

AQA A-LEVEL PHYSICS • 7408

# PHYSICS



EXAM QUESTION PACK

3.4.1 FORCE, ENERGY AND MOMENTUM • PACK 1

SCORE

/217

PERCENTAGE

%

STEMUP

# These questions belong to AQA, not to us.

The examination questions, mark schemes and examiner reports in this pack were written and published by AQA. They are past assessment materials, reproduced here so that students can revise from them.

## What we do not own

STEMUP is not affiliated with AQA and does not own, and makes no claim to own, any of the question, mark scheme or examiner report material in this pack. AQA has not endorsed, approved or been involved in the production of it. AQA and the qualification titles used here belong to their respective owners and appear for identification only.

## Where to find the originals

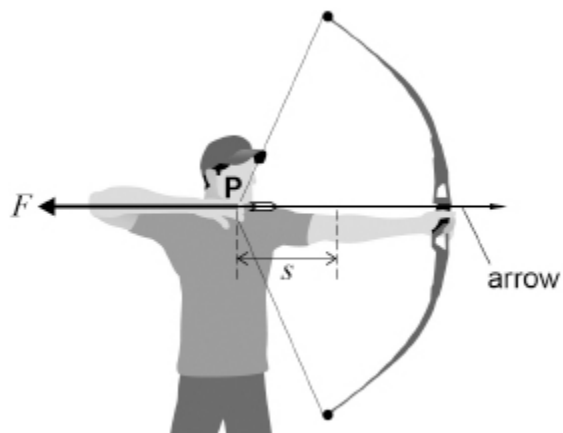
AQA publishes its past papers, mark schemes and examiner reports free of charge. Always check the current specification at [aqa.org.uk](http://aqa.org.uk) before you revise, because content and wording can change between series.

If you hold the rights to any material in this pack and would like it amended or removed, contact [admin@stemup.co.uk](mailto:admin@stemup.co.uk) and we will act on it.

1.

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

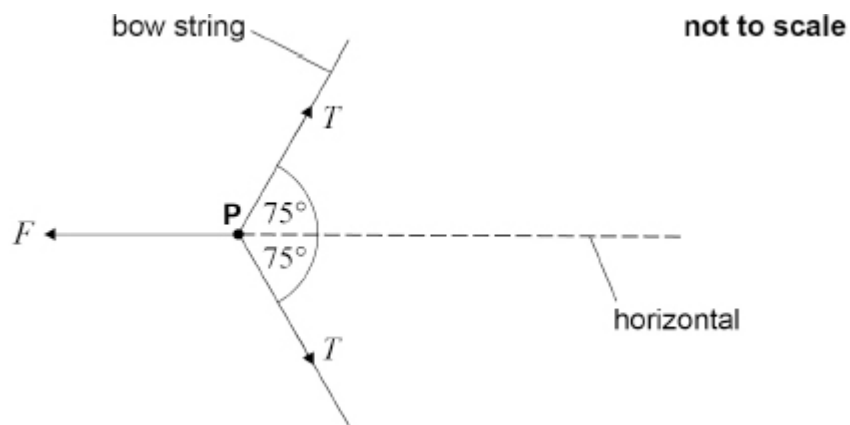
**Figure 1**



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  $75^\circ$  to the horizontal.

**Figure 2**



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

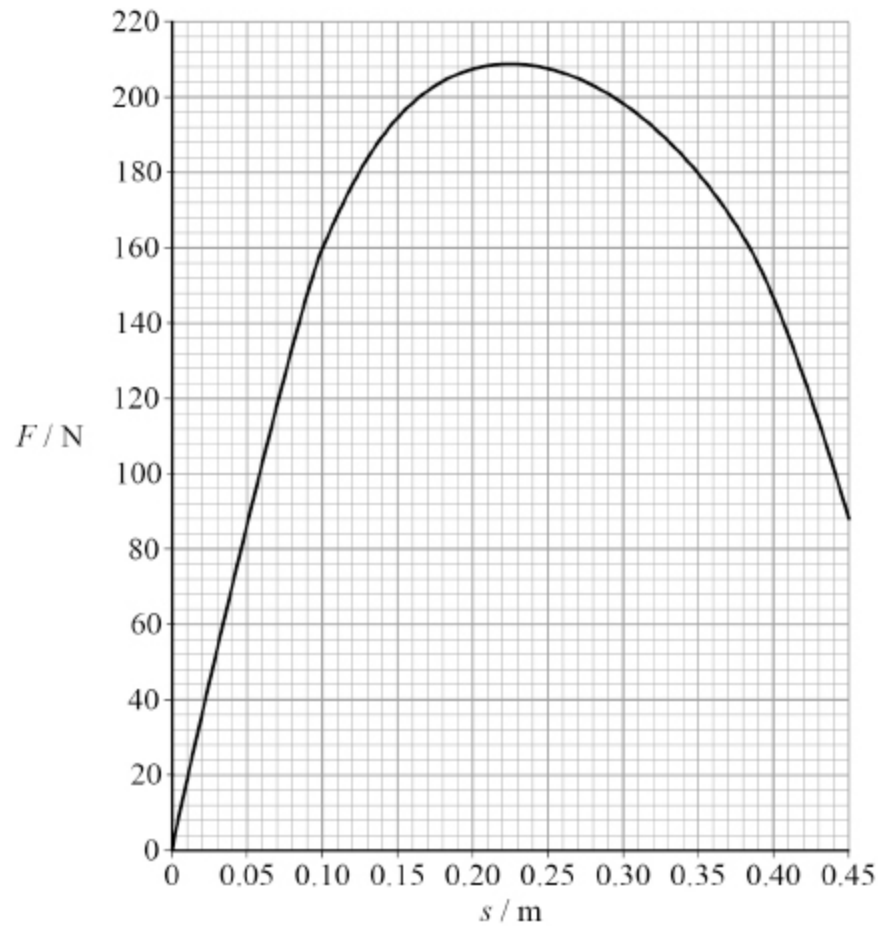
Calculate  $T$ .

$$T = \underline{\hspace{2cm}} \text{ N}$$

(2)

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 = \_\_\_\_\_  $\text{m s}^{-2}$

**(2)**

The arrow is replaced with a different arrow of mass  $m$ .

The archer pulls **P** back by a distance  $s_r$  so that the energy stored in the bow is 64 J and  $F$  is 160 N.

(c) Deduce  $s_r$ .

---

---

---

---

$$s_r = \text{_____ m}$$

**(2)**

(d) The bow has an efficiency of 0.82

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

Calculate  $m$ .

$$m = \text{_____ kg}$$

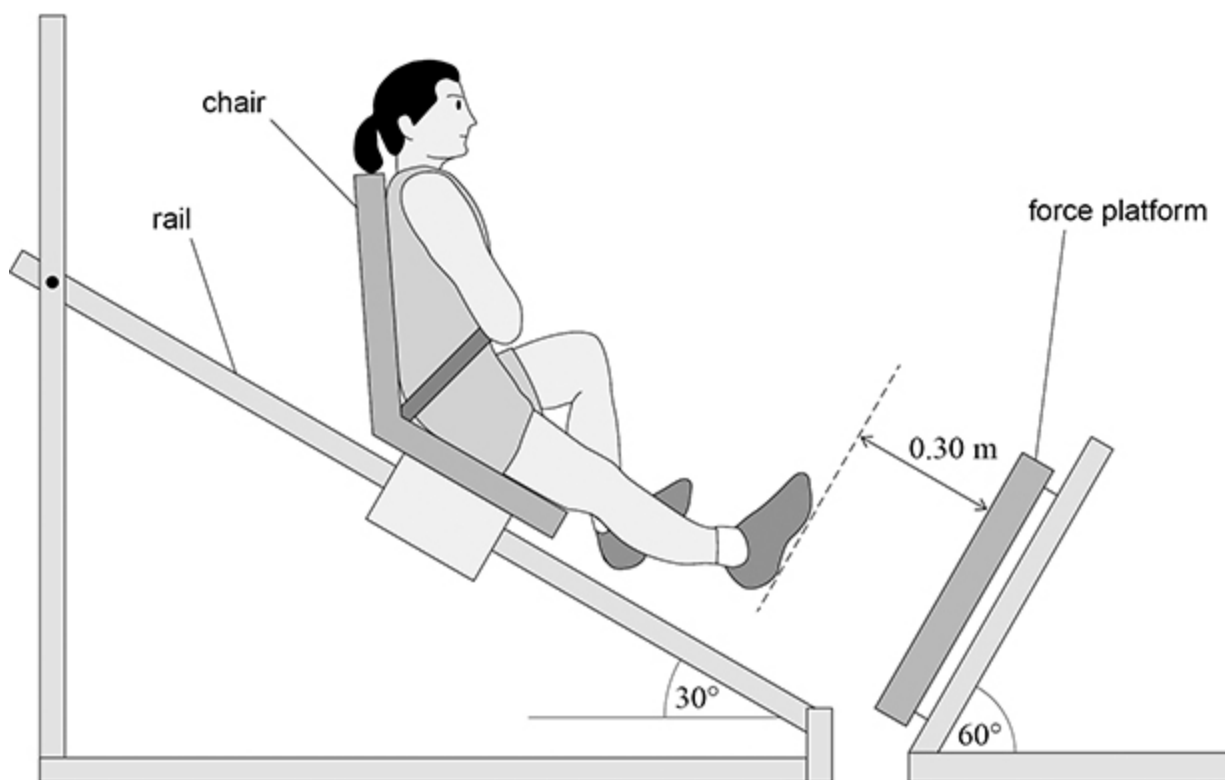
**(3)**

**(Total 9 marks)**

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 m

angle between rail and floor =  $30^\circ$

angle between platform and floor =  $60^\circ$

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

(1)

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

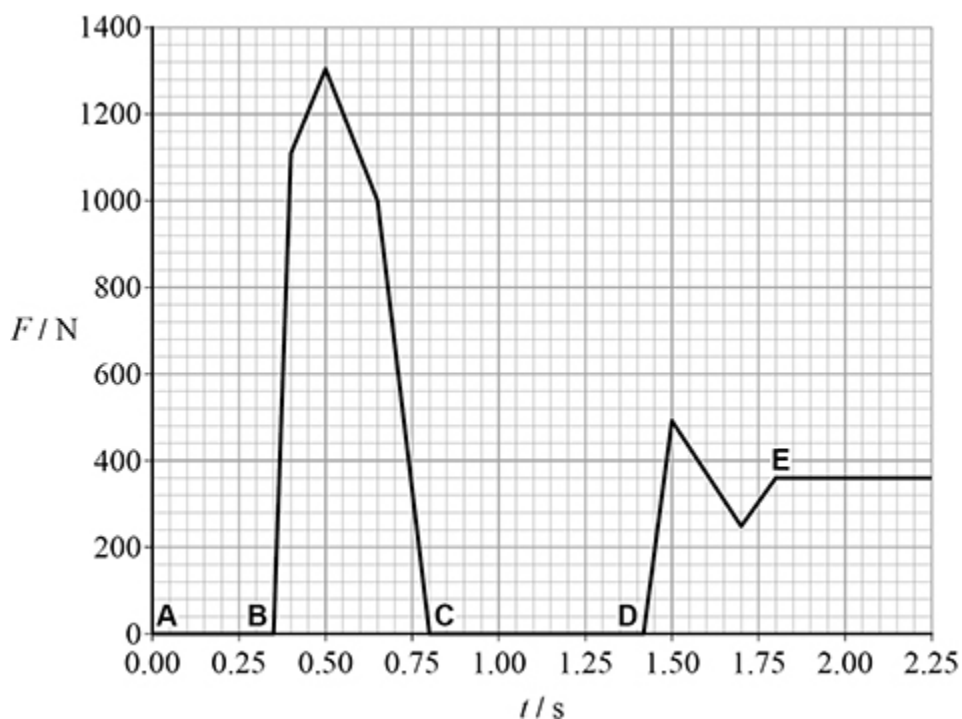
speed = \_\_\_\_\_  $\text{m s}^{-1}$

(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

- (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)

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<sup>-1</sup>

☐

B 27 mm s<sup>-1</sup>

☐

C 54 mm s<sup>-1</sup>

☐

D 110 mm s<sup>-1</sup>

☐

(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**

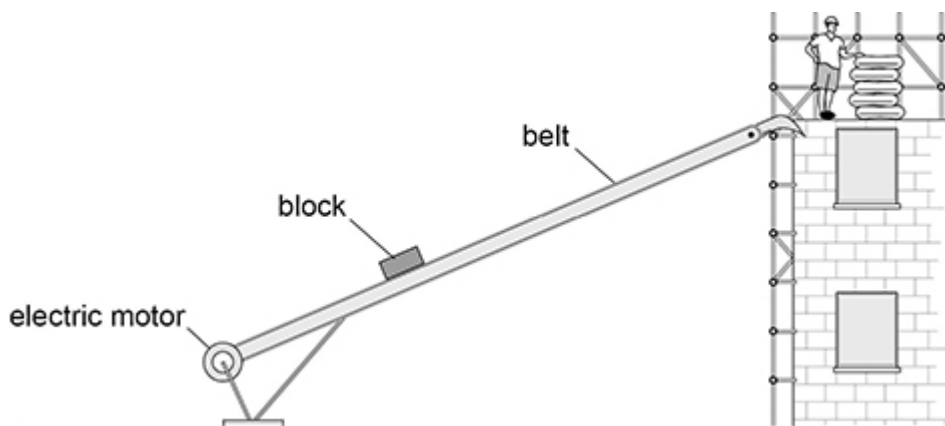
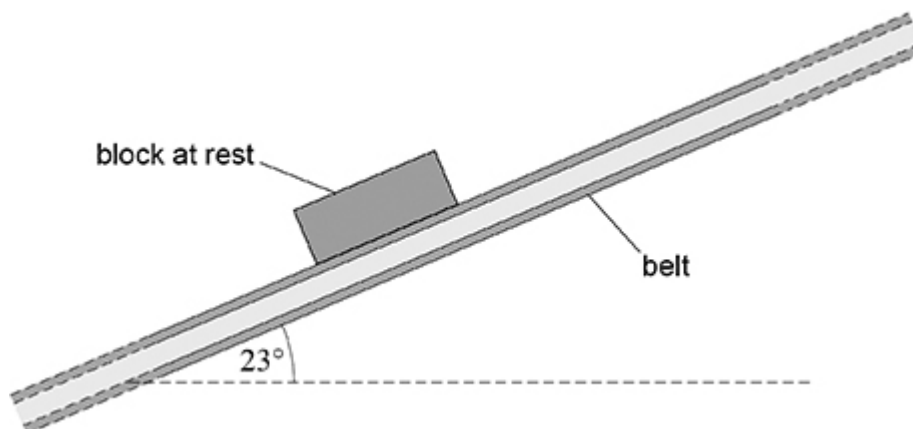


**Figure 2** shows an enlarged view of one block on the belt. The belt is inclined at 23° to the horizontal. The mass of the block is 19 kg.

**Figure 2**



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

- (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  $0.32 \text{ m s}^{-1}$  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)

- (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  $0.32 \text{ m s}^{-1}$  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 = \_\_\_\_\_

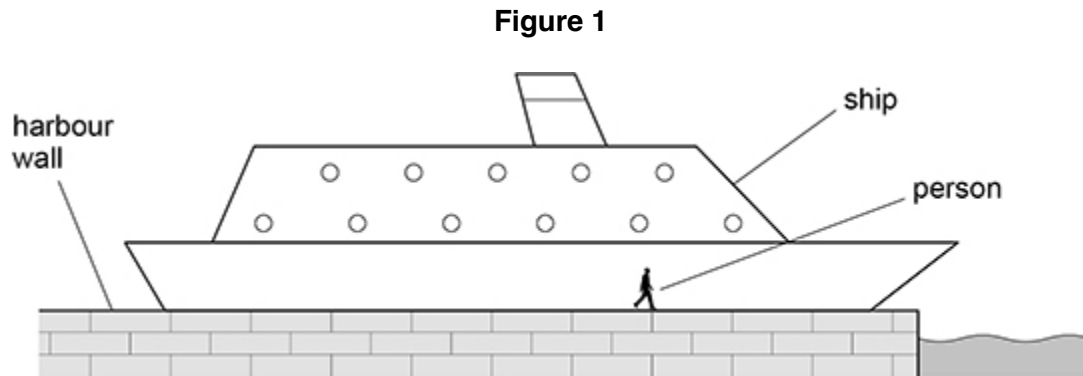
**(4)**

**(Total 9 marks)**

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.



The momentum of the ship is approximately  $1 \times 10^7 \text{ N s}$ .

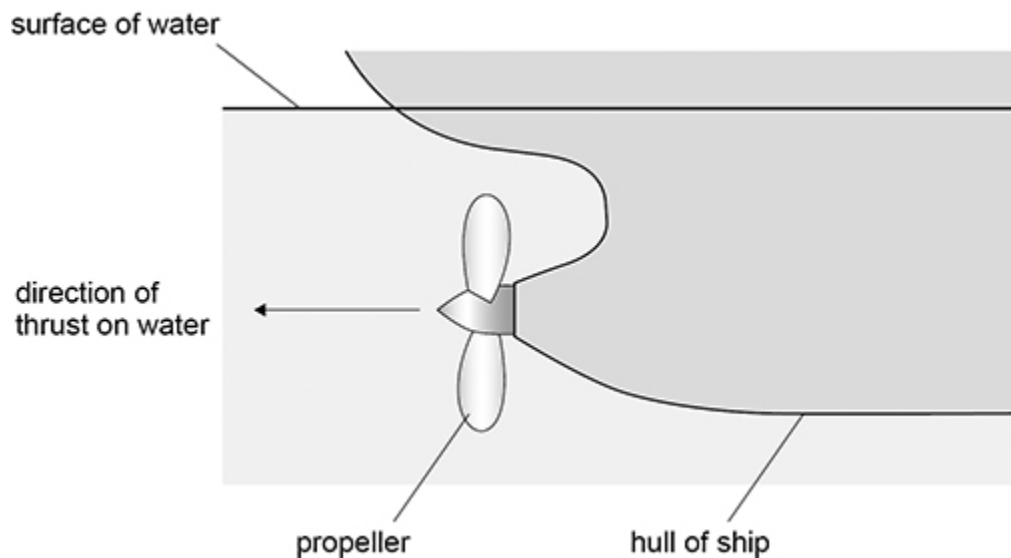
Estimate the mass of the ship.

mass of ship = \_\_\_\_\_ kg

(2)

- (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.

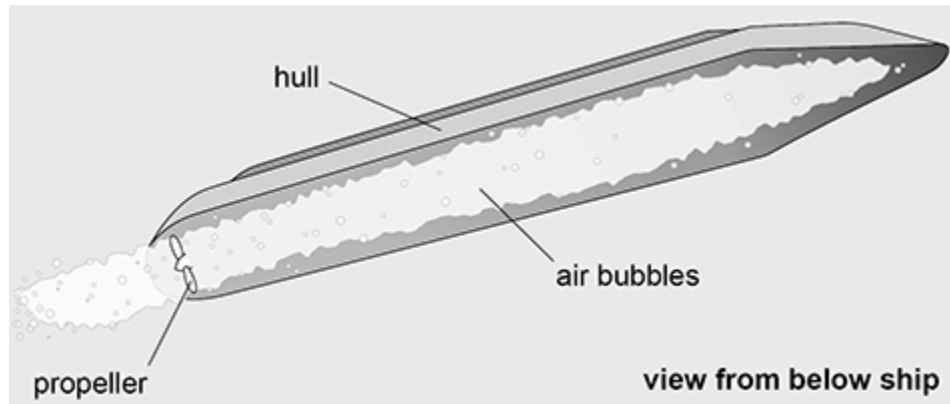
[illegible]

**(4)**

- (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.

---

---

---

---

---

---

---

---

---

---

---

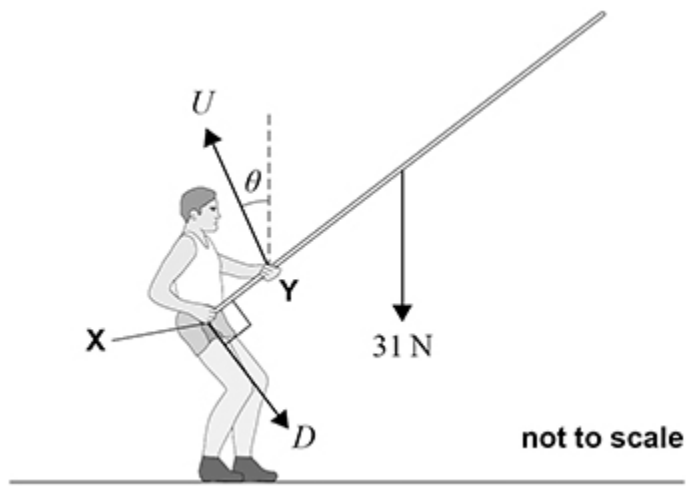
(3)

(Total 9 marks)

6.

**Figure 1** shows an athlete holding a vaulting pole at an angle of  $40^\circ$  to the horizontal.

**Figure 1**



Forces  $D$  and  $U$  are exerted on the pole by the athlete's right and left hands respectively.

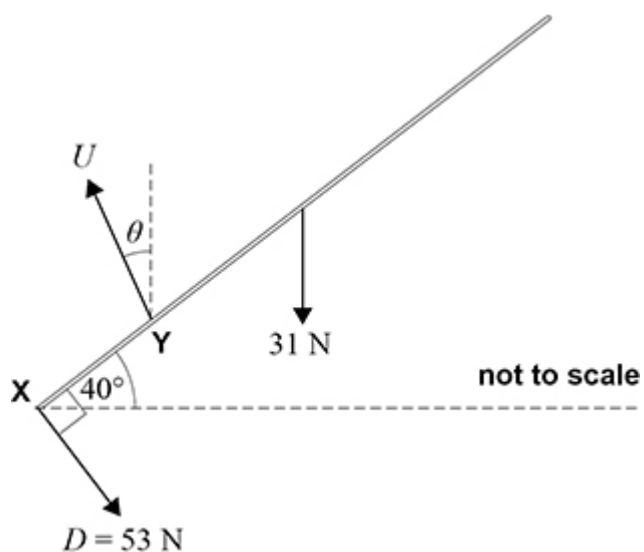
$U$  is applied at point  $Y$  at an angle  $\theta$  to the vertical.

The magnitude of  $D$  is  $53\text{ N}$  and is applied at  $90^\circ$  to the pole at  $X$ .

The uniform pole is in equilibrium. It has a weight of  $31\text{ N}$ .

**Figure 2** shows the forces acting on the pole.

**Figure 2**



- (a) Determine, using a scale Figure,  $\theta$  and the magnitude of  $U$ .

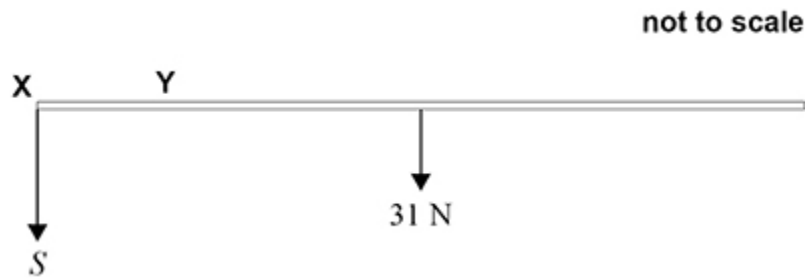
$$\theta = \underline{\hspace{2cm}}^\circ$$

$$\text{magnitude of } U = \underline{\hspace{2cm}} N$$

**(4)**

- (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**.

---

---

---

---

---

---

---

---

---

---

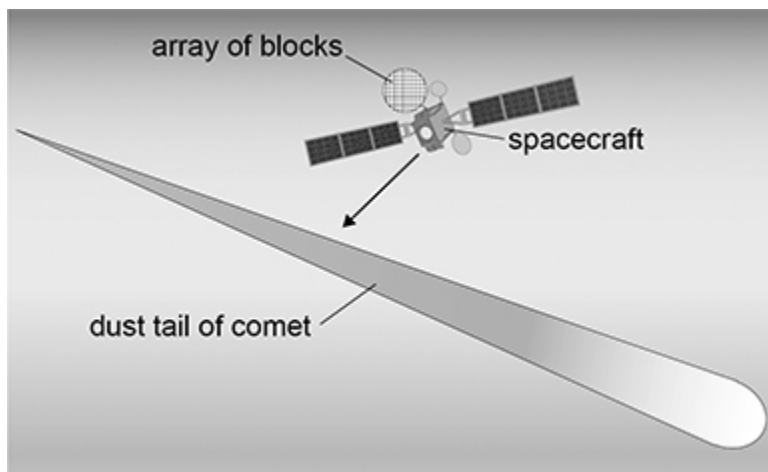
(3)  
(Total 7 marks)

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  $1.1 \times 10^{-9}$  kg. It has a speed of  $5.9 \times 10^3$  m s<sup>-1</sup> 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.

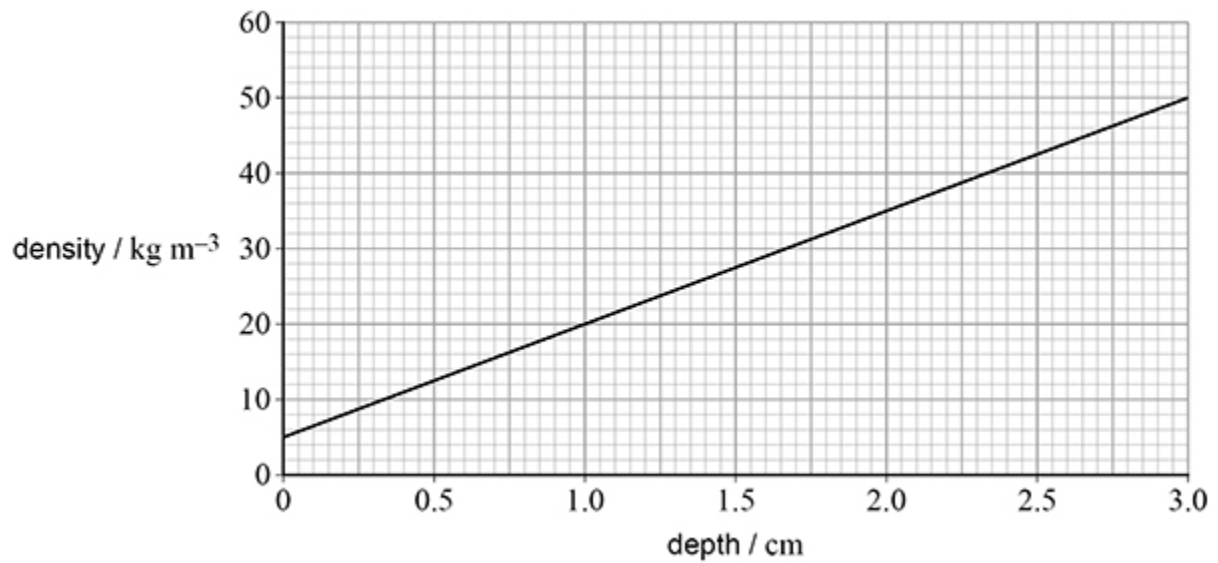
Calculate the average force acting on **P** as it is brought to rest.

average force = \_\_\_\_\_ N

(2)

- (c) The block is rectangular with an area of cross-section of  $8.0 \text{ cm}^2$  and a thickness of  $3.0 \text{ cm}$ . **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)

- (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)

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



What is the tension in the tow rope?

**A** 3000 N☐**B** 4100 N☐**C** 7800 N☐**D** 8900 N☐

(Total 1 mark)

**11.**

A tennis ball has a mass of 58 g.

The ball is dropped from rest from a height of 1.8 m above the ground and falls vertically.

The ball rebounds vertically to a height of 1.1 m.

The effect of air resistance is negligible.

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

**A** 0.040 N s

☐

**B** 0.075 N s

☐

**C** 0.215 N s

☐

**D** 0.614 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

☐

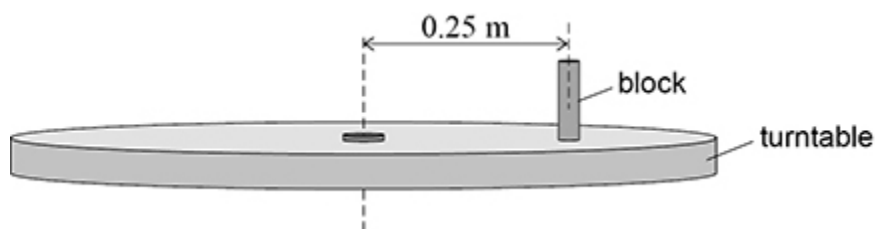
**(Total 1 mark)**

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 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.

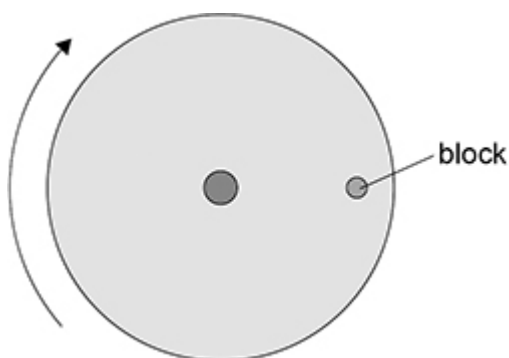
time = \_\_\_\_\_ s

(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)

- (c) The mass of the block is 0.12 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)**

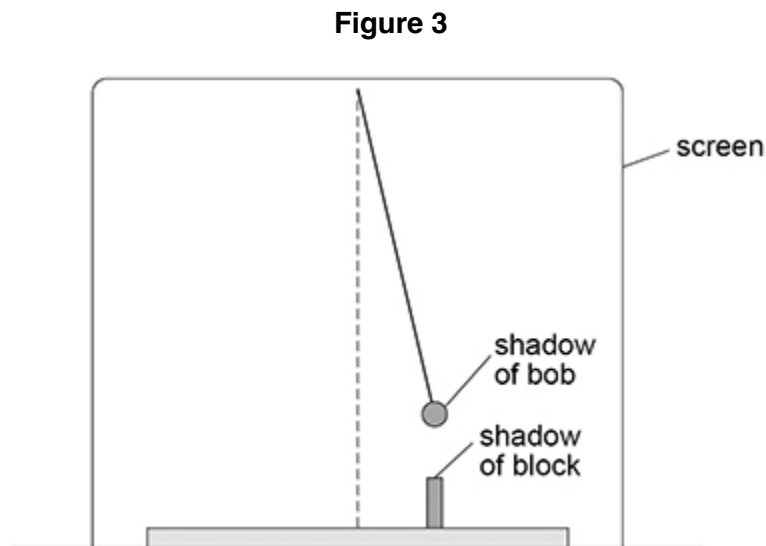
- (e) The teacher adjusts the angular speed of the turntable so that the block completes one rotation every 2.50 s.  
She sets up a simple pendulum above the centre of the turntable so that it swings in phase with the movement of the block.

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.



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  $10^4 \text{ J}$  ☐

B  $10^6 \text{ J}$  ☐

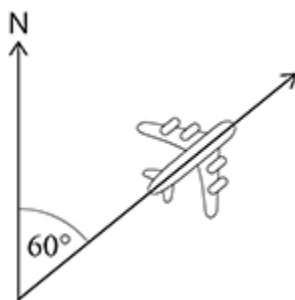
C  $10^8 \text{ J}$  ☐

D  $10^{10} \text{ J}$  ☐

(Total 1 mark)

**15.**

An aeroplane flies horizontally at  $150 \text{ m s}^{-1}$  along a bearing  $60^\circ$  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)**

17.

Object **P** has a mass of 7500 kg and travels at  $12 \text{ m s}^{-1}$ .

Object **Q** has a mass of 2500 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

☐

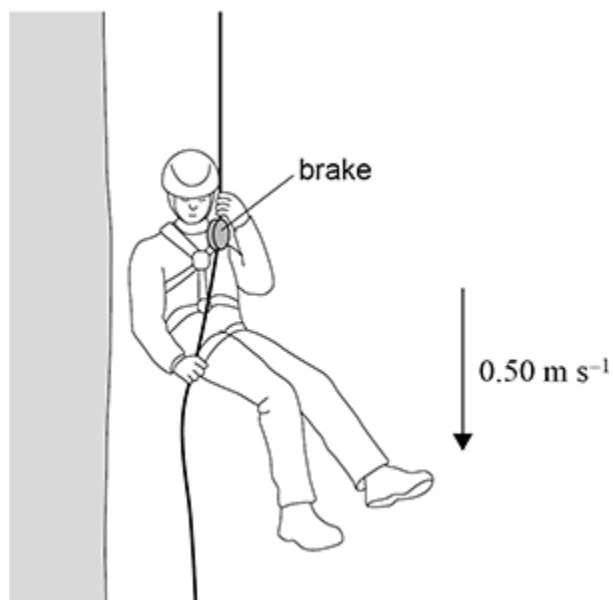
**D** 2.0 MJ

☐

(Total 1 mark)

**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

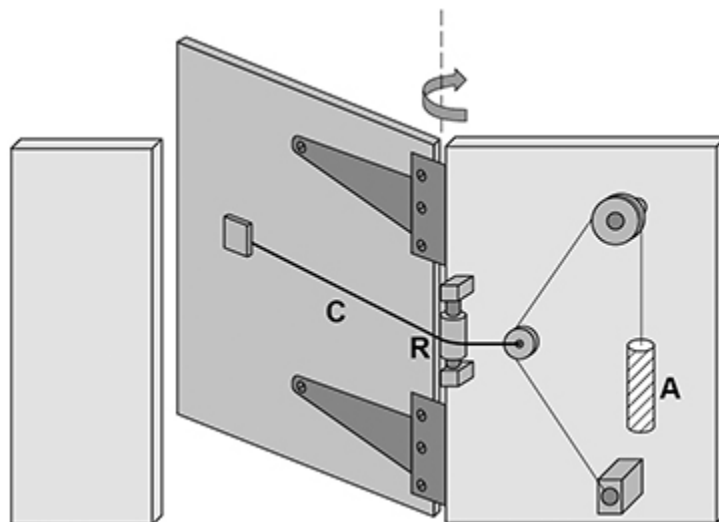
☐

(Total 1 mark)

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 =  $4.8 \times 10^{-2}$  m

length = 0.23 m

weight = 35 N

The table below gives the density of three available materials.

| Material | Density / $\text{kg m}^{-3}$ |
|----------|------------------------------|
| concrete | $2.4 \times 10^3$            |
| iron     | $7.8 \times 10^3$            |
| brass    | $8.6 \times 10^3$            |

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

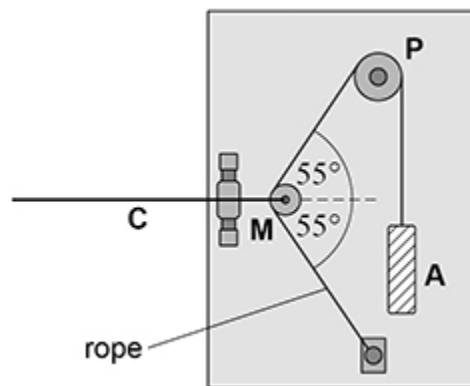
---

---

(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 N and the weight of moveable pulley **M** is negligible.

- (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**.

---

---

---

---

---

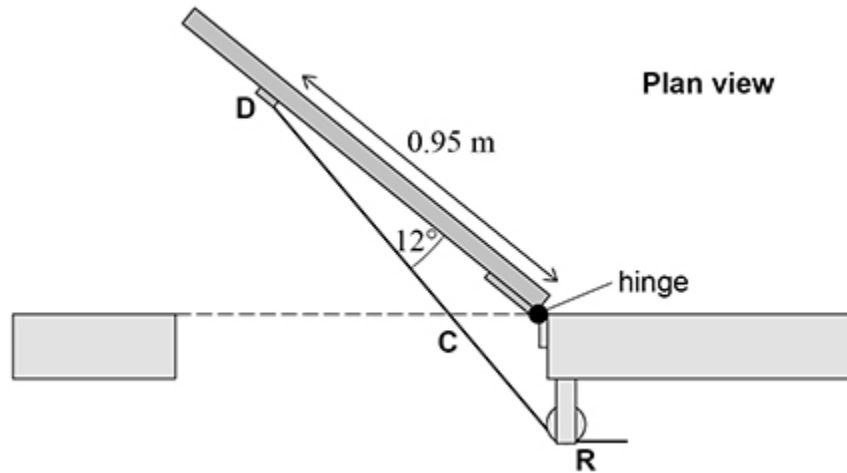
(2)

- (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  $12^\circ$ .

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)

- (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 \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

2 \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

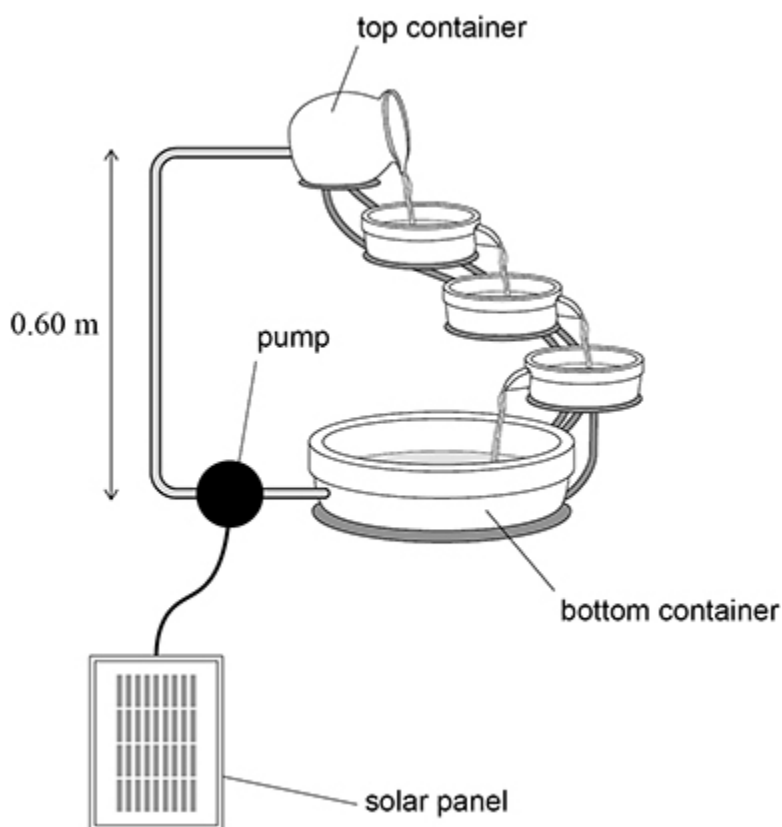
\_\_\_\_\_

(4)

(Total 13 marks)

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)

**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              |                       |
|----------|-------------------------------------------|-------------------|-----------------------|
| <b>A</b> | consists of two equal parallel forces     | $\text{N m}^{-1}$ | <input type="radio"/> |
| <b>B</b> | produces translational motion             | $\text{N m}$      | <input type="radio"/> |
| <b>C</b> | consists of two equal and opposite forces | $\text{N m}$      | <input type="radio"/> |
| <b>D</b> | produces rotational motion                | $\text{N m}^{-1}$ | <input type="radio"/> |

(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 |                       |
|----------|---------------------|--------------------------------|-----------------------|
| <b>A</b> | increasing upwards  | constant downwards             | <input type="radio"/> |
| <b>B</b> | increasing upwards  | decreasing upwards             | <input type="radio"/> |
| <b>C</b> | constant upwards    | constant downwards             | <input type="radio"/> |
| <b>D</b> | decreasing upwards  | constant downwards             | <input type="radio"/> |

(Total 1 mark)

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 |                       |
|----------|-------------|---------------------|-----------------------|
| <b>A</b> | $t_P = t_Q$ | $d_P = d_Q$         | <input type="radio"/> |
| <b>B</b> | $t_P = t_Q$ | $d_P > d_Q$         | <input type="radio"/> |
| <b>C</b> | $t_P < t_Q$ | $d_P = d_Q$         | <input type="radio"/> |
| <b>D</b> | $t_P < t_Q$ | $d_P > d_Q$         | <input type="radio"/> |

(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 cm and then released to oscillate about the equilibrium position.

**M** returns to the equilibrium position for the first time 0.50 s after release.

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

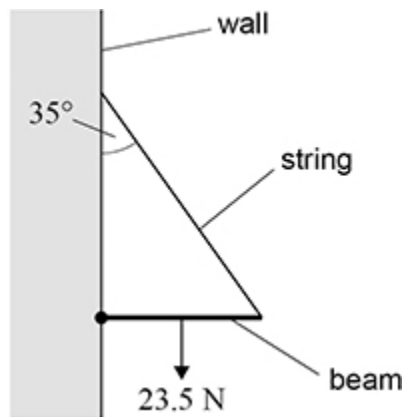
|          | Amplitude / cm | Period / s |                       |
|----------|----------------|------------|-----------------------|
| <b>A</b> | 10             | 1.0        | <input type="radio"/> |
| <b>B</b> | 10             | 2.0        | <input type="radio"/> |
| <b>C</b> | 20             | 2.0        | <input type="radio"/> |
| <b>D</b> | 20             | 1.0        | <input type="radio"/> |

(Total 1 mark)

**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  $35^\circ$  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

☐

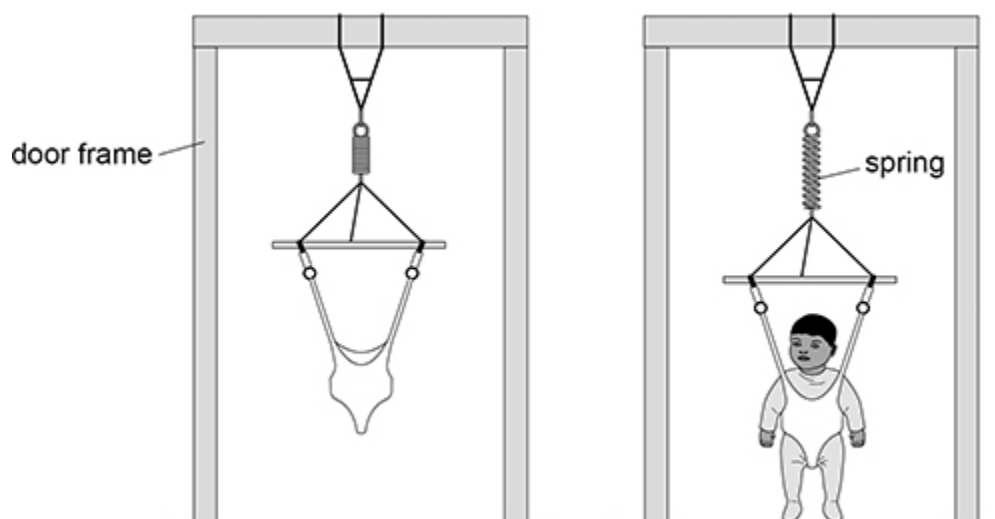
**D** velocity

☐

(Total 1 mark)

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<sup>-1</sup>

☐

B 10–100 N m<sup>-1</sup>

☐

C 100–1000 N m<sup>-1</sup>

☐

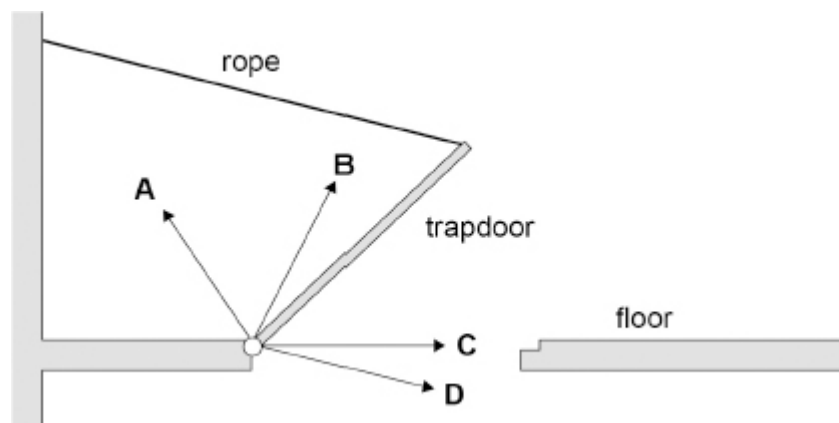
D 1000–10 000 N m<sup>-1</sup>

☐

(Total 1 mark)

29.

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



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

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  $\frac{k}{mg}$

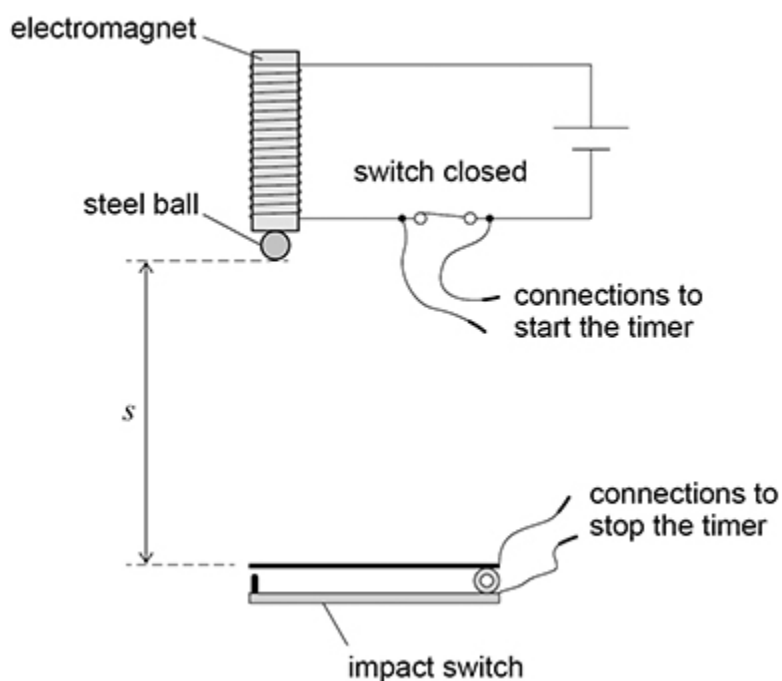


(Total 1 mark)

**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.

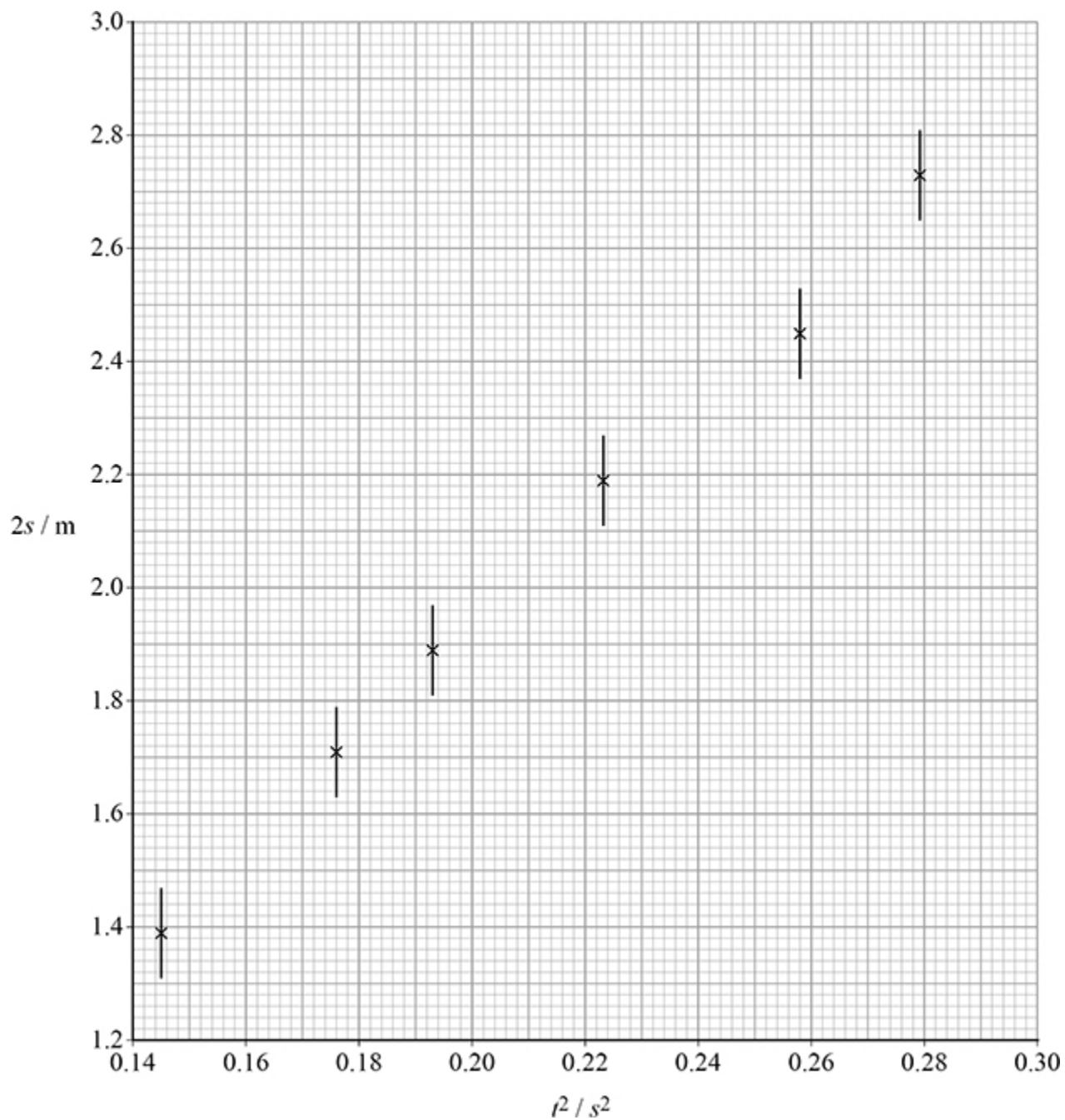
The ball falls vertically onto an impact switch and this stops the timer.

The timer displays the time  $t$  for the ball to fall through the vertical distance  $s$  shown in **Figure 1**.

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**



- (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  $s = \underline{\hspace{2cm}}$  m

**(1)**

- (b) Determine

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

$G_{\text{max}} = \underline{\hspace{2cm}}$

$G_{\text{min}} = \underline{\hspace{2cm}}$

**(3)**

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

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

$$g = \text{_____} \text{ m s}^{-2}$$

(2)

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

$$\text{percentage uncertainty} = \text{_____} \%$$

(2)

A fault develops in the apparatus.

When the switch is opened there is now a 30 ms 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)

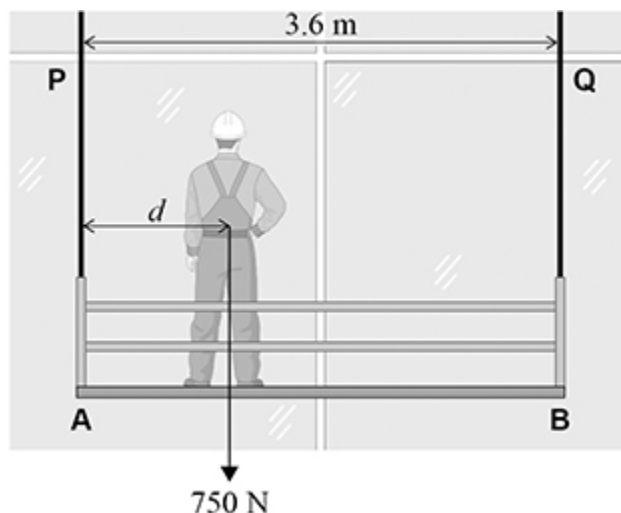
(Total 10 marks)

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  $1150\text{ N}$ .

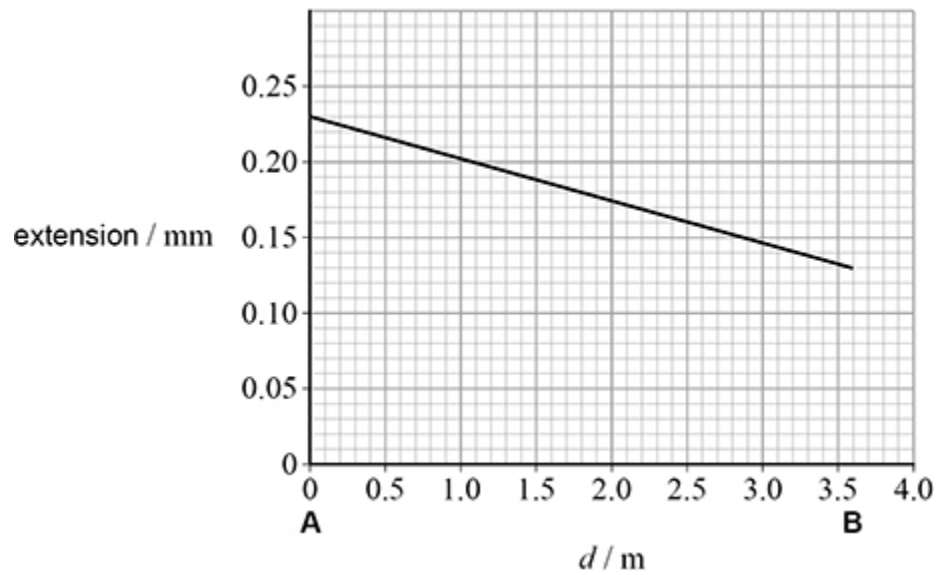
Calculate  $d$  for this position.

$$d = \text{_____ m}$$

**(3)**

**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  $6.0 \times 10^{-5}$ .

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

$$d = \text{_____ m}$$

**(2)**

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

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

$$\text{tensile stress} = \text{_____ N m}^{-2}$$

**(1)**

- (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.

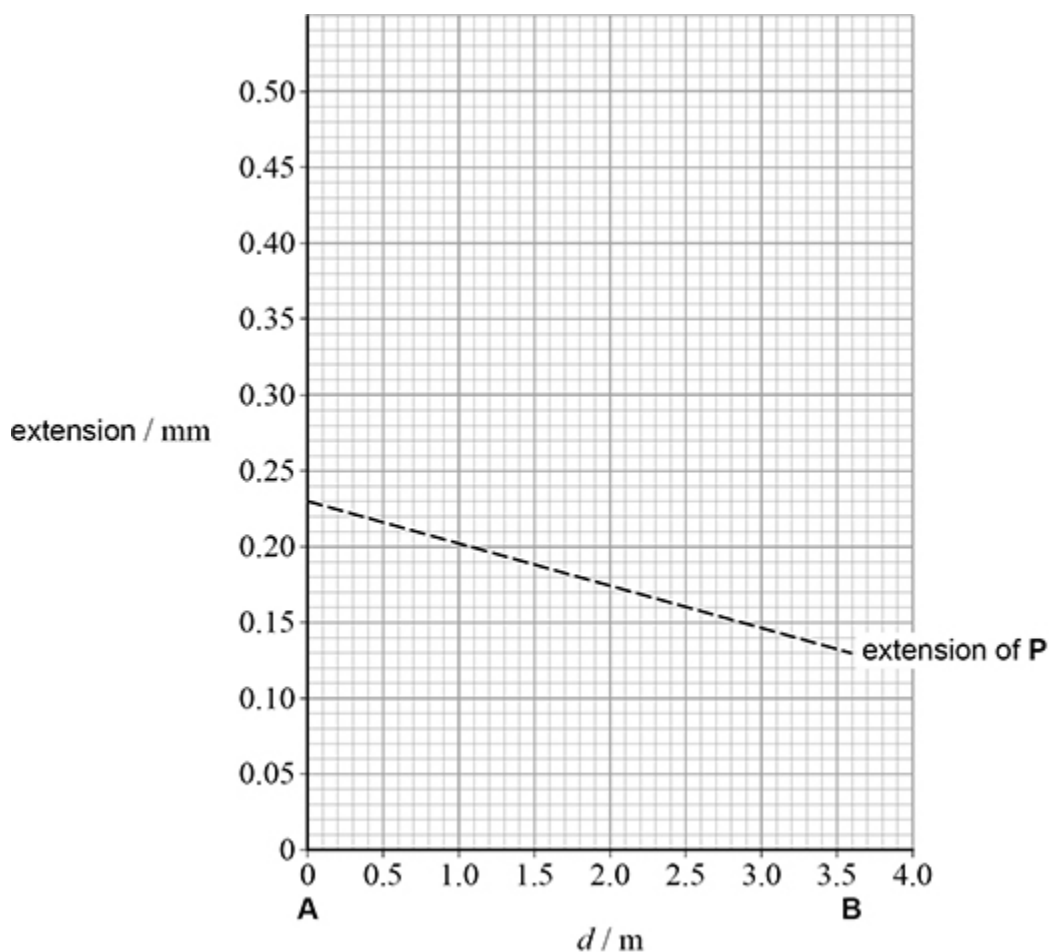
|                    | Unstretched length | Radius        | Young modulus of cable material |
|--------------------|--------------------|---------------|---------------------------------|
| Original cables    | $L$                | $r$           | $E$                             |
| Replacement cables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

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**



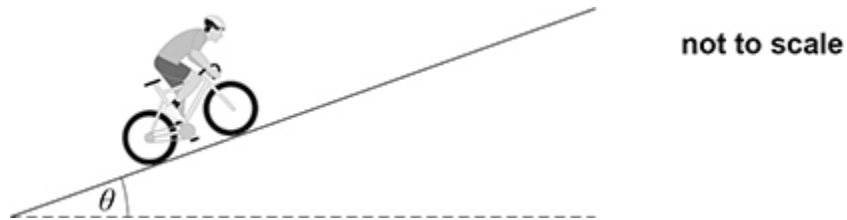
(3)

(Total 9 marks)

**33.**

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

**Figure 1**



The angle  $\theta$  of the slope of the hill is constant.

The total mass  $m$  of the cyclist and bicycle is 65 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 W.

The cyclist has a steady speed of  $1.63 \text{ m s}^{-1}$ .

Assume that air resistance is negligible at this speed.

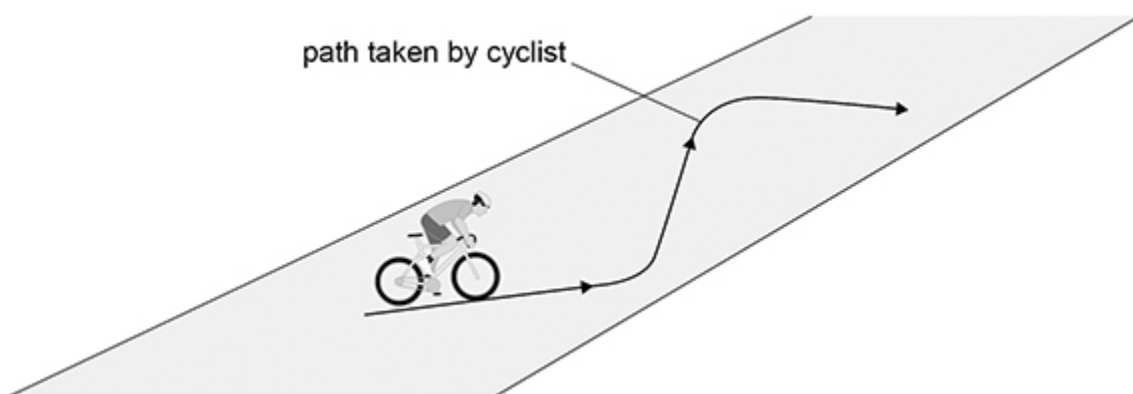
Calculate  $\theta$ .

$$\theta = \text{_____}^\circ$$

**(2)**

**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).

---

---

---

---

---

---

---

---

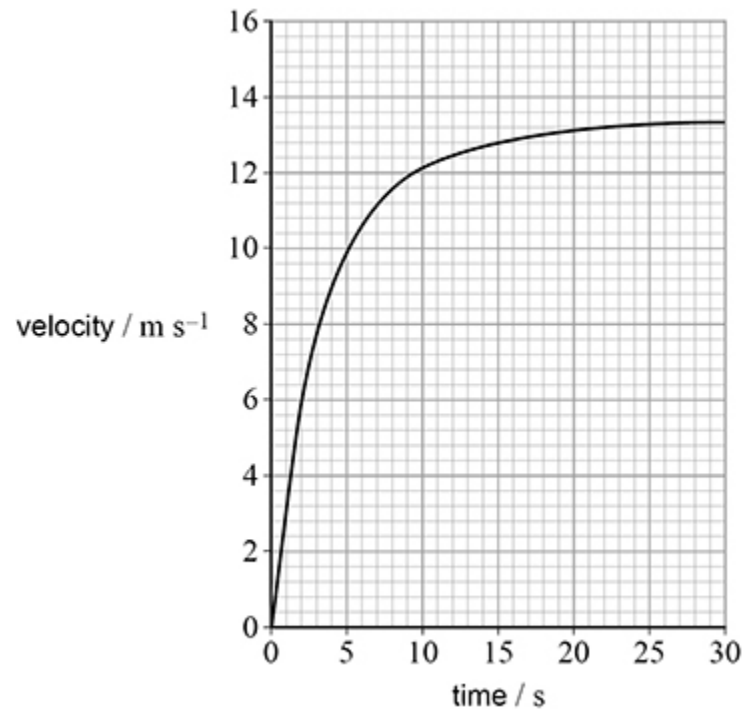
---

(3)

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 s after she begins to go down the hill.

acceleration = \_\_\_\_\_ m s<sup>-2</sup>

**(3)**

- (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**.

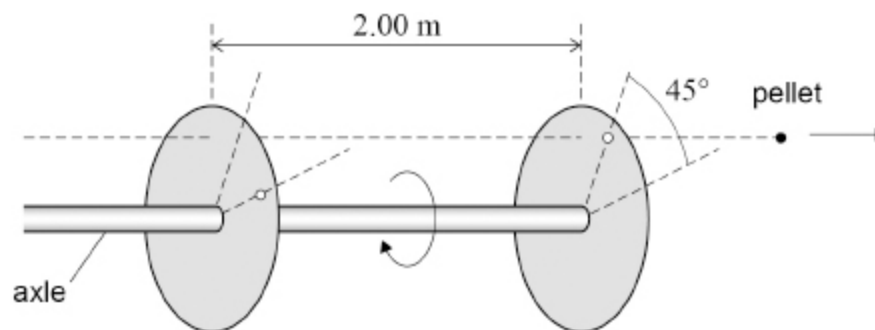
[illegible]

**(4)**

**(Total 13 marks)**

**34.**

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



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  $45^\circ$ .

The speed of the pellet between the discs is  $300 \text{ m s}^{-1}$ .

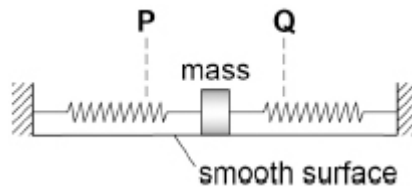
How many revolutions does each disc complete in one second?

- |               |                       |
|---------------|-----------------------|
| <b>A</b> 19   | <input type="radio"/> |
| <b>B</b> 118  | <input type="radio"/> |
| <b>C</b> 740  | <input type="radio"/> |
| <b>D</b> 1074 | <input type="radio"/> |

(Total 1 mark)

35.

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



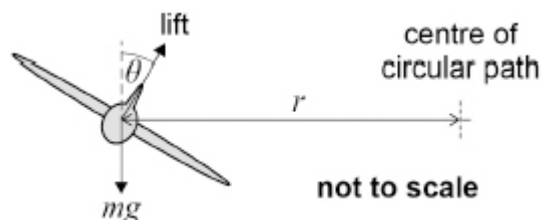
Which quantity has its magnitude at a minimum value when the mass is at **Q**?

- |                                                         |                       |
|---------------------------------------------------------|-----------------------|
| <b>A</b> the acceleration of the mass                   | <input type="radio"/> |
| <b>B</b> the kinetic energy of the mass                 | <input type="radio"/> |
| <b>C</b> the potential energy of the mass-spring system | <input type="radio"/> |
| <b>D</b> the resultant force of the springs on the mass | <input type="radio"/> |

(Total 1 mark)

36.

When an aircraft turns in a horizontal circular path, it banks at an angle  $\theta$ .



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  $\theta$ .

What is  $\tan \theta$ ?

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.

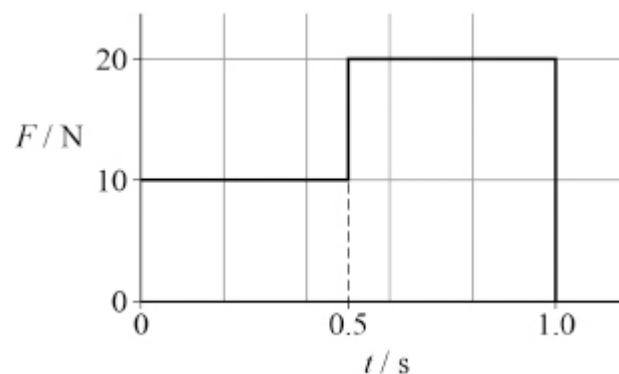
☐

(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  $t$ .



What is the speed of the object when  $t = 1.0 \text{ s}$ ?

**A**  $3.75 \text{ m s}^{-1}$



**B**  $5.00 \text{ m s}^{-1}$



**C**  $7.50 \text{ m s}^{-1}$



**D**  $15.0 \text{ m s}^{-1}$



(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**

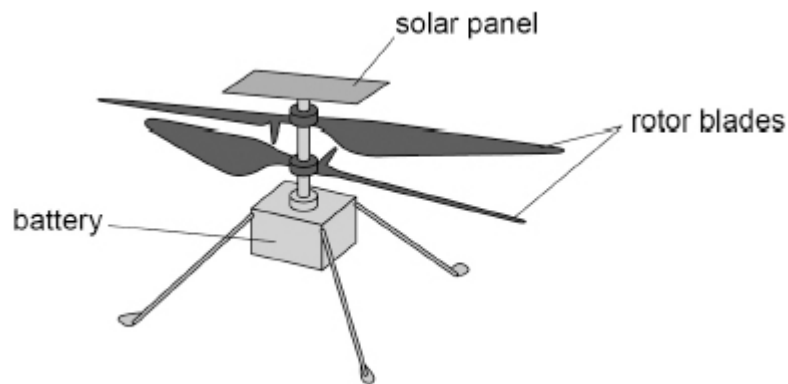
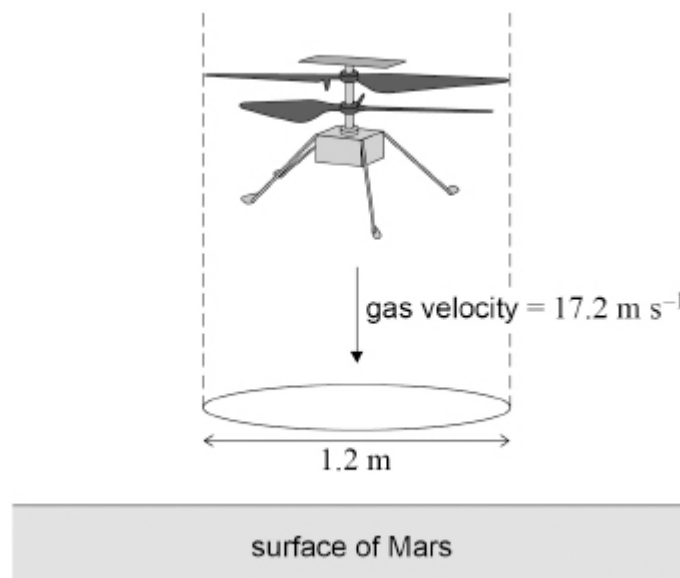


**Figure 2** shows the helicopter hovering at a constant height above the surface of Mars. The rotor blades move a column of atmospheric gas vertically downwards at a velocity of  $17.2 \text{ m s}^{-1}$ . The diameter of this column is  $1.2 \text{ m}$ .

**Figure 2**



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

Show that the helicopter moves approximately  $0.4 \text{ kg}$  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  $3.72 \text{ N kg}^{-1}$ .

- (b) Calculate the mass of the helicopter.

mass = \_\_\_\_\_ kg

**(3)**

- (c) The battery stores  $0.035 \text{ kW h}$  of energy before a flight.  
The flight lasts for  $39 \text{ s}$ .  
The battery has a power output of  $340 \text{ W}$  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.

---

---

---

---

---

---

---

---

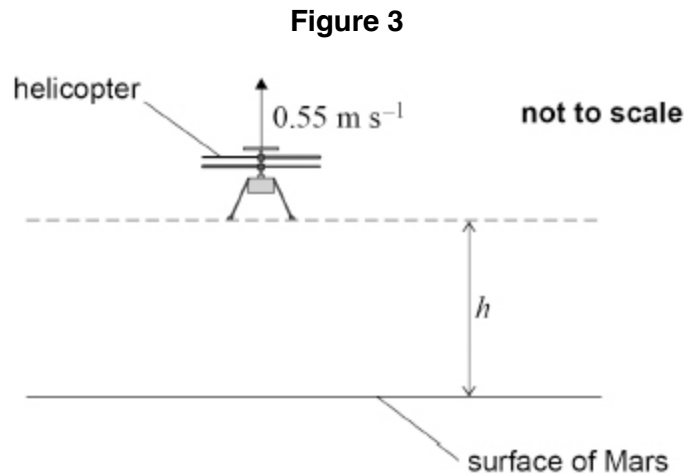
---

---

**(3)**

**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.



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)**

- (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.

---



---



---



---



---

(2)

(Total 17 marks)

**40.** Which is a pair of vectors?

A weight and work

☐

B force and energy

☐

C displacement and momentum

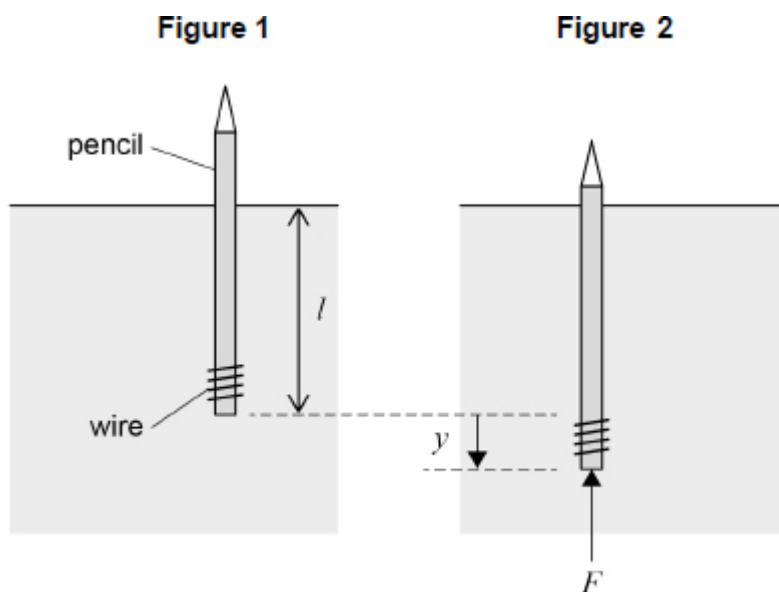
☐

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.



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

$\rho$  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

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

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 = \_\_\_\_\_  $\text{m s}^{-2}$

**(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.

---

---

---

---

---

---

---

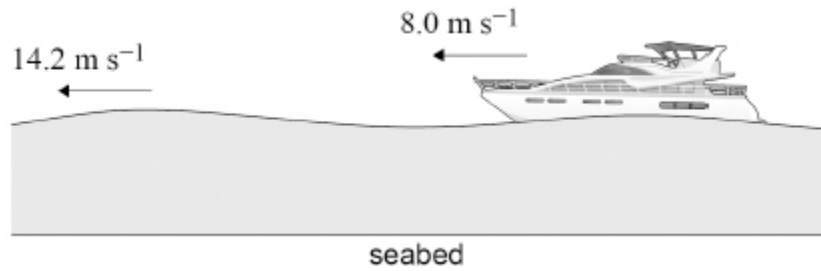
---

**(2)**

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

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

**Figure 3**



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

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

There are two options:

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

Deduce which is the better option.

Support your answer with a calculation.

---

---

---

---

---

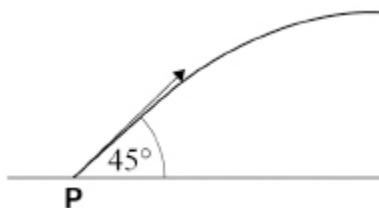
---

(3)

(Total 9 marks)

42.

A ball is kicked from point **P** on level ground. The ball initially travels at  $45^\circ$  to the horizontal. The ball reaches its maximum height after a time of  $2.0 \text{ s}$ . Air resistance can be ignored.



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    |                       |
|----------|-------------------|---------------------|-----------------------|
| <b>A</b> | power             | mass × displacement | <input type="radio"/> |
| <b>B</b> | force             | work done × time    | <input type="radio"/> |
| <b>C</b> | power             | work done × time    | <input type="radio"/> |
| <b>D</b> | force             | mass × displacement | <input type="radio"/> |

(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?

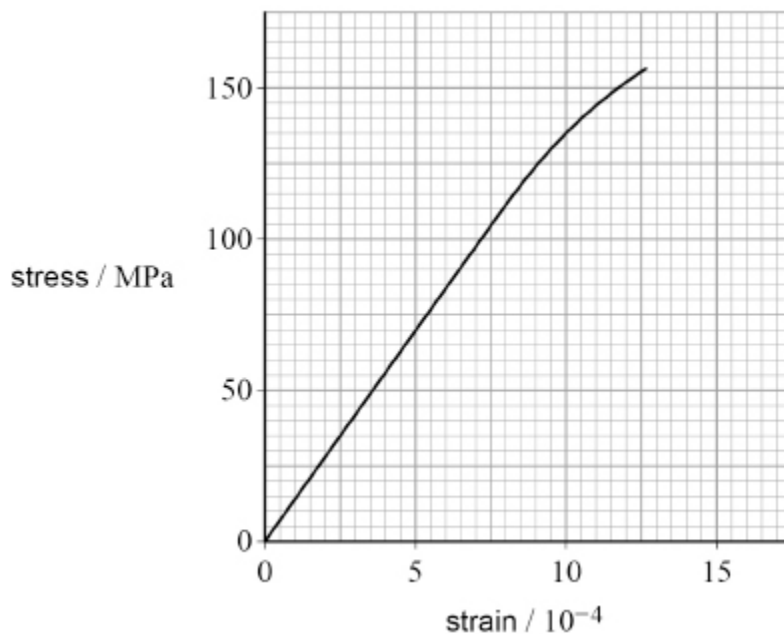
- A** 2 m s<sup>-1</sup> ☐
- B** 4 m s<sup>-1</sup> ☐
- C** 8 m s<sup>-1</sup> ☐
- D** 10 m s<sup>-1</sup> ☐

(Total 1 mark)

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.

---



---

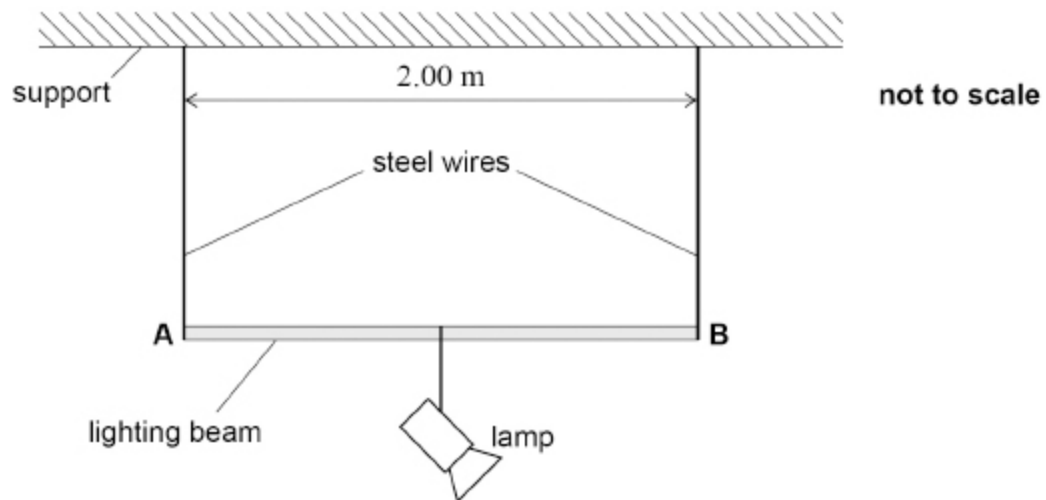


---

(1)

**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 =  $2.10 \times 10^{11}$  Pa

(c) Calculate the extension of each wire.

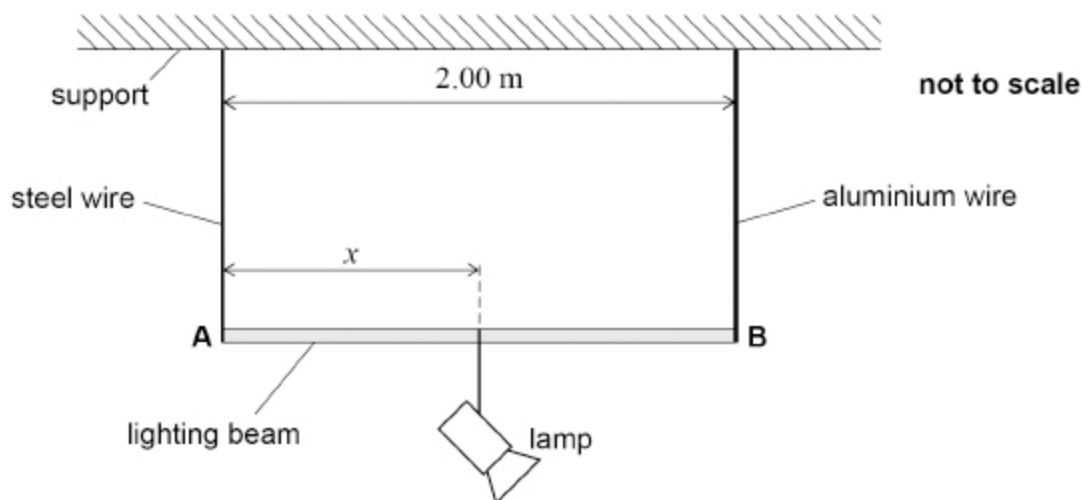
extension = \_\_\_\_\_ m

(3)

- (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  $7.00 \times 10^{10}$  Pa.

Deduce distance  $x$ .

$$x = \text{_____ m}$$

(5)

(Total 10 marks)

46.

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

|          | Speed                   | Journey time       |                       |
|----------|-------------------------|--------------------|-----------------------|
| <b>A</b> | $10 \mu\text{m s}^{-1}$ | 100 s              | <input type="radio"/> |
| <b>B</b> | $10 \text{ km s}^{-1}$  | $0.01 \mu\text{s}$ | <input type="radio"/> |
| <b>C</b> | $1 \text{ nm s}^{-1}$   | 1 Gs               | <input type="radio"/> |
| <b>D</b> | $0.1 \text{ Mm s}^{-1}$ | 100 ns             | <input type="radio"/> |

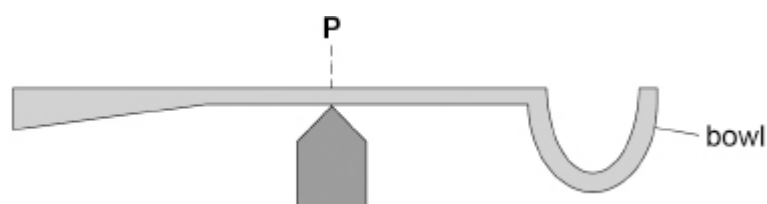
(Total 1 mark)

47.

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

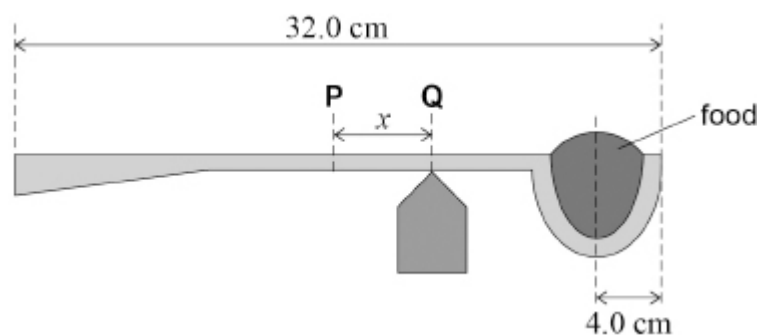
The empty spoon balances when a pivot is placed under a point **P** halfway along the spoon.

**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.

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

---

---

---

---

(2)

- (b) The empty spoon has mass  $m$  .

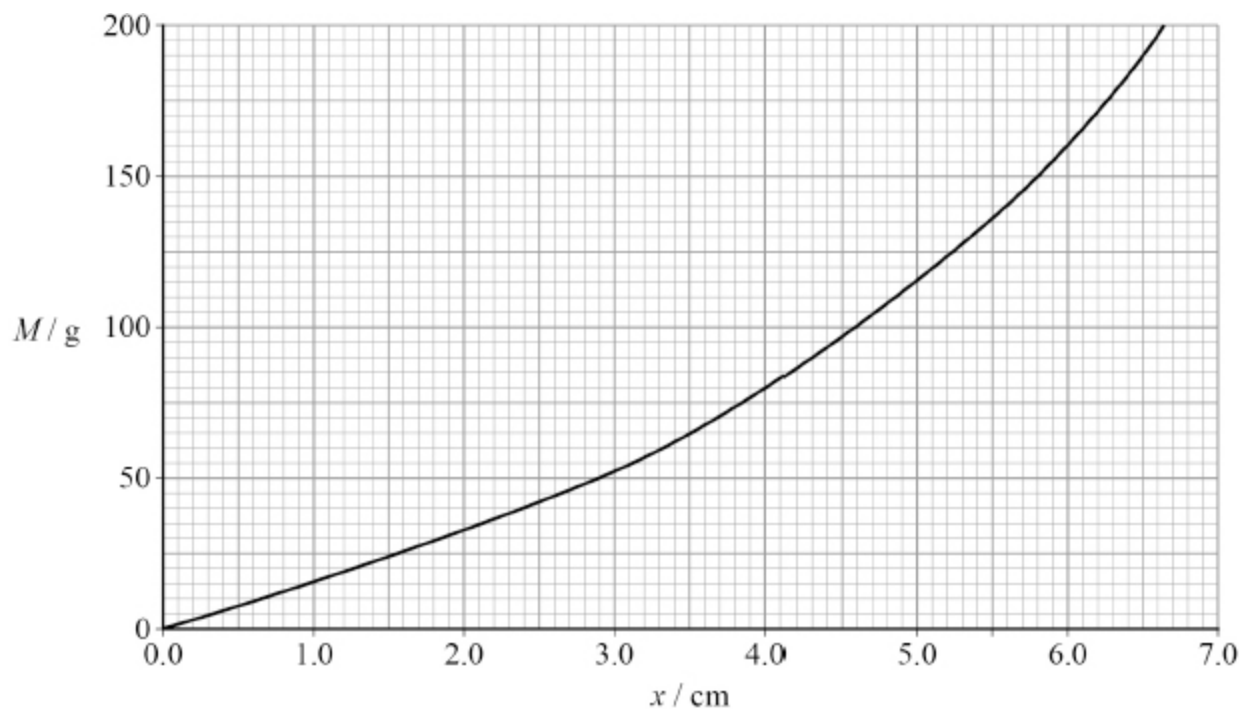
Show that, for the arrangement in **Figure 2**,

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

(2)

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

**Figure 3**



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

weight = \_\_\_\_\_ N

**(3)**

- (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.

---

---

---

---

---

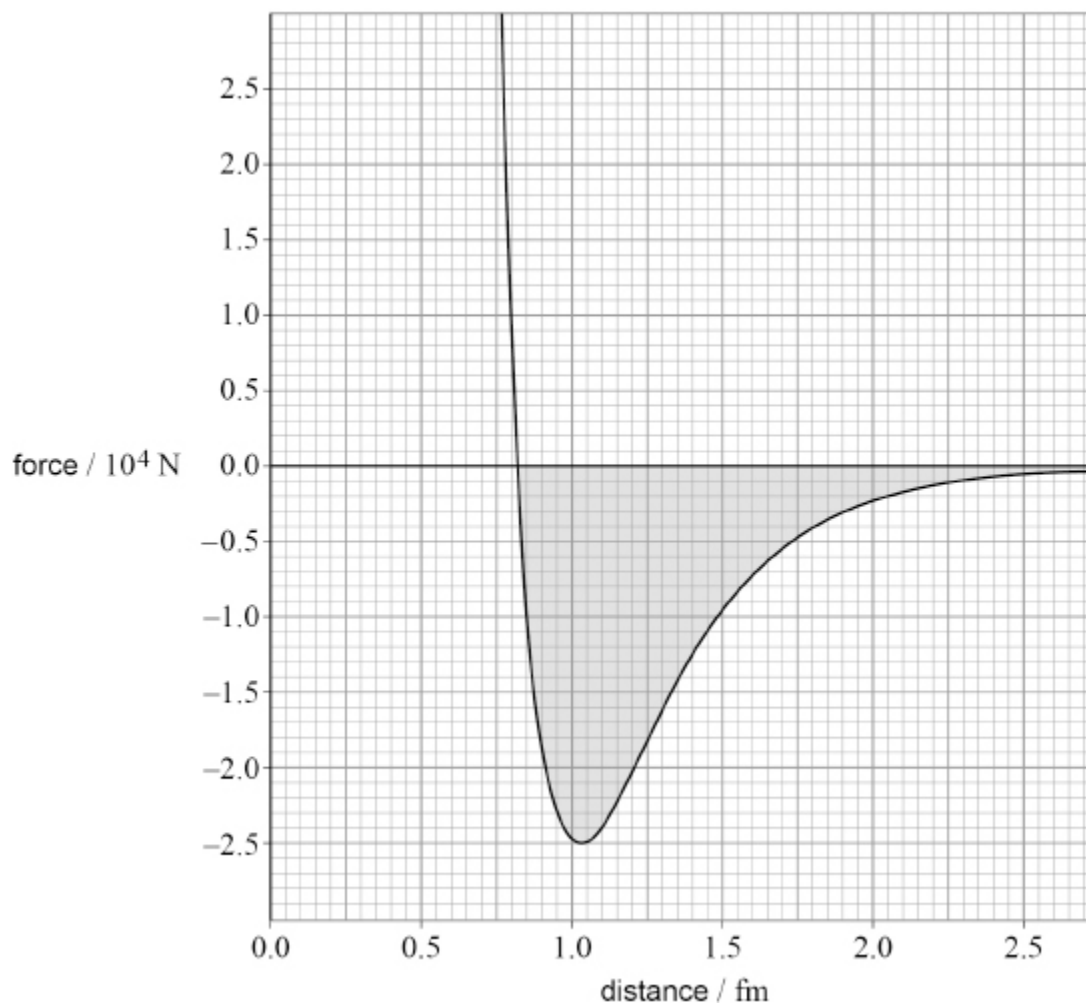
---

(3)

(Total 10 marks)

48.

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



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  $1230 \text{ km h}^{-1}$ .

This was the average speed achieved by a jet-powered car in two runs. Each run was measured over a distance of  $1.61 \text{ km}$ .

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

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

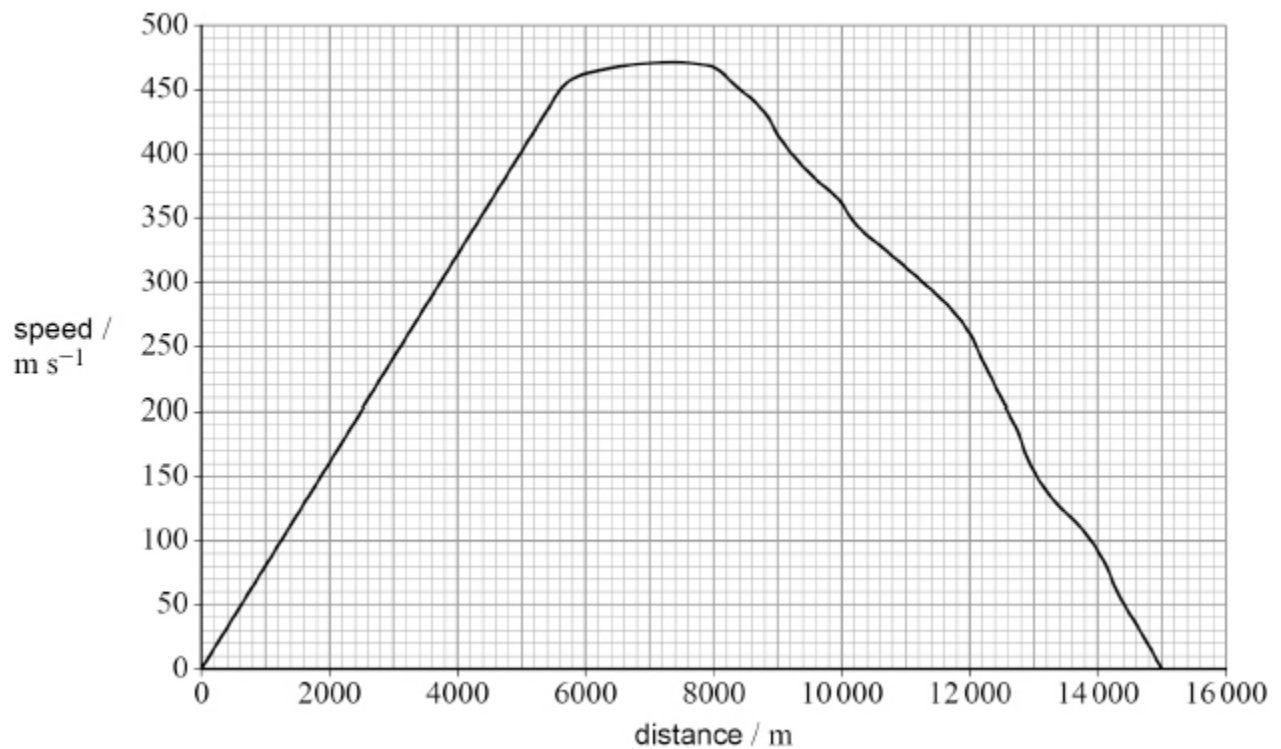
time = \_\_\_\_\_ s

(2)

- (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  $6.50 \times 10^3 \text{ kg}$ .

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

kinetic energy = \_\_\_\_\_ J

(2)

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

$$\text{acceleration} = \text{speed} \times \text{gradient of line}$$

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.

$$\text{percentage of input power} = \text{_____} \%$$

**(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)**

**50.**

A pellet of mass 25 g travelling horizontally at  $40 \text{ m s}^{-1}$  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**  $2.5u$

☐

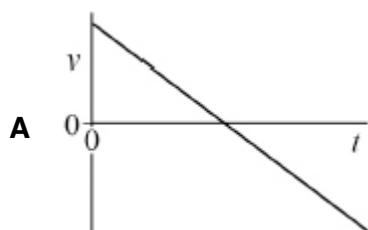
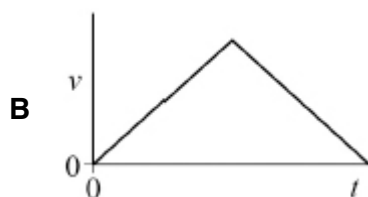
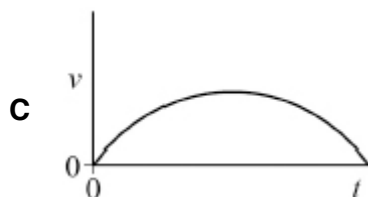
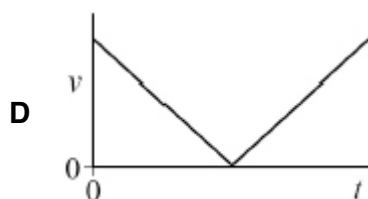
(Total 1 mark)

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?


☐

☐

☐

☐

(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**  $\sqrt{2}v$

☐

**C**  $v\sqrt{2}$

☐

**D**  $2v$

☐

(Total 1 mark)

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 / $\mu\text{s}$ | 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  $\frac{T_1}{T_2}$ .

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

Tick ✓ **one** box.

$$6.0 \times 10^{-5}$$

☐

$$3.0 \times 10^{-4}$$

☐

$$9.0 \times 10^{-3}$$

☐

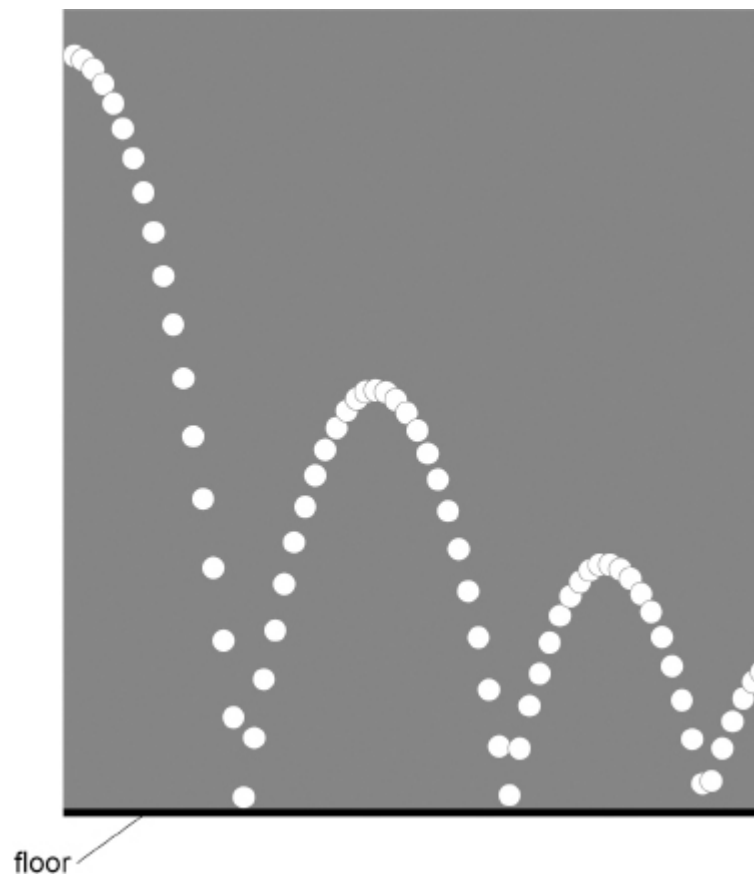
$$4.5 \times 10^{-2}$$

☐

(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**



Suggest why  $T_1$  must be very short for this experiment.

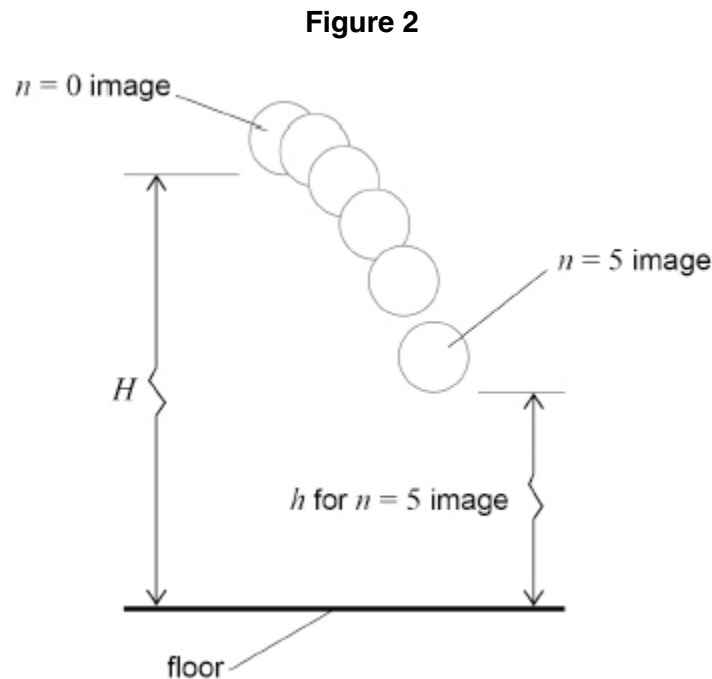
---

---

---

(1)

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



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.

- (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.

$$H = 1550 \text{ mm}$$

$$f = 31.0 \text{ Hz}$$

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

**(3)**

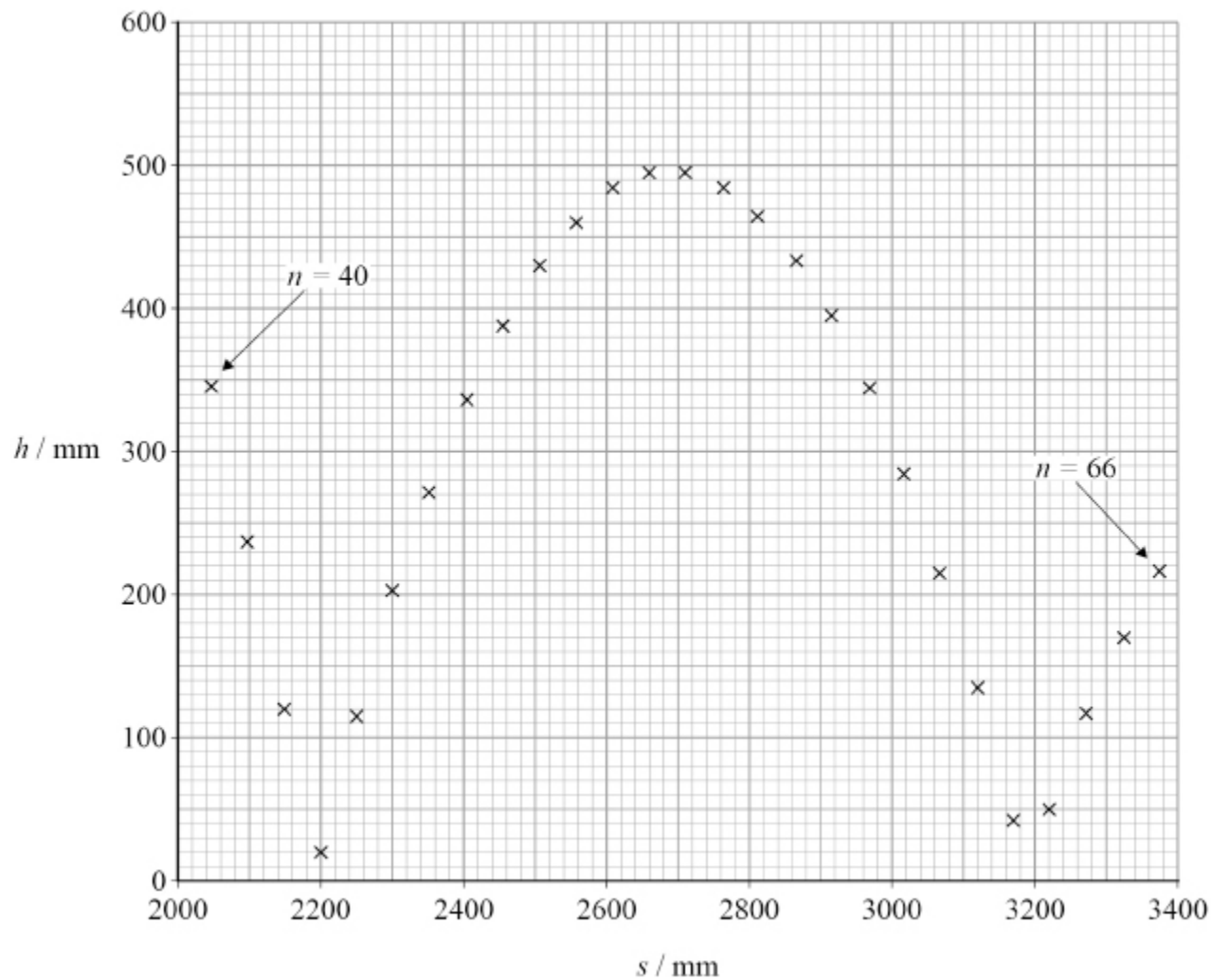
- (d) Determine  $u_0$ .

$$u_0 = \text{_____} \text{ m s}^{-1}$$

**(3)**

**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**



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

horizontal velocity = \_\_\_\_\_  $\text{mm s}^{-1}$

(2)

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

time = \_\_\_\_\_ s

(3)

(Total 13 marks)

## Mark schemes

1.

- (a) Attempts to set forces equal with double a component of tension.

**OR**

Attempts to set forces equal with single horizontal component of tension ( $T \cos \theta$ ) ✓

( $T =$ ) 310 (N) ✓

*Expect to see  $F = 2T \cos 75$  **OR**  $80 = T \cos 75$*

*Condone  $F = 2 T \sin 75$  **OR**  $160 = 2 T \sin 75$*

*OR  $F = 2T \sin$  (their acute angle)*

*OR  $F = 2T \cos$  (their acute angle)*

***OR**  $\frac{80}{\sin 75}$  seen **and** 83 N on answer line.*

*Condone  $F = T \cos 75$  **OR**  $160 = T \cos 75$*

***OR** ( $T =$ )  $\frac{160}{\cos 75}$  with 620 N on answer line*

*An answer of 83 N due to  $F$  and  $T$  being interchanged obtains zero marks.*

*Alternative*

*closed triangle (75-75-30) of forces*

*An attempted use of Sine or Cosine Rule seen with correct closed triangle **MP1***

*Accept answer correctly rounded to at least 2 sf.*

*Answer = 309 (N) to 3 sf*

*Calculator display= 309.0962644*

2

- (b) Read off for  $F = 208$  N

**OR**

use of  $F = ma$  ✓

*Range for read-off is 208 N to 210 N*

*In use of  $F = ma$ :*

- must see substitution for  $F$  and  $m$*
- condone either POT error in  $m$  or  $F$  outside range but not both.*

( $a =$ ) 9900 ( $\text{m s}^{-2}$ ) ✓

*Accepted range = 9900 to 10000*

*Penalise  $1 \times 10^4$  N as a 1 sf answer.*

2

- (c) Area under graph calculated in J for either  $s = 0.10 \text{ m}$  or  $s = 0.385 \text{ m}$  ✓  
 $s = 0.385 \text{ m}$  is approximately 64 blocks, 1 J per block (64 J)  
 $s = 0.10 \text{ m}$  gives 8 blocks at 1 J per block (8 J)  
 Or  $\frac{1}{2} \times 0.1 \times 160 = 8 \text{ J}$  (less than 64 J)

$s_r = 0.385 \text{ m}$  ✓

Range for  $s_r$  between 0.38 m and 0.385 m

Do not accept  $W = Fs$  for **MP1**

Do not accept  $s_r = 0.4 \text{ m}$  for **MP2**

2

- (d) (Energy transferred to arrow  $\Rightarrow$ )  $0.82 \times 64$

**OR**

converts  $190 \text{ km h}^{-1}$  to  $52.8 \text{ m s}^{-1}$  or working seen ✓

Energy transferred to arrow = 52.48

$52.8 = 52.7 = \frac{475}{9}$  accept any answer that rounds to 53

Use of  $E_k = \frac{1}{2} mv^2$  ✓

Use of is:

- A rearranged expression where  $m$  would be subject.
- Substitution: condone one error in the substitution either  $v$  or  $E_k$  where  $m$  would be subject (condone rounding error in  $v$ )

Do not accept their power ( $F v$ ) equal to  $\frac{1}{2} mv^2$

$m = 0.038 \text{ (kg)}$  ✓

Accept answer correctly rounded to at least 2 sf.

$m = 2.2 \times 10^{-16} \text{ kg}$  where incorrect  $v$  of  $6.84 \times 10^8$  is used. (Worth 2 marks) (one error in  $v$ )

$m = 0.056 \text{ kg}$  where incorrect  $E_k$  is used ( $\frac{64}{0.82} = 78$ )

(Worth 2 marks) (one error in  $E_k$ )

Calculator display = 0.03768093075

3

[9]

2.

- (a) (a  $\Rightarrow$ )  $9.81 \sin 30 = 4.9 \text{ (m s}^{-2}\text{)}$  seen ✓

Allow  $g \sin 30$

Accept  $\cos 60$

1

- (b) Substitutes into  $v^2 = u^2 + 2as$  eg  $v^2 = 2 \times 5 \times 0.3$

**OR**

Uses  $\frac{v^2}{2} = g \cdot 0.3 \cos 60$  ✓

1.7 (m s<sup>-1</sup>) ✓

*Do not allow 9.81 for  $a$  in suvat equation.*

2

- (c) attempt to find area between 0.35 s (**B**) and 0.80 s (**C**) <sub>1</sub> ✓

*Max 1 for counting (small) squares **AND** a conversion factor of 2 N s stated*

*Do not allow use of approximated shapes.*

*For <sub>1</sub> ✓ need to see working for at least one part of the area under the graph.*

*May see:*

*Triangle:  $0.5 \times 0.05 \times 1100 = 27.5$*

*Trapezium:  $0.5 \times (1100 + 1300) \times 0.10 = 120$*

*Trapezium:  $0.5 \times (1000 + 1300) \times 0.15 = 172.5$*

*Triangle:  $0.5 \times 0.15 \times 1000 = 75$*

answer in range 390 to 400 (N s) <sub>2</sub> ✓

*Treat "400" as a 2 sf answer.*

2

- (d) uses a relevant time in suvat equation(s) to get  $s$  <sub>1</sub> ✓

*For <sub>1</sub> ✓ condone 9.81 for  $a$ .*

*Do not allow <sub>1</sub> ✓ or <sub>3</sub> ✓ for solutions that use  $u = 1.7 \text{ m s}^{-1}$*

*For <sub>1</sub> ✓ allow 0.60 to 0.63 s for duration **C** to **D**.*

1. Direct method:  $s = \frac{1}{2} at^2$

2. a) Obtains  $u$  first using  $v = u + at$  **OR**

$$s = ut + \frac{1}{2} at^2$$

2. b) Then  $s$  using  $s = \frac{1}{2} (u + v)t$  **OR**

$$v^2 = u^2 + 2as$$

doubles their  $s$  **OR** halves their **C** to **D** duration <sub>3</sub> ✓

*Expect to see  $u = 1.5 \text{ (m s}^{-1}\text{)}$*

answer that rounds to 0.5 (m) <sub>3</sub> ✓

*For <sub>3</sub> ✓ accept 0.44 (m).*

3

- (e) reads resting force from graph = 360 N **OR** divides an incorrect reading by 5 (4.91 N/kg) <sub>1</sub> ✓

72 (kg) or 73 (kg) <sub>2</sub> ✓

for <sub>1</sub> ✓ allow use of their **part (c)** with  $\Delta v = 3.2 \text{ m s}^{-1}$

2

[10]

3.

C

[1]

4.

- (a) arrow between block and belt pointing upwards along the belt

1

- (b) ( $F =$ )  $19g \sin 23^\circ$  to give 72.8 (N) ✓

Allow 2 sf answer.

1

- (c) uses  $F = \frac{\Delta(mv)}{\Delta t}$

Allow for MP1 use of appropriate kinematic equation for  $a$  **AND** use of  $F = ma$

$$F = 12 \text{ (N)} \checkmark$$

their (b) + 12 (N) ✓

Expect 82 or 85 (N)

3

- (d) uses  $V$  and  $I$  to get total input power or energy ✓

$$P_{\text{input of motor}} = 110 \times 5.0 = 550 \text{ W}$$

$$E_{\text{input}} = 550 \times \frac{8.0}{0.32} = 13\,750 \text{ J}$$

uses efficiency equation ✓

$$P_{\text{useful to belt}} = 550 \times 0.28 = 150 \text{ W}$$

$$E_{\text{useful}} = 3850 \text{ J, from } 154 \times \frac{8.0}{0.32}, \text{ or } 13\,750 \times 0.28$$

determines power or energy to move one block ✓

$$P_{\text{block}} = 22 \text{ or } 23 \text{ W}$$

$$E_{\text{block}} = 560 \text{ or } 580 \text{ J}$$

divides (total) useful power or energy by individual power or energy to give answer of 6 blocks ✓

Allow ecf for MP4 only for their (c)

4

[9]

5.

- (a) Use of  $p = mv$  or estimates walking speed = 1 or 2 m/s ✓

*Allow use of where  $m$  has been made the subject and  $p$  has been substituted.*

Accept any answer in range  $2 \times 10^6$  to  $10 \times 10^6$  (kg) ✓

*Range on answer:*

*(Using speeds in range  $0.5 \text{ ms}^{-1}$  to  $2.5 \text{ ms}^{-1}$ )*

*Accept 1 significant figure answer*

2

- (b) **Max 4**

There is a force on the water (from the propeller) and this produces an equal force on the propeller (from the water in the opposite direction) ✓

Correctly links to Newton's 3<sup>rd</sup> law ✓

This force on the ship equals the drag force on the ship ✓ Correctly links to Newton's 1st law ✓

Force is needed to change the water's momentum ✓ Correctly links to Newton's 2<sup>nd</sup> law ✓

*Must link correct law to at least one correct statement for all 4 marks*

4

- (c) (When system is enabled,) drag decreases by more than thrust

**Or**

(When system is enabled,) decrease in work done (per second) against drag (at any speed) is greater than the decrease in the work done by the propeller (at any rotational speed) ✓

*Work done (per second) by drag decreases and work done (per second) by propeller decreases (at any rotational speed) ✓*

To maintain constant momentum then drag must equal thrust ✓

Propeller can operate at lower rotational speed so that thrust again equals drag

**Or**

Engine does less work (and less fuel needs burnt) ✓

*3rd MP: Accept answer in terms of power =  $Fv$*

3

[9]

6.

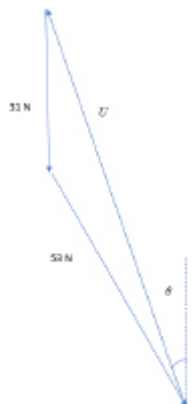
- (a) Closed triangle of forces drawn ✓

Appropriate scale ✓

$\theta = 23$  to  $27$  ( $^\circ$ ) ✓

$U = 77$  to  $81$  (N) ✓

Accept scale where  $10$  N is represented by at least  $1$  cm.



Treat each marking point independently.

Do not accept answers for  $U$  and  $\theta$  without a scale diagram.

Maximum of 3 marks for a free-body diagram where forces have been drawn to scale. (Check figure 8)

4

- (b)  $V$  is vertical / Force at **Y** is now vertical /  $V$  does not have a horizontal component /  $V = S + 31$  /  $V$  is perpendicular to the pole /  $V$  is of greater magnitude than  $U$  / Force at **Y** has increased in magnitude ✓

(Because)  $S$  and weight (or  $mg$ ) are both vertical (in **Fig 3**) ✓

(Because) greater moment of weight (about **Y**) in **Fig 3** / smaller moment of weight (about **Y**) in **Fig 1** / (Because)  $S$  is larger in magnitude than  $D$  (to produce a greater moment (about **Y** because they are equal distances from **Y**)) ✓

3

[7]

7.

- (a) (Work done = lost KE =  $\frac{1}{2} mv^2$  =)  $0.019$  (J) ✓

1

(b) Use of  $W = Fs$  ✓

( $F =$ ) 0.66 (N) ✓

*Condone POT error in substitution*

*ECF from (a)*

**Alternative:**

*Use of an appropriate suvat equation **and** use of  $F = ma$  ✓*

*( $t = 9.8 \times 10^{-6} \text{ s}$ )*

*( $a = 6.0 \times 10^8 \text{ m s}^{-2}$ )*

*Condone POT error in substitution*

*No ECF from 3.1 this route ( $F =$ ) 0.66 (N) ✓*

- (c) Use of Volume = Thickness x area of cross-section✓

*Condone POT errors apart from final answer ( $V = 8 \times 10^{-4} \times 0.03$ )*

*Or ( $V = 2.4 \times 10^{-5}$ )*

$$(\text{Average density}) = \frac{50+5}{2} = 27.5 \checkmark$$

$$\text{Use of density} = \frac{\text{mass}}{\text{volume}} \checkmark$$

*Condone use of their density and volume*

$$(\text{mass}) = 6.6 \times 10^{-4} \text{ (kg)} \checkmark \text{ c.a.o}$$

#### Alternative:

Use of Volume = Thickness x area of cross-section✓

*Condone POT errors apart from final answer*

$$(V = 8 \times 10^{-4} \times 0.03 \text{ Or } (V = 2.4 \times 10^{-5})$$

$$\text{Use of density} = \frac{\text{mass}}{\text{volume}} / (\text{mass}) = 1.2 \times 10^{-3} \text{ or } 1.2 \times 10^{-4} \checkmark$$

$$(\text{Average mass}) = \frac{1.2 \times 10^{-3} + 1.2 \times 10^{-4}}{2} \checkmark$$

$$= 6.6 \times 10^{-4} \text{ (kg)} \checkmark \text{ c.a.o}$$

*Condone use of their density and volume ( $50 \text{ kg m}^{-3} = 1.2 \times 10^{-3}$ )*

*( $5 \text{ kg m}^{-3} = 1.2 \times 10^{-4}$ )*

#### Alternative:

Condone POT errors apart from final answer

Attempts to determine the area under the graph:

Formula for area of a rectangle added to the formula for area of a triangle seen  
/ formula for the area of trapezium seen✓

$$5 \times 0.03 + \frac{(50-5) \times 0.03}{2} = 0.825 \text{ (kg m}^{-2}\text{)}$$

$$\text{or } \frac{50+5}{2} \times 0.03 = 0.825 \text{ (kg m}^{-2}\text{)} \checkmark$$

Multiplies their area by  $8 \times 10^{-4}$ ✓

$$\text{Mass} = 6.6 \times 10^{-4} \text{ (kg)} \checkmark \text{ c.a.o}$$

(d) **Q** has a larger volume (for the same mass and KE) /

**Q** has a larger surface area (for the same mass and KE) ✓

**Q** will experience a greater resistive force (at any given speed) / **Q** will displace more matter per unit distance ✓

**Q** will do more work per unit distance / **Q** will transfer more of its kinetic energy per unit distance / **Q** will experience a greater deceleration ✓

*Must have **Q** will travel a shorter distance for all 3 marks.*

3

[10]

8.

D

[1]

9.

C

[1]

10.

B

[1]

11.

D

[1]

12.

C

[1]

13.

(a) Use of time = angle / angular speed ✓

To get 3.5 (s) ✓

*Alternative for MP1: Accept distance ÷ speed when circumference has been calculated.*

*Accept answers that round to 3.49*

2

(b) Arrow towards centre of turntable. ✓

1

(c) Use of  $F = mr\omega^2$  ✓

OR

determination of centripetal acceleration and then  $F = ma$  ✓

To give 0.097 N ✓

*Shown by substitution.*

*Condone use of diameter or radius halved in MP1.*

*Accept negative answer.*

*Calculator value: 0.0972*

2

- (d) States block is (constantly) changing direction ✓

Uses appropriate Newton law of motion to link evidence (to show that a force acts) ✓

*Alternative 1*

Block constantly changing direction (at constant speed) ✓

Uses N1 to show that a force must apply ✓

*Alternative 2*

Changing direction shows (centripetal) acceleration ✓

Uses N2 to show that a force must apply ✓

*Reference can be to the name of the law or to a description of what the law says.*

*Condone lack of “resultant force” in N1 and N2.*

*Use of “changing velocity” without reference to direction is not enough for MP1.*

2

- (e) Use of pendulum equation by substitution or manipulation ✓

To give 1.55 m ✓

*Allow 2+ sf*

*Allow answer that rounds to 1.55*

*Use of  $g = 10 \text{ N kg}^{-1}$  gives 1.58 – do not allow for MP2*

2

- (f) *Amplitude* – the pendulum shadow amplitude becomes less than the block shadow amplitude ✓

*Phase* – time period decreases/changes OR frequency increases/changes (as pendulum amplitude gets less) therefore phase changes ✓

*Must see a comparison for MP1*

*Condone:*

*the time periods/ frequencies remain identical therefore the shadows remain in phase*

2

[11]

14.

B

[1]

15.

A

[1]

16. C [1]

17. C [1]

18. D [1]

19. (a) Volume of A = area  $\times$  length =  $4.16 \times 10^{-4} \text{ m}^3$

OR

Mass of A =  $W/g = 3.6 \text{ kg}$  ✓

*Condone POT error in MP1*

Use density equation ✓

*Do not allow use of weight in density equation*

Compares

a calculated property of brass (e.g. weight, length or diameter) with A

OR

the calculated density of A with density of brass

*Do not accept  $8.3 \times 10^3$  for density of A .*

OR

the calculated mass of A with the calculated mass of brass

*Award zero marks for an unsupported answer "Brass"*

and therefore brass ✓

*Only award MP3 if answer "brass" given.*

Example:

Volume of A = area  $\times$  length =  $4.16 \times 10^{-4} \text{ m}^3$  ✓

Mass if brass = density  $\times$  volume =  $3.58 \text{ kg}$  ✓

Weight =  $3.58 \times 9.81 = 35 \text{ N}$  (which is weight of A) and therefore brass is correct.

3

(b) Use of  $T = (35) \cos 55$  ✓

2  $\times$  their  $T (= 40 \text{ N})$  ✓

2

- (c) Angle (to horizontal) decreases ✓

(Weight/tension in rope remains constant at 35 N )

So horizontal components (from tension in rope) increase ✓

*Do not award MP2 if answer suggests that tension in rope increases.*

(Therefore tension in cable must increase)

*Do not allow "tension increases" for credit.*

2

- (d) Component of the force at right angle to door

$$= 41 \cos (90-12) / 41 \sin (12)$$

$$= 8.5 \text{ N } \checkmark$$

$$\text{Moment} = 8.5 \times 0.95 = 8.1 \text{ (N m) } \checkmark$$

*Alternative:*

$$\text{Perpendicular distance} = 0.95 \sin (12)$$

$$= 0.198 \text{ m } \checkmark$$

$$\text{Moment} = 41 \times 0.198 = 8.1 \checkmark$$

Allow ecf from their value of weight component .

*Allow ecf from their value of perpendicular distance.*

*(Calculator value is 8.098 160 3)*

*Award zero marks for simply multiplying  $41 \text{ N} \times 0.95 \text{ m}$ .*

2

(e) ALTERNATIVE 1

Increase weight / density / mass / volume of **A** ✓

Increases tension (and therefore moment) ✓

ALTERNATIVE 2

Position pulley **R** further (out) from gate hinges / increase diameter of pulley **R**. ✓

Increases angle and therefore bigger perpendicular component (and therefore moment). ✓

*Any 2 alternatives*

ALTERNATIVE 3

Decrease angle of rope eg by putting P and fixed point closer together / further to right. ✓

Increases tension (and therefore moment). ✓

*If more than two answers given, mark first two. Ignore the 1 and 2 in answer lines.*

ALTERNATIVE 4

Move **D** further from hinge/**R** OR make **C** longer. ✓

Increases perpendicular distance (and therefore moment). ✓

4

[13]

20. B

[1]

21. B

[1]

22. C

[1]

23. A

[1]

24. D

[1]

25. B

[1]

26. A

[1]

27. B [1]
28. C [1]
29. B  $B$  [1]
30. A  $\frac{mg}{k}$  [1]
31. (a)  $(\pm) 0.04 \text{ (m)}$  ✓  
Correct answer only

1

- (b)  $G_{\max}$  line ruled through bottom of first error bar and through top of fifth error bar  
**OR**  $G_{\min}$  line ruled through top of first error bar and through bottom of sixth error bar  $_1\checkmark$

$_1\checkmark$  requires at least one line to be well-drawn i.e. thin, single, continuous

$G_{\max}$  between 10.7 and 10.9  $_2\checkmark$

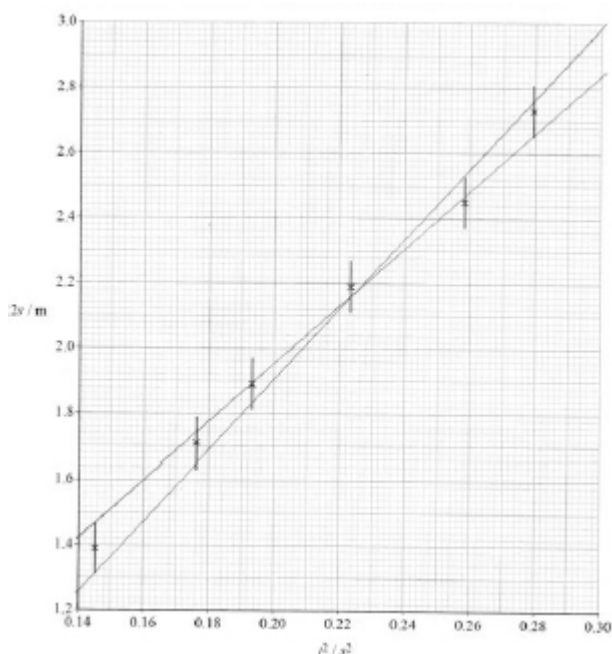
For  $_2\checkmark$  expect a 3 sf value. Accept 2 sf value only if it comes from expected range. Condone 4 sf value.

$G_{\min}$  between 8.7 and 8.9  $_3\checkmark$

For  $_3\checkmark$  accept 2 or 3 sf values only

For  $_{23}\checkmark$  at least one  $\Delta t^2$  step  $\geq 0.08$  ( $s^2$ ) (i.e. half width of grid)

Ignore any unit given with  $G_{\max}$  or  $G_{\min}$



3

- (c) uses  $g = \frac{G_{\max} + G_{\min}}{2}$  with their values from part (b)  $_1\checkmark$

evaluates mean of their  $G_{\max}$  and  $G_{\min}$  to 2 sf  $_2\checkmark$

If no other mark given, allow 1 mark for a value of  $9.7$  ( $m s^{-2}$ ) from a well-drawn best-fit line.

Give no credit for an unsupported answer.

Treat "10" as a 2 sf answer.

2

- (d) absolute uncertainty in  $g$   $_1\checkmark$

Mark each point independently. If no other mark given, allow 1 mark for a percentage uncertainty (1 or 2 sf) based on the full range (rather than half the range).

For  $_1\checkmark$  must use their  $G_{\max}$  **AND/OR** their  $G_{\min}$  e.g.

$$\Delta g = \frac{G_{\max} - G_{\min}}{2} \quad \text{OR } G_{\max} - \text{their } g \quad \text{OR } \text{their } g - G_{\min}$$

May be seen in working for percentage uncertainty e.g.

$$\left( \frac{G_{\max} - g}{g} \right) \times 100 \quad \text{OR} \quad \left( \frac{g - G_{\min}}{g} \right) \times 100$$

$$\text{OR} \quad \left( \frac{G_{\max} - G_{\min}}{G_{\max} + G_{\min}} \right) \times 100$$

$$\text{percentage uncertainty in } g = \frac{\text{their } \Delta g}{\text{their } g} \times 100 \quad _2\checkmark$$

For  $_2\checkmark$  allow 1 or 2 sf

2

- (e) systematic error  $\checkmark$

'zero error' is neutral

1

- (f) points/line displaced to right owtte

**OR**

line moves down

**OR**

(vertical) intercept is decreased / now has negative intercept  $\checkmark$

Must refer to a property of the graph; comments about error bars are neutral; ignore (new) calculated values of  $t^2$ .

Accept 'gradient is decreased' / 'graph (or line) becomes a curve of decreasing gradient' owtte.

No credit for 'points move down' / ' $t^2$  values are increased'.

Allow answers in form of their own diagram or on **Figure 2**.

1

[10]

**32.**

- (a) attempted use of principle of moments:

seen by one correct side of an attempted principle of moments equation.

*examples of acceptable responses for MP1*  $1150 \times 3.6$  **or**  $1400 \times 3.6$  **or**  $1800 \times 1.8 + 750(3.6 - d)$  **or**  $1800 \times 1.8 + 750 \times d$  **or**  $750 \times d + 1800 \times 1.8$  ✓

full use of principle of moments ✓

*Condone **one** error in distance or signs or force in an attempted use of principle of moments (must have 3 forces multiplied by 3 distances)*

$(d =) 2.4 \text{ (m)}$  ✓

*For moments about **B** (or **Q**):*

$$1150 \times 3.6 = 1800 \times 1.8 + 750(3.6 - d) /$$

$$1150 \times 3.6 = 1800 \times 1.8 + 750x$$

### Alternative

Finds component of tension in **P** due to worker's weight = 250 N /

Finds tension in **P** (due to weight of worker) by dividing weight of platform by 2 and subtracts from 1150 N

### OR

Finds component of tension in **Q** due to worker's weight = 500 N /

Finds tension in **Q** (due to weight of worker) by dividing weight of platform by 2 and subtracts from 1400 N ✓

Recognises the ratio of weight distribution to worker position relative to cables **P** and **Q**

$250 \text{ N} : 500 \text{ N} = 3.6 - d : d$  ✓ (principle of moments)

*x seen (with appropriate working) as 1.2 m or 2.4 m (even when not answer line) gains MP1 and MP2*

*Moments about **A** (or **P**):*

$$750 \times d + 1800 \times 1.8 = 1400 \times 3.6$$

*Alternative for MP1 and MP2:*

*Moments about worker's centre of gravity:*

$$1150 \times d + 1800(1.8 - d) = 1400(3.6 - d)$$

*MP1 for one correct side of equation seen.*

*MP2 all correct terms seen (condone one error).*

$(d =) 2.4 \text{ (m)}$  ✓

*$d = 1.2 \text{ m}$  **with supporting working gains** MP1 and MP2 (need principle of moments)*

- (b) Extension = 0.18 m **or** use of  $\epsilon = \frac{\Delta L}{L}$  **or** reads off  $d$  correctly for their extension  
(+/- half a square) (where working for extension seen) ✓

Use of  $\epsilon = \frac{\Delta L}{L}$  is by rearrangement to make  $\Delta L$

the subject **and**  $6 \times 10^{-5} \times 3$  seen (condone use of  $L = 3.6$  m here).

Condone POT error on extension

( $d =$ ) 1.8 m ✓

Some supporting use of graph for read-off seen

Allow range of 1.75 m to 1.85 m

2

- (c) ( $\sigma =$ )  $1.1(4) \times 10^7$  (N m<sup>-2</sup>) ✓ c.a.o

1

- (d) Straight line with negative gradient that intercepts extension axis and has a  $d$  range of 3.5 m to 3.7 m ✓

Penalise double and thick lines (limit on thickness of line: must be less than half square thick)

Straight line passes through (0, 0.46) ✓

Within 1/2 square

Straight line passes through (3.6, 0.26) ✓

Within 1/2 square

Condone accuracy within a square **max 1** for MP2 and MP3

3

[9]

**33.**

- (a) (component of total weight parallel to slope =)  $640 \sin \theta$  ✓

Allow  $mg \sin \theta$  or  $65g \sin \theta$  or  $638 \sin \theta$

or  $637.7 \sin \theta$  or  $637.65 \sin \theta$

Condone labelling this component as  $W$  in statements such as

$W = 640 \sin \theta$

Do not accept

$W \sin \theta$  unless  $W$  is defined as  $mg$

1

(b) use of  $P = Fv$  ✓

*Ecf from part (a) for MP1 and MP2*

*Use of  $P = Fv$  by substitution and rearrangement to make  $F$  the subject.*

*Expect to see ( $F =$ ) 190(.184) (N)*

*Accept a correctly rounded answer to 2 or more significant figure.*

$(\theta =) 17(.4) (^{\circ})$  ✓

*(Calculator displays: 17.35298907 for  $mg \sin \theta$  and  $65g \sin \theta$  and  $637.65 \sin \theta$ )*

*As an alternative to 17.35298907 may see Calculator display or answer of:*

- 17.34316751 for  $638 \sin \theta = 17(.3)$
- 17.3515853 for  $637.7 \sin \theta = 17(.4)$
- 17.28726034 for  $640 \sin \theta = 17(.3)$

*Common ecf:*

*$(65g \cos \theta = 190) = 72.6 (^{\circ})$  or  $73(^{\circ})$  scores MP1 and MP2*

*$(65 \tan \theta = 190) = 71.1 (^{\circ})$  or  $71(^{\circ})$  scores MP1 and MP2*

*Use of  $W = Fs \cos \theta$  is only acceptable as an ecf where  $F = 65g$  and component of weight is given as  $65g \cos \theta$  (or equivalent) in part (a)*

*Alternative MP1:*

*height gain per second = 0.486 m **and** distance along the slope per second = 1.63 m*

**OR**

*Use of  $\sin \theta = \frac{\text{height gained per second}}{\text{distance travelled per second}}$*

(c) Less (useful) power output ✓

Same gain in (gravitational) potential energy (in climbing hill) / same amount of work done (in climbing hill) / gains same height (in climbing hill) ✓

Gains less (gravitational) potential energy every second ✓

**OR** (component of weight doing work against)

Less (useful) power output ✓

Effective  $\theta$  has decreased /  $mg \sin \theta$  has decreased / component of the weight parallel to the slope has decreased ✓

*General marking principle:*

*MP1 less (useful) power output*

*MP2 basic point*

*MP3 explains consequences of basic point in terms of power (MP3 is an extension of MP2, quoting*

$P = \frac{\Delta W}{\Delta t}$  *without linking to an appropriate explanation is insufficient).*

Smaller force does less work per second ✓

**OR** (component of vertical velocity)

Less (useful) power output ✓

The vertical component of the velocity has decreased / height gained per second decreases ✓

*Loses MP1: where conflicting statements made about (useful) power output / states more power output / total power output is same.*

*Loses MP3 for conflicting statements made in support of explanation.*

*Accept  $\theta$  as the effective angle to the slope.*

$(P =) mg v \sin \theta$  has decreased /  $P = \frac{\Delta W}{\Delta t}$  has decreased / less work done

(against the weight) per second / Less gain in (gravitational) potential energy per second ✓

**OR** (distance travelled)

Less (useful) power output ✓

Less force is exerted over greater distance (for same change in height) ✓

Smaller force does less work per second ✓

*Treat 'inputs more energy' or 'does more work' as neutral.*

*Condone  $P = E/t$  has decreased as MP3*

- (d) Draws tangent which touches curve between 9 and 11 s ✓

*Must see an attempt to draw a tangent to curve to score any marks.*

Determine gradient of a tangent drawn at 5s / Determines gradient of tangent drawn at 10s ✓

*Read-offs must be within square of accuracy  $\frac{1}{2}$*

*Condone one read-off error.*

*For tangent at  $t = 5s$ , expect to see an answer of 0.61 to 0.71 ( $m s^{-2}$ ). MAX 2 marks for this.*

(acceleration =) 0.21 ( $m s^{-2}$ ) ✓

*Accept answers in range 0.15 to 0.27 ( $m s^{-2}$ )*

*Accept 2 or 3 significant figures only.*

**MAX 1 mark**

*Condone a correctly determined gradient for a tangent to the curve at **any other point between 5 and 11 seconds.***

3

- (e) Air resistance increases (with speed) / resistive forces increase (with speed) / Energy is transferred from the cyclist (due to work done) by resistive forces ✓

*Condone 'frictional forces increase with speed' Treat kinetic energy is transferred from the cyclist as neutral.*

**MAX 3 from:**

Initially, any of the gravitational potential energy that is transferred is transferred to kinetic energy of cyclist ✓

As speed increases, less of the gravitational potential energy transferred per second is transferred to kinetic energy of cyclist ✓

As speed increases, energy transferred per second to the air increases / as the speed increases, the energy transferred per second from the cyclist increases ✓

At top speed, the gravitational potential energy that is transferred (per second) is transferred to the air / the gravitational potential energy (transferred per second) is being transferred (from the cyclist) due to work done by resistive forces ✓

*The answer must be written in terms of energy transfers*

4

[13]

34.

A

19

[1]

35.

B

*the kinetic energy of the mass*

[1]

36.

D

$$\frac{v^2}{rg}$$

[1]

37.

C

*The acceleration is unchanged.*

[1]

38.

C

$$7.50 \text{ m s}^{-1}$$

[1]

39.

(a) (Use of volume (per sec) =)  $\frac{\pi d^2}{4} \times 17.2$  ✓

$$(\text{Volume per second} =) 19.45 \text{ (m}^3 \text{ s}^{-1}) = \frac{774\pi}{125}$$

$$\frac{\pi d^2}{4} \times 17.2 = \frac{9\pi}{25} \times 17.2$$

Use of  $\rho = \frac{m}{V}$  ✓

*Substitutes their volume (per second) and density where  $\frac{m}{t}$  would be subject. Do not award MP2 if 2 errors are made in substitution.*

(mass per second =)  $0.389 \text{ (kg s}^{-1})$  ✓

*Answer seen to at least 2 sf.*

*Calculator display = 0.3890548342*

3

- (b) Use of  $F = \frac{m}{t} \times v$  or ( $F =$ ) 6.69 N or 6.708 (N) or 6.88 (N)

**OR**

Use of  $W = mg$

**OR** statement:

Upward force = weight ✓

*Possible ECF from (a) where their  $m$  rounds to 0.4 kg.*

*$W = 3.72m$  seen or  $3.72m$  as the subject of a force equation.*

*Do not allow  $3.72 \times 0.4$  as use of  $W = mg$*

Applies condition for equilibrium by setting  $F = mg$

**OR**

$$6.69 = 3.72 m \text{ or } 6.708 = 3.72 m \text{ or } 6.88 = 3.72 m \checkmark$$

( $m =$ ) 1.80 (kg) ✓

*Accept answer correctly rounded to at least 2 sf.*

$$F = 6.88 \text{ N where } \frac{m}{t} = 0.4$$

$$m = 1.85 \text{ kg or } 1.8 \text{ kg}$$

(c) Use of  $E = Pt$

OR

converts kWh to J ✓

$$(E \Rightarrow) 340 \times 39 \text{ or } 13260 \text{ (J)}$$

$$(0.035 \text{ kWh} \Rightarrow) 35 \times 3600 \text{ or } 126000 \text{ (J)}$$

**Alternative MP1** converts to any of the following units of energy.

$$\bullet 0.34 \text{ (kW)} \times 0.0108 \text{ (h)} \text{ or } 0.00368 \text{ (kWh)}$$

$$\bullet 0.035 \text{ kWh} = 35 \text{ (Wh)}$$

$$\bullet 340 \text{ (W)} \times \frac{13}{1200} \text{ (h)} \text{ or } \frac{221}{60} \text{ (Wh)} \text{ or } 3.683 \text{ (Wh)}$$

Or equivalent e.g W mins

Do not accept incorrect unit.

Do not accept incorrect subject.

**MP2**

Do not allow answers obtained using incorrect power  $\left(\frac{126000}{39}\right)$

$$\frac{340}{\text{incorrect power}} \text{ such as } \frac{340}{\frac{126000}{39}}$$

(=) 11% ✓

Accept answer correctly rounded to at least 2 sf.

Calculator display = 10.5238

(d) Incorrect:

- this will increase weight **OR** helicopter must provide a greater lift **OR** (more mass therefore) greater GPE (for same height) **OR** (more mass therefore) greater KE (for same speed) **OR** idea that more energy is required. ✓
- the helicopter must displace more (atmospheric) gas (every second to produce greater lift force) **OR** blades must spin faster✓
- the helicopter must do more work every second (so will transfer stored energy at a greater rate) **OR** the helicopter needs more power to fly✓

**OR**

Incorrect:

- this will increase weight ✓
- atmosphere is too thin and can't displace sufficient mass of gas per second **OR** blades can't spin **fast enough**✓
- can't get off ground due to insufficient lift force ✓

*Do not accept increase in resistive forces or increase in drag for increase in weight.*

***Must state that it is incorrect for all 3 marks.***

*Maximum of 2 marks for suggestions that more than doubles flight time.*

*Accept lift or thrust or upward force.*

*A maximum of 1 mark for **MP3** and **MP1** where only mark seen is : idea that more energy is required.*

***MP2 can be scored independent of this.***

3

(e) Use of an appropriate equation of motion:

$$v = u + at \text{ ✓}$$

*By correct substitution including signs **or** correct rearrangement to make  $t$  subject.*

$$(t =) 0.15 \text{ (s) } \text{ ✓}$$

*Accept answer correctly rounded to at least 2 sf.*

*Calculator display = 0.14784946236559*

2

(f) Use of  $v^2 = u^2 + 2as$

**OR**

Use of  $v = u + at$  **and**  $s = ut + \frac{1}{2}at^2$  **ECF**

**OR**

$$mg\Delta h = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 \checkmark$$

(h =) 0.61 (m)  $\checkmark$  **ECF**

**MP1** (Downward journey)

Allow  $s = 0.65\text{m}$

$$2.2^2 = 0^2 + 2 \times 3.72 \times s$$

**OR**

$$2.2 = 0 + 3.72 t \text{ **and** } s = 0 + \frac{1}{2} 3.72 t^2 \text{ **ECF**}$$

**OR**

$$m \times 3.72 \Delta h = \frac{1}{2} m 2.2^2$$

**MP1** (Upward journey)

Allow  $s = 0.041\text{ m}$  obtained from

$$s = 0.55 \times 0.15 - \frac{1}{2} 3.72 \times 0.15^2 \text{ **ECF**}$$

**OR**

$$0^2 = 0.55^2 - 2 \times 3.72 \times s$$

Check possible **ECF** for  $t$  from (e) used in calculation.

Condone sign suppression in **MP1** where answer of 0.65 m or 0.041 m or 0.6(1) m is seen.

Accept answer correctly rounded to at least 2 sf.

Calculator display = 0.60987903225806

(g) Student is correct:

Weight is the only force acting on the helicopter.

**OR**

Acceleration =  $(-3.72 \text{ ms}^{-2})$  ✓

Due to **Newton's 2<sup>nd</sup> law**, the acceleration acts in the **same direction** as the weight (which is always downwards).

**OR**

Due to **Newton's 2<sup>nd</sup> law**, the acceleration is **constant** because the (mass and) weight are **constant** ✓

*MP1 statement that the object is in freefall. Where (resultant) force is mentioned must be identified as weight.*

*Where acceleration is quoted must have correct unit.*

*Accept  $F=ma$  as a statement of Newton's 2<sup>nd</sup> law.*

*MP2 Accept no mention of force being weight where mass is included their answer, for e.g.:*

*Due to **Newton's 2<sup>nd</sup> law** the acceleration is constant because the force **and** mass are constant.*

*Neutral for statements that refer to deceleration / acceleration.*

*Do not accept arguments based on drag or air resistance affecting the motion of the helicopter.*

**Zero marks** for statement that indicates the **acceleration varies**.

*Must state that student is correct **or** that the acceleration is constant to gain 2 marks.*

2

[17]

40.

C

*displacement and momentum*

[1]

**41.**

- (a) Equates resultant force to  $ma$

and shows  $a$  proportional to  $y$ , as  $A\rho mg$  are all constant ✓

*In MP1:*

*Condone upthrust/buoyancy force for resultant force*

$$F = ma = -A\rho y g$$

$$\rho = -\frac{A\rho y g}{m}$$

*Condone missing minus signs in MP1.*

Minus sign included and explained:

(restoring) force/acceleration directed to centre of oscillation ✓

(hence SHM)

*In MP2:*

*Minus because force/acceleration is in opposite direction to  $y$*

*OWTTE*

2

- (b) ( $T = 2\pi/\omega$ ) so  $\omega = \sqrt{\frac{g}{l}}$  ✓ (= 10.74 rad s<sup>-1</sup>)

$$(a_{\max} = -\omega^2 y_{\max} = \frac{g}{l} \times y_{\max} = (9.81 \div 0.085) \times 0.005)$$

*Alternative for MP1:*

*calculates time (0.58(5) s) AND then uses  $\omega$  from this time*

0.58 (m s<sup>-2</sup>) ✓ from some correct working

*MP2 for correct calculation of acceleration.*

2

- (c) Idea that (at resonance) frequency of forced vibrations equals natural/resonant frequency  
1 ✓

Idea that amplitude (of vibrations/oscillations) is at a maximum 2 ✓

*Accept fully labelled graph of amplitude vs driving frequency with resonance frequency clearly labelled 1 ✓ and an amplitude peak. 2 ✓*

*Condone 'wave frequency' for 'driving frequency'*

*Ignore references to phase*

2

(d) stopped: wave frequency ( $=\frac{v}{\lambda}$ ) = 0.12 Hz <sub>1✓</sub>

moving: when ship continues at 8 m s<sup>-1</sup>, forcing frequency will be further from resonant frequency <sub>2✓</sub>

Moving option is better with reason,

eg for stopped option wave/forcing frequency very close to natural frequency, (so amplitude of oscillations will be high)

**OR**

for moving option resonance does not occur <sub>3✓</sub>

*<sup>1✓</sup> is for calculation of (driving) frequency when stopped. Condone reference to 'frequency of waves'.*

*If no reference to ship being stopped, evidence can come from the substitution. Reject simple "0.12 (Hz)"*

*<sup>2✓</sup> is for a relevant comment about the moving situation*

*OR*

*calculation of forcing frequency with the ship moving (giving 0.05 Hz)*

*For <sup>2✓</sup> accept incorrect calculation from adding speeds provided comment that this frequency is further from resonant frequency.*

*<sup>3✓</sup> is for statement of why moving is the better option*

*Allow answer for <sup>3✓</sup> that mentions that damping will be highly likely, so amplitudes may not reach high enough values to prevent operation*

3

[9]

42.

C

45 m

[1]

43.

D

force mass × displacement

[1]

44.

B

4 m s<sup>-1</sup>

[1]

**45.**

- (a) Evidence of appropriate use of Figure 1 e.g.

$$105 \times 10^6 \div 7.5 \times 10^{-4}$$

*Some evidence that Figure 1 is used:*

*calculation based on a point on line between 75 MPa and 125 MPa*

*OR calculation from point on straight line extended*

*OR*

*Use of triangle from more than half of the linear section.*

leading to an answer in the range  $1.38$  to  $1.42 \times 10^{11}$  Pa ✓

*Allow 2 sf answer  $1.4 \times 10^{11}$  (Pa).*

1

- (b) Idea that wire undergoes only (very) small (increase in) strain beyond the linear section before fracture ✓

*Reject idea that there is **no** increase in strain.*

*Condone 'extension' or '(plastic) deformation' for 'strain'.*

*Condone 'shortly after' for 'beyond'*

*Accept: does not show 'necking' before fracture*

*Accept: fracture occurs very near the limit of proportionality (condone 'elastic limit').*

*Accept references to a particular value of strain e.g.  $9 \times 10^{-4}$  to  $12.7 \times 10^{-4}$*

1

- (c) Evidence of determination of total load or load on one wire ✓

(halves load)

Use of  $E = \frac{(\text{their } F) \times L}{A \times \Delta L}$  ✓

$$\Delta L = 1.1(4) \times 10^{-3} \text{ (m)} \quad \checkmark$$

$$\text{Total load} = (4.4 + 16.0) \times 9.8(1) = 200(.1) \text{ N}$$

*Allow 'g' for 9.8(1)*

*Expect to see  $F = 100 \text{ N}$  and*

*$A = 5.03 \times 10^{-7} \text{ m}^2$ . Condone use of  $d$  in calculation of cross-sectional area  $A$  in MP2.*

*Or separate calculations using  $\sigma = F \div A$ ,  $E = \sigma \div \text{strain}$ ,  $\text{strain} = \Delta L \div L$*

*Condone POT error in MP2.*

3

- (d) Evidence of extension/strain in each wire is the same  $_1\checkmark$

Substitutes data leading to  $F_a = 1.33 F_s$   $_2\checkmark$

Calculates  $F_s$  or  $F_a$   $_3\checkmark$

Evidence of an attempt at a moment equation  $_4\checkmark$

Distance = 1.18 m  $_5\checkmark$

$\Delta L = \{FL \div AE\}$  steel =  $\{FL \div AE\}$  aluminium  $\{F \div d^2 E\}$  steel =  $\{F \div d^2 E\}$  aluminium  $_1\checkmark$

$$\frac{F_s}{0.8^2 \times 210} = \frac{F_a}{1.6^2 \times 70}$$

$F_a = 1.33 F_s$  OR  $F_s = 0.752 F_a$   $_2\checkmark$

$$1.33 F_s + F_s = 200 \text{ N}$$

$$F_s = 86 \text{ N}, F_a = 114 \text{ N} \text{ } _3\checkmark$$

Attempt to take moments about A or B or other suitable point, expect to see  $16.0gx = 228 - 4.4g$   $_4\checkmark$

Note that an answer of 1.14 m comes from not taking into account the weight of the beam

Award **max 4** for this approach.

ECF for MP2 and MP3 in MP4

5

[10]

46.

A

$$10 \mu\text{m s}^{-1} \quad 100 \text{ s}$$

[1]

47.

- (a) idea that moments are balanced or that there is no resultant moment  $\checkmark$

Answer must relate to the context e.g. reference to **Q** or weight of food/spoon

Allow 'force  $\times$  distance' or ' $F \times d$ ' for 'moment'.

(because)

(overall) centre of mass is now beneath/at **Q**

**OR**

line of action of (overall) weight is through **Q**  $\checkmark$

'Anticlockwise moment of weight of spoon about **Q** = clockwise moment of weight of **M** about **Q**' gains both marks.

2

- (b) statement of balanced moments seen e.g.  $mgx = Mg(16 - 4 - x)$ , leading to required formula  
✓ ✓

*For 1 mark: condone absent  $g$  if credible evidence for '12 -  $x$ ' presented e.g.  $mx = M(16 - 4 - x)$  or  $mx = M(28 - 16 - x)$*

**OR**

*condone lack of evidence for '12 -  $x$ ' if  $g$  is shown e.g.  $mgx = Mg(12 - x)$ .*

*Need to see  $g$  and evidence for '12 -  $x$ ' for both marks. Evidence for '12 -  $x$ ' need not be in an expression of a moment.*

*Allow 9.81 or 9.8 instead of  $g$ .*

2

- (c) max two from: ✓ ✓
- reads off a pair of values (e.g. 115 g, 5.0 cm)
  - substitutes into formula
  - multiplies their  $m$  by  $g$

answer that rounds to 1.5 or 1.6 (N) ✓

*Allow correct conversion of  $M$  to kg and/or  $x$  to m for read offs or in the substitution.*

*Expect to see 160 g for mass of spoon.*

*Allow credit for an algebraic solution to get  $m$ :*

*e.g. when  $m = M$ ,  $\frac{m}{M} = \frac{(12 - x)}{x} = 1$*

*So,  $12 = 2x$ ,  $x = 6.0$  cm. Reads off  $M$  at 6.0 cm to get 160 g.*

3

- (d) (absolute) uncertainty in  $M$  increases as  $M$  increases ✓

(because) as  $M$  increases:

marks on the scale get closer **OR** range of values of  $M$  for a fixed range of  $x$  increases (or vice versa) ✓

the gradient (in Figure 3) increases so the scale markings are unequal **OWTTE** ✓

*MP1 only awarded supported by some relevant explanation. Treat 'percentage' uncertainty as neutral.*

*Allow MP2 and MP3 for quantitative evidence given using Figure 3 e.g. from 0 g to 25 g,  $\Delta x \sim 1.5$  cm; from 175 g to 200 g,  $\Delta x \sim 0.4$  cm **OR** calculates gradients at low and high  $M$ .*

3

[10]

48.

D

work done.

[1]

49.

- (a) Conversion of  $1230 \text{ km h}^{-1}$  to  $\text{m s}^{-1}$

*Expect to see  $342 \text{ m s}^{-1}$  ( $341.7$ )*

OR

Calculates time for  $343 \text{ m s}^{-1}$  run

*Expect to see  $4.69 \text{ s}$*

OR

Calculates total time (using total distance,  $3.22 \text{ km}$ , and speed record)

*Expect to see  $9.42 \text{ s}$*

OR

Calculates unknown speed ✓

*Expect to see  $340.3 \text{ m s}^{-1}$*

Answer that rounds to  $4.73 \text{ (s)}$  ✓

*Do not accept 2sf for final answer.*

2

- (b) speed from graph:  $450 \text{ m s}^{-1}$  ✓

*Accept  $445 - 455 \text{ m s}^{-1}$*

Use of their speed and KE equation to give consistent answer ✓

*Expect to see  $6.6 \times 10^8 \text{ (J)}$*

2

- (c) **MAX three** from: ✓✓✓

- Use of graph to determine gradient
- Uses (their) speed and (their) gradient to give acceleration
- Use of  $F = m \times (\text{their } a)$  to give resultant force
- Use of  $P = (\text{their } F) \times (\text{their speed})$

Final answer between  $16\%$  and  $17\%$  ✓

*Expect to see  $450 \text{ m s}^{-1}$  for their speed*

*Evidence for gradient may be on figure*

*Allow ECF from (b)*

•  $\frac{450}{5600} = 0.080(4)$

• *Expect to see  $450 \times 0.08 = 36(.2) \text{ m s}^{-2}$*

• *Expect to see  $2.35 \times 10^5 \text{ N}$*

• *Expect to see  $450 \times 2.35 \times 10^5 = 106 \text{ MW}$*

*Reject power that is calculated assuming a constant speed.*

4

- (d) Identifies distance decelerating

**AND**

max velocity =  $(470 \pm 5) \text{ m s}^{-1}$  ✓

Uses *suvat* equation(s)

to get  $a = (-) 15 \text{ m s}^{-2}$  which is less than  $3g$  (so yes). ✓

*allow 7000 m to 7600 m*

*allow answer consistent with their distance that rounds to 15 or 16*

*give full credit to calculations that show that an acceleration of  $3g$  would stop the car in a (much) shorter distance, with a statement that this means that the actual acceleration must be (much) less than  $3g$ .*

*For MP2 allow calculation of*

*gradient  $\times$  average speed to give*

$a = (-) 15 \text{ m s}^{-2}$  which is less than  $3g$  (so yes)

2

[10]

50. B

800 N

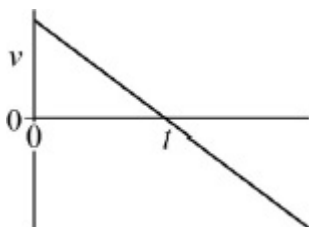
[1]

51. A

$0.40u$

[1]

52. A



[1]

53. C

$v\sqrt{2}$

[1]

54. D



[1]

55. (a)  $4.5 \times 10^{-2}$  ✓

CAO

1

(b) (short  $T_1$ )

so images are not blurred (or wtte)

*must refer to quality / property of images, eg 'images are sharp' / 'focused' / 'clear' / 'defined';*

*allow '(images of) ball are circular' / 'spherical' / 'not elongated' or wtte: accept sketch*

*'increasing distance between images' / 'image is accurate' are neutral*

OR

to determine position of the ball (in each image or wtte) ✓

*allow 'to see (point) where ball is' / idea that (centre of) ball needs to be a 'single point' / 'ball does not move during each flash (  $T_1$  )'*

*comments about the motion / trajectory of ball eg 'see a clear pattern' are neutral*

*comments about the duty cycle / flash rate are neutral*

1

(c) correct rearrangement to a three-term equation;

1

$\frac{H-h}{n}$  as the subject eg  $\frac{H-h}{n} = \frac{u_0}{f} + \frac{gn}{2f^2}$   $_1\checkmark$

valid suggestion for quantity plotted on x-axis;

allow use of  $y = mx + c$  aligned with  $\frac{H-h}{n} = \frac{u_0}{f} + \frac{gn}{2f^2}$

suitably annotated to identify  $x$   $_2\checkmark$

explains how  $g$  found using the gradient for **their** x-axis;

insist on  $g$  as subject whether explanation is in words or expressed as an equation  $_3\checkmark$

for  $_1\checkmark$  condone  $\frac{H-h}{n} = \frac{u_0}{f} + \frac{g}{2n} \left( \frac{n}{f} \right)^2$

$_3\checkmark$  is contingent on  $_2\checkmark$ ;

for a correct equation or if no equation is seen mark  $_2\checkmark$  and  $_3\checkmark$  as below:

| for $_2\checkmark$ | for $_3\checkmark$                          |
|--------------------|---------------------------------------------|
| $n$                | $g = \text{gradient} \times \frac{2f^2}{n}$ |
| $\frac{n}{2}$      | $g = \text{gradient} \times \frac{f^2}{n}$  |
| $\frac{n}{f}$      | $g = \text{gradient} \times \frac{2f}{n}$   |
| $\frac{n}{2f}$     | $g = \text{gradient} \times \frac{f}{n}$    |
| $\frac{n}{f^2}$    | $g = \text{gradient} \times \frac{2}{n}$    |
| $\frac{n}{2f^2}$   | $g = \text{gradient}$                       |

for an incorrect equation with  $n$  in the 'mx' term allow ECF for  $_2\checkmark$  and  $_3\checkmark$

2

(d)  $n = 17 \pm 1$  <sub>1</sub>✓

<sub>1</sub>✓ expect integer  $n = 17 \pm 1$  but see valid unusual approach below

1

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

OR

use of  $H = u_0 t + \frac{1}{2} g t^2$  (eg with  $t$  from  $\frac{n}{31}$ ) <sub>2</sub>✓

$u_0$  correctly evaluated to (minimum) 2 sf <sub>3</sub>✓

for <sub>2</sub>✓ either approach 'use of' means full substitution without error (with  $h = 0$  shown or implied by omission) so that  $u_0$  is the only unknown;

condone  $g = \pm 9.79$  OR  $\pm 9.8(1)$ ;

condone POT error / mixed units for  $H$  and  $g$

1

valid alternative method:

use of **Figure 1** to determine non-zero  $h$  for integer  $n > 0$

for <sub>1</sub>✓ a valid  $h$  for their integer  $n (\leq 16)$

eg when  $n = 5$ ,  $h = \frac{89 \text{ (mm)}}{99 \text{ (mm)}} \times 1550 \text{ (mm)} = 1393 \text{ (mm)}$

for <sub>2</sub>✓ full sub including a valid  $h$  for their  $n$

for <sub>3</sub>✓  $u_0$  correct for their  $n$  and  $h$

eg for  $n = 5$  and  $h = 1393$ ,  $u_0 = 0.18(4) \text{ (m s}^{-1}\text{)}$  <sub>3</sub>✓

for <sub>3</sub>✓ see table for  $u_0$  with  $n = 16$  OR  $18$  AND/OR for the (intermediate) rounding of  $t$ ;

accept  $> 3$  sf that rounds to values in table:

|                         | subs $n, f$ | truncates $t$ |      |
|-------------------------|-------------|---------------|------|
| expected                | $t = 17/31$ | 3 sf          | 2 sf |
| $t / \text{s}$          | (0.548387)  | 0.548         | 0.55 |
| $u_0 / \text{m s}^{-1}$ | 0.14        | 0.15          | 0.13 |

|                         |             |       |      |
|-------------------------|-------------|-------|------|
| ECF                     | $t = 16/31$ | 3 sf  | 2 sf |
| $t / \text{s}$          | (0.516129)  | 0.516 | 0.52 |
| $u_0 / \text{m s}^{-1}$ | 0.48        | 0.48  | 0.44 |

|                |             |       |      |
|----------------|-------------|-------|------|
| ECF            | $t = 18/31$ | 3 sf  | 2 sf |
| $t / \text{s}$ | (0.580645)  | 0.581 | 0.58 |

|                         |       |       |       |
|-------------------------|-------|-------|-------|
| $u_0 / \text{m s}^{-1}$ | -0.17 | -0.18 | -0.17 |
|-------------------------|-------|-------|-------|

1

(e) calculates the horizontal velocity;

divides a valid horizontal displacement  $s_2 - s_1$  by a time  $_1\checkmark$

*for  $_1\checkmark s_2 - s_1$  in range 490 to 1000 (mm);*

*expect time to be found from counting intervals between flashes but allow use of **their (f)** result;*

*condone use of distance between contacts with time of  $\frac{19}{31}$  and  $\frac{20}{31}$ ;*

horizontal velocity in range 1550 and 1650 ( $\text{mm s}^{-1}$ )  $_2\checkmark$

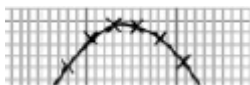
*$_2\checkmark$  is not contingent on  $_1\checkmark$*

*allow 2 sf  $1.6 \times 10^3 (\text{mm s}^{-1})$*

2

(f) determines  $h_{\max}$  (at top of bounce) using an annotation to **Figure 3** <sub>1</sub>✓

eg



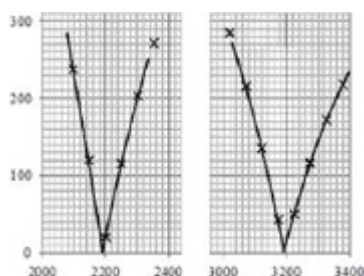
valid attempt to find time  $t$  between contacts by using *suvat* with  $u = 0$ , eg time =

$$(2 \times) \sqrt{\frac{2 \times \text{their } h_{\max}}{9.81 \text{ OR } 9.79}} \quad 2\checkmark$$

OR

determines  $s$  for both contacts OR determines  $s_2 - s_1$  using annotations to **Figure 3** <sub>1</sub>✓

eg



valid attempt to find  $t$  by =  $\frac{\text{their } s_2 - s_1}{\text{their horizontal velocity in } 01.5} \quad 2\checkmark$

time in range 0.61(0) to 0.65(0) (s) <sub>3</sub>✓

for <sub>1</sub>✓ annotation should be a smooth curve through (at least) top 4 points,  $n = 51$  to  $54$ ; don't insist on seeing a horizontal line to the  $h$  axis

for <sub>2</sub>✓ accept mixed units / POT in substitution / time to maximum height calculated / valid working in (e)

OR

for <sub>1</sub>✓ annotation should be at least one smooth (allow straight) line to define each contact;

eg (at least) through  $n = 41/42$  OR  $43/44$  to  $h = 0$  AND through  $n = 61/62$  OR  $63/64$  to  $h = 0$

for <sub>1</sub>✓ or <sub>2</sub>✓ accept valid working in (e);

accept use of horizontal distance = 1000 (mm)

for <sub>2</sub>✓ do not condone use of integer number

of intervals, eg  $t = \frac{19}{31} = 0.61(3)$  OT

$$t = \frac{20}{31} = 0.645$$

<sub>3</sub>✓ is contingent on <sub>2</sub>✓;

exception: award <sub>3</sub>✓ for  $t$  in range if obtained by estimating a

**non-integer** number of intervals, eg  $t = \frac{19.5}{31}$



## Examiner reports

1.

- (a) 43% of students scored two marks with a further 20% gaining one mark. Many students tried to resolve 160 N rather than  $T$ ; this made the calculation considerably more challenging, and these students typically scored zero marks. Many were unsure whether to use sine or cosine or failed to appreciate that  $F$  was shared between the two horizontal components of the tensions acting at P.
- (b) 51% of students obtained two marks with a further 33% obtaining one mark. Many students did not score the second mark because they:
- did not change the mass into kg
  - converted the mass into weight.

Some students attempted to use an equation of motion due to their inability to assimilate the information provided. This showed a limited development of exam technique through limited awareness of the purpose of the stimuli provided.

- (c) This part proved inaccessible to most students with over 94% of students achieving zero. Many attempted to use  $W = Fs$  even though the force was not constant over the distance shown in **Figure 3**. Another significant proportion of students used  $W = \frac{1}{2} F \Delta L$ , again scoring zero due to the non-linear relationship between  $F$  and  $s$  shown in **Figure 3**. Over 60% of students achieved at least one mark in this part. Grade A students typically achieved all three marks with grade E students able to make some progress. One mark was usually obtained for a correct conversion of  $\text{km h}^{-1}$  to  $\text{m s}^{-1}$  but quite often this was the only credit-worthy work seen in the working.

Common errors seen included:

- incorrect re-arrangement of  $E_k = \frac{1}{2} m v^2$
- forgetting to use 82% of the available energy as the kinetic energy.

Many students attempted to use  $P = Fv$  because they thought that efficiency was a reference to power in this context.

2.

- (a) A surprisingly large number of students struggled with this relatively simple 'show that' question. This was used to establish that the motion down, and up, the rail occurred under the condition of constant acceleration.
- (b) About 40% of students gained full marks by realising that the answer could be obtained using a 'suva $t$ ' equation or by considering the transfer from stored gravitational potential energy to kinetic energy. About 40% of the cohort made no relevant progress. Students are reminded not to give final answers in surd form as they will not gain the mark.
- (c) Most students knew that they needed to obtain the area of the graph between **B** and **C**. The graph was deliberately constructed without curves so that students could obtain this area by geometry. Crude attempts to count the squares were not rewarded. A significant number of students thought they could use  $F \Delta t$ , even though the value of  $F$  varies throughout the time period.
- (d) Only about 15% of students gained any credit in this question. The rest of the cohort failed to realise that this could be solved using 'suva $t$ ' equations. Students who were successful commonly used  $s = \frac{1}{2} at^2$  with half the duration from **C** to **D**, and then doubled their answer.

- (e) A large number of students did not attempt this question or made no valid point. The questions followed the sequence of the leg jump from **A** to **E**, and students were expected to use a reading from the graph beyond **E** to determine the mass.

**3.** This was one of the easiest questions in this 2022 paper.

**8.** This was one of the hardest questions in this 2022 paper. It had distractors that were more popular than the correct answer.

In this question, all four options were similarly popular. It was clear that many students did not spot the word 'extra' in the question, for example.

**11.** This was one of the hardest questions in this 2022 paper. It had distractors that were more popular than the correct answer.

This question was a difficult multi-step calculation. Most students chose B, and the next most popular was D, the correct answer.

**12.** This was one of the hardest questions in this 2022 paper. It had distractors that were more popular than the correct answer.

Responses to this question indicated how poorly Newton's third law of motion is understood. The correct answer was the least popular option. Clearly many students do not realise that the pair of forces act on different objects and are the same type of force.

**13.** The question was based on a practical demonstration of the relationship between simple harmonic motion (shm) and circular motion.

The calculations in (a), (c) and (e) were very straightforward and caused little trouble for most students.

(b) was more challenging. Examiners were lenient in their interpretation of the arrow, but several students lost the mark through carelessness. When drawing a direction such as this students should use a ruler and avoid ambiguity in the construction.

In order to answer (d) correctly students had to be clear about the evidence on which their answer was based. Stating that the velocity is changing, without any mention of direction, was not interpreted by examiners as evidence. Many students invoked Newton's 3<sup>rd</sup> law without success.

Answers to (f) were often incomplete. Examiners were expecting to see a comparison, but many students only discussed the effect on the pendulum. In order to gain the phase mark some supporting discussion was needed. This was partly because both no change and an in-phase change were acceptable, depending on the depth of the student's discussion.

**19.** Most students were able to answer (a) correctly and obtain full marks. Partial credit was available for students who got the wrong answer, but answers needed to be set out with sufficient clarity for any mark to be awarded. Students should be encouraged to make each step in their calculations clear.

The relatively poor performance of students in (b) and (c) demonstrated much misunderstanding about the components of forces. It was made clear in the question that the tension in the rope was the same throughout, but many students showed little awareness of this.

The moment calculation in (d) proved to be much more accessible. Partial credit was available to students who made one error in their answer.

There were many alternative answers to (e) and all of them were given credit. Students often failed to gain marks by making vague statements that failed to set out clearly the physics behind their suggestions. Several students suggested, incorrectly, that shortening the rope so that A was higher would make a difference.

**21.** Generally, students were less successful in answering this question than the other questions in this 2022 paper.

**22.** Generally, students were more successful in answering this question than the other questions in this 2022 paper.

**24.** Generally, students were less successful in answering this question than the other questions in this 2022 paper.

**26.** Generally, students were less successful in answering this question than the other questions in this 2022 paper.

**27.** Generally, students were more successful in answering this question than the other questions in this 2022 paper.

**29.** This question was the most demanding; fewer than 40% of students got it right and the correct answer was not the most popular choice.

This question was about the equilibrium of forces. The most popular answer was A. Drawing the weight of the trapdoor and the tension in the rope on the diagram would have shown their lines of action. This would have indicated B as the only force with a line of action that would pass through a common point and therefore give no turning effect.

- 31.**
- (a) The most common response was 0.08, with a large majority of students failing to appreciate that the  $y$ -axis was a plot of  $2s$  and so the absolute uncertainty had been doubled.
  - (b) Students were more successful in drawing the line for the minimum gradient than for the maximum gradient. A common mistake was to draw the line for the maximum gradient through the bottom of the error bar for the first plot and through the top of the error bar for the final plot. This bypassed the fifth plot and was, consequently, incorrect.
  - (c) Examiners marked this question based on the student's values for (b). A value to 2 sf was expected.
  - (d) Very few students used their value for  $g$  from (c), with many opting to make a comparison using 9.81.
  - (e) About 60% of students gave the correct answer.
  - (f) Just under half the cohort gave a correct description of how the graph would change. Those who simply stated what would happen to the values, rather than to the plotted points or line, did not get credit.

**32.**

- (a) Over 25% of the students obtained all three marks. Many of these students had labelled **Figure 1** with distances and forces and gave clear working that was easy to follow. A common incorrect answer was 1.2 m. This was usually caused by incorrect use of  $d$  in the moments equation.
- (b) Most students gained at least one mark in this calculation. The reasons seen for failing to gain the second mark included: use of 3.6 m for  $L$ , thinking that the extension was the answer, and an inaccurate read-off from **Figure 2**. These errors reflect a lack of exam technique; students did not cope well in situations where key information was provided in the opening stem of the question.

Students should be encouraged to use a ruler to draw straight lines on diagrams to ensure an appropriate degree of accuracy in reading data from graphs.

- (c) Over 70% of students gained this mark. This calculation was much simpler than the previous question with both pieces of data provided close to the question. The best answers seen typically followed the steps of writing the equation, substituting the data, re-arranging to make the stress the subject, and placing the answer to an appropriate number of significant figures on the answer line.
- (d) Most students gained at least one mark by drawing an appropriate line with a negative gradient. Just over 20% gained two marks; these students appreciated that that extension had doubled and were able to determine the new extension for  $d = 0$  but then incorrectly drew a line parallel to the original line.

**33.**

- (a&b) Almost 40% of students scored one mark in (a) and 36% scored two marks in (b). A significant number of students who could not do (a) were able to do the calculation in (b). This suggests that these students knew the process involved in determining the component of the weight parallel to the slope but were unaware of the technical term used to describe it. Many students were able to use  $P = Fv$  in question (b) to determine the force but were unable to relate this force to the component of the weight parallel to the slope.
- (c) Less than 10% of the cohort obtained two or more marks. Students did not seem to have any real-world appreciation of this 'zig-zag' path being easier than the direct path in **Figure 2**. They thought that the cyclist had travelled further, had encountered more resistive forces, and had done more work with a greater power output. These students offered efficiency-type arguments to explain why they thought that the useful power output had changed. Many of those who did appreciate that the effective angle had been diminished thought that the power output had increased by omitting the idea that the cyclist maintained the same steady speed.
- (d) Students had more success here with 32.7% of them able to score all three marks. However, over 45% of the students were unable to score any marks. Many of these students attempted to use  $v = u + at$  thus not appreciating that motion was non-uniform or that this equation can only be applied to situations where the acceleration is constant.

- (e) This question proved too challenging for this cohort of students. Less than 5% of the students were able to obtain more than three marks. The answers seen were typical of work at GCSE level. The marks scored were limited to statements that air resistance increased with speed or that the gravitational potential energy was being converted into kinetic energy. Many students disregarded the instruction to outline the energy transfers and instead answered in terms of resultant forces and accelerations. The type of analysis that one would expect from more able AS students was rarely seen. A significant number of students stated that the cyclist was losing kinetic energy even though the velocity did not decrease.

39.

- (a) Students performed well in this part with 47% of students achieving all three marks. Those who made more limited progress were unfamiliar with how to determine the volume of air displaced each second and instead used  $2\pi rh$  or  $\frac{4}{3}\pi r^3$ . Here again, realising that this is a “show that” question was crucial; students must ensure that their working clearly demonstrates *all* the steps they have made to produce the answer. Some students presented a one significant figure answer and this limited them to a maximum of two marks.
- (b) This part of the question expected students to appreciate that the displacement of the gas produced an upwards force equal to the weight of the helicopter. This was beyond the knowledge and understanding of most. Fewer than 16% of students scored three marks and certainly demonstrated A-grade performance. Over 70% of students scored zero in this part. Many students thought that the mass of gas displaced per second was equal to the mass of the helicopter. Many attempted to use conservation of energy to obtain an answer by setting gravitational potential energy equal to kinetic energy. It was very common to see  $0.4 \times 3.72$  as the only working presented.
- (c) This part of the question was more accessible with almost 60% of students obtaining at least one mark. However, many students demonstrated a limited appreciation of the context and divided the energy stored in the battery by 39 s to find a power. This was incorrect as it assumed that all of the energy stored in the battery was transferred in 39 s. Many poorer performing students were unable to convert kilowatt-hours into joules.
- (d) Almost 60% of students were able to score at least one mark. However, fewer than 10% of students were able to make further progress and not even 1% scored all three marks. Most realised that the helicopter was now heavier and that more work was required to keep it in the air. However, they were unable to describe how the helicopter produces the extra lift required. Also, they were unable to connect the increased amount of work done to power and therefore were unable to explain why the flight time would not double. Students would often make statements without being able to support them with an explanation that demonstrated their knowledge and understanding of the underlying physics.

- (e) 58% of students obtained both marks. Almost 8% did not even attempt this calculation. Mistakes seen included dividing the acceleration by the change in velocity and using an inappropriate equation of motion.
- (f) 11% of students did not attempt this calculation. 32% of students scored one mark, usually for determining the maximum height above the ground or the distance travelled upwards from the position shown in **Figure 3** to the maximum height. These students presented 0.65 m or 0.041 m as their answer without appreciating how this applied to this context.
- (g) The lack of quality of the students' technical language was often the reason for limited progress in this part. Many thought that constant acceleration was the same as constant velocity and developed arguments based on acquisition of a terminal velocity. Many others offered Newton's third law as a reason to support equilibrium and Newton's first law.

**40.**

This question was the easiest with over 75% of students getting it right.

**41.**

This question included some parts that many students found very challenging but also parts that were quite accessible.

- (a) It was clear that many students had little idea about how the equation for SHM can be obtained. Commonly students simply stated the conditions for SHM without relating it to the context.
- (b) The calculation was much more straightforward with over half of students getting both marks. The mark scheme allowed those who could go no further to gain one mark for using a value of  $\omega$  or similar. Common errors included adding the amplitude when calculating the period, or using the total distance submerged as the amplitude when calculating the acceleration.
- (c) This proved to be quite challenging. Students who made no reference to the amplitude being a maximum at resonance were limited to one mark. Other answers showed some difficulty with the idea of driving frequency. Some good answers were seen that made use of a labelled sketch graph.
- (d) This part discriminated very well. More than 60% of students were able to get at least one mark, usually for working out the wave frequency. Nearly 40% of students were able to go further, often for stating that this was close to the natural frequency and therefore the boat should move. Full marks were given for those who also made some reference to what happened to the driving frequency when the boat was moving. This is another example of a question that tests assessment objective AO3. Students should be encouraged to practise answering questions of this kind in preparation for this examination in the future.

**42.**

This question was the most demanding; fewer than 40% of students got it right and the correct answer was not the most popular choice.

This question was about the displacement of a projectile. The most popular answer was A, followed by B. These answers suggested that students did not identify that displacement, and not distance, was required.

**44.**

Part (a) was the one with popular distractors.

**45.**

This question included parts with a range of difficulty, giving most students the opportunity to pick up some marks.

- (a) A straightforward calculation that required students to use an appropriate section of the graph to obtain the Young modulus. Power of ten errors prevented some students obtaining the mark.
- (b) A range of responses was acceptable but the idea that there was no increase in strain beyond the linear section of the graph did not get the mark. These answers implied that students knew what brittle meant but did not apply it to **Figure 1**.
- (c) The calculation was reasonably accessible with nearly half of the students getting full marks. This part discriminated well, giving students who got the wrong value some credit provided their answer was set out sufficiently clearly to show what they were doing. A common error was using 200 N for the load; this gave access to two of the three marks.
- (d) This was also one of the most discriminating on the paper. Over half of the students were able to get at least one mark, usually for providing evidence of a moment equation. Students who did not see that for AB to be horizontal the extensions of the two wires had to be equal made little further progress. The mark scheme produced a range of marks, rewarding students who set out their work sufficiently clearly to obtain intermediate marks. Using the value of extension from part(c) gave partial credit to some of these students.

**46.**

This question was the easiest with over 75% of students getting it right.

**47.**

- (a) Students struggled to make comments about moments that related specifically to this context. Generic statements about balanced moments were insufficient. Students regularly failed to comment on the relevant forces, eg weight of the food, when describing moments.
- (b) This relatively simple derivation was not attempted well by a large majority of the cohort. Few students started with an expression of moments and commonly omitted  $g$  in their working.
- (c) There was a good spread of marks here, although many students failed to connect the equation from part (b) and therefore gained no credit. A large number tried to obtain a gradient.
- (d) Very few students gained any credit. Most students presented arguments in terms of a percentage uncertainty. This, they argued, would decrease as  $M$  increased because the absolute uncertainty in  $M$  would be constant. This is not the case: the absolute uncertainty in a value of  $x$  is constant but, as **Figure 3** shows, this leads to an increasing uncertainty in  $M$ .

**49.**

There was a range of demand to the parts of question 2 that meant it produced a good spread of marks.

- (a) There were several alternative routes available for the first mark, and the majority of students were able to pick up credit for one of them. The second mark proved to be more difficult, with only about half of the students getting both marks. Almost all of the students who worked out the answer correctly realised that a two significant figure (s.f.) answer was inappropriate in the context.

- (b) Few students had any difficulty calculating the kinetic energy. This proved to be one of the most accessible questions on the paper.
- (c) This four-mark part of the question was answered correctly by almost half of the students. It was clear that, although the graph was unusual, the support given here allowed students to access the marks. The mark scheme was designed to credit each step in the calculation separately. Students who set out their answers logically and clearly benefited from this.
- (d) This was much more demanding with only about one in six students receiving both marks. The assessment objective for this part required some flexibility in the approach students could use. Students should be encouraged to develop their skills in answering AO3 questions of this kind.

**54.**

Generally, students were more successful in answering this question (this had a success rate of at least 65%).

**55.**

In this question, based on required practical activity 3, students were required to explain how  $g$  could be determined by a free-fall method using evidence from a strobe photograph.

There was no expectation that students should have direct experience of using a stroboscope but that does not preclude the use of photographic images, made with the aid of a stroboscope, to analyse the motion of a falling object. Mobile phones can produce videos of objects in free fall that perform a similar function. Many students showed through their working that they were well aware of the independent effect of motion in horizontal and vertical directions.

- (a) Over half of the students gave the correct response.
- (b) Students were asked why the duration of each flash should be short. Some stated that this increases the number of images produced, but we expected them to comment on the quality of each image or to explain that this allowed the position of the ball in each image to be determined.
- (c) Much of the work was easy to follow, even though some used the space on page 4 to show a rearranged equation. There were many possible valid solutions, the most popular of which was to suggest that  $\frac{n}{2f^2}$  was plotted on the  $x$ -axis so that  $g$  was the gradient.

Students must make sure that they avoid ambiguous statements such as “we need to find the gradient to get  $g$ ”. They also had to make sure to explain clearly how  $g$  was obtained; a statement in which  $g$  was not the subject, such as “the gradient of the graph is  $\frac{g}{2f^2}$ ”, was not accepted.

- (d) We expected students to use **Figure 1** to identify  $N$ , the image number at the instant the ball hits the floor for the first time. We accepted  $N = 17 \pm 1$  but many missed the intention of the question and tried to substitute  $n = 0$  or 5 into  $H - h = \frac{u_0 n}{f} + \frac{g}{2} \left( \frac{n}{f} \right)^2$ . It should have been obvious that the  $n = 0$  approach could not work. The  $n = 5$  approach led to attempts to measure  $h$  directly from **Figure 2** and, in some instances, this worked, but many failed to recognise the broken dimension convention and wrongly concluded that  $h$  was  $\frac{H}{2}$ .

- (e) We expected them to determine the horizontal velocity by dividing the distance between two suitable images by the corresponding time; we accepted the use of their distance between the second and third contacts (usually 1000 mm) and their time from 01.6.

Comparatively few added suitable annotation to **Figure 3**. Rather than take the expected route of dividing the distance by their (e) result, some used  $s = \frac{1}{2}at^2$  with  $s = 495$  mm and  $g = 9.79 \text{ m s}^{-2}$  but apart from those who forgot to multiply their  $t$  by 2 or who failed to cope with the mixed units, this approach worked well. Some credit was given for determining the time by estimating a non-integer number of intervals between the contacts.