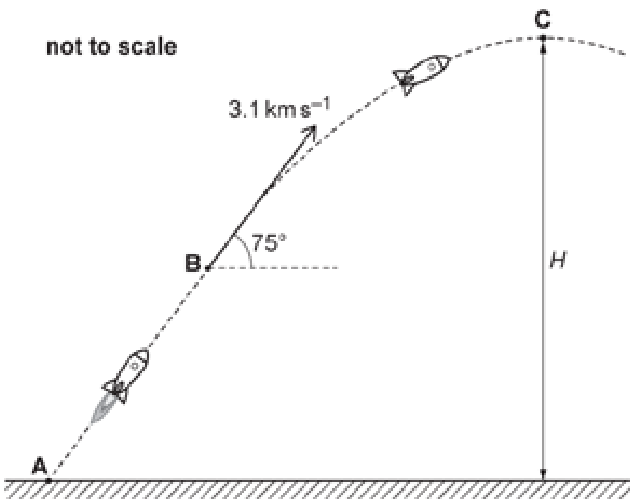
1. A scientist uses a rocket to study the Earth's atmosphere.

The scientist launches the rocket from rest at the point **A** at t = 0 seconds. The force produced by the rocket's engine causes it to accelerate.

At t = 50 seconds, the rocket's engine no longer produce an accelerating force as all of the fuel has been used. The rocket has reached point **B**. Its velocity is now 3.1 km s^{-1} at an angle of 75° to the horizontal.



The rocket reaches its maximum height at point **C**.

- Estimate the vertical displacement H between **A** and **C**. Assume that g = 9.81 m s^{-2} throughout.
- Clearly state any other assumptions required at each stage in your calculations.
- Evaluate the assumption that g = 9.81 m s^{-2} between **A** and **C**, supporting your discussion with a calculation. Assume that the radius of the Earth ≈ 6400 km.

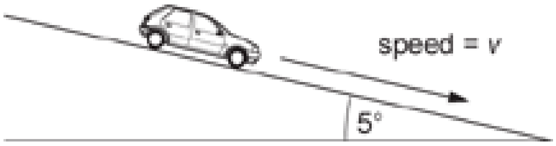
[6]

2(a). A car of weight 9300 N is moving at speed *v*. The total resistive force, *F*, acting against the motion of the car is given by the formula

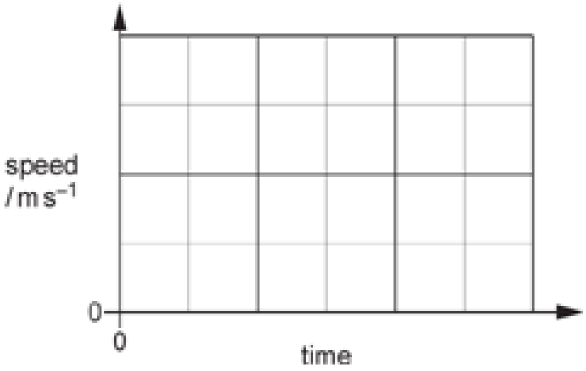
$F = kv^2$

where *k* is a constant.

The car is allowed to roll from rest down a slope of 5° to the horizontal. The engine of the car is not switched on. The car reaches a maximum speed of 30 m s^{-1}.



i. Sketch a graph on the axes below to show how the speed of the car changes over time. Add a suitable value to the vertical axis.



[2]

ii. Explain why the car reaches a maximum speed.

[2]

iii. Show that the value of *k* in the equation $F = kv^2$ is about 1.

[3]

(b). The car is now moving along a straight, level track. The engine of the car delivers a maximum power of 75 kW.

Calculate the maximum speed of the car.

maximum speed of car = ... m s^{-1} **[3]**

(c). Changes are made to the engine of the car so that it can produce double the original maximum power.

Explain why the maximum speed of the modified car is **not** doubled.

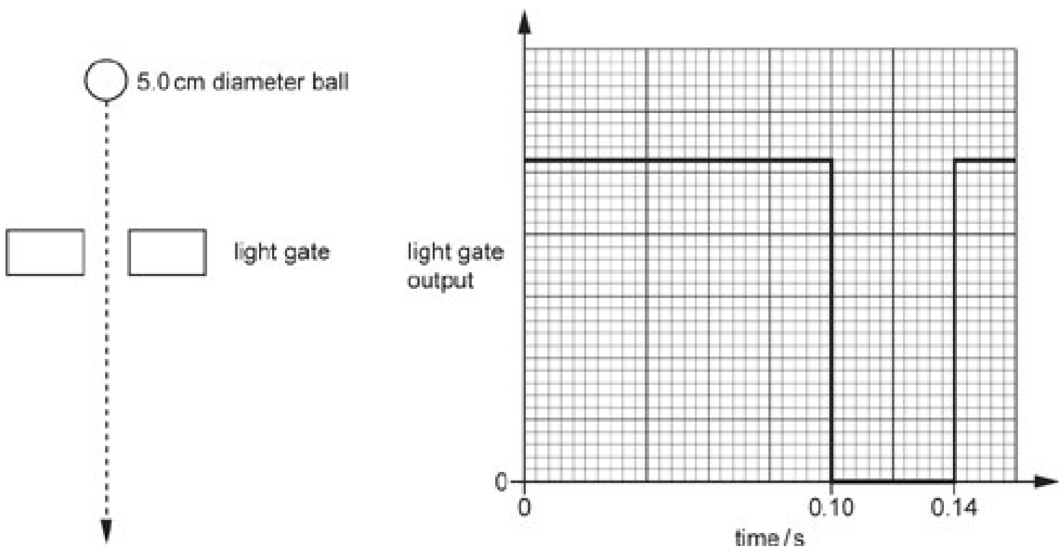
[2]

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

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

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

The graph shows the output from the light gate.



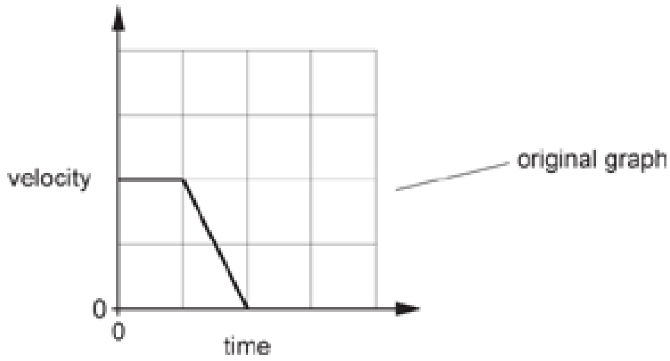
Air resistance has negligible effect on the motion of the ball.

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

A 8.93
B 9.81
C 10.4
D 12.5

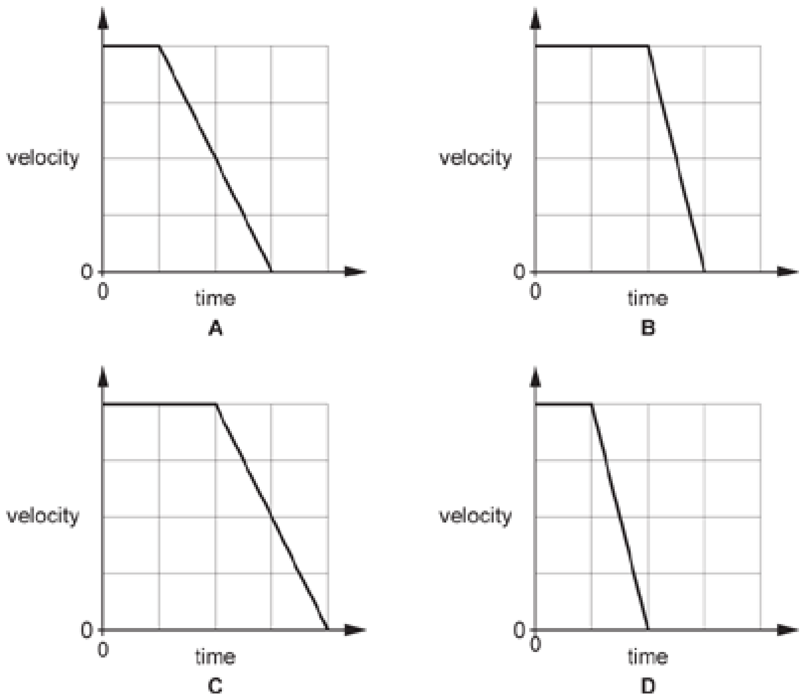
Your answer **[1]**

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



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

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



Your answer **[1]**

5(a). A student investigates the motion of falling objects.

The student releases a heavy ball and allows it to fall from a height of 2.0 m.

Calculate its expected speed when it hits the ground.

Assume that air resistance is negligible.

speed = ... ms^{-1}**[3]**

(b). The student measures the time for a heavy ball to fall from a height of 2.0 m.

They release the ball and, at the same time, start a stopwatch.

They stop the stopwatch when the ball hits the floor.

The student repeats the measurement and records their results.

Time to fall / s	0.62	0.68	0.60

Calculate a value for *g* using the student's results.

g = ... ms^{-2} **[3]**

(c). Suggest **one** improvement the student could make to the investigation described in the previous question.

____

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____

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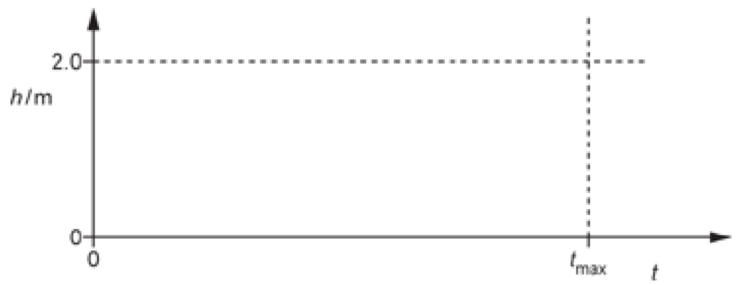
____ **[2]**

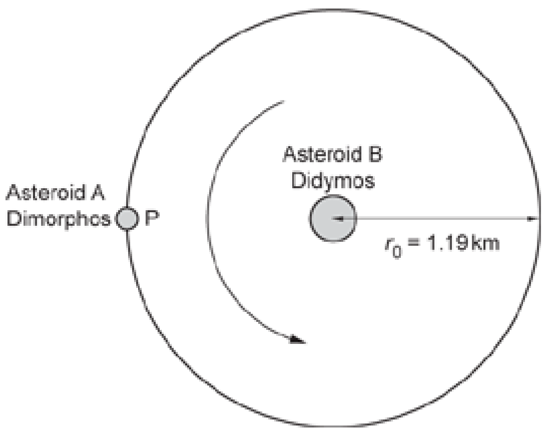
(d). A ball bounces when it hits the floor.

On the axes below, sketch a graph of height, h, against time, t, to represent the motion of the ball from the time, t = 0 when it is released to the time $t = t_{max}$ when it reaches its maximum height **after** hitting the floor.



[2]

6(a). In space, Asteroid A, called Dimorphos travels at constant speed in a circle around a larger Asteroid B, called Didymos. The diagram shows Asteroid A at position P.



The distance r_0 between Asteroid A and Asteroid B is 1.19 km.
The time T_0 for Asteroid A to travel once around Asteroid B is 4.29×10^4 s (11 hours 55 minutes).

Calculate the average speed v, in ms^{-1}, of Asteroid A.

v = ... ms^{-1} **[2]**

(b). Explain **one** similarity and **one** difference between the velocity of Asteroid A at P and its velocity six hours later.

similarity ______________________________

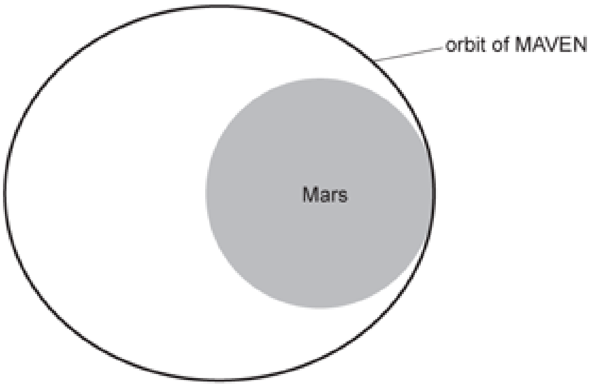
____

difference ______________________________

______________________________ **[2]**

7(a). The MAVEN spacecraft orbits Mars and studies its upper atmosphere.

The diagram below shows the orbit of MAVEN around Mars.



i. Mark an **X** on the diagram to show the point in the orbit where MAVEN has maximum acceleration.

[1]

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

[2]

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

Phobos and Deimos are moons of Mars.

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

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

i. Show that Kepler's 3rd law applies to this data.

[2]

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

1 ______________________________

____

____

2 ______________________________

____

______________________________ **[2]**

8. In an experiment, a trapdoor and electromagnet are used to determine the acceleration of free fall of a ball.

The distance the ball falls is *h* and the time taken for the ball to fall is *t*.

The experiment is repeated for different values of *h*.

The table shows the results. Values of $\sqrt{h}$ have been included.

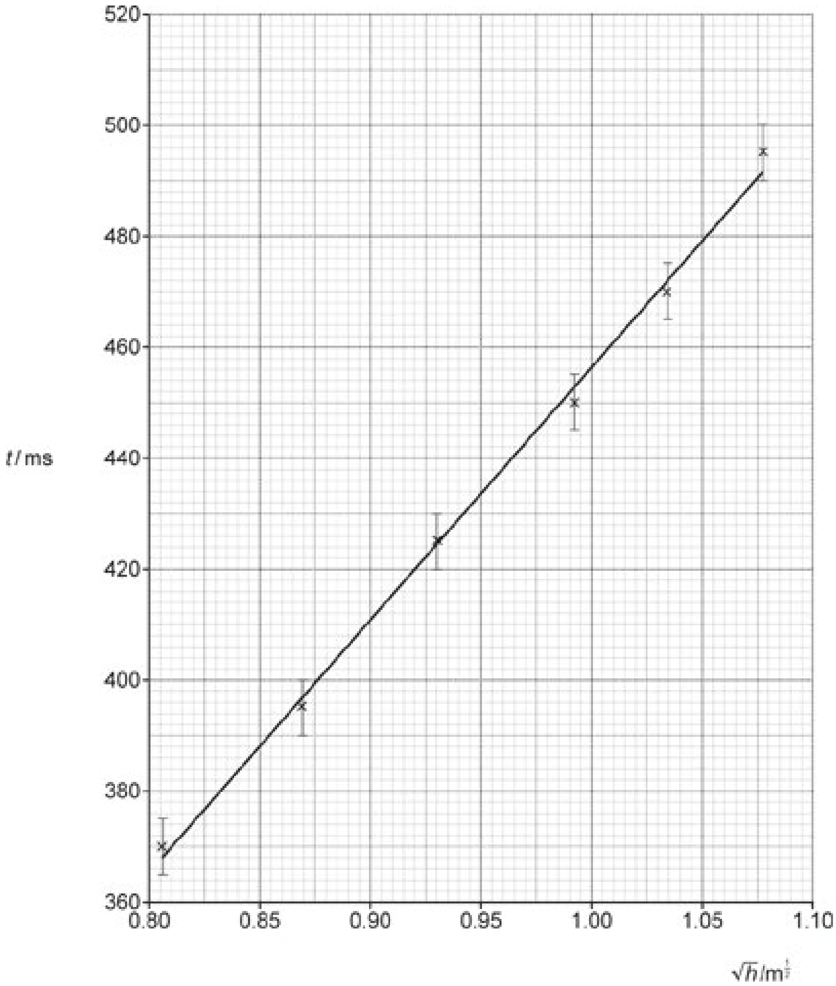
***h*/m**	$\sqrt{h}$ / $m^{\frac{1}{2}}$	**t/ms**
0.650	0.806	370 ± 5
0.755	0.869	395 ± 5
0.865	0.930	425 ± 5
0.985	0.992	450 ± 5
1.070	1.034	470 ± 5
1.160	1.077	495 ± 5

It is suggested that the relationship between *t* and *h* is

$$t = \sqrt{\frac{2}{g}}\sqrt{h} + k$$

where *g* is the acceleration of free fall and *k* is a constant.

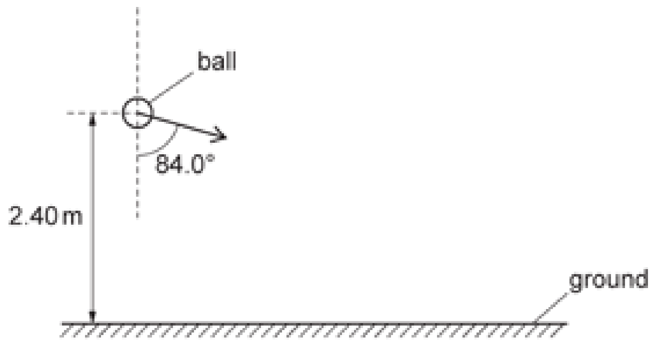
A graph of *t* / ms on the *y*-axis against $\sqrt{h}$ / m$^{\frac{1}{2}}$ on the *x*-axis is plotted.



- Describe how to measure *h* and *t*.
- Use the graph to determine *g*, including the percentage uncertainty.

[6]

9(a). A student throws a ball of mass 0.210 kg. The hand of the student is a vertical distance of 2.40 m above the ground. The ball leaves the student's hand with a velocity of 22.3 m s^{-1} at an angle of 84.0° to the vertical as shown in the diagram.



(not to scale)

Assume that air resistance is negligible.

Show that the vertical component u_v of the velocity of the ball as it leaves the student's hand is about 2.33 m s^{-1}.

[1]

(b). Show that the vertical component v_v of the velocity of the ball as it hits the ground is about 7.25 m s^{-1}.

[2]

(c). Calculate the kinetic energy E_k of the ball as it hits the ground.

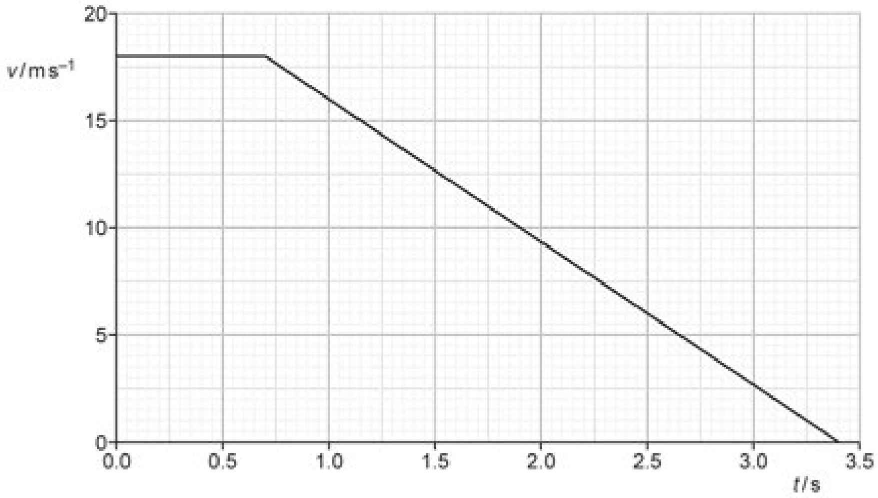
E_k = ...J **[3]**

(d). Explain why the momentum of the ball changes as the ball travels from the hand to the ground.

[2]

10(a). The brakes of a car of mass 1200 kg are being tested on a track. The driver sees a hazard and applies the brakes.

The graph shows the variation of the velocity *v* of the car with time *t* from when the driver sees the hazard to when the car stops.



i. Calculate the acceleration *a* of the car while the brakes are applied.

a = ...m s^{-2} **[1]**

ii. Calculate the average braking force *F* while the brakes are applied.

F = ... N **[1]**

iii. Calculate the total stopping distance *d* of the car.

d = ... m **[2]**

iv. Calculate the work *W* done by the brakes to stop the car.

W = ... J **[2]**

(b). The same driver in the same car repeats the test at half the initial velocity. The braking force is constant.

On the graph, draw the variation of velocity of the car from the time the driver sees the hazard to the time the car stops.

[2]

(c). Explain how your graph would change if:

i. the driver was tired

____

____ **[1]**

ii. the surface of the track was more resistive.

____

____ **[1]**

11(a). The diagram shows a road where vehicles travel at high speeds.

Markings painted on the road surface are spaced 40 m apart.

Drivers are advised to keep at least two markings visible on the road between them and the vehicle in front.

The maximum speed vehicles travel at on the road is 110 km / hr. The table shows data from a driving manual for a vehicle travelling on a straight, horizontal road.

Speed (km / hr)	Braking distance (m)	Stopping distance (m)
110	75	96

i. Calculate the maximum speed *v* of vehicles on the road in S.I. units.

v = ...Unit = ...**[2]**

ii. A vehicle passes over one of the markings.

Calculate time taken to travel the 40 m distance between the two markings.

t = ...s **[1]**

iii. Using the table, explain why having markings 40 m apart helps prevent collisions.

[3]

(b). A vehicle with mass 1600 kg is travelling at 110 km / hr.
The driver sees an obstruction and applies the brakes to bring the vehicle to rest in 5.6 s.

i. Estimate the magnitude of the average resultant force *F* required to bring the vehicle to rest.

F = ... N **[2]**

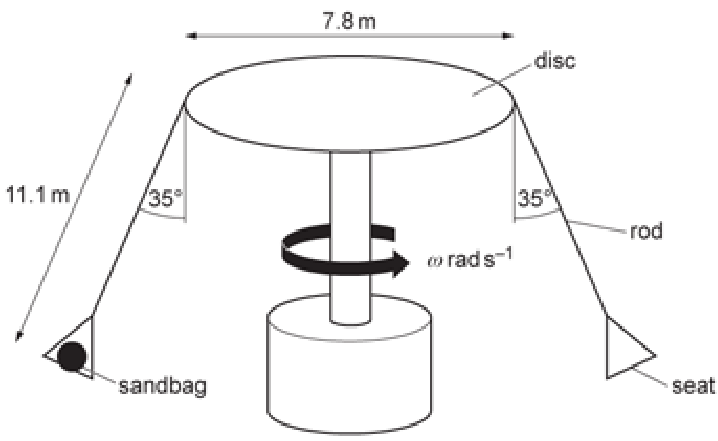
ii. Explain the effect on the distance required to bring the vehicle to rest if the road has an upwards slope.

[2]

12(a). The diagram below shows a fairground ride. Each rider is secured in a seat suspended by a rod.

The distance from the top of the rod to the base of the seat is 11.1 m.

The rod is attached to the edge of a disc of diameter 7.8 m.



(not to scale)

To test the equipment a sandbag is attached to the seat and the ride is started.

The combined mass of the seat and the sandbag is 12 kg.

The rod makes an angle of 35° with the vertical.

i. Draw an arrow labelled T on the diagram to represent the tension in the rod.

[1]

ii. Show that the radius of the circular path followed by the sandbag is about 10 m.

[2]

iii. Calculate the tension *T* in the rod.

T = ...N **[3]**

iv. Show that the angular velocity of the ride is about 0.8 radians per second.

[2]

(b). When the seat is at its highest point the sandbag is 17 m above the ground. The sandbag is released from the seat to model an object being dropped by a rider.

i. Calculate *t*, the time taken for the sandbag to reach the ground.

t = ... s **[2]**

ii. Using your answer to **(a)(iv)**, determine the horizontal displacement *s* travelled by the sandbag before hitting the ground.

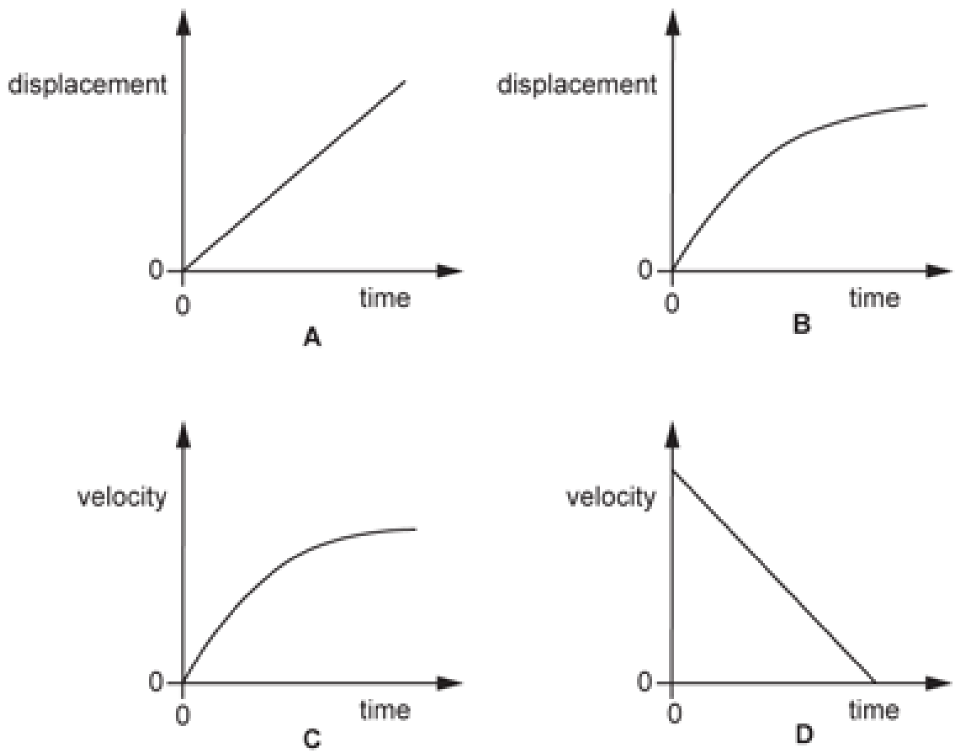
s = ...m **[3]**

iii. Determine, with reasons, the effect on the horizontal displacement travelled if the object released from the ride was a shoe from a rider.

[3]

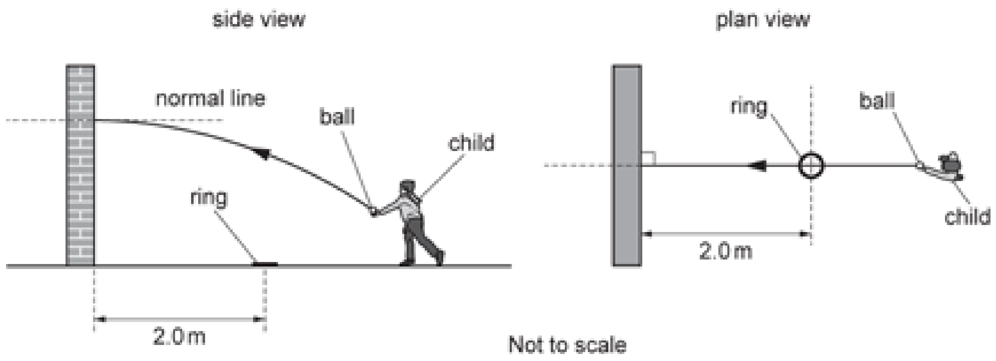
13. The resultant force acting on a moving object is zero.

Which graph shows this?



Your answer ☐ **[1]**

14. In a game, a child throws a ball at a flat, vertical wall. The ball rebounds from the wall. The child wins the game if the ball lands within a circular ring placed on the ground.



The ring has a radius of 15 cm. The centre of the ring is 2.0 m from the wall. The child throws a ball with a mass of 0.058 kg towards the wall.

The ball rebounds normally with a horizontal velocity of 3.6 m s^{-1} and lands on the ground a time of 0.58 s after hitting the wall.

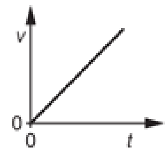
Show that the child wins the game. Air resistance can be assumed to be negligible.

[3]

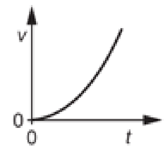
15. An object is released from rest and then falls freely under gravity. Air resistance is negligible.

Which graph shows how the velocity *v* of the object varies with time *t* ?

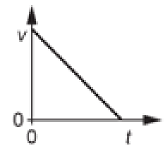
A



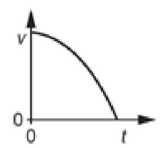
B



C



D



Your answer ☐ **[1]**

16(a). A tent is secured by 3 ropes along each of its long sides, as shown in **Fig. 18. 1**.

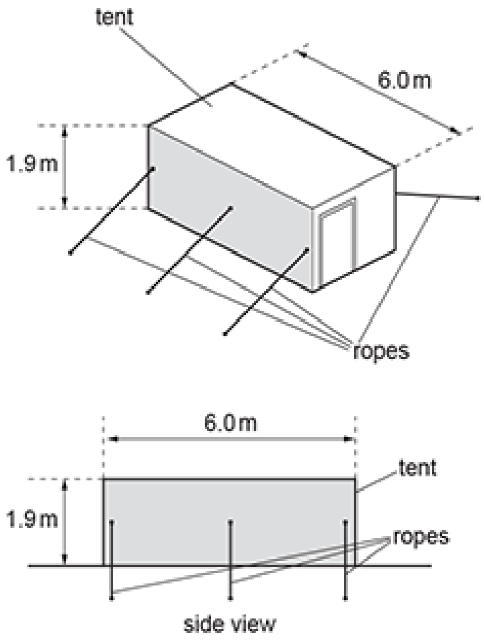


Fig. 18.1

Wind of speed 12 ms^{-1} blows at right angles to the **shaded** side of the tent for 3.0 s. The density of air is 1.2 kg m^{-3}.

i. Show that the mass of air which hits the tent in this time is about 490 kg.

[3]

ii. All of the air incident on the shaded side of the tent is deflected at 90° to the original direction as shown in **Fig. 18. 2**.

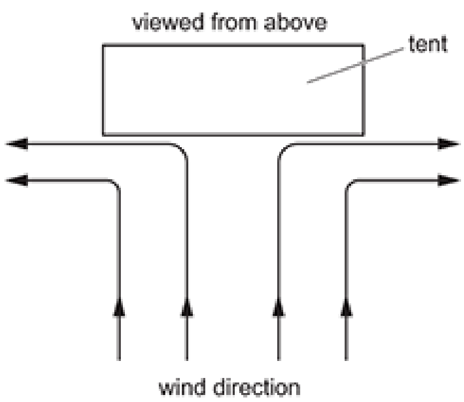


Fig. 18.2

Use the information given in **(a)(i)** to calculate the magnitude of the force *F* exerted by the wind on the shaded side of the tent.

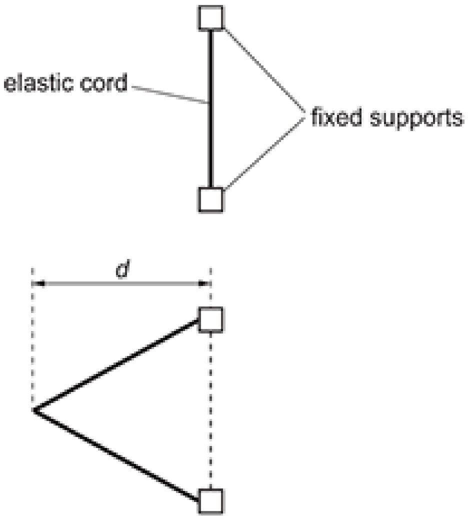
F = ... N **[2]**

(b). *When the wind speed exceeds 20 ms^{-1} the ropes securing the tent break.

Describe, and explain in terms of forces, how the ropes and the shape of the tent could be modified to withstand wind speed exceeding 40 ms^{-1}.

[6]

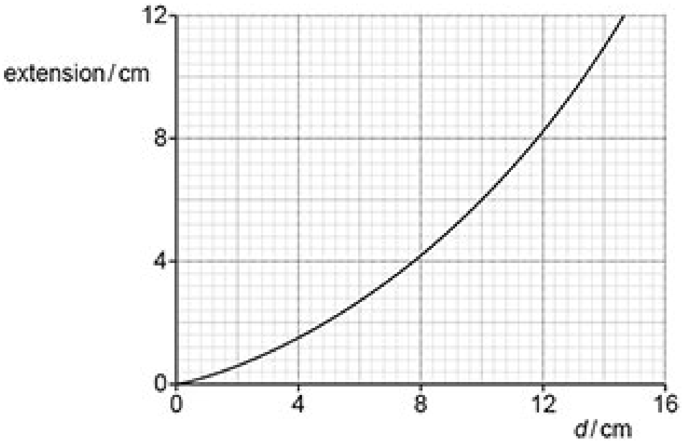
17. A simple catapult is made by an elastic cord fixed to two supports, as shown below.



The unstretched length of the cord is the same as the distance between the supports.
The distance that the centre of the cord has been pulled back is *d*.

The cord has a force constant of 500 Nm^{-1}.

The variation of the extension of the cord with distance *d* is shown below.



A small ball of mass 30 g is placed at the centre of the cord and drawn back with *d* = 10 cm.

The ball is released and launched horizontally from a height of 1.5 m above the horizontal ground.

i. Use the graph to show that the elastic potential energy *E* in the cord is about 1 J.

[3]

ii. Show that the maximum speed at which the ball leaves the catapult is about 8 ms^{-1}.

[2]

iii. Calculate the horizontal distance *R* travelled by the ball before it strikes the horizontal ground. Ignore the effects of air resistance in your calculation.

R = ... m **[3]**

iv. Explain how the value of *R* calculated in **(iii)** compares with the actual value.

[2]

18. An electric engine of mass 17 000 kg has a constant power output of 280 kW and it can reach a maximum speed of 42 ms^{-1} on horizontal rails. The maximum kinetic energy of the engine is 15 MJ.

The speed of the engine is 42 ms^{-1}.
The driver sees an obstruction 167 m from the front of the engine. The engine is switched off and the brakes are applied.
The constant force opposing motion is 120 kN. The reaction time of the driver is 0.40 s.

Show with the help of calculations, that the engine will stop before reaching the obstruction.

[4]

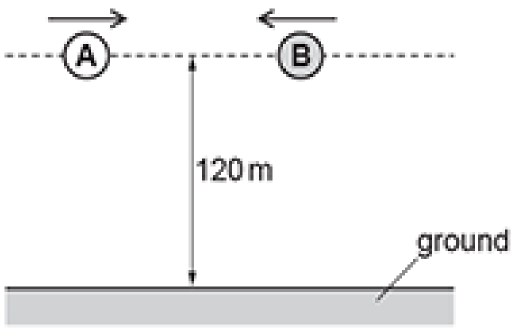
19. A student has plotted a velocity against time graph for a trolley moving down a ramp.

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

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

Your answer **[1]**

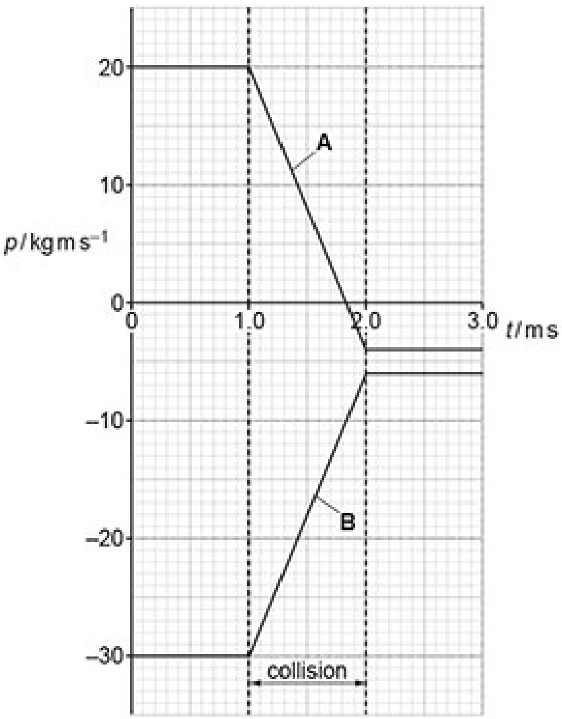
20(a). Two objects **A** and **B** are travelling horizontally and in opposite directions. The objects collide in mid-air at a height of 120 m above the horizontal ground, as shown below.



The mass of **A** is 2.0 kg and the mass of **B** is 3.0 kg.

After the collision the objects are joined together.

The momentum *p* against time *t* graphs for each object before, during and after the collision are shown below.



Calculate the magnitude of the horizontal velocity *v* of the combined objects immediately after the collision.

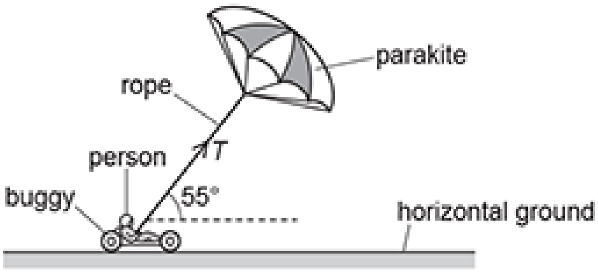
v = ... m s^{-1} **[2]**

(b). Air resistance has negligible effect on the motion of the objects.

Calculate the time taken for the combined objects to reach the ground after the collision.

time taken = ... s **[3]**

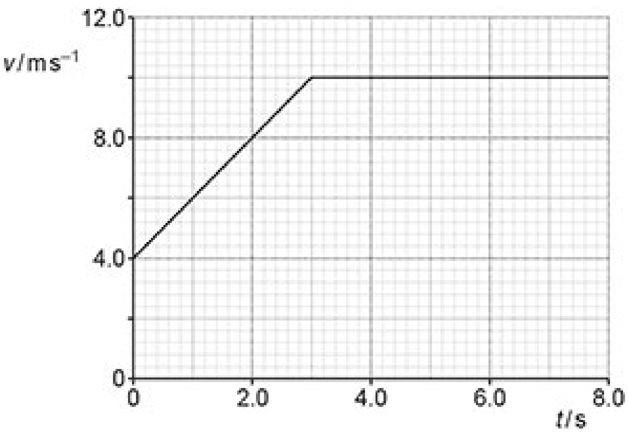
21(a). A person in a buggy is attached to a large parakite by a rope, as shown below.



Strong wind acting on the parakite moves the buggy along horizontal ground.

The rope makes an angle of 55° to the horizontal. The total mass of the buggy and person is 150 kg.

The velocity *v* against time *t* graph for the buggy is shown below.



Calculate the horizontal distance travelled by the buggy from t = 0 to t = 8.0 s.

horizontal distance = ... m **[3]**

(b). At t = 1.0 s the buggy is accelerating.

i. Use the graph to show that the acceleration of the person at t = 1.0 s is 2.0 m s^{-2}.

[1]

ii. At t = 1.0 s the tension T in the rope is 680 N and the total **horizontal** resistance acting on the buggy and person is R.

Calculate R by resolving the tension in the rope horizontally.

R = ... N **[3]**

22(a).

A ball of mass 0.16 kg is dropped from rest from a height of 2.5 m above the ground.

Assume air resistance is negligible.

Calculate

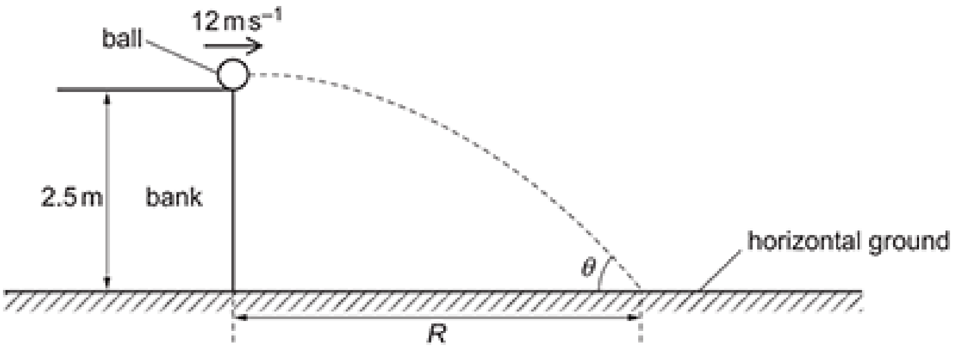
i. the change in gravitational energy E_p

E_p = ... J **[1]**

ii. the velocity v of the ball as it reaches the ground.

v = ... ms^{-1} **[2]**

(b). The ball from **(a)** is now fired horizontally with a speed of 12 ms^{-1} from a bank.
The height of the bank is 2.5 m.
The time for the ball to travel from the edge of the bank to the horizontal ground is 0.71 s.
The path of the ball is shown in the diagram.
The ball hits the horizontal ground a distance *R* from the bottom of the bank.
Assume air resistance is negligible.



Calculate

i. *R*

R = ... m **[1]**

ii. the kinetic energy E_k of the ball as it reaches the ground

E_k = ... J **[2]**

iii. the angle *θ* between the ground and the direction of the ball as it reaches the ground.

θ = ... ° **[1]**

23(a). A student investigates the motion of a steel ball in oil in a laboratory.

The radius *r* of the ball is 8.1 mm.

The student uses a measuring cylinder and a digital balance to determine the density of the oil.
The student records the following measurements:

- mass of empty measuring cylinder = 96 g
- volume of oil added to measuring cylinder = 87 cm^3
- total mass of measuring cylinder and oil = 169 g

Show that the density of the oil is about 840 kg m^{-3}.

[2]

(b). The steel ball is submerged in the oil.

Show that the upthrust acting on the steel ball is 1.8×10^{-2} N.

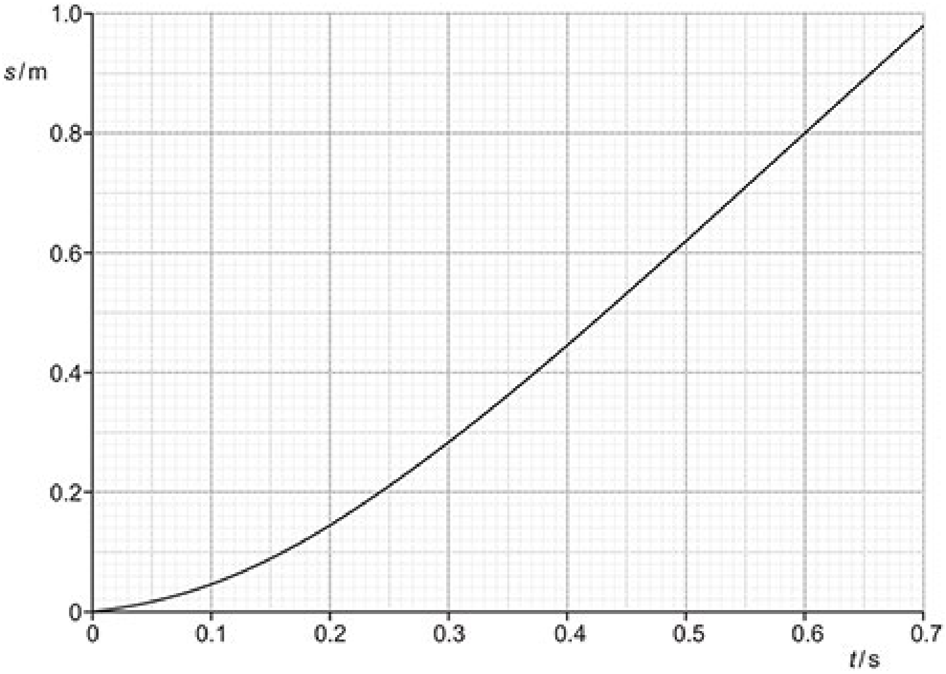
[2]

(c). The student fills a long tube with the oil.

The student drops the steel ball from rest at the surface of the oil at time $t = 0$.

The displacement *s* of the ball is measured from the surface of the oil.

The graph shows the displacement *s* against time *t* for the steel ball from the instant it enters the oil.



i. The terminal velocity *v* of the steel ball is 1.8 m s^{-1}.

Describe and explain how this can be determined from the graph.

____

____

____

____ **[3]**

ii. Use the graph to calculate the velocity *u* of the steel ball at time *t* = 0.20 s.

u = ... m s^{-1} **[2]**

(d). The mass of the steel ball is 17 g.

The drag *F* acting on the steel ball falling through the oil is given by the equation $F = 6\pi\eta rv$

where η is a constant for the oil, *r* is the radius of the steel ball and *v* is the speed of the steel ball through the oil.

At *v* = 1.8 ms^{-1}, the force *F* is equal to the **difference** between the weight of the steel ball and the upthrust acting on the steel ball.

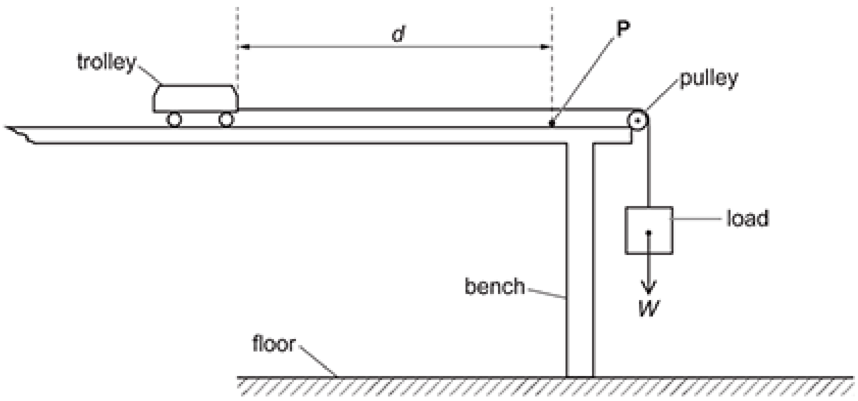
Calculate η.

Include an appropriate unit.

η = ... unit .... **[3]**

24. *A student is investigating the motion of a trolley as it accelerates from rest along a horizontal surface.

The diagram shows the trolley on a horizontal surface. A load of weight *W* accelerates the trolley.



Point **P** is a distance *d* from the initial position of the trolley.
A light gate connected to a timer is used to determine the velocity *v* of the trolley at point **P**.

It is suggested that the relationship between *v* and the mass *M* of the trolley is $\frac{1}{v^2} = \frac{M}{2dW - Q} + R$

where *Q* and *R* are constants.

Describe, with the aid of a suitable diagram,

- how an experiment can be safely conducted to test this relationship between *v* and *M*, and,
- how the data can be analysed to determine Q and R.

[6]

END OF QUESTION PAPER