

AQA A-LEVEL PHYSICS • 7408

PHYSICS



EXAM QUESTION PACK

3.4.1 FORCE, ENERGY AND MOMENTUM • PACK 2

SCORE

/203

PERCENTAGE

%

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1.

An electron has speed v . The electron's kinetic energy is doubled.

What is the new speed of the electron?

A $\frac{v}{\sqrt{2}}$ ☐

B $\sqrt{2}v$ ☐

C $2v$ ☐

D $4v$ ☐

(Total 1 mark)

2.

An object of mass m is accelerated from rest to a velocity v by a constant resultant force F .

What is the work done on the object during this acceleration?

A $\frac{Fv}{2}$ ☐

B Fv ☐

C mv^2 ☐

D $\frac{mv^2}{2}$ ☐

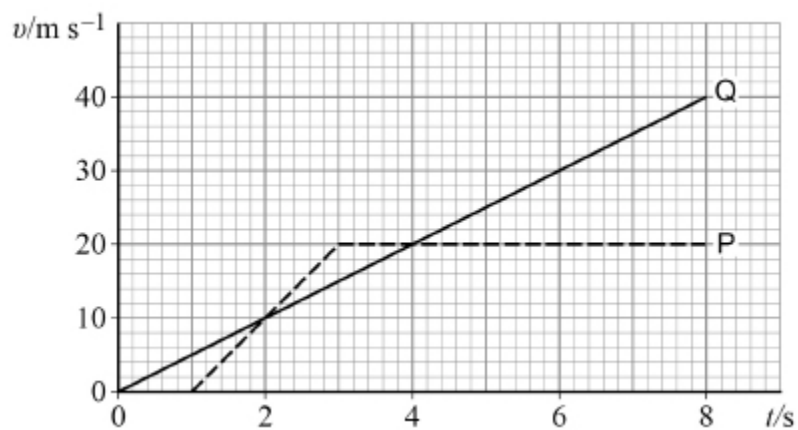
(Total 1 mark)

3.

Two cars **P** and **Q** leave from the same point and travel in the same direction.

Q leaves at time $t = 0$ and **P** leaves one second later.

The figure shows the velocity–time graph for **P** and **Q**.



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

A 40 m

☐

B 80 m

☐

C 160 m

☐

D 180 m

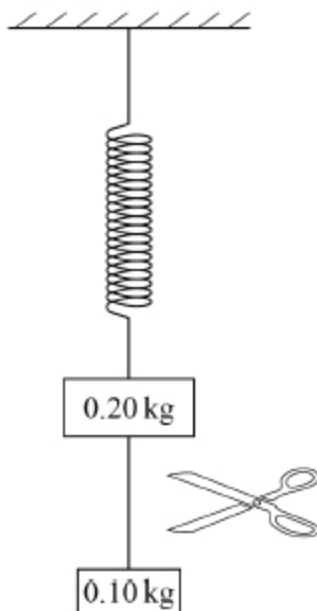
☐

(Total 1 mark)

4.

A 0.20 kg mass is suspended from a spring. A 0.10 kg mass is suspended from the 0.20 kg mass using a thread of negligible mass.

The system is in equilibrium and the thread is then cut.



What is the upward acceleration of the 0.20 kg mass at the instant that the thread is cut?

A 3.3 m s^{-2}

☐

B 4.9 m s^{-2}

☐

C 6.5 m s^{-2}

☐

D 9.8 m s^{-2}

☐

(Total 1 mark)

5.

A lift of mass M is suspended from a cable. The lift descends with a downward acceleration, a . A frictional force F acts on the lift.

What is the tension T in the cable?

A $T = Ma + F$

☐

B $T = Ma - F$

☐

C $T = M(g + a) - F$

☐

D $T = M(g - a) - F$

☐

(Total 1 mark)

6.

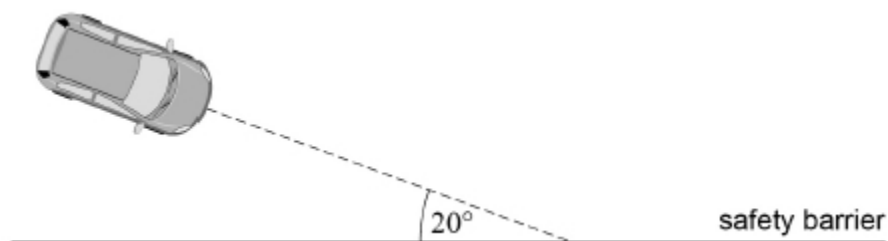
Safety barriers are used on UK motorways to prevent vehicles crossing from one carriageway to the other carriageway. The barriers also absorb some of the kinetic energy of a vehicle and deflect vehicles along the barrier.

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

(a) Show that the initial kinetic energy of the test vehicle is 700 kJ.

(2)

(b) The test vehicle hits a steel safety barrier at an angle of 20° , as shown in the diagram.



Calculate the component of the momentum of the test vehicle in a direction along the line of the safety barrier.

Give an appropriate unit for your answer.

momentum = _____ unit _____

(3)

- (c) Immediately after the collision, the test vehicle moves along the safety barrier with no change in its momentum in this direction.

Show that the kinetic energy lost in the collision is about 80 kJ.

(3)

- (d) The steel safety barrier deforms during the collision. For the barrier to pass the test, the test vehicle should not move more than 1.5 m towards the other carriageway.

The barrier can apply an average force of 60 kN at right angles to the carriageway.

Deduce whether the safety barrier will pass the test.

(3)

- (e) A different safety barrier uses a solid concrete wall which does not deform.
The same standard test is carried out on a concrete wall.

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

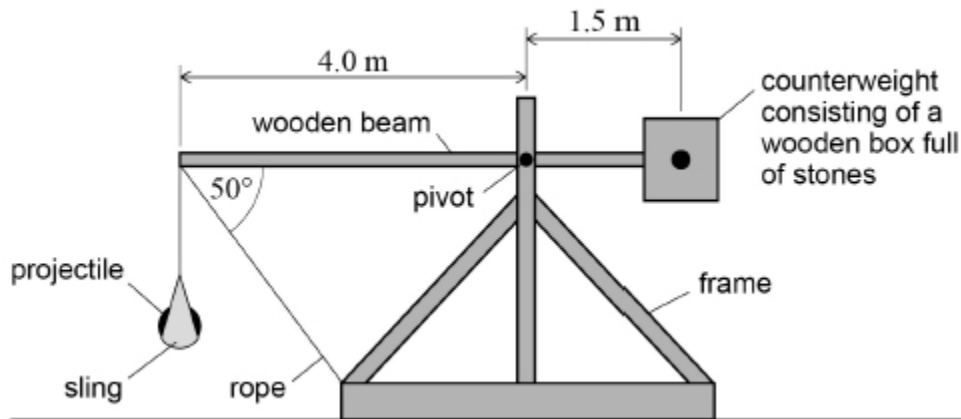
(2)

(Total 13 marks)

7.

Figure 1 shows a simplified catapult used to hurl projectiles a long way.

Figure 1



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

The beam is held horizontal by a rope attached to the frame.

- (a) The catapult is designed so that the weight of the beam and the weight of the **empty** wooden box have no effect on the tension in the rope.

Suggest how the pivot position achieves this.

(2)

- (b) The stones in the counterweight have a total mass of 610 kg and the projectile weighs 250 N.

Calculate the tension in the rope.

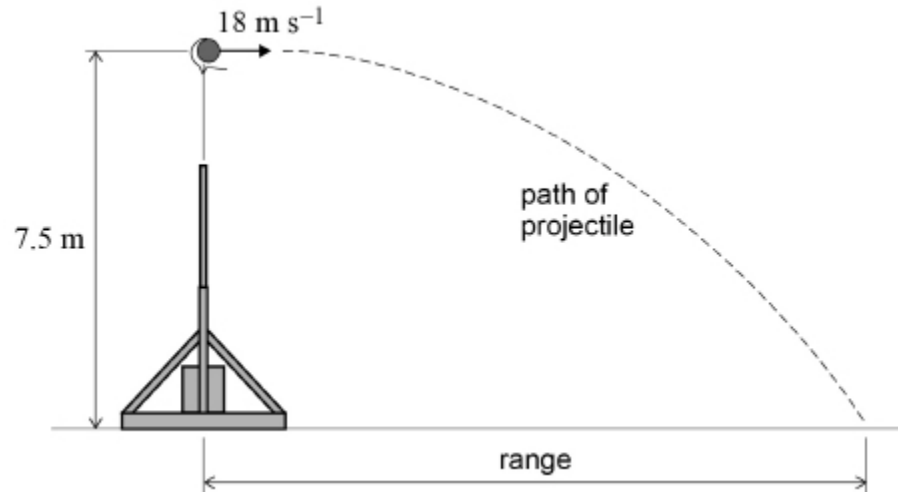
tension = _____ N

(5)

- (c) When the rope is cut, the counterweight rotates clockwise. When the beam is vertical it is prevented from rotating further. The projectile is then released horizontally with a velocity of 18 m s^{-1} , as shown in **Figure 2**.

The projectile is released at a height of 7.5 m above ground level.

Figure 2



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

Calculate the range.
Ignore air resistance.

range = _____ m

(2)

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

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

(3)

(Total 12 marks)

8.

Which quantities can be written in the fundamental units $\text{kg m}^{-1} \text{s}^{-2}$?

A Tensile stress and kinetic energy

☐

B The moment of a force and kinetic energy

☐

C Young modulus and the moment of a force

☐

D Young modulus and tensile stress

☐

(Total 1 mark)

9.

A car of mass 1000 kg accelerates uniformly from rest to a speed of 25.0 m s^{-1} in 50.0 s. The car is travelling along a horizontal road.

What is the average useful power output of the car over this period?

A 0.50 kW

☐

B 2.00 kW

☐

C 6.25 kW

☐

D 12.5 kW

☐

(Total 1 mark)

10.

A railway truck of mass 2000 kg travelling horizontally at 1.5 m s^{-1} collides with a stationary truck of mass 3000 kg.

After the collision they move together.

Which row is correct?

	Speed of the trucks immediately after collision / m s^{-1}	Effect of collision on total kinetic energy
A	0.6	no change
B	0.6	decrease
C	1.0	no change
D	1.0	decrease

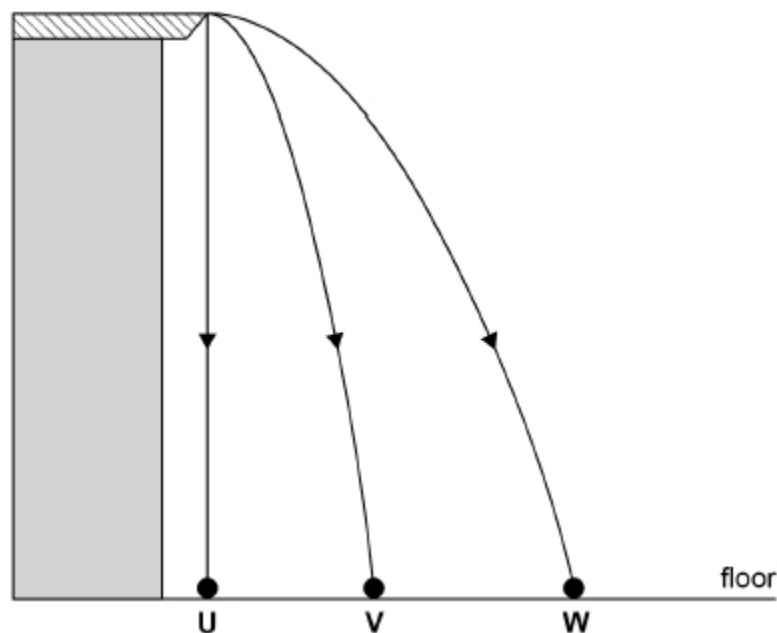
☐☐☐☐

(Total 1 mark)

11.

Three objects **U**, **V** and **W** leave the edge of a bench at the same time. The objects fall in the same vertical plane with negligible air resistance. **U** is released from rest so that it falls vertically. **V** and **W** are projected horizontally.

The paths of the three objects are shown.



Which statement is correct?

A **U** hits the floor before **V** and **W**.

☐

B **W** hits the floor before **V**.

☐

C **W** hits the floor with the greatest speed.

☐

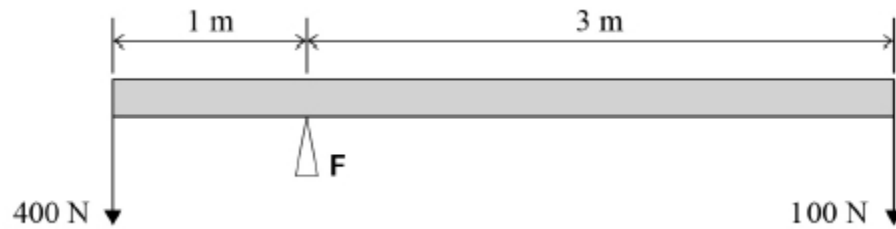
D **U** hits the floor with the greatest speed.

☐

(Total 1 mark)

12.

A uniform rod is balanced horizontally about a support **F**. Forces of 400 N and 100 N act at the ends of the rod, as shown.



What is the reaction force acting on the rod at support **F**?

A 100 N

☐

B 500 N

☐

C 550 N

☐

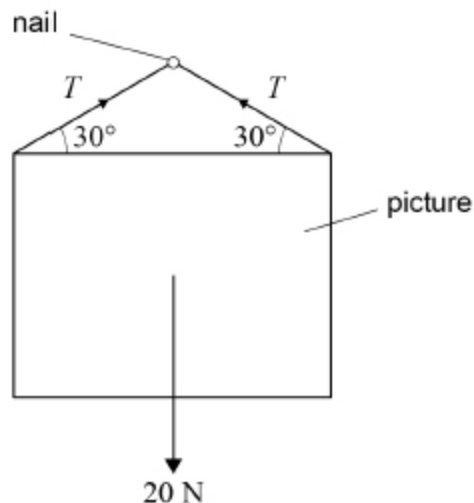
D 600 N

☐

(Total 1 mark)

13.

A uniform picture is suspended from a string which passes over a smooth nail. The tension in the string is T and the weight of the picture is 20 N.



What is T ?

A 10 N

☐

B 12 N

☐

C 20 N

☐

D 40 N

☐

(Total 1 mark)

14.

Which row contains vector quantities only?

A	acceleration	mass
B	displacement	momentum
C	energy	force
D	distance	speed

☐
☐
☐
☐

(Total 1 mark)

15.

What is the approximate average kinetic energy of a cyclist in a race?

A 10 J

☐

B 10 kJ

☐

C 10 MJ

☐

D 10 TJ

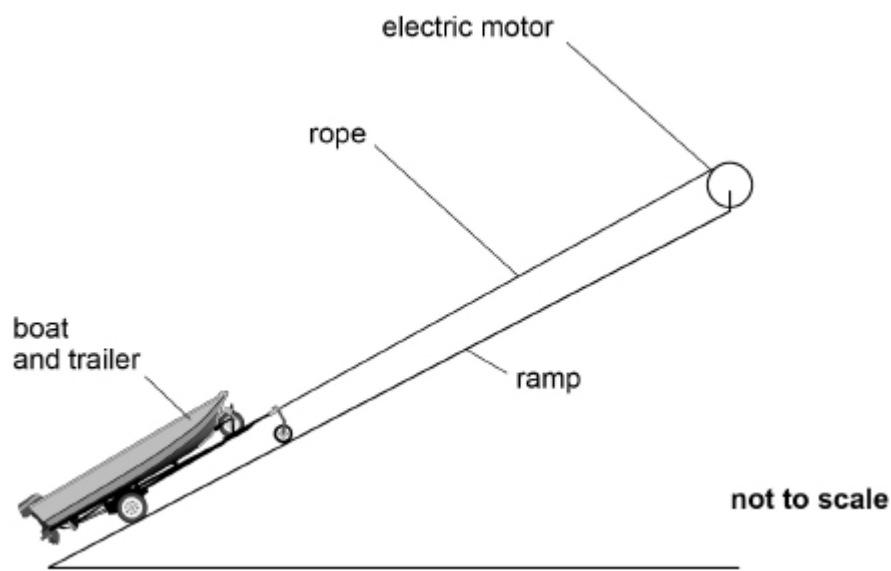
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(Total 1 mark)

16.

This question is about the initial motion of a boat and trailer when pulled up a ramp as shown in **Figure 1**.

Figure 1

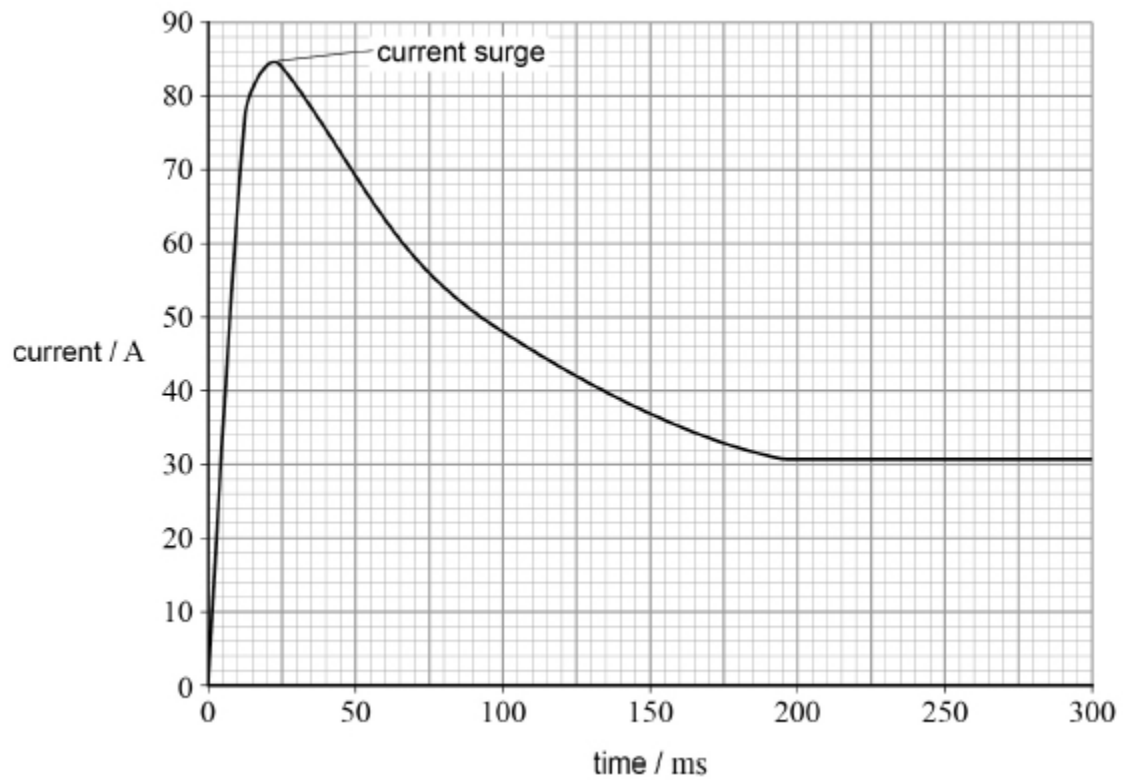


The boat and trailer are pulled by a motor which is connected to a 24 V battery of negligible internal resistance.

The motor is switched on at time $t = 0$

Figure 2 shows how the current in the motor's circuit varies with time.

Figure 2



- (a) Determine the total energy input by the 24 V battery to the motor in the first 200 ms.

total energy input = _____ J

(3)

- (b) The boat and trailer are initially at rest. In the first 200 ms the boat and trailer are raised through a vertical height of 3.3×10^{-2} m and the speed increases to 0.85 m s^{-1} .

Assume that all the useful energy output by the motor is transferred into kinetic energy and gravitational potential energy of the boat and trailer.

The boat and trailer have a total mass of 180 kg.

Determine the average efficiency of the motor during these first 200 ms.

average efficiency = _____

(3)

- (c) Either of the circuits shown in **Figure 3a** and **Figure 3b** could be used to reduce the initial current surge.

Figure 3a

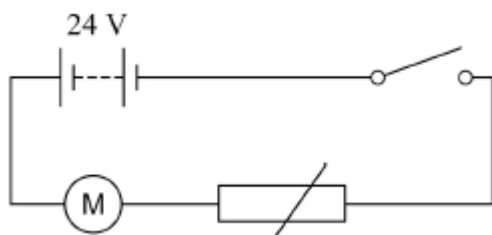
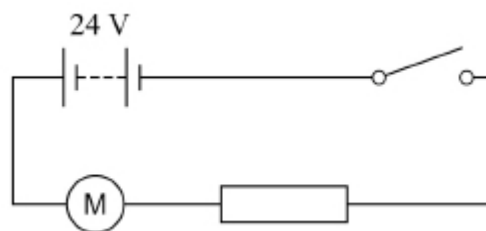


Figure 3b



The thermistor and the fixed resistor have the same resistance when they are at the temperature of the surroundings.

When the surge has ended, the boat and trailer continue to move at a constant speed to the top of the ramp.

Explain, with reference to the properties of the thermistor and the fixed resistor, why using the thermistor is preferable to using the fixed resistor.

(3)

(Total 9 marks)

17.

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

What is the efficiency of the motor?

A $\frac{Wh}{VI t}$ ☐

B $\frac{VI}{Wh t}$ ☐

C $\frac{Wh t}{VI}$ ☐

D $\frac{VI t}{Wh}$ ☐

(Total 1 mark)

18.

This question is about two applications of photon energy and momentum: positron emission tomography (PET) and a solar sail.

The momentum of a photon is $\frac{\text{photon energy}}{\text{speed of light in a vacuum}}$

- (a) In preparing for a PET scan of a patient's brain, a small sample of a substance containing unstable nuclei is injected into the patient.

A positron is emitted when one of the unstable nuclei undergoes β^+ decay.

Explain how the change in quark character in β^+ decay affects the number of neutrons and the number of protons in the unstable nucleus.

(2)

- (b) The positron interacts with an electron, resulting in annihilation. As a result, gamma photons are produced.

The energy of each gamma photon is 0.52 MeV.

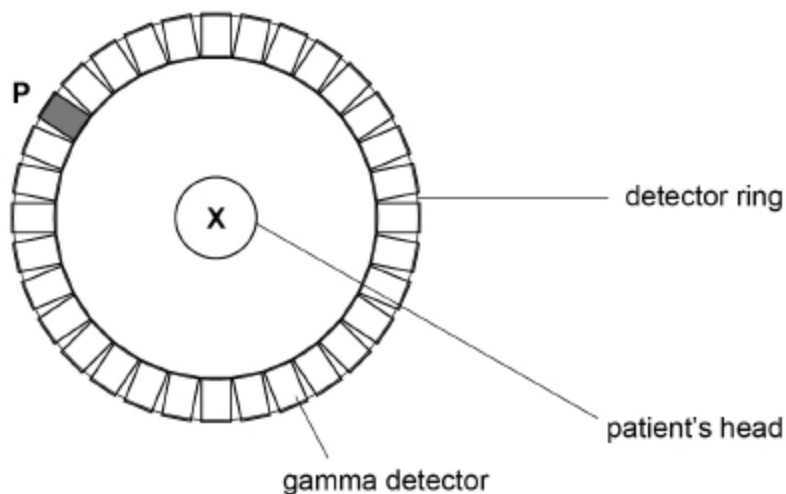
Calculate the momentum, in N s, of one of the gamma photons produced in this annihilation.

momentum = _____ N s

(2)

- (c) **Figure 1** shows a cross-sectional view of the patient's head inside a ring of gamma detectors during the PET scan.

Figure 1



A positron and an electron meet and annihilate at position **X** shown in **Figure 1**. Assume they have negligible kinetic energy when they meet.

Gamma photons are produced in this annihilation and are detected. The arrival of one gamma photon at detector **P** triggers a signal. Detector **P** has been shaded in **Figure 1**.

Identify by shading any other detectors that will be triggered by this annihilation.

(1)

- (d) Explain your answer to question (c).

(2)

- (e) **Figure 2** shows a stream of photons of light, emitted from the Sun, incident on a solar sail. A solar sail is an experimental spacecraft that uses photons of light to accelerate it.

Figure 2

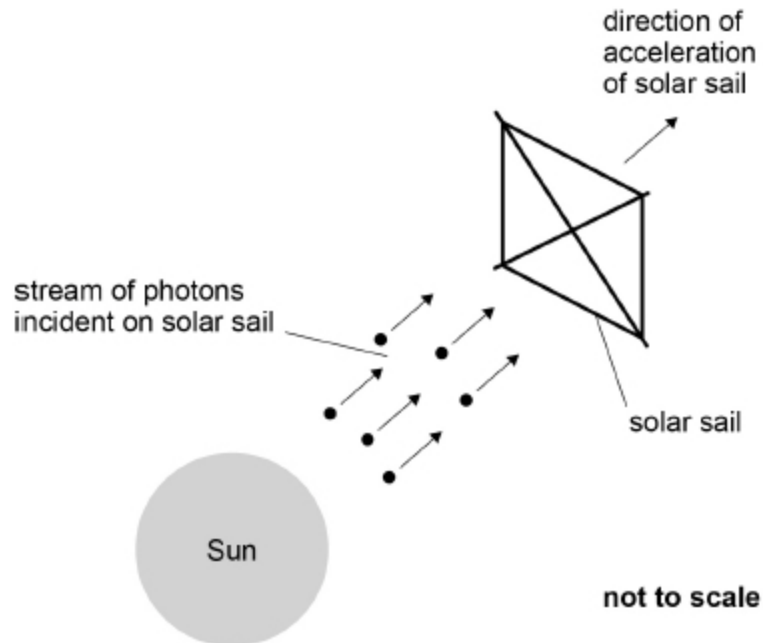
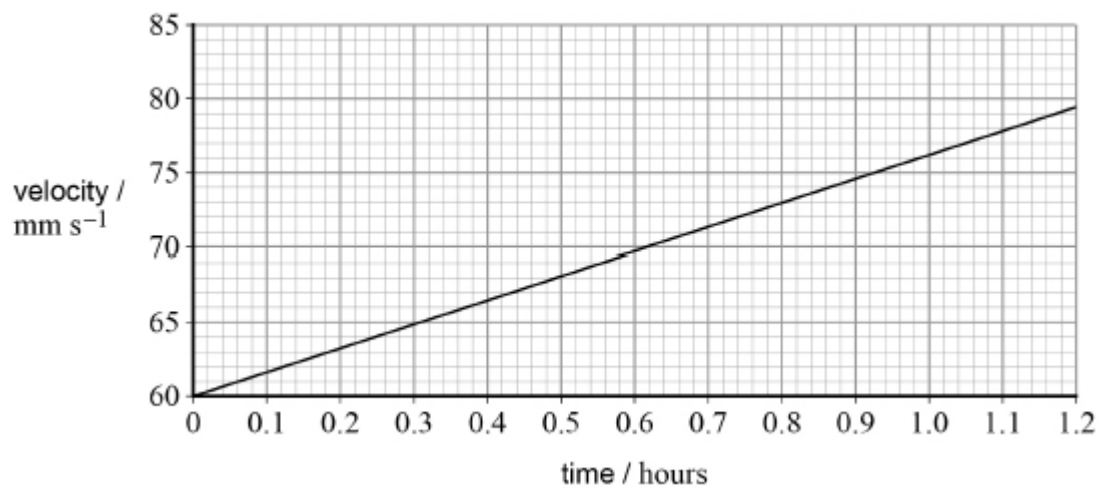


Figure 3 shows the velocity–time graph for the solar sail.

Figure 3



Calculate the acceleration, in m s^{-2} , of the solar sail.

acceleration = _____ m s^{-2}

(2)

- (f) The reflectance of a surface is proportional to the percentage of incident photons that are reflected off the surface.

Explain the effect of increasing the reflectance of the solar sail on the acceleration.
Assume gravity has negligible effect on the solar sail.

(2)

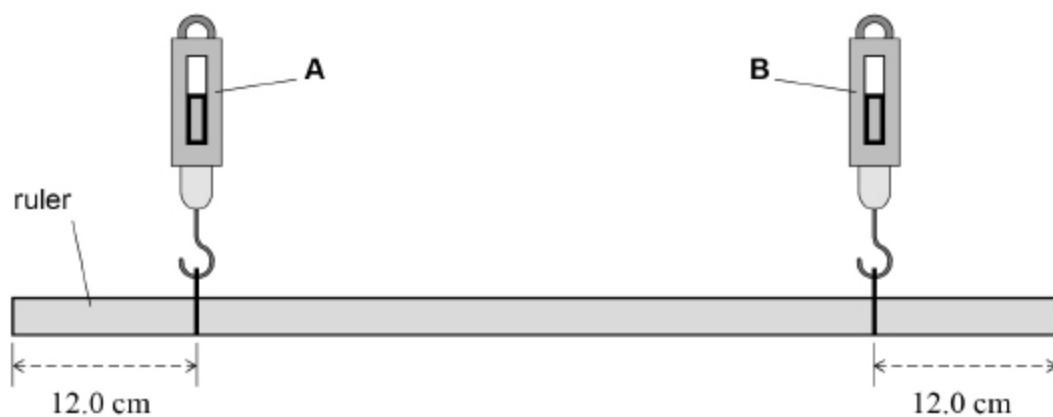
(Total 11 marks)

19.

A student investigates moments by suspending a 100 cm ruler from two force meters, **A** and **B**. **A** and **B** are attached to the ruler 12.0 cm from each end. Their supports are adjusted to make **A** and **B** vertical and the ruler horizontal.

Figure 1 is a simplified diagram of the experiment.

Figure 1



- (a) The ruler is uniform and weighs 1.12 N.

Determine the reading on **A**.

reading = _____ N

(1)

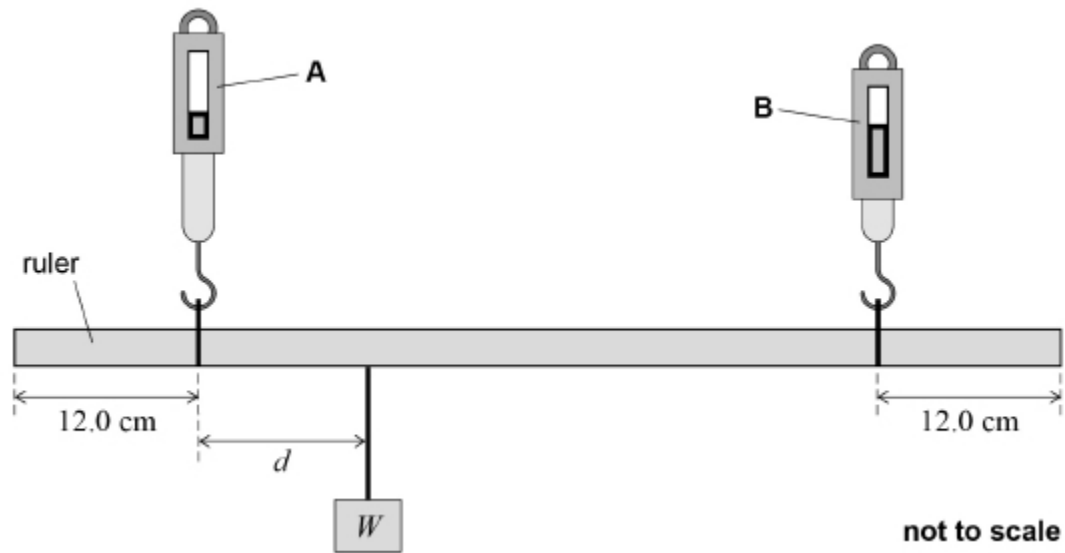
- (b) The student suggests that the forces exerted on the ruler by **A** and **B** act as a couple.

Discuss whether his suggestion is correct.

(2)

- (c) The student hangs a mass of weight W on the ruler between **A** and **B**, as shown in **Figure 2**.
He adjusts the supports so that **A** and **B** are again vertical and the ruler is horizontal. The mass hangs at a distance d from **A**.

Figure 2



The reading on **A** is 0.82 N and the reading on **B** is 0.62 N.

Determine

- W
- d .

$$W = \text{_____ N}$$

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

(4)

- (d) A second student sets up the same apparatus as shown in **Figure 2**.
 She suspends the mass in the same position on the ruler as in question (c).
 She moves the supports to make **A** and **B** vertical but does not make the ruler horizontal.

Discuss whether the readings on **A** and **B** taken by this student are different to those in question (c).

(2)

(Total 9 marks)

20.

A particle of mass m undergoes simple harmonic motion with amplitude A and frequency f .

What is the total energy of the particle?

A $2\pi m f A^2$ ☐

B $2\pi^2 m f^2 A^2$ ☐

C $4\pi^2 m^2 f^2 A$ ☐

D $4\pi^2 m f^2 A^2$ ☐

(Total 1 mark)

21.

The period of a simple pendulum is doubled when the pendulum length is increased by 1.8 m.

What is the original length of the pendulum?

A 0.45 m ☐

B 0.60 m ☐

C 0.90 m ☐

D 3.6 m ☐

(Total 1 mark)

22.

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

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

What is the frequency of the oscillations?

A 0.071 Hz

☐

B 0.67 Hz

☐

C 1.50 Hz

☐

D 14 Hz

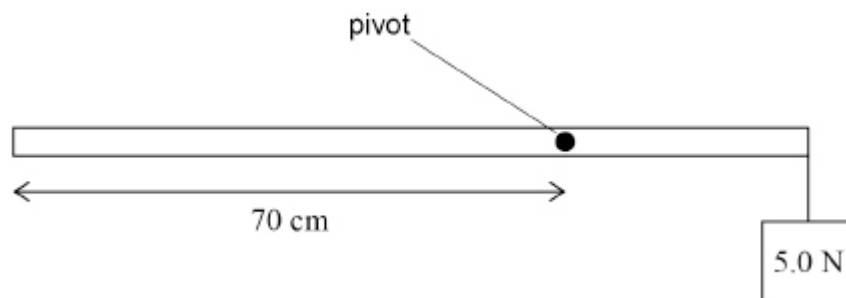
☐

(Total 1 mark)

23.

A uniform metre ruler of weight 2.0 N is freely pivoted at the 70 cm mark.

A student holds the ruler in a horizontal position and suspends a 5.0 N weight from the 100 cm end.



What is the magnitude of the resultant moment when the student releases the ruler?

A 0.15 N m

☐

B 0.19 N m

☐

C 1.1 N m

☐

D 1.9 N m

☐

(Total 1 mark)

24.

A pellet with velocity 200 m s^{-1} and mass 5.0 g is fired vertically upwards into a stationary block of mass 95.0 g . The pellet remains in the block. The impact causes the block to move vertically upwards.

What is the maximum vertical displacement of the block?

A 5.1 m

☐

B 10 m

☐

C 51 m

☐

D 100 m

☐

(Total 1 mark)

25.

Small water drops leave a tap with zero velocity at intervals of 0.20 s . They then fall freely 0.80 m to reach a horizontal surface.

How far has a drop fallen when the previous drop hits the surface?

A 0.16 m

☐

B 0.20 m

☐

C 0.40 m

☐

D 0.60 m

☐

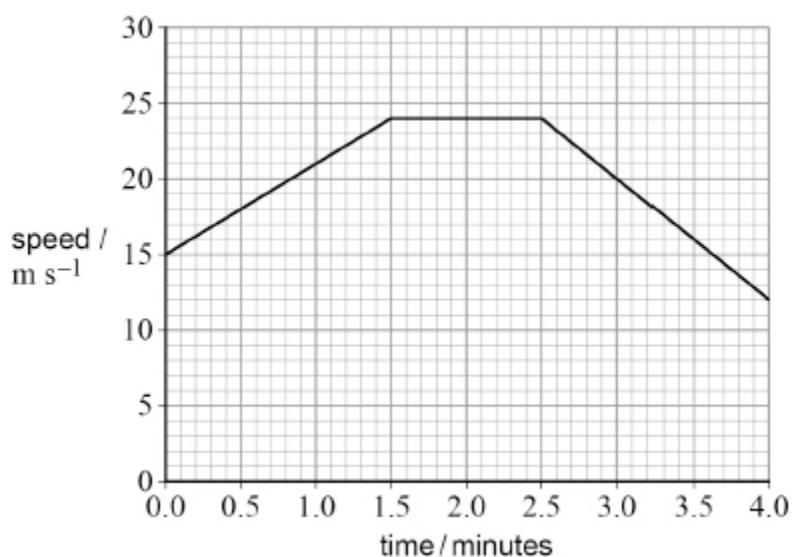
(Total 1 mark)

26.

A pair of cameras is used on a motorway to help determine the average speed of vehicles travelling between the two cameras.

Figure 1 shows the speed–time graph for a car moving between the two cameras.

Figure 1



- (a) The speed limit for the motorway between the two cameras is 22 m s^{-1} .

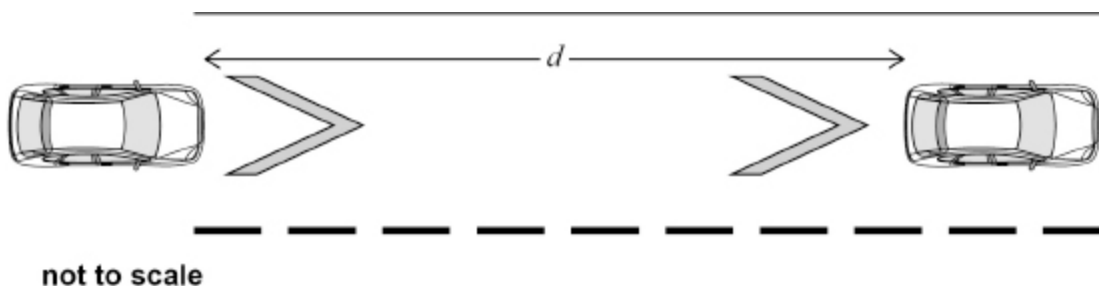
Determine whether the average speed of the car exceeded this speed limit.

(3)

- (b) Markings called chevrons are used on motorways.

The chevron separation is designed to give a driver time to respond to any change in speed of the car in front. The driver is advised to keep a minimum distance d behind the car in front, as shown in **Figure 2**.

Figure 2



Government research suggests that the typical time for a driver to respond is between 1.6 s and 2.0 s.

Suggest a value for d where the speed limit is 31 m s^{-1} .

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

(2)

- (c) The chevron separation is based on the response time, not on the time taken for a car to stop.

The brakes of a car are applied when its speed is 31 m s^{-1} and the car comes to rest. The total mass of the car is 1200 kg.

The average braking force acting on the car is 6.8 kN.

Calculate the time taken for the braking force to stop the car **and** the distance travelled by the car in this time.

time = _____ s

distance = _____ m

(4)

- (d) Suggest why the chevron separation on motorways does not take into account the distance travelled as a car comes to rest after the brakes are applied.

(1)

- (e) At bends on motorways the road is sloped so that a car is less likely to slide out of its lane when travelling at a high speed.

Figure 3 shows a car of mass 1200 kg travelling around a curve of radius 200 m. The motorway is sloped at an angle of 5.0° .

Figure 4 shows the weight W and reaction force N acting on the car. The advisory speed for the bend is chosen so that the friction force down the slope is zero.

Figure 3

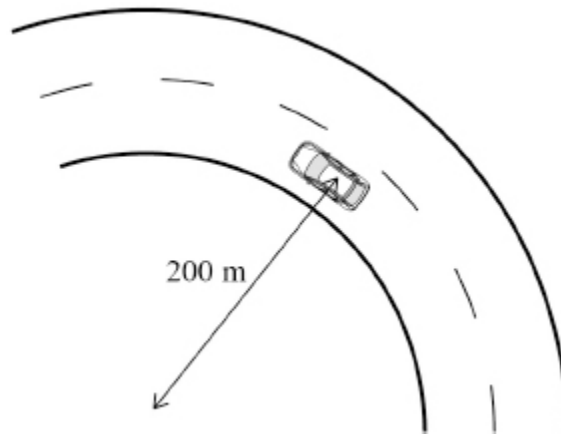
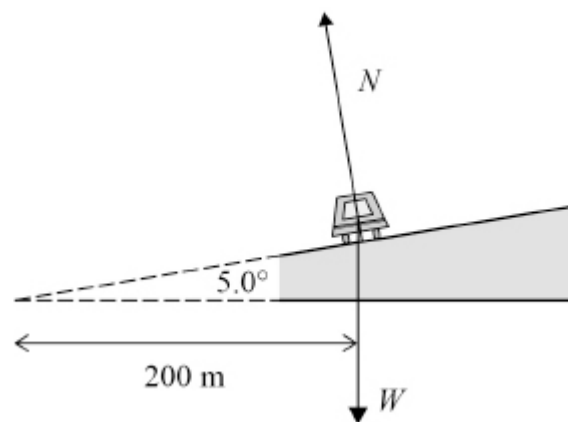


Figure 4



Suggest an appropriate advisory speed for this section of the motorway.

advisory speed = _____ m s⁻¹

(4)

(Total 14 marks)

27.

Mechanical power

A is a vector quantity.

☐

B is measured in J.

☐

C has base units of kg m² s⁻³.

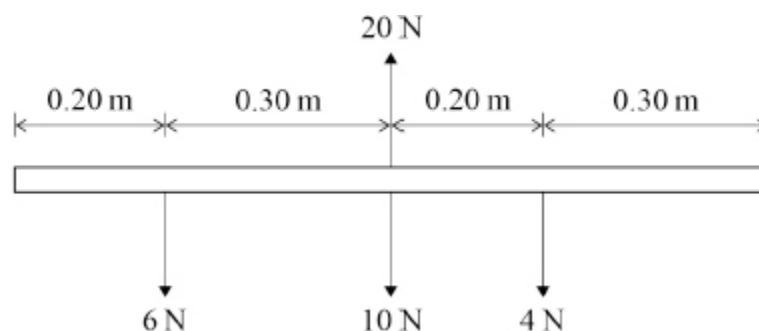
☐

D can be calculated from force × distance moved.

☐

(Total 1 mark)

28. The diagram shows the forces acting on a uniform rod.



Which statement is correct?

- A The rod is in equilibrium. ☐
- B For equilibrium, an anticlockwise moment of 1.0 N m is needed. ☐
- C For equilibrium, a clockwise moment of 1.0 N m is needed. ☐
- D For equilibrium, the 10 N force should be increased to 20 N. ☐

(Total 1 mark)

29. The drag force on a boat is kv^2 , where v is the speed and $k = 64 \text{ kg m}^{-1}$.

The boat's engine has a useful power output of 8000 W.

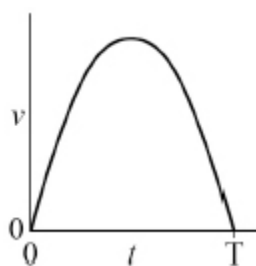
What is the maximum speed of the boat?

- A 0.2 m s^{-1} ☐
- B 5 m s^{-1} ☐
- C 11 m s^{-1} ☐
- D 125 m s^{-1} ☐

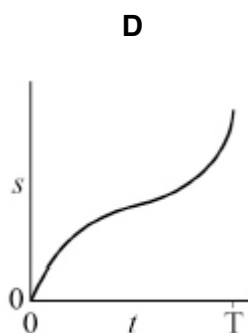
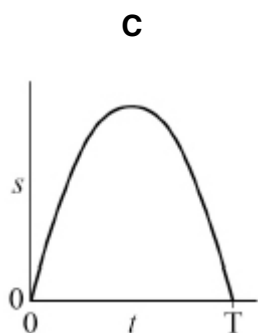
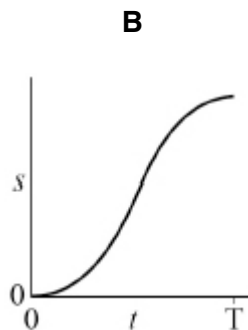
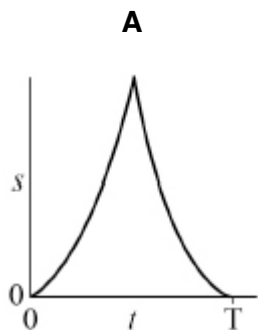
(Total 1 mark)

30.

The diagram shows how the speed v of an object varies with time t .



Which graph shows the variation of distance s with t for the object?



A

☐

B

☐

C

☐

D

☐

(Total 1 mark)

31.

Which row is true for an elastic collision between two objects in an isolated system?

	Kinetic energy	Momentum	
A	conserved	conserved	☐
B	not conserved	conserved	☐
C	conserved	not conserved	☐
D	not conserved	not conserved	☐

(Total 1 mark)

32.

Two ball bearings **X** and **Y** are projected from horizontal ground at the same time.

X has mass $2m$ and is projected vertically upwards with speed u .

Y has mass m and is projected at 30° to the horizontal with speed $2u$.

Air resistance is negligible.

Which statement is correct?

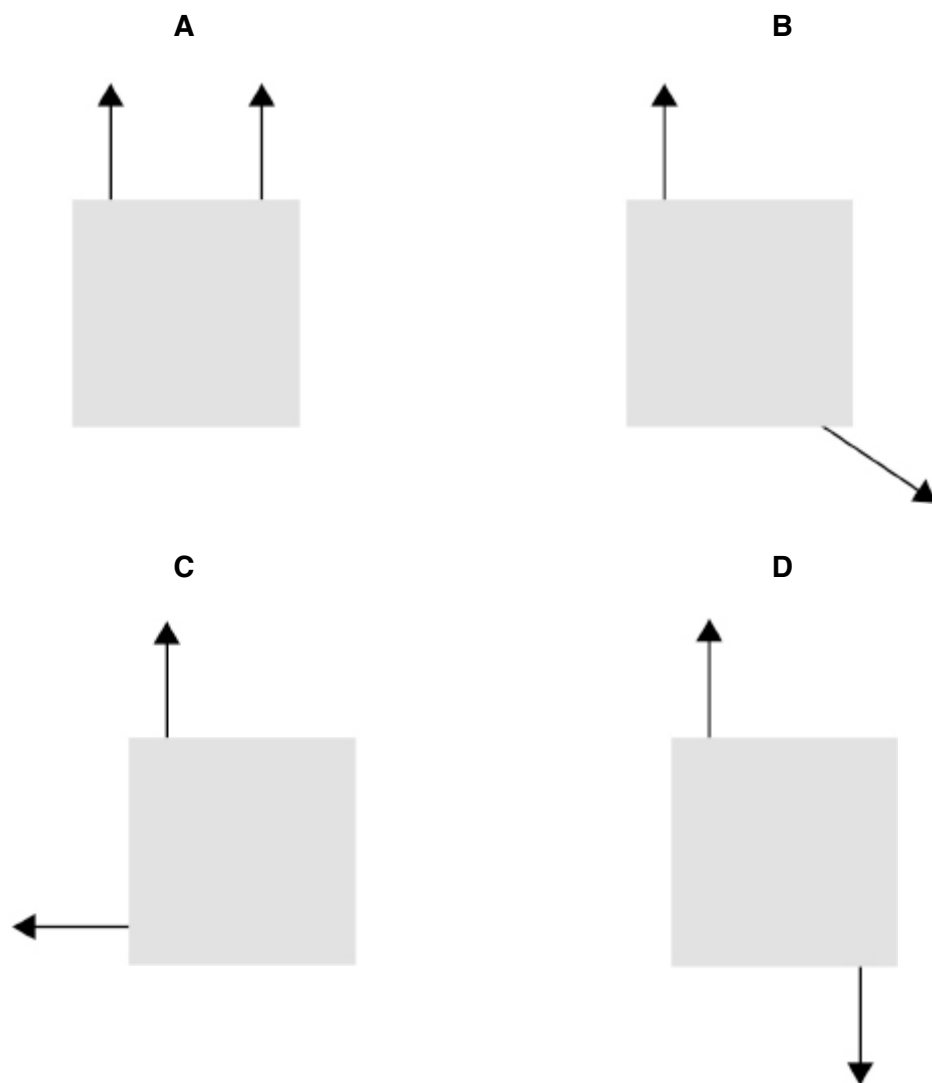
- A** **X** and **Y** have the same initial momentum. ☐
- B** **X** and **Y** reach their maximum heights at different times. ☐
- C** The maximum height reached by **Y** is half that reached by **X**. ☐
- D** **X** and **Y** reach the ground at the same time. ☐

(Total 1 mark)

33.

Each diagram shows two horizontal forces acting on a solid square object seen from above.

All the forces have the same magnitude.



Which system produces a couple about any point inside the object?

A



B



C



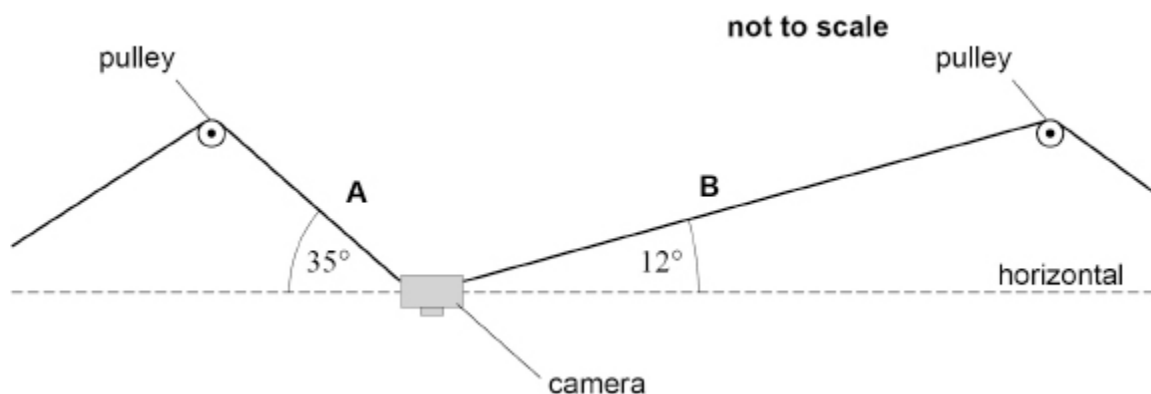
D



(Total 1 mark)

34.

The diagram shows a camera filming a sports event from above. The position of the camera is controlled by two steel cables, **A** and **B**, that pass over fixed, smooth pulleys.



- (a) In the diagram above the camera is stationary. The tension in **A** is 430 N and **A** makes an angle of 35° to the horizontal. **B** makes an angle of 12° to the horizontal.

Calculate the tension in **B**.

tension in **B** = _____ N

(2)

- (b) The cross-sectional area of **A** is $7.0 \times 10^{-6} \text{ m}^2$. The unstretched length of **A** is 150 m.

Calculate the extension of **A** when the tension in it is 430 N.

Young modulus of steel = 210 GPa

extension = _____ m

(2)

- (c) The camera is moved horizontally to the right to a new stationary position. The tension in **A** is now different from that in the diagram above.

Deduce whether the tension in **A** has increased or decreased.

(3)

- (d) The camera’s signal is transmitted as a series of pulses through an optical fibre. The table shows data for two optical fibres **X** and **Y**. Both optical fibres are identical except for their core diameter.

Optical fibre	Core diameter / μm
X	8
Y	50

Deduce which fibre allows a greater pulse transmission rate.

(3)

(Total 10 marks)

35.

Which row describes charge and impulse?

	Charge	Impulse
A	scalar	scalar
B	scalar	vector
C	vector	scalar
D	vector	vector

☐
☐
☐
☐

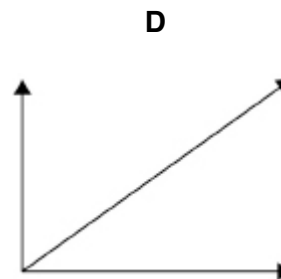
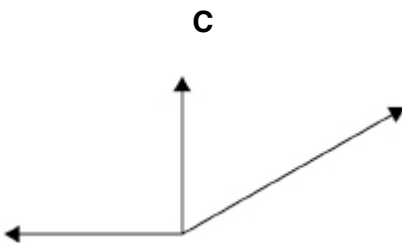
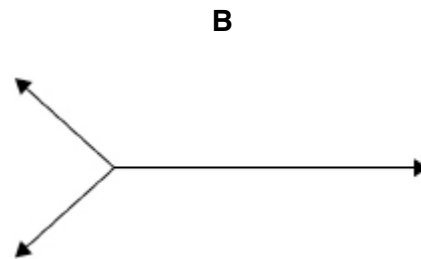
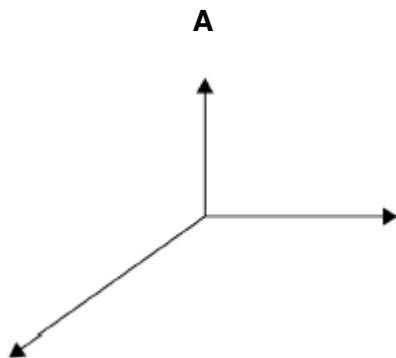
(Total 1 mark)

36.

An object is in equilibrium when acted on by three coplanar forces.

Which free-body diagram is correct?

Each diagram is drawn to scale.



A

☐

B

☐

C

☐

D

☐

(Total 1 mark)

37.

Which quantity is represented by the area under a force–time graph?

A average power

☐

B elastic strain energy stored

☐

C momentum change

☐

D work done

☐

(Total 1 mark)

38.

What is true for an inelastic collision between two isolated objects?

- A Both total momentum and total kinetic energy are conserved.
- B Neither total momentum nor total kinetic energy is conserved.
- C Only total kinetic energy is conserved.
- D Only total momentum is conserved.

☐☐☐☐

(Total 1 mark)

39.

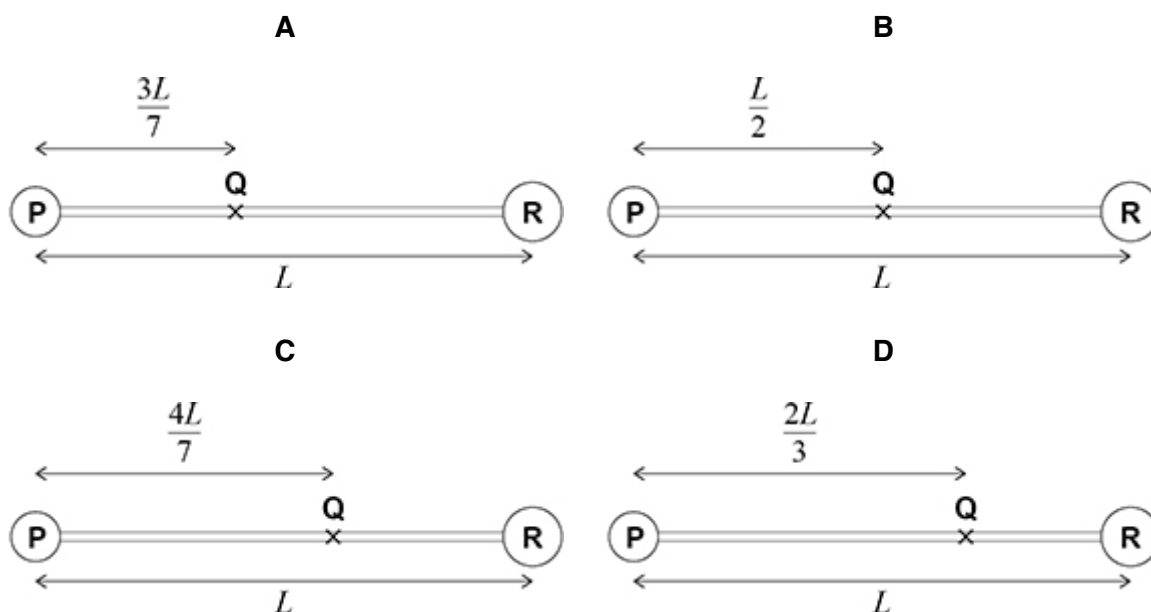
P and **R** are uniform spheres of mass 3 kg and 4 kg respectively.

P and **R** are joined by a rod of negligible mass.

The distance between their centres is L .

The centre of mass of this system is at **Q**.

Which diagram shows the position of the centre of mass?



A

☐

B

☐

C

☐

D

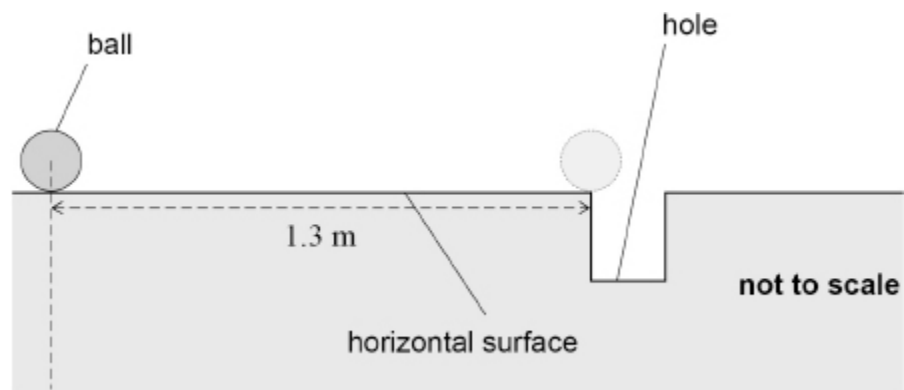
☐

(Total 1 mark)

40.

- (a) **Figure 1** shows a golf ball at rest on a horizontal surface 1.3 m from a hole.

Figure 1



A golfer hits the ball so that it moves horizontally with an initial velocity of 1.8 m s^{-1} . The ball experiences a constant deceleration of 1.2 m s^{-2} as it travels to the hole.

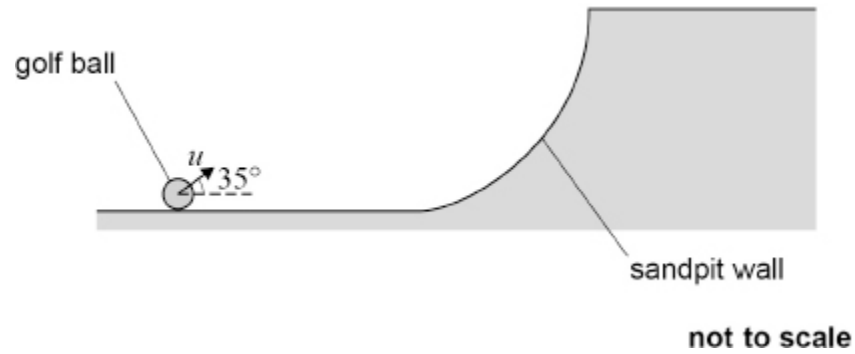
Calculate the velocity of the ball when it reaches the edge of the hole.

velocity = _____ m s^{-1}

(2)

- (b) Later, the golf ball lands in a sandpit. The golfer hits the ball, giving it an initial velocity u at 35° to the horizontal, as shown in **Figure 2**. The horizontal component of u is 8.8 m s^{-1} .

Figure 2

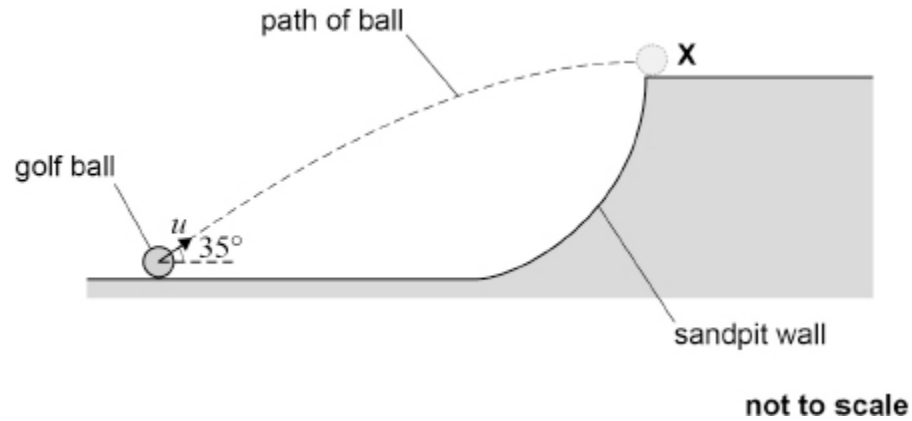


Show that the vertical component of u is approximately 6 m s^{-1} .

(1)

- (c) The ball is travelling horizontally as it reaches **X**, as shown in **Figure 3**.

Figure 3



Assume that weight is the only force acting on the ball when it is in the air.

Calculate the time for the ball to travel to **X**.

time = _____ s

(2)

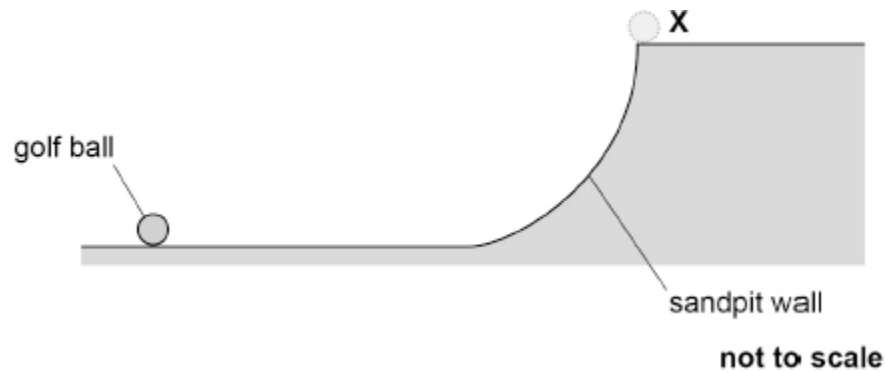
- (d) Calculate the vertical distance of **X** above the initial position of the ball.

vertical distance = _____ m

(2)

The golfer returns the ball to its original position in the sandpit. He wants the ball to land at **X** but this time with a **smaller** horizontal velocity than in **Figure 3**.

Figure 4



(e) Sketch on **Figure 4** a possible trajectory for the ball.

(1)

(f) Explain your reason for selecting this trajectory.

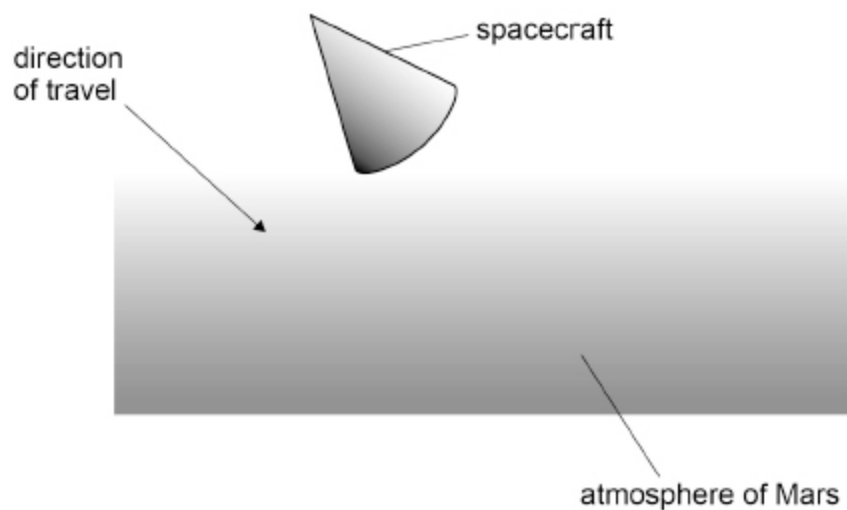
(2)

(Total 10 marks)

41.

A spacecraft entering the atmosphere of Mars must decelerate to land undamaged on the surface.

Figure 1



- (a) **Figure 1** shows the spacecraft of total mass 610 kg entering the atmosphere at a speed of 5.5 km s^{-1} .

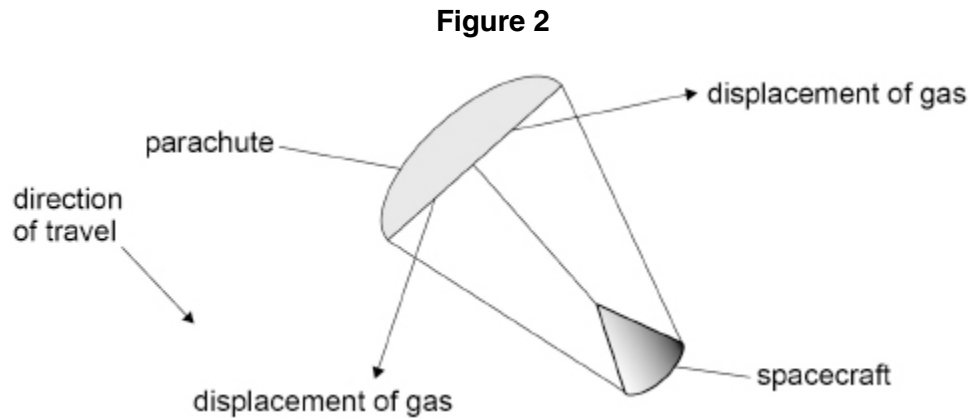
Calculate the kinetic energy of the spacecraft as it enters the atmosphere. Give your answer to an appropriate number of significant figures.

kinetic energy = _____ J

(3)

- (b) A parachute opens during the spacecraft's descent through the atmosphere.

Figure 2 shows the parachute–spacecraft system, with the open parachute displacing the atmospheric gas. This causes the system to decelerate.



Explain, with reference to Newton's laws of motion, why displacing the atmospheric gas causes a force on the system **and** why this force causes the system to decelerate.

(4)

- (c) As the parachute–spacecraft system decelerates, it falls through a vertical distance of 49 m and loses 2.2×10^5 J of kinetic energy.
During this time, 3.3×10^5 J of energy is transferred from the system to the atmosphere.
The total mass of the system is 610 kg.

Calculate the acceleration due to gravity as it falls through this distance.

acceleration due to gravity = _____ m s^{-2}

(3)

- (d) Dust from the surface of Mars can enter the atmosphere. This increases the density of the atmosphere significantly.

Deduce how an increase in dust content will affect the deceleration of the system.

(3)

(Total 13 marks)

42.

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

What is the maximum kinetic energy of the particle?

A $\frac{mA^2}{2T^2}$

☐

B $\frac{\pi^2 mA^2}{2T^2}$

☐

C $\frac{2mA^2}{T^2}$

☐

D $\frac{2\pi^2 mA^2}{T^2}$

☐

(Total 1 mark)

43.

A simple pendulum and a mass–spring system each have a time period T on the Earth.

They are taken to the surface of a planet where the acceleration due to gravity is $\frac{g}{4}$.

What are the time periods of the pendulum and the mass–spring system on this planet?

	Simple pendulum	Mass–spring system	
A	$\frac{T}{2}$	T	☐
B	$2T$	T	☐
C	$\frac{T}{2}$	$2T$	☐
D	$2T$	$2T$	☐

(Total 1 mark)

44.

A suitcase weighing 200 N is placed on a weighing scale in a lift. The scale reads 180 N when the lift is moving.

The lift is

A moving down at a constant velocity.

☐

B moving down with a decreasing velocity.

☐

C moving up at a constant velocity.

☐

D moving up with a decreasing velocity.

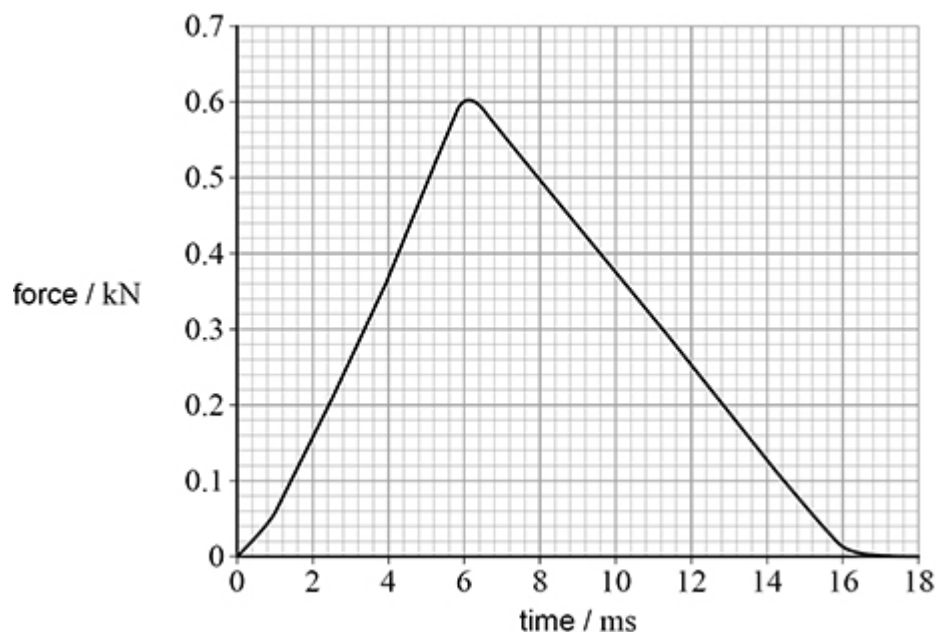
☐

(Total 1 mark)

45.

A golf ball has a mass of 46 g and is initially stationary.

The diagram shows the variation with time of the force acting on the golf ball as it is hit with a golf club.



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

A 5 J

☐

B 50 J

☐

C 250 J

☐

D 500 J

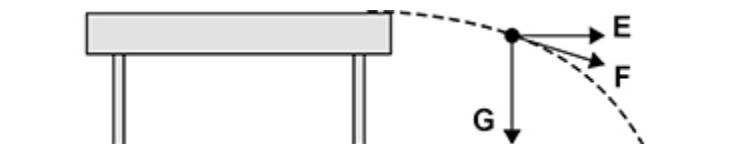
☐

(Total 1 mark)

46.

A coin is projected horizontally from the top of a desk.

The diagram shows the coin at one point in its path. The air resistance is negligible.



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

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

	Acceleration	Momentum	
A	F	F	☐
B	F	E	☐
C	G	F	☐
D	G	E	☐

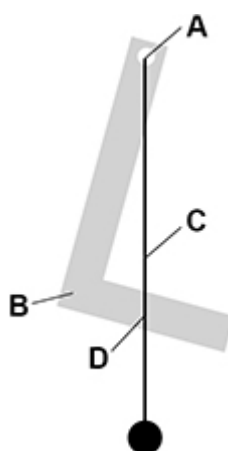
(Total 1 mark)

47.

A uniform piece of card in the shape of the letter L is suspended freely from a horizontal pin.

A plumb line is also suspended from the pin.

The diagram shows the card in its equilibrium position.



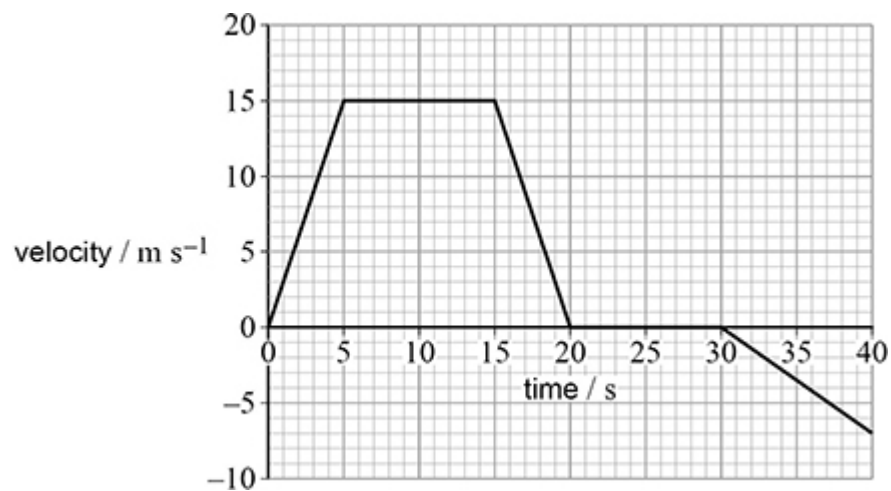
What is the position of the centre of mass of the piece of card?

- A ☐
- B ☐
- C ☐
- D ☐

(Total 1 mark)

48.

A vehicle travels on a straight road, starting at time $t = 0$
The graph shows how its velocity varies with time.



What is the distance of the vehicle from its start position when $t = 40$ s?

- A 115 m ☐
- B 190 m ☐
- C 260 m ☐
- D 370 m ☐

(Total 1 mark)

49.

Which is the shortest distance?

A 10^{-19} Gm

☐

B 10^{-14} km

☐

C 10^{-4} μ m

☐

D 10^7 fm

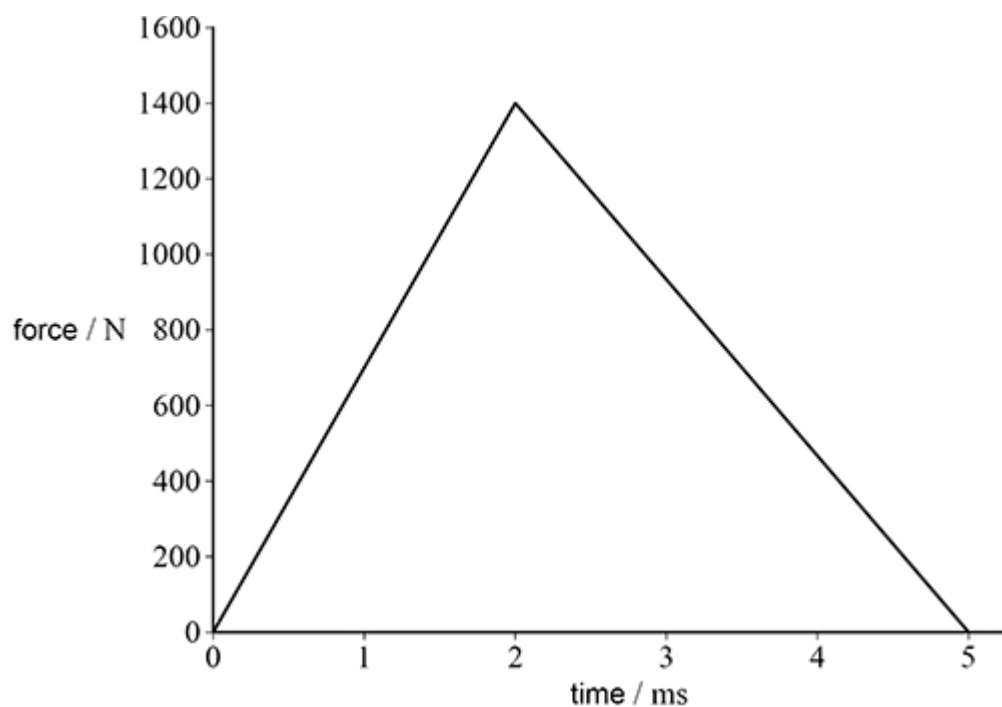
☐

(Total 1 mark)

50.

A stationary ball is free to move. The ball is hit with a bat.

The graph shows how the force of the bat on the ball changes with time.



The ball has a mass of 0.044 kg.

What is the speed of the ball immediately after being hit?

A 13 m s^{-1}

☐

B 60 m s^{-1}

☐

C 80 m s^{-1}

☐

D 160 m s^{-1}

☐

(Total 1 mark)

51.

A mass m is added to a vertical spring that is initially unextended, as shown in **Diagram 1**.

The mass is then lowered until it hangs stationary on the spring, as shown in **Diagram 2**.

The extension of the spring is now ΔL .

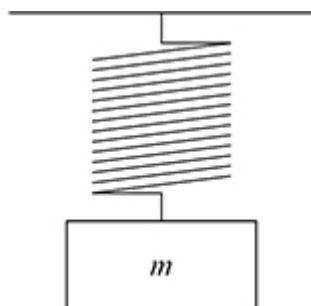


Diagram 1

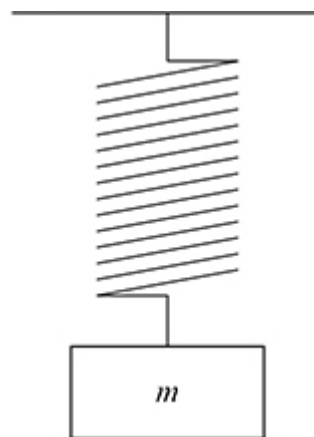


Diagram 2

How much energy is transferred from the mass–spring system?

A $\frac{mg\Delta L}{2}$

☐

B $mg\Delta L$

☐

C $\frac{3mg\Delta L}{2}$

☐

D $2mg\Delta L$

☐

(Total 1 mark)

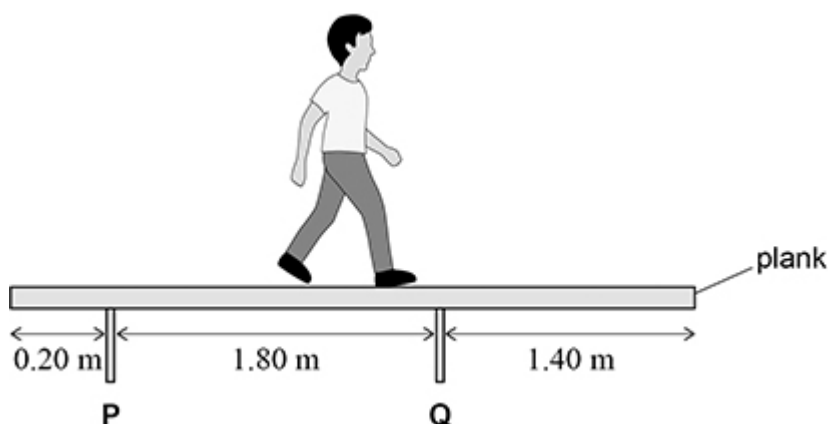
52.

A uniform plank weighs 1200 N and rests on two pillars **P** and **Q**.

P and **Q** are 1.80 m apart.

P is 0.20 m from one end of the plank. **Q** is 1.40 m from the other end of the plank.

A man weighs 800 N and walks along the plank away from pillar **P**.



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

A 0.45 m

☐

B 2.25 m

☐

C 2.45 m

☐

D 3.15 m

☐

(Total 1 mark)

53.

The question below is about three spheres **X**, **Y** and **Z**.

The relative mass and relative diameter of each sphere are given in the table.

	X	Y	Z
relative mass	1	5	1
relative diameter	1	1	5

Each sphere is dropped from rest and accelerates to its terminal speed.

What is true about the accelerations of the spheres at the instant they are released?

A The acceleration of **X** is less than that of **Y**.

☐

B The acceleration of **X** is greater than that of **Z**.

☐

C The acceleration of **X** is the same as that of **Y**.

☐

D The acceleration of **Y** is less than that of **Z**.

☐

(Total 1 mark)

54.

The question below is about three spheres **X**, **Y** and **Z**.

The relative mass and relative diameter of each sphere are given in the table.

	X	Y	Z
relative mass	1	5	1
relative diameter	1	1	5

Each sphere is dropped from rest and accelerates to its terminal speed.

What is true about the terminal speeds?

A The terminal speed of **X** is greater than that of **Y**.



B The terminal speed of **X** is the same as that of **Y**.



C The terminal speed of **Y** is greater than that of **Z**.



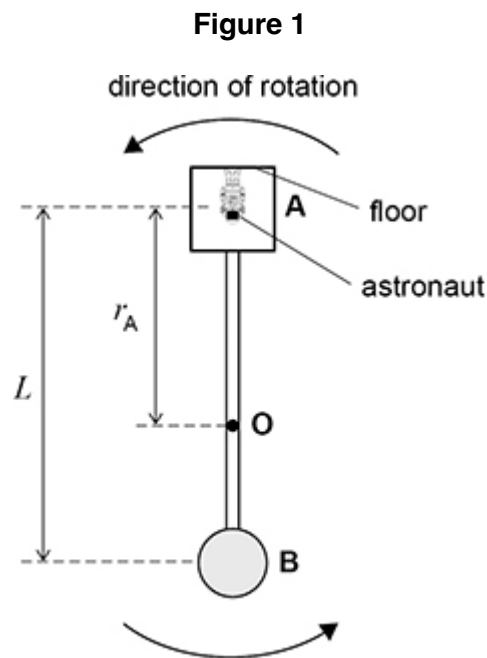
D The terminal speed of **X** is less than that of **Z**.



(Total 1 mark)

55.

Figure 1 shows a rotating spacecraft that is proposed to carry astronauts to Mars.



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

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

- (a) As the spacecraft rotates, a force that imitates the effect of gravity acts on an astronaut who is in contact with the floor.

Explain why.

(2)

- (b) The forces exerted on **A** and **B** by the connecting rod have the same magnitude.

m_A is the mass of **A**

m_B is the mass of **B**

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

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

(2)

(c) In this spacecraft $m_A < m_B$.

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

(2)

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

When loaded,

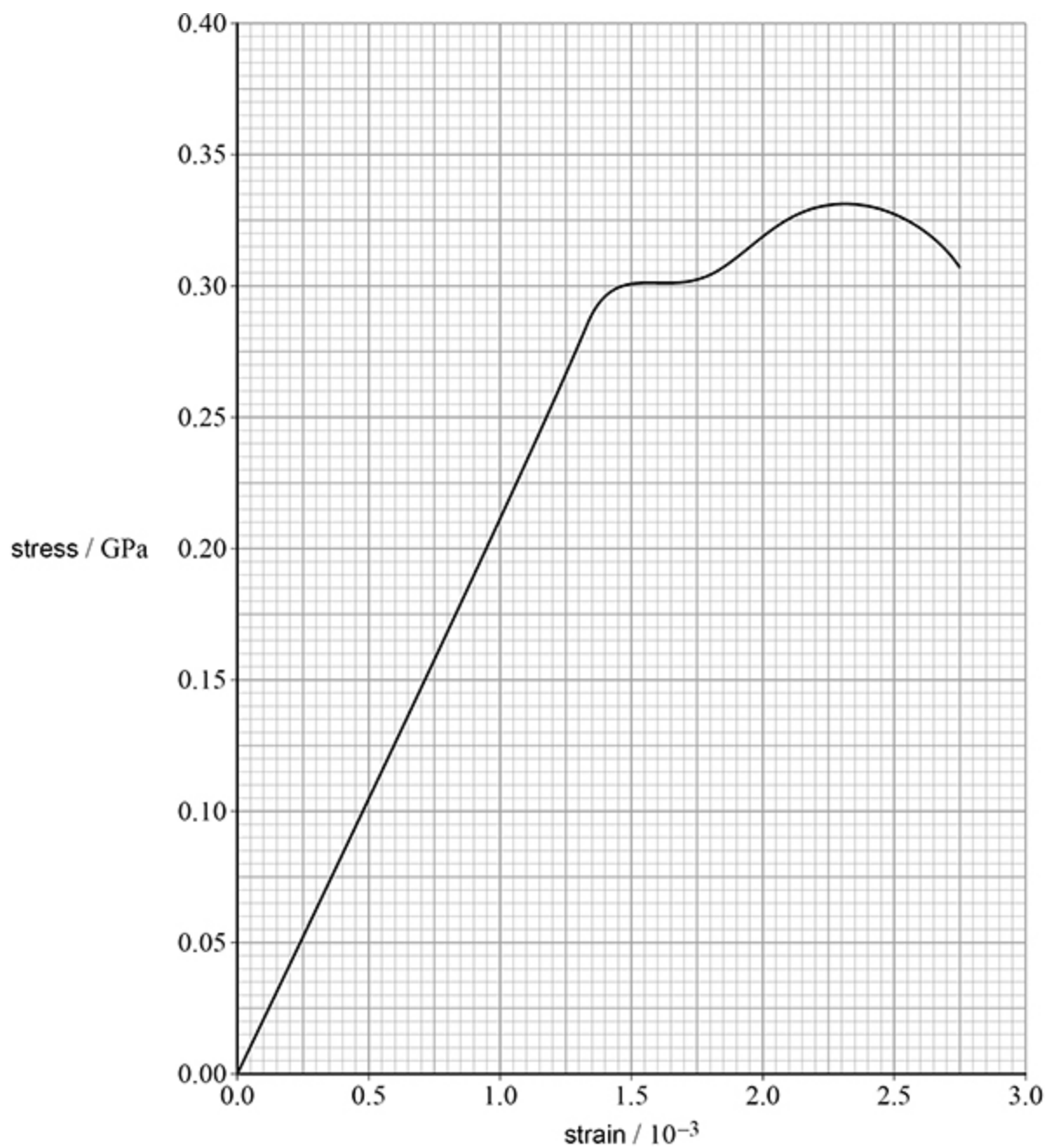
$$m_A = 1.32 \times 10^6 \text{ kg}$$

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

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

Figure 2 shows a stress–strain curve for the metal used for the rigid rod.

Figure 2



- (d) Suggest a suitable diameter for the rod.
Justify your answer.

diameter = _____ m

(5)

(Total 11 marks)

56.

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



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

A 3.2 N



B 7.5 N



C 8.6 N



D 9.6 N



(Total 1 mark)

57.

Figure 1 shows the H-shaped posts used in a game of rugby.

Figure 1

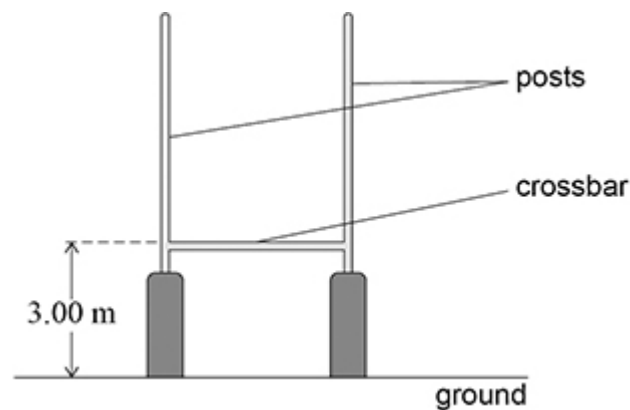
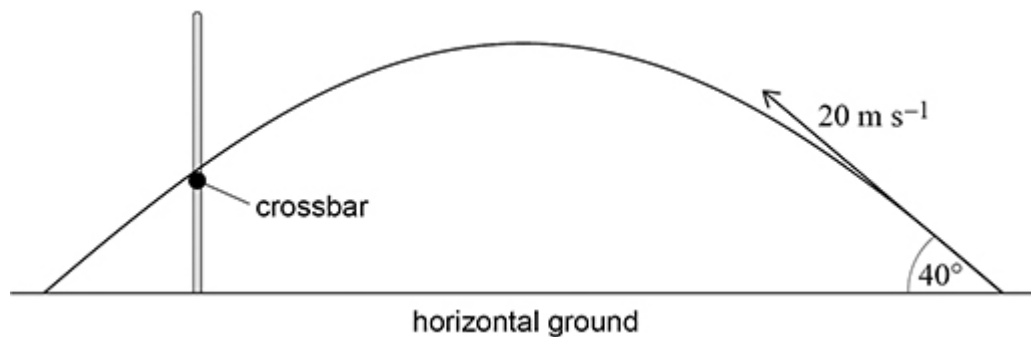


Figure 2 shows the path of a ball that is kicked and just passes over the crossbar. The initial velocity of the ball is 20.0 m s^{-1} at an angle of 40.0° to the ground.

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

Figure 2



The top of the crossbar is 3.00 m above the horizontal ground.

- (a) Show that the minimum speed of the ball in flight is about 15 m s^{-1} .

Explain your answer.

(2)

- (b) The ball just passes over the crossbar at a time t after it is kicked.

Show that t must satisfy the following equation:

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

(2)

(c) There are two solutions to the equation

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

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

In your answer you should

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

solution 1 = _____ s

solution 2 = _____ s

(4)

- (d) Another attempt is made to kick the ball over the crossbar. The initial velocity of the ball is the same as in the first attempt.

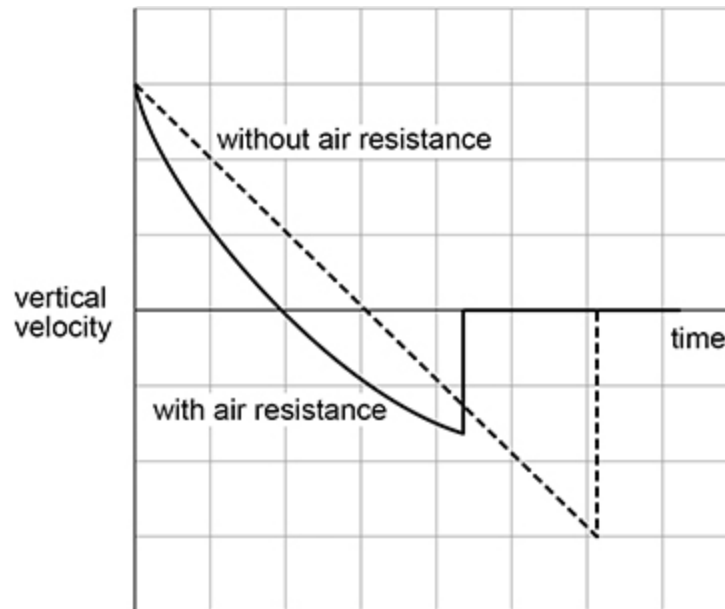
This kick is made from a horizontal distance of 38 m from the posts.

Deduce whether the ball can pass over the crossbar.

(1)

- (e) **Figure 3** shows the variations with time of the vertical velocity of a ball with and without air resistance.

Figure 3



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

In your answer you should refer to

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

[illegible]

(5)

(Total 14 marks)

58.

A Formula 1 racing car uses up its fuel during the race, causing its lap times to decrease.

The lap times decrease because

- A the acceleration of the car increases.
- B the drag forces on the car decrease.
- C the maximum speed of the car increases.
- D the tyres become worn, reducing the friction with the road.

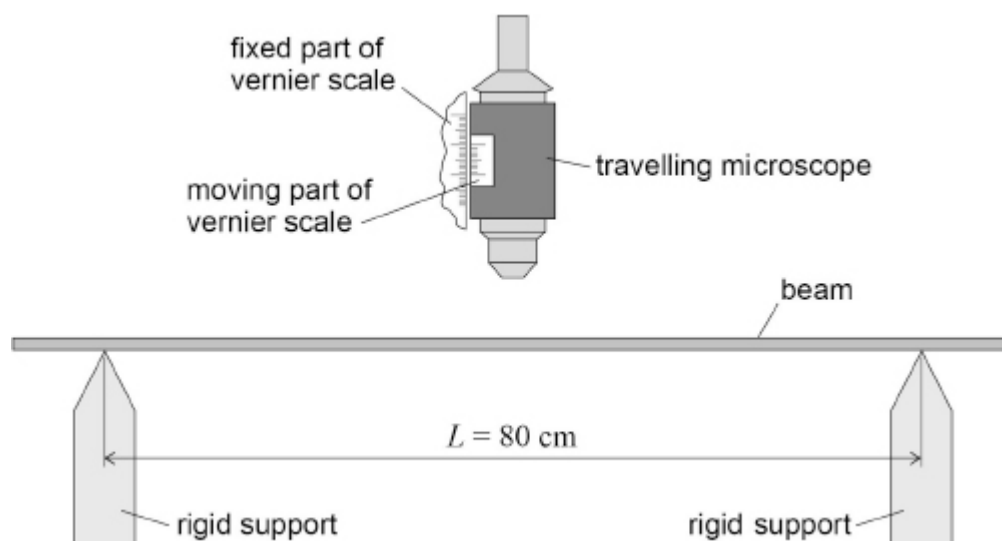


(Total 1 mark)

59.

Figure 1 shows apparatus used to investigate the bending of a beam.

Figure 1



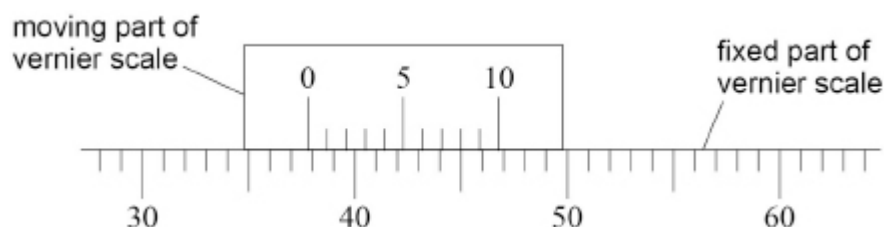
The beam is placed horizontally on rigid supports.

The distance L between the supports is 80 cm.

A travelling microscope is positioned above the midpoint of the beam and focused on the upper surface.

(a) **Figure 2** shows an enlarged view of both parts of the vernier scale.

Figure 2



The smallest division on the fixed part of the scale is 1 mm.

What is the value of the vernier reading R_0 in mm?

Tick (✓) **one** box.

34.8

☐

37.8

☐

45.8

☐

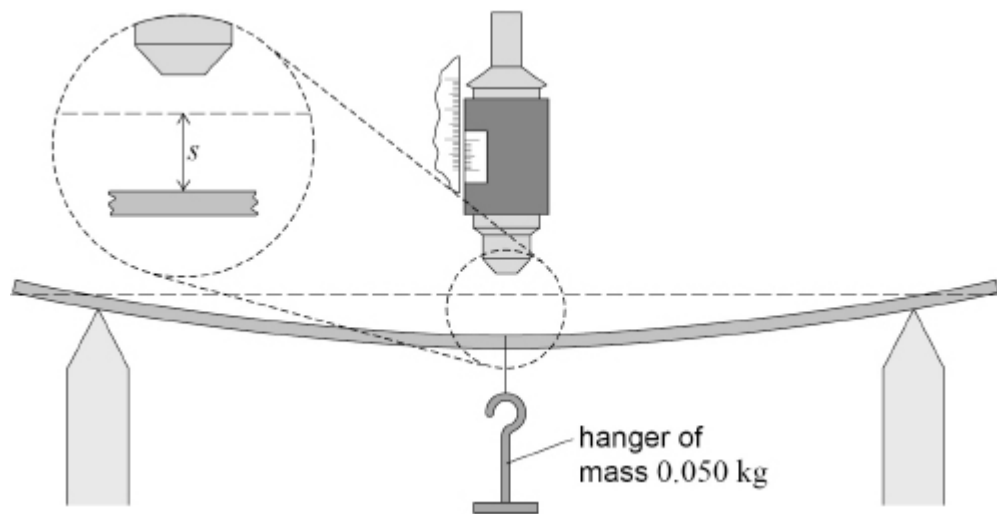
49.8

☐

(1)

- (b) **Figure 3** shows the beam bending when a hanger of mass 0.050 kg is suspended from the midpoint.

Figure 3



The microscope is refocused on the upper surface and the new vernier reading R is recorded.

The vertical deflection s of the beam is equal to $(R - R_0)$.

The total mass m suspended from the beam is increased in steps of 0.050 kg.

A value of s is recorded for each m up to a value of $m = 0.450$ kg.

Further values of s are then recorded as m is decreased in 0.050 kg steps until m is zero.

Student **A** performs the experiment and observes that values of s during unloading are **sometimes** different from the corresponding values for loading.

State the type of error that causes the differences student **A** observes.

(1)

- (c) Student **B** performs the experiment using a thinner beam but with the same width and made from the same material as before.

Discuss **one** possible advantage and **one** possible disadvantage of using the thinner beam.

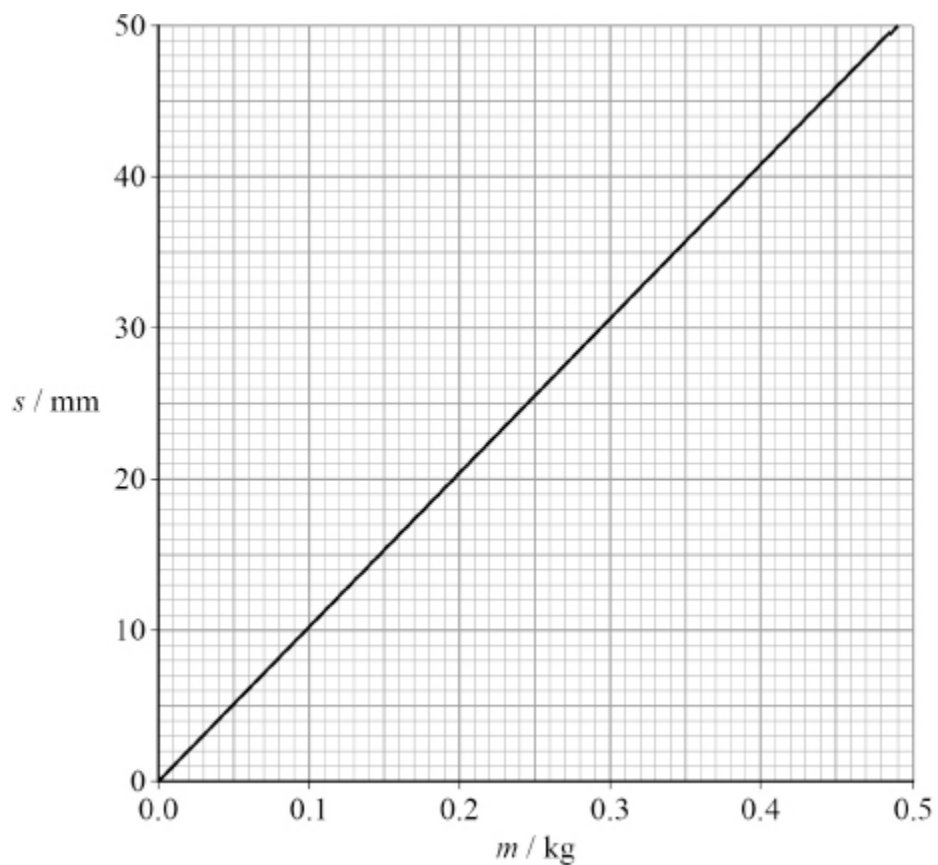
Advantage _____

Disadvantage _____

(3)

- (d) **Figure 4** shows the best-fit line produced using the data collected by student **A**.

Figure 4



It can be shown that $s = \frac{\eta m}{E}$

where E is the Young modulus of the material of the beam and η is a constant.

Deduce in s^{-2} the order of magnitude of η .

$$E = 1.14 \text{ GPa}$$

order of magnitude of $\eta = \underline{\hspace{2cm}} \text{ s}^{-2}$

(4)

- (e) Student **C** performs a different experiment using the same apparatus shown in **Figure 1**. A mass M is suspended from the midpoint of the beam. The vertical deflection s of the beam is measured for different values of L .

Figure 5 shows a graph of the results for this experiment.

Figure 5

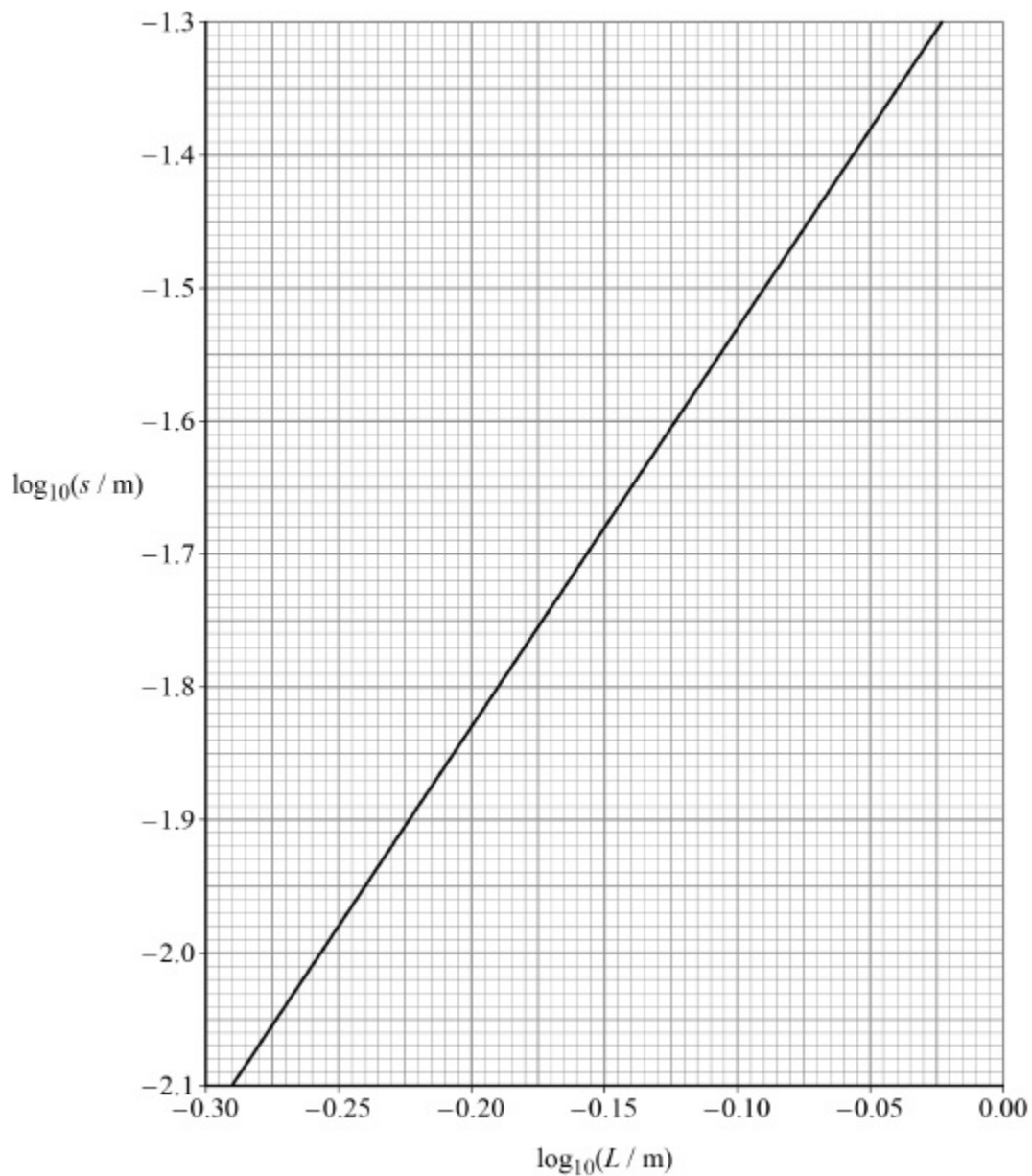


Figure 5 shows that $\log_{10}(s / \text{m})$ varies linearly with $\log_{10}(L / \text{m})$.

State what this shows about the mathematical relationship between s and L . You do **not** need to do a calculation.

(1)

- (f) Deduce, using **Figure 5**, the value of s when $L = 80 \text{ cm}$.

$s =$ _____ m

(2)

- (g) Determine M using **Figure 4**.

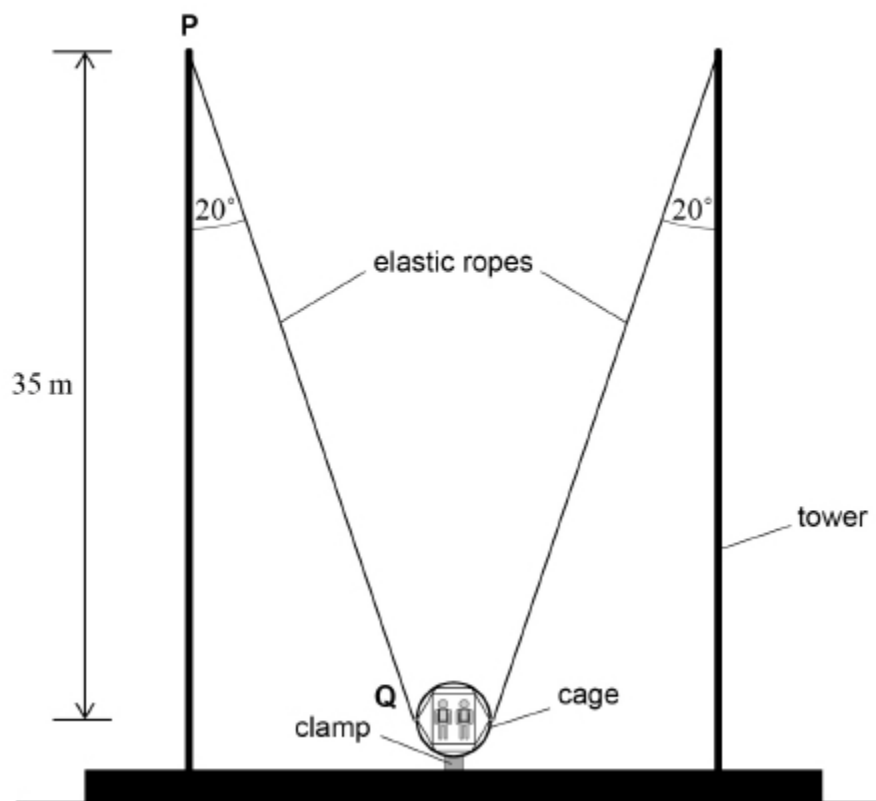
$M =$ _____ kg

(1)

(Total 13 marks)

60.

The diagram shows a fairground ride called a 'reverse bungee'.



Two identical stretched elastic ropes are fixed to a cage with passengers inside. The loaded cage is held in place by a clamp. When the clamp is released the elastic ropes accelerate the loaded cage vertically into the air.

P is the point where the rope attaches to the top of the vertical tower.

Q is the point where the rope attaches to the cage. **Q** is level with the centre of mass of the loaded cage.

Before release, the tension T in each elastic rope is 3.7×10^4 N and each rope makes an angle of 20° with the vertical tower.

The total mass M of the loaded cage is 1.2×10^3 kg and the mass of the elastic ropes is negligible.

- (a) Show that the downward force F exerted by the clamp on the loaded cage is about 6×10^4 N.

(4)

- (b) Calculate the initial acceleration of the loaded cage when the clamp is released.

acceleration = _____ m s^{-2}

(2)

- (c) The unstretched length of each elastic rope is 24 m. The ropes obey Hooke's Law for all extensions used in the ride.

The **vertical** distance between points **P** and **Q** on the diagram above is 35 m.

Show that the total elastic potential energy stored in both ropes before the loaded cage is released is about 5×10^5 J.

(4)

- (d) The designers of the ride claim that the loaded cage will reach a height of 50 m above **Q**.

Deduce whether this claim is justified.

(3)

- (e) The designers also claim that the loaded cage reaches a maximum speed of at least 90 km h^{-1} .

Calculate, in J, the kinetic energy of the loaded cage when it travels at 90 km h^{-1} .

kinetic energy = _____ J

(3)

- (f) Deduce without further calculation whether the maximum speed claim is justified.

(1)

(Total 17 marks)

Mark schemes

1. B [1]
2. D [1]
3. A [1]
4. B [1]
5. D [1]
6. (a) Conversion of 110 km h^{-1} to 31 m s^{-1} ✓
 $= \frac{1}{2} \times 1.5 \times 10^3 \times \text{their conversion}^2$ with a consistent answer ✓
 $(= 7(.2) \times 10^5)$
Allow ecf for incorrect or failure to carry out speed conversion
Expect answer to be calculated correctly and to 2+ sf.
Accept 700 kJ as 2 sf 2
- (b) Component of velocity = $31 \times \cos (20)$
OR
 evidence of using momentum = mass $\times$ velocity (eg $1.5 \times 10^3 \times$ a velocity) ✓
 $= 4.4 \times 10^4$ ✓
 For unit only accept kg m s^{-1} **OR** N s ✓
Allow ecf for speed from part (a)
Accept $4.65 \times 10^4 \text{ kg m s}^{-1}$ for max 2
Use of 30.6 m s^{-1} gives 43 kN s 3
- (c) (KE before collision = 700 kJ)
 Speed (parallel to barrier) after $(= 31 \times \cos 20) = 28.7 \text{ m s}^{-1}$ ✓
 KE after $(= \frac{1}{2} \times 1.5 \times 10^3 \times 28.7^2) = 618 \text{ kJ}$ ✓
 Change = $700 - 618$ ✓ $(= 82 \text{ kJ})$

OR

Speed (perpendicular to barrier) after = $31 \times \sin 20$ (= 10.5 m s^{-1}) ✓

Loss of KE (= $\frac{1}{2} \times 1.5 \times 10^3 \times 10.5^2$) = 82 kJ ✓

Justification that total KE = KE due to speed parallel to barrier + KE due to speed perpendicular to barrier ✓

Allow ecf for speed from part (a)

Use of $KE = p^2/2m$ can gain full credit.

Allow ecf for momentum in part (b)

Final answer depends on extent to which candidate has rounded in earlier parts. Allow correctly evaluated solutions for full credit.

In this question, do not insist on final answer to 2+ sf.

If there is a suggestion that KE is a vector or can be resolved, do not award MP3.

3

(d) Evidence of work done = force $\times$ distance

Eg Force = $82\,000 / 1.5$ OR their value for part (c) $\div$ part (a) ✓

Allow 80 kJ for energy

= $5.5 \times 10^4 \text{ N}$ ✓

This is less than braking force – so yes. ✓

OR energy approach

- work done by barrier = $60 \text{ kN} \times 1.5 \text{ m}$ ✓
- 90 kJ ✓
- which is $> E_k$ of vehicle, so yes ✓

OR impulse argument

- evaluate time taken to stop, 0.26 s ✓
- impulse value leading to distance or force ✓
- conclusion consistent with correct method of calculation ✓

OR use of $F = ma$ and suvat :

- $F = ma$ leading to $a = (-)40 \text{ m s}^{-2}$ ✓
- suvat leads to 1.37 m ✓
- which is $< 1.5 \text{ m}$, so yes ✓

General scheme for alternatives and reverse arguments is:

- *first step calculation*
- *subsequent calculation(s) leading to comparative value. Allow ecf for error in first step.*
- *conclusion consistent with correct method of calculation*

Alternative suvat method:

- *uses suvat to get $a = 36.5 \text{ m s}^{-2}$*
- *uses $F = ma$*
- *which is $< 60 \text{ kN}$, so yes*

3

(e) (Steel barrier is better because)

Increase time of contact as material deforms ✓

Reference to impulse (= change in momentum = Ft) implies smaller force (on dummy) ✓

OR

Increasing stopping distance as material deforms ✓

Reference to work done (= Fs) implies smaller force (on dummy) ✓

Allow correct discussion leading to concrete barrier is worse.

Alternative second mark for either alternative can be awarded for correct reference to $F = ma$

2

[13]

7.

(a) The centre of mass of the beam and box is at the pivot ✓

Idea that moments balance / sum of the moments is zero at this position ✓

OR

The anticlockwise moment (of weight of the beam) = clockwise moment (of weight of the box) ✓

Links pivot position to a consideration of moments ✓

Accept one route or the other, do not accept points from both.

Allow max 1 for "the pivot is to the right of the centre (of mass) of the beam"

'pivot' on its own does not get the first mark

Award 2 for $1.25 \times \text{weight of beam} = 1.5 \times \text{weight of empty box}$

Confusion of moments with eg work done/forces = max 1

2

(b) Clockwise moment = $610 \times 9.81 \times 1.5$ (= 8976 N m) ✓

Anticlockwise moment = $250 \times 4 + T \sin 50 \times 4.0$ (N m) ✓

Use of clockwise = anticlockwise ✓

Use of $T \sin 50^\circ$ seen / relates vertical component to tension ✓

T (= $1994 / \sin 50^\circ$) = 2600 (N) ✓

Credit any evidence to work out a moment with one mark

Condone cos 50 in MP2.

Allow ecf for clockwise moment

Allow ecf for anticlockwise moment

Use of $g = 10 \text{ N kg}^{-1}$ gives 2990 N Omission of 4.0 m ($g = 9.8$) gives 10410 N. Use of cos 50 ($g = 9.8$) gives 3100 N

Allow max 4 for use of $g = 10 \text{ N kg}^{-1}$.

5

(c) $7.5 = \frac{1}{2} g t^2$ ✓

($t = 1.2 \text{ s}$)

(calculate distance)

s (= $ut = 18 \times 1.2$) = 22 (m) ✓

Allow ecf from incorrect t for MP2

2

(d) **(Range will be greater:)**

component of velocity upwards ✓

rock will spend longer in the air ✓

greater t ✓

therefore the range is greater ✓

OR

(Range will be smaller)

Counterweight will fall less far before projectile released ✓

Less energy transferred to rock ✓

Initial speed of rock less/horizontal velocity reduced ✓

therefore the range is smaller ✓

OR

(balanced arguments)

therefore the range is unchanged / answer is indeterminate ✓

Candidates can argue from both lists to reach a balanced view suggesting that there is no change.

Full credit can be obtained from 2 deductions from one list ✓ ✓+ consistent conclusion ✓

1 deduction from each list ✓ ✓+ consistent conclusion ✓

Do not allow an unsupported conclusion.

*Conclusion must be consistent with **correct** statements.*

Treat incorrect statements as neutral.

Do not reward arguments based on a longer time of flight.

MAX 3

[12]

8. D

[1]

9. C

[1]

10. B

[1]

11. C

[1]

12. D

[1]

13. C

[1]

14. B

[1]

15. B

[1]

16.**(a) Method 1:**Attempts to determine area under curve / by counting squares ₁✓Multiplies their (total) area (or charge) by 24 (V) ₂✓240 (J) ₃✓*Allow POT error on area of square in ₁✓ and ₂✓**Evidence seen by calculations **or** from counting squares **or** from division of area into **at least two** recognisable geometrical shapes (triangles, rectangles, trapezia)**answer in range 220 J to 264 J***Method 2:**Attempt to determine average current (over first 200 ms in range 45 A to 55 A) ₁✓Use of $E = I \times V \times t$ ₂✓240 (J) ₃✓*Substitutes current value (or Δ current) with $t = 200$ ms and $V = 24$
V. Condone POT**Allow as two stage $Q = It$ and $E = QV$* *Or $P = VI$ **and** $E = Pt$* *answer in range 220 J to 264 J*

3

(b) (KE (gained) =) 65(.0) (J) **or****(PE (gained) =) 58(.3) (J) ₁✓**Use of efficiency = $\frac{\text{an output energy}}{\text{ans from part 04.1}}$ *Allow output energy = 65 /58/ 120 /123 or candidate ke + pe***or (total output = 65 + 58 =) 123 (J) ₂✓***Allow ecf from (a) for all 3 marks.***(Efficiency =) 0.51 or 51% ₃✓***Answer to at least 2 sf. Range is 0.467 to 0.56 (46.7 % to 56 %)*

3

- (c) Heating occurs / temperature increases when there is a current (in the thermistor) (due to I^2R) _{1✓}

(When the temperature increases) the resistance of thermistor decreases (whereas fixed resistor remains high) _{2✓}

(Lower resistance from thermistor means) less wasted power _{3✓}

OR

(Lower resistance from thermistor means) more pd dropped across the motor (less wasted voltage) _{3✓}

Alternatively: (Lower resistance from the thermistor means) less voltage drop across thermistor _{3✓}

3

[9]

17.

A

[1]

18.

- (a) Neutron number increases by one **and** proton number decreases by one _{1✓}

Or

A proton changes/decays to a neutron _{1✓}

(because) up (quark) changes to a down (quark) _{2✓}

Allow use of symbols: N increases by one and Z decreases by one

Allow this expressed as an equation symbols for proton and neutron.

Allow u (quark) changes to d (quark)

Allow $uud \rightarrow dud$

Where decay equation is attempted, condone incorrect leptons (quarks must be correct).

2

- (b) Conversion of 0.52 MeV to eV seen $_1\checkmark$

Or

Conversion of 0.52 MeV to J $_1\checkmark$

Or

Use of $p = \frac{E}{c}$ $_1\checkmark$

($p =$) 2.77×10^{-22} or 2.8×10^{-22} $_2\checkmark$ **c.a.o**

5.2×10^5 (eV) seen for MP1

Condone POT error in conversion to joule

Expect to see: 8.32×10^{-14} (J) for MP2

With substitution of student's value for E (where conversion hasn't been completed or completed incorrectly)

2

- (c) Shades detector opposite **P** $\checkmark$

The leader line from label 'patient's head' passes through a box.

Expect to see shaded the box below the 'leader line' box.

Allow either of the boxes adjacent to expected box.

Penalise more than one box shaded.

1

- (d) 2 photons (are produced) / Photons must move off in opposite directions (along the same line) $_1\checkmark$

The photons must have equal and opposite momentum / must conserve momentum $_2\checkmark$

2

- (e) Use of (gradient =) $\frac{\Delta v}{\Delta t}$ 1✓

Condone power of ten errors and leaving time in hours (or incorrect conversion to seconds)

Correct read off; condone errors in read off that lead to $\pm 1 \text{ mm s}^{-1}$ in Δv and $\pm 0.02 \text{ h}$ in Δt .

For 1 mark expect to see

$$(79-60) \div 1.18$$

$$(65-60) \div 0.3$$

$$(70-60) \div 0.6$$

$$(75-60) \div 0.92$$

$$(76-60) \div 1$$

Max 1 for answer where there is failure to notice false origin. MP2 is available in this case where there is only the false origin error.

$$4.5(1) \times 10^{-6} \text{ (m s}^{-2}\text{)} \quad 2✓$$

$$\text{Range} = 4.40 \times 10^{-6} \leq \text{accepted value} < 4.65 \times 10^{-6}$$

2

- (f) Acceleration increases 1✓

Condone correct acceleration statement linked to incorrect explanation.

Larger change in momentum (because more photons are reversing direction of motion) therefore a larger force on solar sail 2✓

Or

More momentum gained per second (from the photons) 2✓

Or

Larger force on photons therefore larger force on sail 2✓

2

[11]

19.

- (a) 0.56 (N) ✓

1

- (b) Definition of couple as two equal forces acting in opposite directions ✓

Moment of a couple is independent of the point about which moments are taken ✓

Forces (are equal but) don't act in opposite directions, therefore it is not correct ✓

Combined moment of the two forces depends on the point about which moments are taken, therefore not correct. ✓

2

- (c) Use of total upward force = total downward force
1 mark for any attempt to equate upward and downward forces.
Response may be on diagram.

eg $0.87 + 0.62 = 1.12 + W$ ✓

0.32 (N) ✓

Attempt to use Principle of Moments ✓

0.14 (m) ✓

Allow MP4 if (their W) $\times$ (their d) = 0.0448

4

- (d) Readings (on A and B) would be the same/1.44 (N) ✓

(Because) total downwards force/weight is same

OR

All (perpendicular) distances affected by the same factor

($\cos \theta$) ✓

2

[9]

20. B

[1]

21. B

[1]

22. C

[1]

23. C

[1]

24. A

[1]

25. B

[1]

26.

- (a) Evidence of distance travelled = area under graph = $1755 + 1440 + 1620 = 4815$ ✓
Full marks can be credited for use of suvat.

Average speed = total distance/time taken = $4815/240$

= 20.1 m s^{-1} ✓ (at least 3sf)

Which is less than (speed) limit, (and therefore the answer is No). ✓

Allow ecf for distance in MP2

Only award MP3 for incorrect speed if attempt made to calculate distance correctly e.g. area under graph OR a.e. in distance or speed

Alternative for MP2 and MP3

Calculation of distance travelled at speed limit = 5280 m ✓

Which is greater than distance travelled (so no). ✓

Alternative for MP1 and MP2:

Total area = $80.25 \text{ m s}^{-1} \text{ min}$ ✓

Time = 4 min

Average = 20.1 m s^{-1} ✓

3

- (b) Using reaction time of 2.0 s ✓

1

Use of distance = speed × time = 62 m .

62 m (would be appropriate). ✓

Award MP2 if 1.6 s (to give 50 m) or 1.8 s (to give 56 m) or 1.7 s (to give 53 m) or average of two distances used

Allow 60 m .

1

- (c) Use of $F = ma$ to calculate acceleration.

$$a = 6800/1200 \checkmark = 5.7 \text{ m s}^{-2}$$

evidence of use of suvat to calculate s or t , $\checkmark$

to give $t = 5.5 \text{ s}$ $\checkmark$

$s = 85 \text{ m}$. $\checkmark$

If no other mark given, allow 1 mark for

$$mv = 1200 \times 31 (= 37200)$$

Alternative for MP1 and MP2

$$t = \frac{mv - mu}{F}$$

Allow ce for a .

Allow ce for either incorrect s or t .

4

- (d) (It is assumed that) the car in front would take the same time/travel the same distance as the car behind when braking/ only difference is reaction time of the driver of car behind. $\checkmark$
Or
Car in front cannot stop instantaneously (so car behind will have time/distance to bring car to rest).or words to that effect

Alternative:

suggestion that total stopping distance is too large (drivers would ignore it/inefficient use of motorway)

1

(e) Correct use of $\cos (5)$ ✓

E.g.

$$mg = N \cos (5)$$

Correct use of $\sin (5)$ ✓

E.g.

$$N \sin (5) (= mv^2/r)$$

So

$$mv^2/r \text{ seen } \checkmark$$

$$\text{And } v = (rg \tan(5))^{1/2}$$

$$\text{Gives } v = (200 \times 9.81 \times \tan (5))^{1/2} = 13$$

So speed limit = 13 m s^{-1} ✓

May see $\cos (85)$ for $\sin (5)$

Alternative for MP1 and MP2: Evidence of $mg \tan (5)$

fourth mark is for answer and suggesting this as the speed limit.

Max 3 if $mg = N$ used

4

[14]

27.

C

[1]

28.

C

[1]

29.

B

[1]

30.

B

[1]

31.

A

[1]

32.

D

[1]

33.

D

[1]

34.

- (a) Attempt to resolve **A** or **B** eg $430 \times \cos 35^\circ$ or $T_B \times \cos 12^\circ$ ✓

360 (N) ✓

If no other mark given, allow $430 \times \sin 35^\circ = T_B \times \sin 12^\circ$ to give 1190 N for 1 mark.

2

- (b) Substitution of F and A into Young modulus or stress equation ✓

4.4×10^{-2} (m) ✓

Condone POT error for Young modulus

2

- (c) Angle of **A** decreases or angle of **B** increases ✓

Accept references to 35° or 12°

Any correct application of trig or geometry to the situation

(eg $T_B/T_A = \cos \theta_A / \cos \theta_B$ so as θ_A decreases, $\cos \theta_A$ increases, $\cos \theta_B$ decreases, so T_B/T_A increases)

OR

eventually θ_B will equal 35° , $\theta_A = 12^\circ$ so forces will be reversed (as system is symmetrical)

OR

sum of vertical components remains unchanged and vertical component of tension becomes less as angle **A** decreases ✓

*Allow idea that more of the weight is supported by **B***

T_A decreases, following some relevant discussion ✓

3

- (d) Greater rate occurs when pulses are shorter (in time)/less modal dispersion ✓

Allow reverse arguments

Smaller diameter (leads to less modal dispersion) means smaller range of path lengths ✓

Accept idea of fewer reflections

X is more suitable because narrower core leads to lower modal dispersion or reduced pulse broadening ✓

3

[10]

35.

B

[1]

36.

A

[1]

37.

C

[1]

38.

D

[1]

39.

C

[1]

40.

(a) Use of an appropriate equation of motion ✓

Where $v^2 = u^2 + 2as$ is correctly stated, condone one error in substitution e.g. sign of a

Where other equations are used it must be clear that v can be determined.

Must see v as subject and an attempt to determine t .

($v =$) 0.35 (m s^{-1}) ✓

Allow more than 2 sf where correct.

2

(b) Use of $\tan 35 = u_v / 8.8$

Or

Use of $u \cos 35 = 8.8$ and $u_v = u \sin 35$

and

6.2 or 6.16 with supporting a calculation ✓

Alternative: credit use of sine rule

Must see answer to at least two significant figures

1

(c) Use of an appropriate equation of motion ✓ ECF

Condone their incorrect value of u in this substitution.

Condone errors in signs in substitution Where other equations are used it must be clear how t can be determined.

Must see t as subject and an attempt to determine s .

($t=$) 0.63 (s) ✓ ECF

0.61 (s) for use of $u = 6 \text{ m s}^{-1}$

*For MP2, where their value of u is used, the answer must be consistent with this value. **Only** allow this use where their value of u , to 1 significant figure, = ($5 < u < 7$) m s^{-1}*

Condone 1 significant figure answer where U is 1 sig fig.

2

- (d) Use of an appropriate equation of motion ✓ ECF

*Where equation is correctly stated, condone one error in substitution e.g. **one error on sign** of a substituted value **or** one incorrect value substituted (of course, ecf is acceptable)*

- (h =) 1.9 (m) ✓ ECF

$h = 1.83 \text{ m}$ for use of $u = 6 \text{ m s}^{-1}$ allow ecf on t (check (c))

*For MP2, where their value of u is used, the answer must be consistent with this value. **Only** allow this use where their value of u , to 1 significant figure, = $(5 < u < 7) \text{ m s}^{-1}$*

allow reverse calculation where $u=0$ and $v = 6 \text{ m s}^{-1}$

2

- (e) Smooth curve with maximum turning point seen, curve starts at the ball and finishes at **X** ✓

Curve should be approximately parabolic in shape.

*Curve must start below the label 'golf ball' and ends within 5mm of the ball or the label **X**. Curve must have a maximum turning point.*

1

- (f) (Increase the angle to horizontal so) the ball must go higher (and increases its time in the air)

Or

(Increase the angle to horizontal so) the ball must have a greater (initial) vertical velocity ✓

(Covers the same horizontal distance over) a longer time in the air (so has a smaller horizontal velocity) ✓

Alternative:

Increased angle (to horizontal of projection) so smaller horizontal velocity ✓

must be falling towards ground to land at **X** ✓

(Increase the angle to horizontal so that) the vertical velocity greater than the horizontal / increase the vertical decreases the horizontal

2

[10]

41.

- (a) Use of $E_k = \frac{1}{2} mv^2$ ✓

(Kinetic energy =) $9.2 \times 10^9 \text{ (J)}$ ✓

Condone POT error on 1st MP

Allow use where v where has been converted from 5.5 km h^{-1}

An answer to 2 significant figures (with some working) ✓

Significant figure mark requires evidence of some relevant working.

3

(b) **Why force on the gas:**

The gas's momentum is changing ✓

This requires a force according to **Newton's 2nd law** ✓

Or

The gas is being accelerated ✓

This requires a force according to **Newton's 2nd law** ✓

Max 3 for why there is a force on the gas and why there is a resistive force on the system

*Must have **why the system decelerates** to obtain all 4 marks.*

The reason why the resultant force causes the deceleration rather than the acceleration.

Why (resistive) force on system:

The gas exerts a force on the parachute (with an equal magnitude and opposite direction force) / there is air resistance (on the system) / there is drag (on the system) / there is a resistive force (on the system) ✓

(because) the Parachute exerts a force on the gas according to **Newton's 3rd law** ✓

Allow statement that is equivalent to N1 / N2 / N3.

Allow: air resistance (or drag) increases.

Allow: there is an upward force

*must have a clear action-reaction pair for this **N3** mark.*

Why system decelerates:

The resistive force is greater than the weight so there is a resultant force

Or

The **resultant** force is acting in the opposite direction (to its motion). ✓

acceleration in same direction as resultant force according to **Newton's 2nd law** ✓

*allow the **resultant** force is vertically upwards*

Or

Links to violation for conditions of Newton's 1st law and therefore cannot continue at constant velocity.

- (c) Attempt at determining difference = $3.3 (\times 10^5) - 2.2 (\times 10^5)$ or difference = $1.1 (\times 10^5)$ ✓

1st mark: Credit an application of conservation of energy (allow written statement, or equation without substitution)

Ignore signs on difference and answer.

MP2 allow their energy in a substitution that is, otherwise correct.

Condone an answer = $18.4 (\text{m s}^{-2})$ is worth 2 marks.

Use of $E_p = mgh$ ✓

(g =) $3.7 (\text{m s}^{-2})$ ✓

Condone $mgh = \frac{1}{2} mv^2$ where rearranged to make g subject.

Condone $610 \times g \times 49 = \text{their energy}$

Alternative:

- *Attempt to use appropriate equations of motion to determine acceleration*

$v^2 = u^2 + 2as$ rearranged to make a the subject (condone use of their values for v and u and / or $g = a$)

- *Attempt to use $W = Fs$ to determine the air resistance F_D (or $F_D = 6734(.7) (\text{N})$ seen)*

- *Attempt to determine g from the deceleration of the system*

$$g = \frac{F_D - ma}{m}$$

3

- (d) More mass to **displace** / more particles to **collide with** / more gas / dust to displace ✓

Must have some interaction with parachute-spacecraft.

N/E to say there are more particles / gas / dust / mass

(at any given speed)

Greater (rate of) change of momentum / More work done (per unit distance) /

Greater (resistive) force / more kinetic energy transferred (per unit distance) ✓

Greater **resultant** force **on** the system (therefore greater deceleration) / greater loss of velocity per second (therefore greater deceleration) ✓

3rd MP for greater resultant force: allow the idea that the difference between the drag and weight has increased

3rd MP

Allow clear statement that links:

- *rate of change of momentum of gas / dust to rate of change of momentum of system*
- *rate of work done on gas / dust to rate of work done by system*

3

[13]

42.	D	[1]
43.	B	[1]
44.	D	[1]
45.	C	[1]
46.	C	[1]
47.	C	[1]
48.	B	[1]
49.	B	[1]
50.	C	[1]
51.	A	[1]
52.	B	[1]
53.	C	[1]
54.	C	[1]
55.	(a) Centripetal force acts inwards / towards the centre of rotation ✓ Links reaction force to centripetal force ✓	

- (b) Equates forces AND states **either** centripetal force with correct symbols✓

$$F = m_A r \omega^2$$

$$F = m_B (L - r) \omega^2$$

In MP1 condone: equations containing v ; use of ω_A and ω_B for the angular velocities.

cancelling ω ✓

$$m_A r \omega^2 = m_B (L - r) \omega^2$$

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

E.g.

In MP2 it must be clear that the angular velocity and not the velocity.

2

- (c) The angular speed is the same for A & B or

Rotational radius for B less than that for A ✓

Both of these points AND $v = r\omega$ so velocity of A is greater.✓

Alternative for MP2:

Both of points in MP1 AND

A travels greater distance in the same time.

2

- (d) Use of safety factor e.g. maximum stress $\ll 0.300$ GPa ✓

$$F = ma = 1.32 \times 10^6 \times 3.7 \checkmark (= 4.9 \times 10^6 \text{ N})$$

$$A = \frac{F}{\sigma} \text{ valid substitution } \checkmark$$

$$\sqrt{\frac{4.9}{\pi}} \checkmark (\text{expect } > 0.144 \text{ m})$$

Valid justification for selection of maximum stress used e.g. using a stress that is from the linear / elastic section of the graph or reference to either safety factor or trying to limit weight of cable. ✓

Alternative for MP1: they can work through for a stress of 0.3 GPa and then increase the diameter, if justified as a safety factor. Do not allow use of stress ≈ 0.3 GPa for full marks.

Allow ecf for stress and force

5

[11]

56.

D

[1]

57.

- (a) horizontal velocity = $20 \cos 40^\circ = 15.3 \checkmark$ (m s⁻¹)

Needs minimum 3 sf

For MP1 it must be clear that the horizontal velocity has been determined.

horizontal velocity (is constant) / minimum when vertical velocity = 0 $\checkmark$

2

- (b) (vertical velocity) $v = 20 \sin 40^\circ (= 12.9) \checkmark$ (m s⁻¹)

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

$$-3 = -12.9t + \frac{1}{2} \times 9.81t^2 \text{ or } 3 = 12.9t - \frac{1}{2} \times 9.81t^2 \checkmark$$

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

For second mark both suvat equation and substitution must be shown. Equation may be rearranged before substitution

2

- (c) Use of quadratic formulae with +, - or $\pm \checkmark$

$$\text{eg } t = \frac{12.9 \pm \sqrt{(-12.9)^2 - 4 \times 4.91 \times 3.00}}{2 \times 4.91}$$

0.258 s and 2.37 s $\checkmark$

Two correct answers alone scores first 2 marks.

Time to reach 3 m once on the way up and once on the way down (OWTTE) $\checkmark$

Larger value $\checkmark$

ecf available for last 2 marks

4

- (d) $s = vt = 20 \cos 40^\circ \times 2.37 = 36.3$ m so no $\checkmark$

ecf from (c)

Calculation must be seen

1

- (e) Gradient is the acceleration **AND**

area under graph = vertical distance travelled✓₁

Without air resistance:

comment about gradient✓₂

comment about area✓₃

With air resistance

comment about gradient✓₄

comment about area✓₅

For each comment on the graph a reason must be given not just a description.

e.g for ✓₂

• constant gradient = g or 9.81 m s^{-1}

e.g. for ✓₄

• initially steeper gradient since air resistance in same direction as weight (so $a > g$)

• when line crosses time axis, gradient = $g / 9.81$ / gradient without air resistance as air resistance = 0 when $v = 0$ /

• After crossing time axis, gradient decreases as air resistance increases with speed

E.g. for ✓₃ or ✓₅

• total area under graph = 0 since ball starts and finishes on ground

*• area between graph and axis is max height/ **vertical** distance*

*• without air resistance reaches a higher height as area greater
statement referring to area under both graphs gains ✓₃ and ✓₅*

5

[14]

58.

A

[1]

59.

(a) 37.8 ✓

CAO

1

(b) random (error)

condone 'statistical' ✓

the following are neutral:

'parallax' / 'human (error)' / '(some) results are anomalous'

1

(c) advantage (of using thinner beam):

(same load produces) larger (values of) s or wtte 1✓

so

the percentage uncertainty / error (in s) is reduced 2✓

for 1✓ accept 'beam bends / deflects more'

'beam extends more' / 'easier to bend' are neutral

for 2✓ the following are neutral:

'easier to make readings' / 'values (of s) are more accurate' / 'more precise' / 'less mass needed' / 'wider range of readings'

disadvantage (of beam bending more):

idea that beam may undergo plastic deformation 3✓

so

the graph will be non-linear / curve or wtte 4✓

or

beam 'may break' / 'slip off knife edges' **and** relevant comment about safety / health / hazard / 'cannot get unload data'

or

reduces range of m or wtte **and** relevant comment about the effect on the graph, eg increase scatter 34✓ = 1 MAX

for 3✓ accept / 'beam may become permanently deformed' or wtte / 'necking may occur' / 'hysteresis may occur' / 'beam can reach (go past) elastic limit'

the following are neutral:

'causes systematic error' / 'beam may go past limit of proportionality' / 'need to increase height of supports' / 'beam may bend under own weight'

MAX 3

(d) $E \approx 10^9$

or

1.14×10^9 seen 1✓

for 1✓ accept 10^9 seen in working

1

correct manipulation seen in **body of answer** of $s = \frac{\eta m}{E}$ 2✓

for 2✓ **either**

substitution of their E and data from **Figure 8**

leaving η as only unknown: allow POT in s but not in m

eg $\eta = \frac{\text{their } E \times 25.5 (\times 10^{-3})}{0.25}$ or

substitution of their E and result of a gradient calculation: allow POT in Δs but not in Δm

eg $\eta = 1.14 \times 10^9 \times 1.02 (\times 10^{-1})$ or

calculation involving orders of magnitude (expect 10^{-1} but allow 10^2 for gradient)

eg $\eta \approx 10^9 \times 10^{-1}$

2

correct raw result (allow POT in E) 3✓

for 3✓ expect 1.16×10^8 but allow 1 sf gradient eg leading to 1.14×10^8

(on answer line) order of magnitude consistent with their raw result 4✓

for 4✓ $\eta = 10^8$ or 8 only; allow use of their E

award 34✓ = 1 MAX for use of gradient ≈ 100

leading to order of magnitude = 10^{11} or 11 only

1

- (e) identifies that s and L are linked by a power law ✓

accept any correct expression (unless there is talk-out) with s or $\log s$ as the subject;

treat any quantities other than s and L as constant except E and η
possible answers are:

$$s \propto L^n$$

allow $s \propto L^m$ if m identified as constant

$$s \propto L^3$$

$$s = kL^n$$

$$\log s = n \log L + (\log) k$$

$$\log s = 3 \log L + (\log) k$$

$$\log s = \log L^3 + (\log) k$$

reject

$$s = L^n$$

$$\log s = n \log L$$

$$\log s \propto n \log L$$

$$10^s \propto 10^L$$

' s and L are linked logarithmically'

' s is directly proportional to L '

1

- (f) $(\log L =) -0.097$ seen

for 1✓ accept any $\log L$ rounding to -0.097 ;

1

or

working on **Figure 5** confirming a value of $\log L$ between -0.095 and -0.100 1✓

uses **Figure 5** to obtain s in range 2.9 to 3.1×10^{-2} (m) 2✓

working can be suitable ruled line or mark on the best-fit line / on graph axes

for 2✓ accept 29, 30 or 31 mm etc

reject 1sf 3×10^{-2} (m)

1

use of wrong base

$$\ln L = -0.22(3);$$

uses **Figure 5** to obtain s in range 1.49 to 1.51×10^{-1} or 1.5×10^{-1} (m) 12✓

accept 15 cm etc

- (g) use of **Figure 4** to determine M ✓
 their (final answer to) (f) $\times$ gradient of **Figure 4** ($9.8 \pm 2.5\%$)
 minimum 2sf
 condone use of 1sf s

1

[13]

60.

- (a) Attempt to calculate weight of cage
 eg $1.2 \times 10^3 \times 9.81$ or 1.18×10^4 seen ✓

Attempt to find vertical component of tension T_V in one rope
 eg $3.7 \times 10^4 \cos 20$ or 3.5×10^4 seen ✓

Uses $F =$ twice their tension – their weight ✓
If weight not calculated, allow MP3 for doubling their tension or their resolved component

$$5.8 \times 10^4 \text{ (N)} \checkmark$$

4

- (b) Use of $F = ma$ with $6 \times 10^4 \text{ N}$ or their (a) ✓
 $50 \text{ (m s}^{-2}\text{)} \checkmark$

Allow 48 (m s⁻²).

2

- (c) Calculation of length of rope
 eg $35/\cos 20$ or 37.2 seen ✓

Allow methods using $F = k\Delta L$ and $E = \frac{1}{2} k\Delta L^2$

Calculation of extension of one rope or calculation of total extension of both ropes
 eg their length–24 or 13.2 or 26.4 seen ✓

Use of $E = \frac{1}{2} F\Delta L$
 e.g. $\frac{1}{2} \times 3.7 \times 10^4 \times 13.2 = 2.44 \times 10^5 \text{ (J)} \checkmark$

$$4.9 \times 10^5 \text{ (J)} \checkmark$$

4

- (d) Use of $E_{\text{lost}} = \Delta E_p$

eg $1.2 \times 10^3 \times 9.81 \times h = 5 \times 10^5 \checkmark$

No credit for use of suvat in either method and MP3 must come from correct Physics.

First method is for calculation of max h and comparison with 50 m.

$h = 42 \text{ (m)} \checkmark$

Allow h from their (c) if it rounds to 5×10^5

$42 < 50 \text{ (m)}$, so claim not justified $\checkmark$

OR

Use of $\Delta E_p = mg\Delta h$ with 50 m

eg $1.2 \times 10^3 \times 9.81 \times 50 \checkmark$

Second method is for calculation of ΔE_p and comparison with E .

$\Delta E_p = 5.9 \times 10^5 \text{ (J)} \checkmark$

$5.9 \times 10^5 > 5 \times 10^5$, so claim not justified $\checkmark$

3

- (e) $90 \text{ km h}^{-1} = 25 \text{ m s}^{-1} \checkmark$

The conversion mark stands alone.

1

Use of $E_k = \frac{1}{2} mv^2$

eg $\frac{1}{2} \times 1.2 \times 10^3 \times (\text{their } v)^2 \checkmark$

$3.8 \times 10^5 \text{ (J)} \checkmark$

ecf for their v

2

- (f) If their $E_k > 5 \times 10^5$, claim is unjustified

OR

If their $E_k < 5 \times 10^5$, claim may be justified depending on gain in E_p or losses due to resistive forces $\checkmark$

1

[17]

Examiner reports

5.

This question was answered correctly by less than half of the students. By far the most popular distractor was C. Had students chosen to draw a small force diagram, it may have helped them to determine the sign of the different forces in relation to the acceleration and thereby obtain the correct answer.

6.

- (a) This very straightforward calculation was answered correctly by the vast majority of students. An occasional error was the failure to convert the speed to metres per second.
- (b) This calculation was slightly more demanding, with some students attempting to use the energy given to them in the previous calculation. This approach, whilst unnecessarily long, did gain full credit when carried out correctly. One common error was the use of sine rather than cosine when calculating the momentum, or omitting the mass altogether. Another common error was the use of N m for the unit, suggesting some confusion with energy.
- (c) Students managed to find some very different approaches to what is essentially a straightforward multi-step calculation. Answers that appeared to be taking a component of the kinetic energy, and therefore treating it as a vector, did not gain full credit.
- (d) AO3 questions of the type in question (d) leave students free to choose the approach they wish to take. Each approach was treated on merit and was awarded full marks if correct. The most common, and successful, approach was a consideration of the work done by the barrier and therefore the average force that needed to be applied by the barrier to remove the perpendicular component of the car's velocity. Occasional errors were related to incorrect physics, for example using the wrong *suvat* (kinematic) equation, or errors in algebra and computation. Unfortunately, many students were unable to see a way through this question that gave them any credit. This may have been due to students giving up or to them being unable to achieve the 'show that' values given in previous parts. Students should be encouraged to make use of the 'show that' values in these instances as they are there to allow access to later questions.
- (e) This question had several routes to the correct answer, the most popular being the consideration of time and an impulse route, or the consideration of distance and a work done route. Less commonly a route involving Newton's second Law of Motion was seen. A failure to express ideas clearly was the most common reason why students did not achieve full credit here.

7.

- (a) This question discriminated well. Students who argued in terms of the centre of mass were more likely to gain full credit. Although incorrect equations were not penalised on this occasion, teachers and students should be aware that this may not be the case in future examinations. A common error was the assumption that the centre of mass of the beam was 2.0 m from the pivot, or that the mass of the sling had to be considered, rather than the mass of the beam. A failure to express ideas clearly also cost some students marks.
- (b) There were five marks available for this extended calculation and almost half of the students obtained all five. The mark scheme allowed students to make errors in several parts of the calculation without over-penalising them. Common errors included missing g from the weight of counterweight stones, or using the incorrect angle for the component of the tension. Occasionally the distance to the rope was missed in the equation for the turning effect of the tension. In multi-step calculations of this kind, students should be encouraged to set out their work logically and make it clear what they are doing at each step so that consequential error marks can still be awarded.

- (c) This two-step calculation was completed correctly by many students, and those who made an error in the calculation of the time still had access to the second mark point.
- (d) Despite the fact that this question assessed AO3, a range of good answers were seen. Generally, students realised that the vertical velocity would cause the time of flight to be longer and then linked this to an increase in range. Some answers were less clear, and it was sometimes difficult to understand whether the student was arguing for or against a range increase. Students who suggested that a shorter time of flight would occur did not gain credit.

8. Many students had difficulty in analysing the base units of these quantities. Where working was seen, it often included errors in the use of indices.

9. Less than 40% of students selected the correct response. The most common incorrect answer was D.

10. A significant number of students selected answer A; these students were unaware of the conditions required for collisions to be elastic.

11. Over 60% of students selected the correct answer. The most common incorrect response was D; these students had a limited understanding of the independence of the vertical and horizontal velocities.

12. This question proved to be very challenging. Around 11% of students were able to select the correct answer. The most frequent answer, however, was A; this showed that the students had a very limited appreciation of the situation. They had difficulty in realising that the weight had not been included in the diagram and that the reaction force had to be equal to the sum of the downward forces.

13. Less than half of students were able to perform this calculation correctly. Many have difficulty in resolving forces and dealing with equations in equilibrium situations. The most frequent incorrect answer was A; these students assumed the weight was shared between the tensions but failed to take into account that this was only the vertical component.

14. This was a straightforward recall question and around 88% of students were able to select the correct answer.

15. Students had a good appreciation of the order of magnitude of the energy in this context.

- 16.**
- (a) One mark was gained by at least 75% of the cohort. This was usually for use of $E = IVt$ with $t = 200$ ms. Generally, grade A students appreciated that the charge was the area under the curve and determined this to an acceptable level of accuracy.
 - (b) The most effective answers typically scored at least two marks. Most students who gained 1 mark determined either the potential energy (p.e.) or kinetic energy (k.e.) correctly. Many students did not recognise the sum of the p.e. and k.e. as the useful energy output, often using only p.e. Others didn't realise that the answer to part (a) was the input energy and instead attempted to find some ratio of p.e. to k.e.
 - (c) Many students gained 1 mark for stating that the resistance of the thermistor would decrease. Only the most successful answers gave an explanation of why this property was useful in this context. The most able students were able to provide quality descriptions that incorporated the potential-divider aspect of the series circuit.

18.

- (a) Almost half of students achieved both marks. However, over 30% scored zero. Students gaining 1 mark did so by correctly identifying this proton–neutron conversion. Students gaining more than 1 went on to describe correctly how the quark character changed. Students scoring zero usually thought that a neutron converted to a proton in beta-plus decay.
- (b) Students need to take more care in reading the opening stem to a question. The required equation was provided and any use of this obtained credit. Many students were unable to convert 0.52 MeV to joule. This conversion is a key skill expected of AS physics students and should be treated as such.
- (c/d) Over 80% of students were able to select the appropriate detector. They were familiar with the fact that two photons would be produced in the annihilation event. The most effective answers contained detailed explanations supporting the conclusion.
- (e) Many students gained some credit for attempting to determine the gradient of the graph. Common mistakes included: failure to appreciate that the velocity axis had a false origin, failure to convert the time from hours correctly, leaving the velocity in mm s^{-1} , and failure to read-off accurately from the graph.
- (f) Many students were able to state that the acceleration would increase. Only the most able students were able to provide a good explanation of why this was the case. A significant number of students thought that the acceleration would decrease because *'less of the photon's energy was absorbed'*.

19.

This question required students to have an understanding about systems in equilibrium.

- (a) Nearly 70% of students determined the answer by considering the balance of forces.
- (b) This question was poorly answered, with over 60% gaining no credit. The definition of a couple was required and this was not well expressed. Only about 12% of students could define a couple and then explain why **A** and **B** could not be a couple. It was very common to read that **A** and **B** were a couple because of the symmetry of the system.
- (c) This question proved challenging for many students and barely 20% achieved full marks. Of the remaining cohort, few were competent in selecting an appropriate pivot position for the application of the moments principle.
- (d) This question was not answered well. Students could have helped themselves by drawing a diagram of the new situation. Had they then drawn the vertical forces on this diagram, they may well have realised that the readings would be the same. Most students, however, considered the question in terms of moments and drew incorrect conclusions.

26. Much of the work on motion in this question was relatively straightforward and, in a typical series, students would be expected to score well on it. Although the average scores on most of the question parts were higher than the paper average, a large number of errors in basic understanding were seen. In (a), for example, many students struggled to work out the area, or suggested that the average speed was the average of the speeds of the three sections. In (b), a surprisingly large number of students did not identify the slower response time as the appropriate one for the calculation. Many careless errors in the use of *suvat* equations were also seen in (c). It was pleasing to note in (d) that several students understood the premise of the question and indicated that the chevrons would be too far apart and therefore people would ignore them or that the car in front would also take some distance to come to rest. Very few fully correct answers were seen in (e). Although most students attempted to apply ideas of circular motion, the angle of the slope was largely ignored. Many answers suggesting $N = mg$, or applying the equation of circular motion down the slope rather than horizontally, were seen.

27. The performance of these students on the multiple-choice questions was poorer than in previous years but not quite so poor as their performance in Section A.

Question 29 proved to be the most difficult, with the majority of students choosing option B.

Perhaps these students used $\frac{V}{3}$ as the “lost” volts rather than the terminal pd.

There were several other questions where a distractor was more popular than the correct answer. In question 16 the most popular answer was D. Students choosing this possibly failed to understand the difference between a π and a 2π phase difference.

In question 19 the most popular answer was C. The majority of students failed to spot that the angle given was between the two second-order maxima, rather than the central maximum and the second order.

In question 27 the most popular answer was C. Students choosing this distractor probably believed that the resistance of the thermistor increases with temperature.

55. Circular motion is a demanding topic for many students. Answers to these questions indicated the difficulties students commonly have with the ideas of reaction force, centripetal force and angular speed. The multi-step calculation in question (d) proved too difficult for many students, some of whom did little more than work out the Young Modulus, which was not needed. Some of these students made a little progress when they used their calculated Young Modulus to determine a quantity that they could have simply read from the graph. The idea of a safety factor was usually either missed or not understood.

57. Some of the more straightforward calculations in this question were completed successfully by most students and it was pleasing to note how many could successfully solve a quadratic equation. Students generally had more difficulty understanding what the answers represented. Little attempt was made in question (e) to discuss the graph in any detail beyond simple statements about what is represented by the gradient and area. A surprisingly large number of students suggested the graph showed the path of the ball, and made contradictory statements because of this.

59. This question was about the bending of a beam and tested ideas about different types of error, orders of magnitude, and the interpretation of log-log graphs.

In part (a) a popular distractor for the vernier reading was 45.8. Nearly 60% gave the correct answer of 37.8.

The word ‘*random*’ was supplied by 40% to earn the mark in (b), although just as many preferred ‘*systematic*.’ ‘*Human error*’ is not a term examiners allow or expect students to use.

About 70% of students obtained a mark in (c) for stating that the thinner beam would deflect more. Some went on to identify correctly that this would reduce the percentage uncertainty in s . The third mark could be earned in a variety of ways, e.g. suggesting that the beam could become permanently deformed. We expected students to understand the distinction between elastic limit and limit of proportionality.

Many knew the meaning of the *Giga* prefix in the value of Young modulus in (d) and could then combine this with data obtained from Figure 4. A common error was failing to notice that s was in millimetres. Many students still do not understand what is required when we ask them to make an order-of-magnitude calculation (specification objective MS 1.4), the majority leaving their raw values for η on the answer line. Only 15% supplied the expected answer 8 or 10^8 ; we did not accept 1×10^8 . A worrying number seemed confused by the unit on the answer line and spoiled a perfectly acceptable result by carrying out some additional mathematical operation.

Part (e) addressed specification objective MS 3.11 which identifies that logarithmic plots are used ‘to test power-law variations’. This was the least accessible question on the paper, many claiming that Figure 5 showed an exponential relationship. This question exposed lack of knowledge in the same way as did the question about logarithmic scales from 2019. Successful students, of which there were less than 5%, suggested a mathematical expression such as $s = kL^n$, k being identified as a constant.

In (f), about 75% got as far as identifying $\log L = -0.097$ but some failed to see the next step and used Figure 5 incorrectly.

Part (g) discriminated well in favour of the stronger students, but over 20% did not attempt this part.

60.

This contextual question tested the ability to present ‘*show that*’ calculations and fundamental ideas about forces and energy transfers.

- (a) In this question, students needed to find the vertical component of the tension, then take into consideration the two ropes and, finally, resolve the weight of the loaded cage. Credit was given to students when they clearly demonstrated these steps. Nearly 40% of students achieved full marks. Answers of a high standard were easy to follow and required little interpretation by the examiner. Students should consider briefly annotating their steps (*Two ropes so double my tension*) when giving ‘*show that*’ answers.
- (b) This question tested an understanding of Newton’s laws. Over 60% of students achieved both marks. Many students understood that they needed to use $F = ma$ but did not appreciate, from Newton’s third law, that the force given in (a) was needed. Students should be aware that a ‘*show that*’ question often provides a value that will be used subsequently.
- (c) This question proved to be slightly more challenging than (a). Again, students gained credit for showing clear evidence of any of the steps in this calculation. A common error was to use the force from (a) in a Hooke’s Law calculation.

- (d) Around one-third of the cohort gained full credit for this question. As a '*deduce*' question, there needed to be a conclusion about the justification of the claim. Over 50% of students gained no marks or did not attempt the question at all. Many did not make the connection with (c) and failed to consider energy transfers. A large number of students applied *suvat* (kinematic) equations but the acceleration is not uniform in this situation.
- (e) About 50% of students were able to convert the speed and to use it in the kinetic energy equation. Credit was given for an incorrect or no conversion of the speed so long as the substitution in the kinetic energy equation was fully correct. Mistakes in writing the 'square' exponent or in actually squaring the speed on the calculator were commonly seen.
- (f) In this question, students needed to compare their answer to (e) to the '*show that*' value of (c). Even though an error was carried forward, many students struggled to give a relevant conclusion.