Forces in Action Motion with non-uniform acceleration

1. The frictional force acting on an object falling vertically through water is directly proportional to its speed squared.

What is the correct relationship between *P*, the rate of work done against the frictional force, and the speed *v* of the object?

A $P \propto v^{-1}$
B $P \propto v$
C $P \propto v^2$
D $P \propto v^3$

Your answer ☐ **[1]**

2. A ball of mass *m* is dropped into water. A constant upthrust *U* acts on the ball as it travels down through the water. The acceleration of the ball is *a* when the drag is *D*.

The acceleration of free fall is *g*.

What is the correct expression for the acceleration *a*?

A $a = g - \frac{U+D}{m}$
B $a = g - \frac{U-D}{m}$
C $a = g - \frac{D-U}{m}$
D $a = g + \frac{U+D}{m}$

Your answer ☐

[1]

3 (a). A student uses a motion-sensor connected to a laptop to investigate the motion of a hollow ball of mass 1.2 × 10^{-2} kg falling through air.

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

The upthrust on the ball is negligible.

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

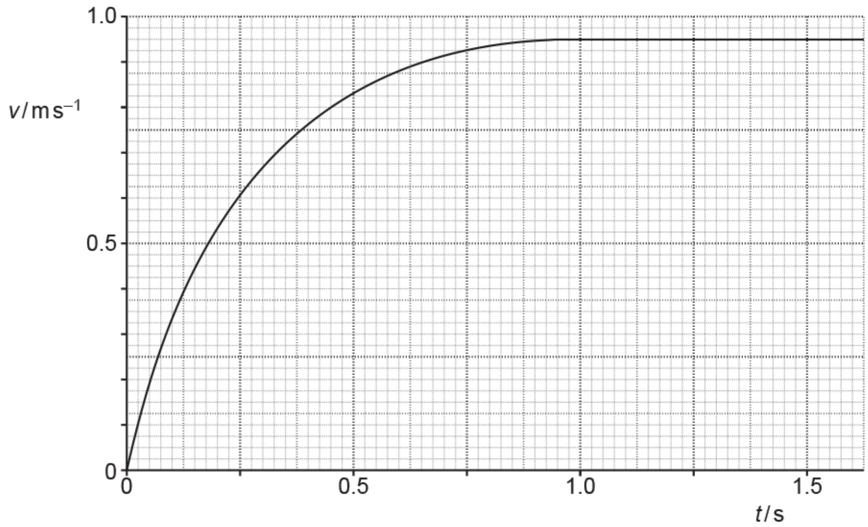


Fig. 17

Calculate the resultant force *F* acting on the ball at *t* = 0.25 s.

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

(b). Use your answer in the part above to calculate the drag on the ball at time *t* = 0.25 s.

drag = ... N **[3]**

4 (a). This question is about **upthrust** and other forces acting on a sealed hollow tube in water.

One end of a string is attached to the bottom of the tube and the other end of the string is attached to the bottom of the container. The string exerts a downward force *F* on the tube.
At time $t = 0$, the tube is half submerged in the water, as shown in Fig. 23.1.

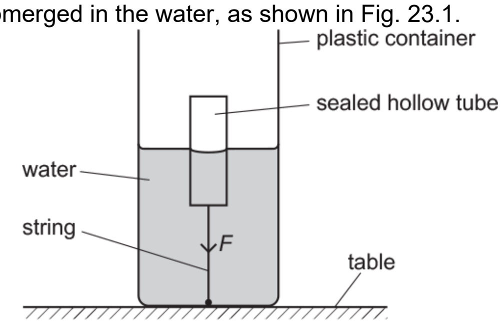


Fig. 23.1

The container is slowly filled with water at a constant rate until the container is full.
Fig. 23.2 shows the graph of *F* against time *t*.

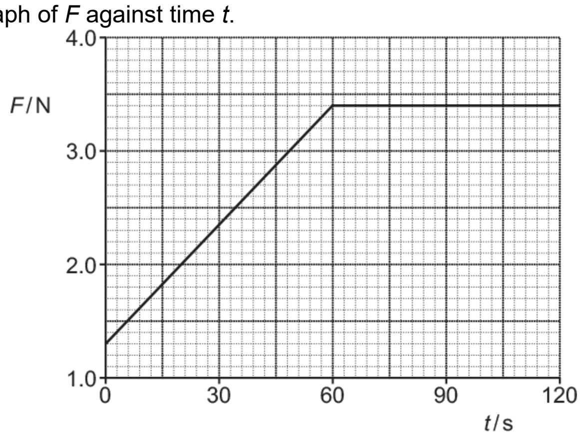


Fig. 23.2

The container is now full of water.
The string is cut and the tube accelerates vertically upwards through the water.
The weight of the tube is 0.80 N and the upthrust on the tube is 4.2 N.

Calculate the **initial** upward acceleration a of the tube.

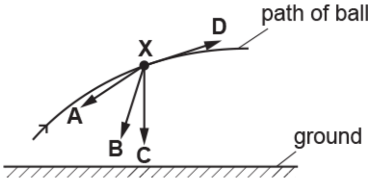
a = ____________________ m s^{-2} **[3]**

(b). State why the acceleration of the tube decreases as it travels vertically upwards through the water.

____

____ **[1]**

5. A ball is thrown through the air. The ball experiences a small amount of drag compared to its weight.
At a particular time the ball is at point **X**.
Which arrow best represents the direction of the resultant force on the ball when it is at **X**?

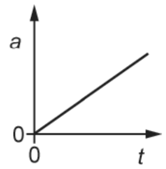


Your answer [1]

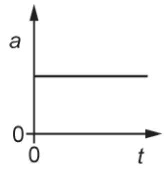
6. A ball, made from scrunched-up paper, is dropped from rest at time $t = 0$.
It reaches terminal velocity before it hits the ground.

Which acceleration a against time t graph is correct for the ball in flight?

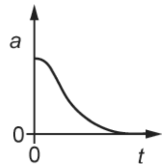
A



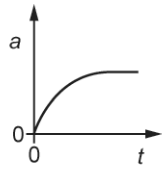
B



C



D



Your answer [1]

7. The air resistance F acting on an object falling vertically through air is given by the expression $F = 0.13\ v^2$

where v is the speed of the object.

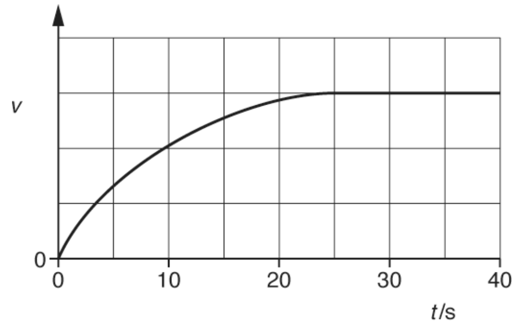
The mass of the object is 30g.

What is the terminal velocity of this object?

A 0.20 m s^{-1}
B 0.48 m s^{-1}
C 1.5 m s^{-1}
D 2.3 m s^{-1}

Your answer ☐ **[1]**

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



Which statement is correct about this object?

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

Your answer ☐ **[1]**

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

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

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

A $a = 0$

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

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

D $a = g$

Your answer ☐ **[1]**

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

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

A The ball has a downward acceleration.

B The force acting on the ball is F.

C The ball experiences greatest drag.

D The weight of the ball is equal to the drag.

Your answer ☐ **[1]**

11. A sheet of A4 paper is held horizontal and then dropped from rest from the top of a tall building. It falls towards the ground below, reaching terminal velocity. The same piece of paper is then crumpled into a small ball and then dropped from the same height. It also reaches terminal velocity.
Which of the following will change in the second situation?

A. The maximum magnitude of the air resistance.
B. The weight of the paper.
C. The time taken to reach terminal velocity.
D. The initial acceleration when dropped.

Your answer

[1]

12. A piece of flat A4 paper is dropped and falls to the floor. The same piece of paper is then collapsed into a ball and dropped again.

Which of the following will change in the second situation?

A. the maximum magnitude of the air resistance
B. the weight of the paper
C. the time taken to reach terminal velocity
D. the initial acceleration when dropped

Your answer

[1]

13. A paper cone is held above the ground and dropped. It falls vertically and reaches terminal velocity before it hits the ground.

Which statement correctly describes the **resultant** force on the falling cone before it reaches terminal velocity?

A decreasing and upwards
B decreasing and downwards
C increasing and downwards
D increasing and upwards

Your answer **[1]**

14. A seabird dives vertically into water.
The seabird is briefly stationary at its **greatest** depth.
In water, the upthrust on this seabird is always greater than the weight of the seabird.

Which statement is correct at the instant of greatest depth?

A The seabird experiences greatest drag.
B The seabird has an upward acceleration.
C The upthrust on the seabird is equal to drag.
D The weight of the seabird is equal to drag.

Your answer ☐ **[1]**

15. Two balls **X** and **Y** are dropped from a very tall building. Both balls reach terminal velocity before hitting the ground. The balls have the same diameter. The mass of **X** is greater than the mass of **Y**.

Which statement is correct?

A. The balls hit the ground at the same time.
B. The terminal velocity of **Y** is greater than that of **X**.
C. The initial acceleration of both balls is the same.
D. The balls have the same kinetic energy just before hitting the ground.

[1]

Your answer ☐

16. A balloon is travelling vertically downwards at a constant acceleration. The upthrust on the balloon is U, its weight is W and it experiences air resistance F.

Which statement is correct?

A. $F + W > U$
B. $W + U > F$
C. $F > W + U$
D. $W > U + F$

Your answer ☐

[1]

17. In a hockey match a hockey ball is hit 18.0 m from the front of the goal. The ball leaves the hockey stick with initial velocity v at an angle θ to the horizontal ground. The ball passes over the goal at a maximum height of 2.0 m as shown in Fig. 3.

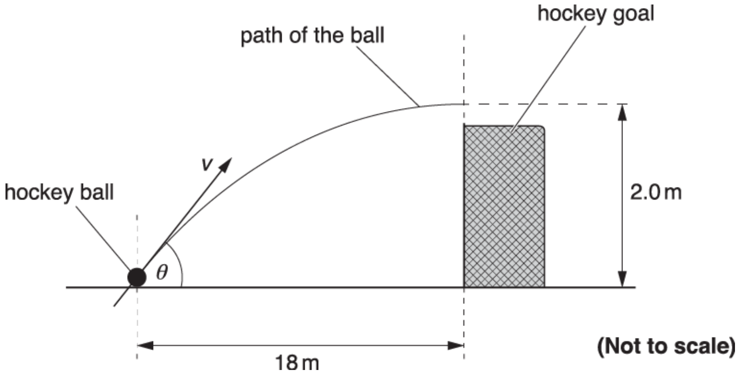


Fig. 3

The hockey ball is replaced with a ball that is affected by air resistance. This ball is hit with the hockey stick so that it leaves the stick with the same initial velocity v.

On **Fig. 3** sketch the path the ball is likely to take.

[2]

18 (a). Fig. 2.1 shows the path of a golf ball which is struck at point **F** on the fairway landing at point **G** on the green. The effect of air resistance is negligible.

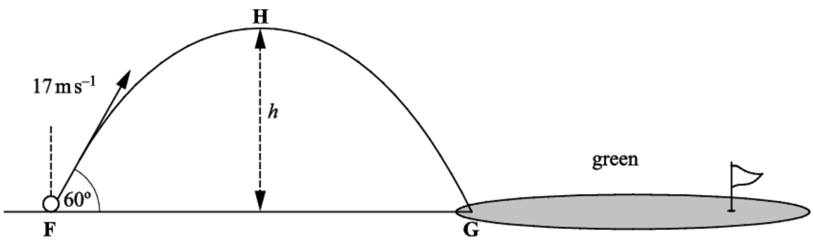


Fig. 2.1

The ball leaves the club at 17 m s^{-1} at an angle of 60° to the horizontal at time t = 0.

At t = 1.5 s the ball reaches point **H**. Calculate

i. the maximum height h of the ball

h = ... m **[3]**

ii. the distance between the points **F** and **G**.

distance **FG** = ... m **[2]**

(b). Suppose the same golfer standing at **F** had hit the ball with the same speed but at an angle of 30° to the horizontal. See **Fig. 2.2**.

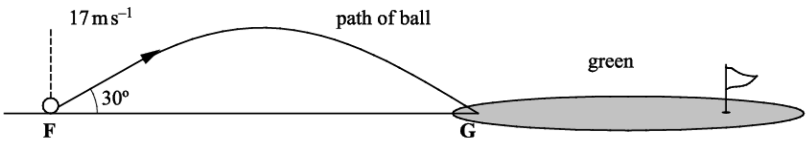


Fig. 2.2

Show that the ball would still land at **G**.

[3]

(c). Compare the magnitude and direction of the two velocities as the ball lands at G and using this information suggest, with a reason, which trajectory you would choose to travel a longer distance after hitting the green at G.

[2]

19 (a). A student investigates the motion of a tennis ball of mass 57 g which falls vertically from rest, then bounces once on a soft horizontal surface.
Fig. 1 shows the variation with time *t* of the velocity *v* of the tennis ball falling from rest until it hits the soft surface.

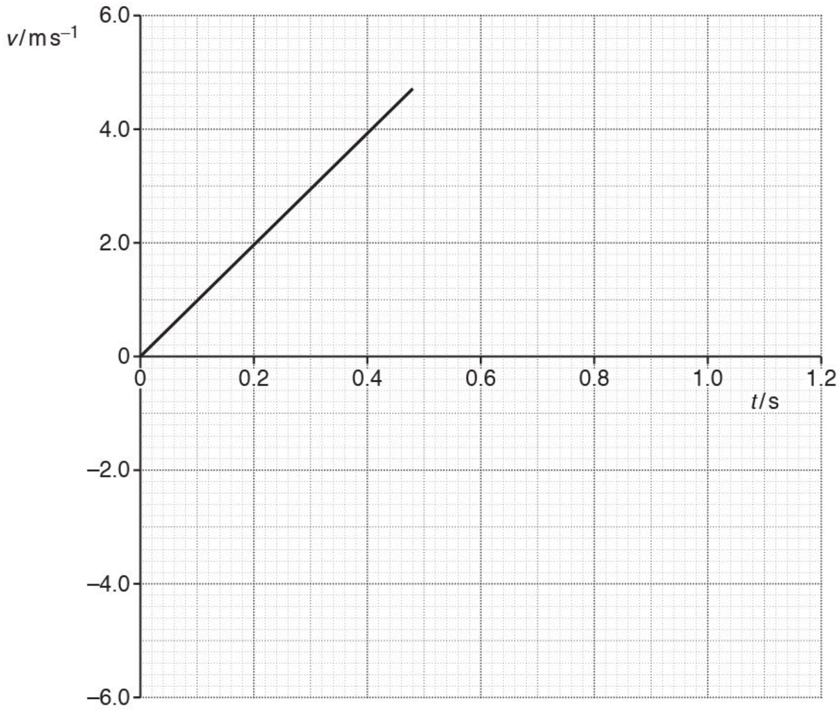


Fig. 1

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

Use Fig. 1 to show that

i. the acceleration of the falling ball is about 10 m s^{-2}

[1]

ii. the kinetic energy of the ball just before impact with the surface is 0.63 J.

[2]

(b). The ball leaves the surface with 80% of the kinetic energy just before impact.

i. Calculate the magnitude of the velocity *v* of the ball as it leaves the surface.

v = ... m s^{-1} **[3]**

ii. Complete Fig. 1 to show the variation of the velocity of the ball after it leaves the surface until it is at rest again.

[2]

iii. Determine the maximum height h reached by the ball after it bounces.

h **= .... m [2]**

(c). The student repeats the experiment with a different ball that is affected by air resistance.

Explain how the graph in Fig. 1 now appears from the time the ball is released to the time it hits the surface.

[2]

20. A student uses a motion-sensor connected to a laptop to investigate the motion of a hollow ball of mass 1.2×10^{-2} kg falling through air.

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

The upthrust on the ball is negligible.

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

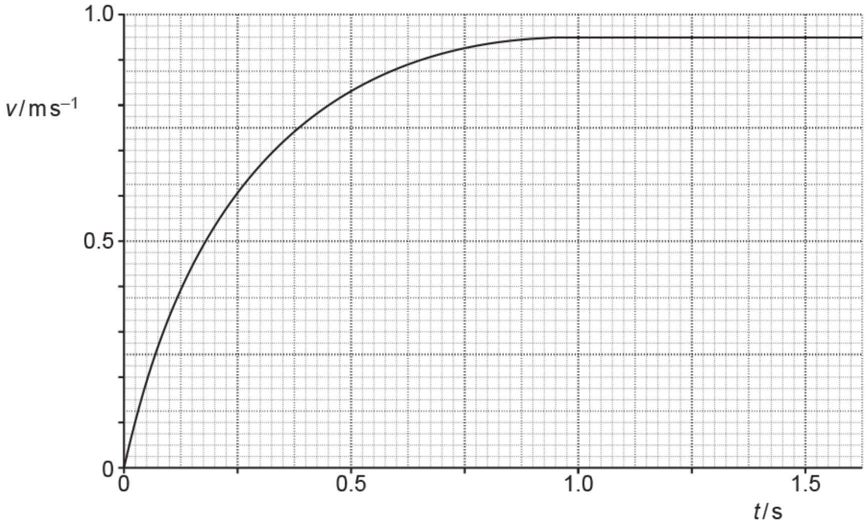


Fig. 17

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

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

[2]

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

[2]

21. Fig. 21.2 shows the displacement *x* against time *t* graph of an oscillator damped in air.

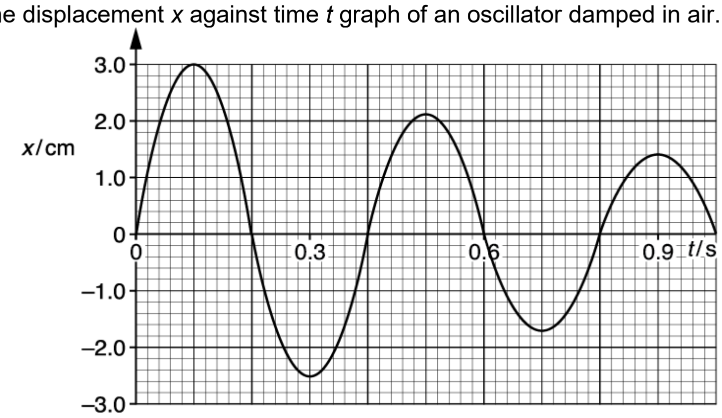


Fig. 21.2

i. According to a student, the amplitude of the oscillator decays by the same fraction every half oscillation. Analyse Fig. 21.2 to assess whether or not the student is correct.

[2]

ii. State and explain at which time the oscillator dissipates **maximum** energy.

[2]

22. A cyclist moves along a horizontal road. She pushes on the pedals with a constant power of 250 W. The mass of the cyclist and bicycle is 85 kg. The total drag force is $0.4v^2$, where v is the speed of the cyclist.

i. Calculate the energy provided by the cyclist each minute when the overall efficiency of the cyclist's muscles is 65%.

energy = ... J **[2]**

ii. Calculate the drag force and hence the instantaneous acceleration of the cyclist when the speed is 6.0 ms^{-1}.

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

23. A student wishes to investigate how the terminal velocity v of a metal sphere varies with the radius r of the sphere as it travels through a liquid.
It is suggested that

$$v = Kr^2$$

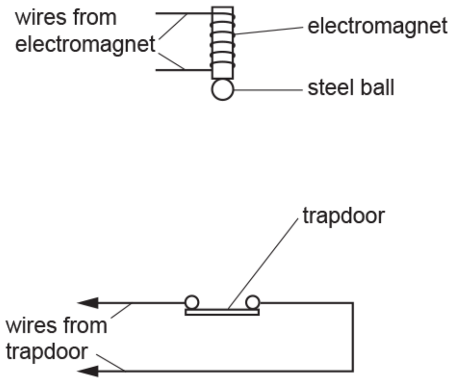
where K is a constant.

Describe with the aid of a suitable diagram how an experiment can be safely conducted, and how the data can be analysed to determine K.

[6]

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

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



A steel ball is dropped from an electromagnet. The ball falls vertically. The ball hits a trapdoor and opens the trapdoor.
The ball travels a distance s from the bottom of the electromagnet to the trapdoor in a time *t*.

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

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

[2]

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

[4]

25 (a). When riding at a steady speed on the flat, a cyclist provides a constant power of 200 W to the rear wheel of his bicycle. The total mass of bicycle and rider is 120 kg.

The total resistive forces *R* acting against the motion of the bicycle and the rider vary with the velocity *v* of the bicycle as shown in Fig. 1.

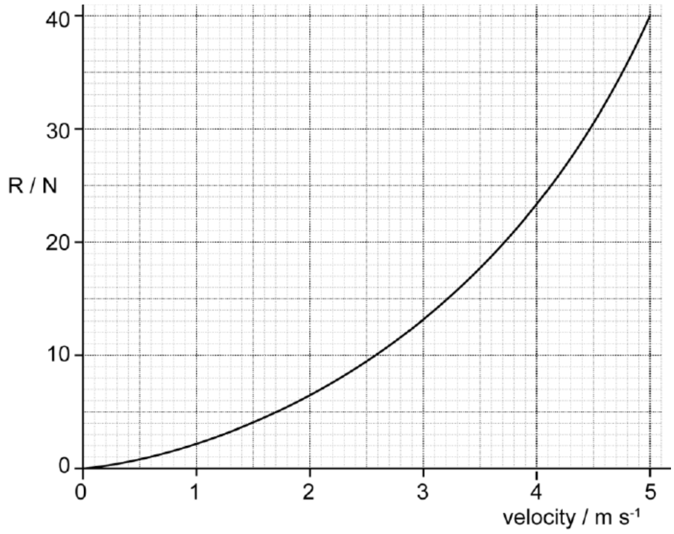


Fig.1

i. The cyclist starts from rest. He pedals steadily along a horizontal road. This exerts a constant forward force of 40 N on the bicycle.

Use Fig. 1 to state and explain how the acceleration and velocity of the bicycle vary as the cyclist travels along the road.

[3]

ii. Calculate

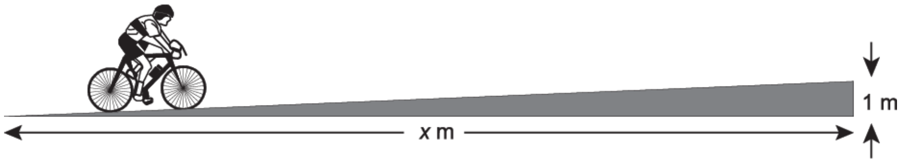
1. the initial acceleration of the bicycle

acceleration = ... $m\ s^{-2}$ **[1]**

2. the maximum speed of the cyclist.

maximum speed = ... $m\ s^{-1}$ **[2]**

(b). The cyclist reaches a hill.



The cyclist has to double the power provided to the rear wheel to maintain the same maximum speed reached on the flat road.

Assume that the total resistive force is unchanged.

The gradient of the hill is 1 in *x*.

Calculate x.

x = ... m **[3]**

26. Fig. 18.2 shows a cylinder fully submerged under the water surface before it has come to rest. The cylinder is moving vertically **down**.

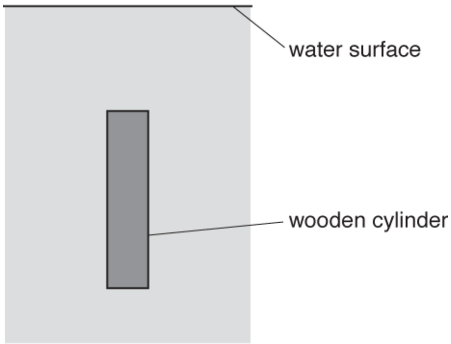


Fig. 18.2

i. Add arrows to Fig. 18.2 to show the **three** forces acting on the wooden cylinder. Label the arrows.

[3]

ii. Describe and explain how the **resultant** force on the wooden cylinder varies from the moment the cylinder is fully submerged until it reaches its deepest point.

[3]

END OF QUESTION PAPER