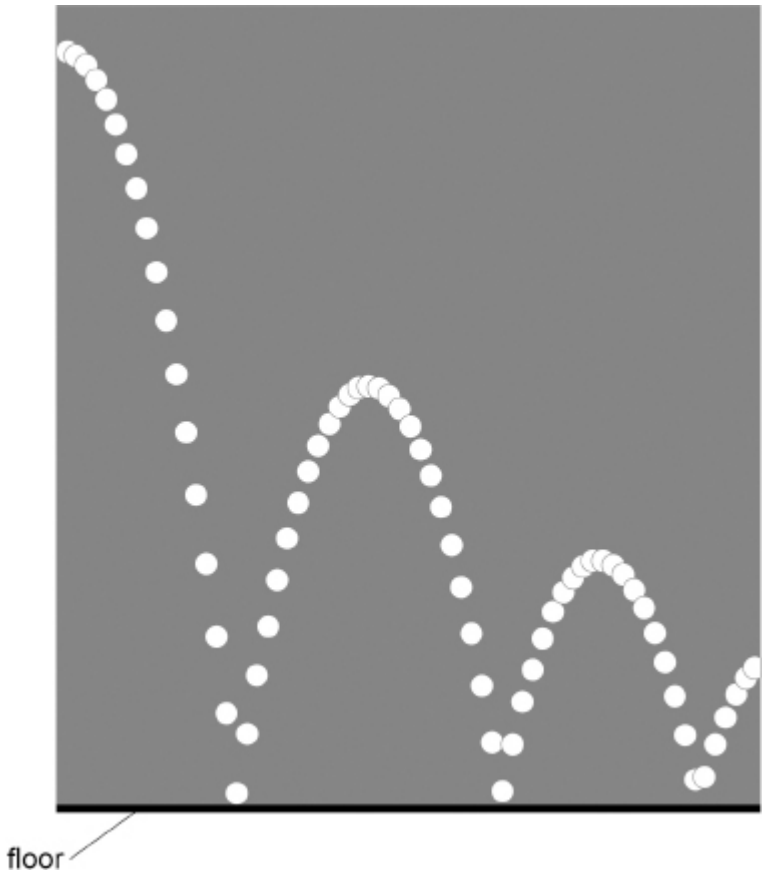
9.0×10^{-3} ☐

4.5×10^{-2} ☐

(1)

(b) **Figure 1** shows images produced in an experiment in which a bouncing ball is illuminated by a stroboscope.
The stroboscope flashes at a constant frequency.

Figure 1



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Suggest why T_1 must be very short for this experiment.

_____

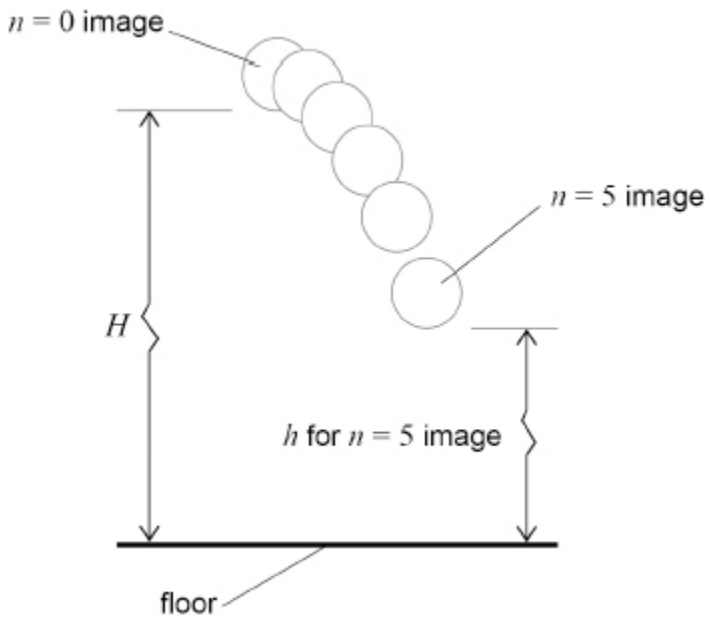
_____

_____

(1)

Figure 2 shows the first six images starting with n = 0, where n is the image number.

Figure 2



The images are used to determine:

H, the vertical distance from the bottom of the ball to the floor when n = 0

h, the vertical distance from the bottom of the ball to the floor for each non-zero value of n.

The $n = N$ image is produced at the instant that the ball hits the floor for the first time. For n between 0 and N it can be shown that

$$H - h = \frac{u_0 n}{f} + \frac{g}{2}\left(\frac{n}{f}\right)^2$$

where

u_0 is the vertical velocity of the ball when n = 0

g is the acceleration due to gravity

f is the frequency of the flashes.

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(c) In order to find g, a graph is plotted with values of $\frac{H-n}{n}$ on the y-axis.

Suggest what is plotted on the x-axis.
Go on to explain how g is determined from this graph.

_____

_____

_____

_____

_____

_____

The following data are recorded.

H = 1550 mm
f = 31.0 Hz

The graphical analysis of data from **Figure 1** gives g as 9.79 m s^{-2}.

(3)

(d) Determine u_0.

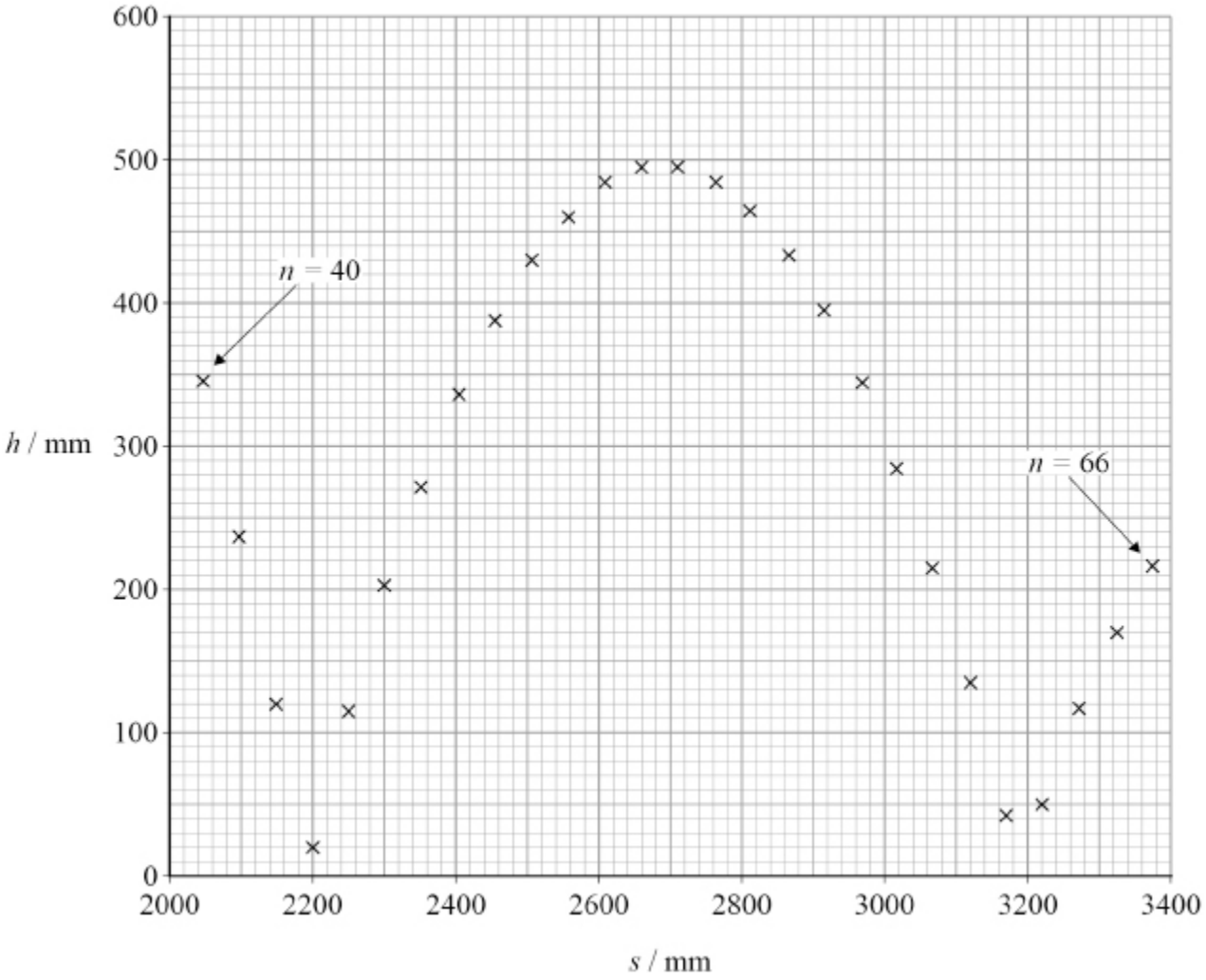
u_0 = _____ m s^{-1}

(3)

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Figure 3 shows positions of the bottom of the ball for n = 40 to n = 66
In this range of positions, the ball makes contact with the floor for the second and third times.
Values of h, the vertical distance from the bottom of the ball to the floor, are plotted on the y-axis.
Values of s, the horizontal displacement from a point on the floor below the centre of the n = 0 image, are plotted on the x-axis.

Figure 3



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(e) Determine, in $\mathrm{mm\ s^{-1}}$, the horizontal velocity of the ball between the second and third contacts of the ball with the floor.

horizontal velocity = _____ $\mathrm{mm\ s^{-1}}$

(2)

(f) Determine the time between the second and third contacts.
Annotate **Figure 3** to show your method.

time = _____ s

(3)

(Total 13 marks)

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