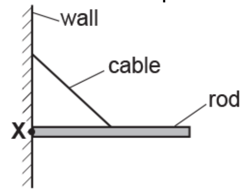
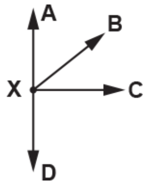
Forces in Dynamics

1. The diagram shows a uniform rod at rest in a horizontal position.



The rod is hinged at point **X**. A cable is attached to a vertical wall and the midpoint of the rod.

Which arrow best represents the direction of the force on the rod at point **X**?



Your answer [1]

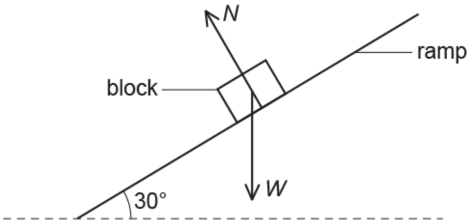
2. An object of mass 0.12 kg is lifted through a height of 0.60 m at a constant speed 3.0 m s^{-1}.

What is the minimum power needed to lift the object?

A 0.36 W
B 0.54 W
C 3.5 W
D 4.1 W

Your answer [1]

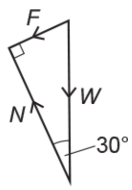
3. A wooden block is **stationary** on a ramp.

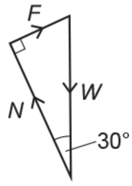


The diagram is **not** drawn to scale.

The block has weight *W*. The normal contact force on the block is *N*. The frictional force *F* on the block is not shown on the diagram.

Which triangle of forces diagram is correct?

A


B


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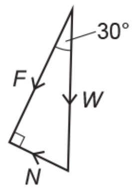
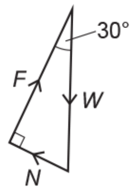


D


Your answer

[1]

4. 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]

5. A cable is attached to an object of weight 30 N. The object is pulled vertically upwards with an acceleration of 6.0 m s^{-2}.

What is the tension in the cable?

A 12 N

B 18 N

C 30 N

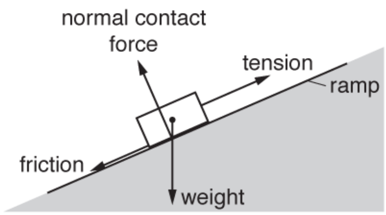
D 48 N

Your answer ☐

[1]

6. A block moves at **constant** speed up a ramp.

The diagram below shows all the forces acting on the block.



Which force does no work on, or against, the object as it travels up the ramp?

A weight
B friction
C tension
D normal contact force

Your answer [1]

7. A satellite is in a circular orbit around the Earth. The vertical **height** of the satellite above the surface of the Earth is 3200 km. The radius of the Earth is 6400 km.

What is the ratio

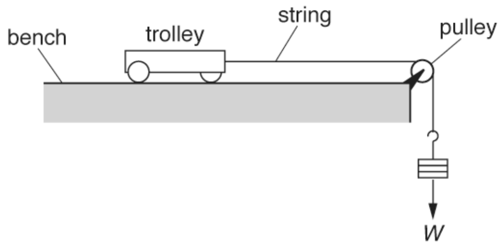
$$\frac{\text{weight of satellite in orbit}}{\text{weight of satellite on the Earth's surface}}?$$

A 0.25
B 0.44
C 0.50
D 0.67

Your answer

[1]

8. A trolley of mass *M* is pulled along a horizontal table by a force W provided by a mass hanging from the end of a string as shown.



Frictional forces are negligible. The acceleration of free fall is *g*.

What is the correct equation for the acceleration *a* of the trolley?

A $a = \frac{W}{M}$

B $a = g$

C $a = \frac{W}{2M}$

D $a = \frac{W}{M + \frac{W}{g}}$

Your answer [1]

9. 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 $0.20\ \text{m s}^{-1}$

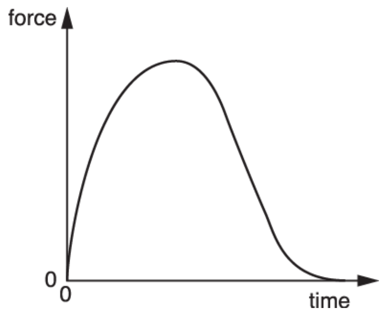
B $0.48\ \text{m s}^{-1}$

C $1.5\ \text{m s}^{-1}$

D $2.3\ \text{m s}^{-1}$

Your answer [1]

10. The graph shows the resultant force on a football as it is kicked.



Which of the following graphs relating to this kick would have the same shape as the graph above?

A acceleration of the ball against time
B kinetic energy of the ball against time
C momentum of the ball against time
D velocity of the ball against time

Your answer

[1]

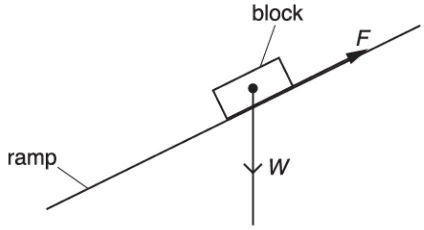
11. Which pair of quantities have the same S.I. base units?

A force, strain
B force, stress
C pressure, stress
D strain, upthrust

Your answer

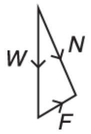
[1]

12. A block of wood is at rest on a ramp.
The weight of the block is *W* and the frictional force on the block is *F*.



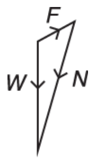
A triangle of forces diagram can be used to determine the magnitude and the direction of the normal contact force *N*.

Which is the correct diagram for this triangle?

A 

B 

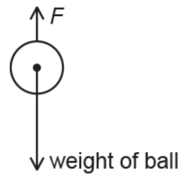
C 

D 

Your answer

[1]

13. 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]**

14 (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.

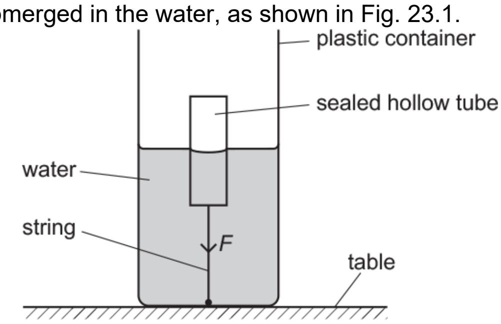


Fig. 23.1

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*.

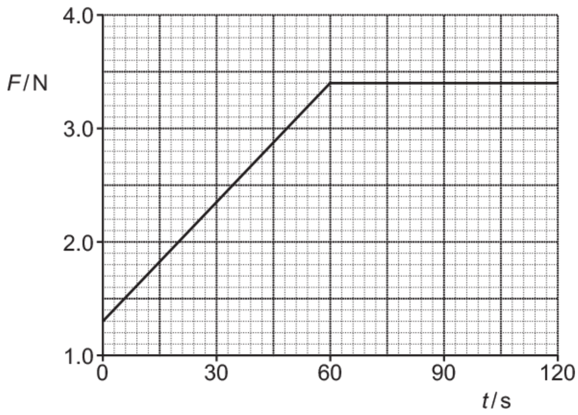


Fig. 23.2

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]**

15 (a). The International Space Station (ISS) orbits the Earth at a height of 4.1×10^5 m **above** the Earth's surface.

The radius of the Earth is 6.37×10^6 m. The gravitational field strength g_0 at the Earth's surface is 9.81 N kg^{-1}.

Both the ISS and the astronauts inside it are in free fall.

Explain why this makes the astronauts feel **weightless**.

____

____

____ **[1]**

(b).

i. Calculate the value of the gravitational field strength g at the height of the ISS above the Earth.

g = ... N kg^{-1} **[3]**

ii. The speed of the ISS in its orbit is 7.7 km s^{-1}. Show that the period of the ISS in its orbit is about 90 minutes.

[2]

(c). Use the information in **(b)(ii)** and the data below to show that the root mean square (r.m.s.) speed of the air molecules inside the ISS is approximately 15 times smaller than the orbital speed of the ISS.

- molar mass of air = 2.9×10^{-2} kg mol^{-1}
  temperature of air inside the ISS = 20 °C
-

[3]

(d). The ISS has arrays of solar cells on its wings. These solar cells charge batteries which power the ISS. The wings always face the Sun.

Use the data below and your answer to **(b)(ii)** to calculate the **average** power delivered to the batteries.

- The total area of the cells facing the solar radiation is 2500 m^2.
- 7% of the energy of the sunlight incident on the cells is stored in the batteries.
- The intensity of solar radiation at the orbit of the ISS is 1.4 kW m^{-2} outside of the Earth's shadow and zero inside it.
- The ISS passes through the Earth's shadow for 35 minutes during each orbit.

average power = ... W **[4]**

16 (a). This question is about the motion of a ball suspended by an elastic string above a bench. The mass of the string is negligible compared to that of the ball. Ignore air resistance.

Fig. 6.1

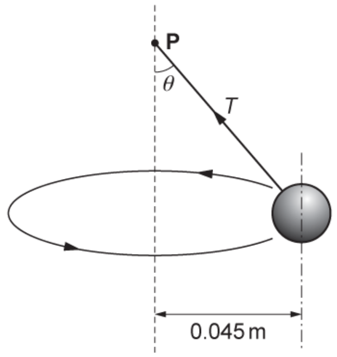


Fig. 6.2 (not to scale)

In Fig. 6.1 the ball of weight 1.2 N hangs vertically at rest from a point **P**. The extension of the string is 0.050 m. The string obeys Hooke's law.

In Fig. 6.2 the ball is moving in a horizontal circle of radius 0.045 m around a vertical axis through **P** with a period of 0.67 s. The string is at an angle θ to the vertical. The tension in the string is T.

On Fig. 6.2 draw and label one other force acting on the ball. **[1]**

(b).

i. Resolve the tension T horizontally and vertically and show that the angle θ is 22°.

[2]

ii. Calculate the extension x of the string shown in Fig. 6.2.

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

(c). Whilst rotating in the horizontal plane the ball suddenly becomes detached from the string. The bottom of the ball is 0.18 m above the bench at this instant. The ball falls as a projectile towards the bench beneath. Fig. 6.3 shows the view from above.

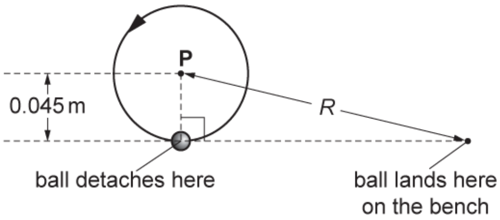


Fig. 6.3

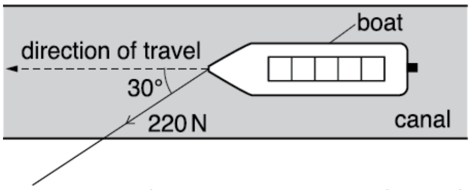
Calculate the horizontal distance *R* from the point on the bench vertically below the point **P** to the point where the ball lands on the bench.

R = ... m **[4]**

(d). Returning to the situation shown in Fig. 6.2, state and explain what happens when the rate of rotation of the ball is increased.

[2]

17. A canal boat is pulled by a single rope.
The tension in the rope is 220 N. The rope makes an angle of 30° to the direction of travel.
The speed of the boat is 1.8 m s^{-1}.



What is the work done per second by the 220 N force in the direction of travel?

A 61 J s^{-1}

B 200 J s^{-1}

C 340 J s^{-1}

D 400 J s^{-1}

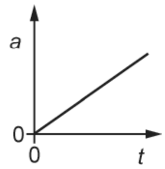
Your answer

[1]

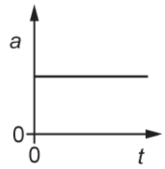
18. A ball, made from scrunched-up paper, is dropped from rest at time *t* = 0.
It reaches terminal velocity before it hits the ground.

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

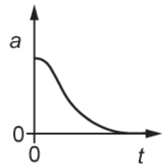
A



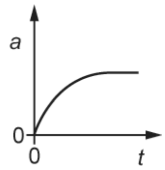
B



C



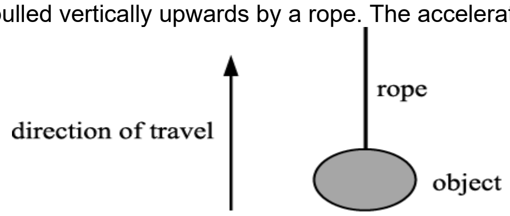
D



Your answer

[1]

19. An object of mass 7.0 kg is pulled vertically upwards by a rope. The acceleration of the object is 2.0 m s^{-2}.



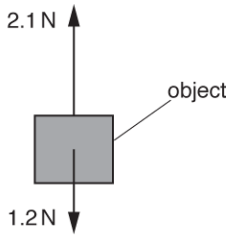
What is the tension in the rope?

A. 14 N
B. 55 N
C. 69 N
D. 83 N

Your answer

[1]

20. The diagram shows two opposite vertical forces of magnitude 1.2 N and 2.1 N acting on an object.



Which of the following statements could be correct?

1 The object is accelerating and moving up.

2 The object is decelerating and moving down.

3 The magnitude of the resultant force is 0.9 N.

A Only 3

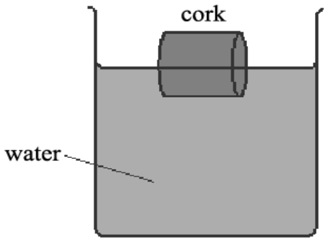
B Only 1 and 3

C Only 2 and 3

D 1, 2 and 3

Your answer [1]

21. A bottle cork floats on water. It is partially submerged in the water.



Which of the following statements is / are true?

1. The net force acting on the cork is equal to the weight of the water displaced.
2. The weight of the cork is equal to the upthrust on the cork.
3. The upthrust on the cork is equal to the mass of the water displaced.

A. 1, 2 and 3
B. Only 2 and 3
C. Only 3
D. Only 2

Your answer

[1]

22. 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]

23. A brick of mass *m* has sides of lengths *a, b* and *c,* where $a < b < c$. The brick is placed on a horizontal table such that the pressure it exerts on the table is a maximum.

What is the maximum pressure *p* acting on the table?

A $p = \frac{mg}{ab}$

B $p = \frac{mg}{ac}$

C $p = \frac{mg}{bc}$

D $p = \frac{mg}{abc}$

Your answer

[1] **24.** A 0.30 kg mass is hung from a spring. The length of the spring is now 16.0 cm.
The length of the spring becomes 17.5 cm when an **additional** 0.20 kg mass is hung from the spring. The spring obeys Hooke's law.

What is the force constant of the spring?

A 11 N m^{-1}
B 12 N m^{-1}
C 130 N m^{-1}
D 330 N m^{-1}

Your answer **[1]**

25. A small block of wood is placed in deep water.
The block is at rest with 80% of its volume under the surface of water.
The weight of the block is 6.0 N.

What is the upthrust acting on the block?

A 0
B 1.2 N
C 4.8 N
D 6.0 N

Your answer **[1]**

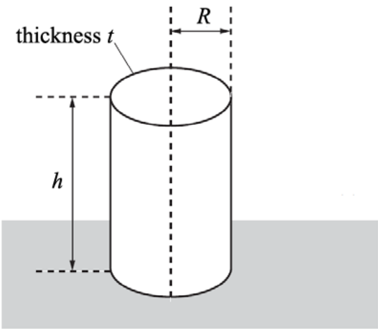
26. A seabird dives vertically into water.
The seabird is briefly stationary at its **greatest** depth.
In water, the upthrust on this seabird is always greater than the weight of the seabird.

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]**

27. A group of civil engineers are assessing whether or not to use solid concrete pillars or hollow metal tubes to support a building. One such tube is shown below. The tube is placed on a horizontal surface. The tube is made of metal of thickness *t*. The tube has height *h* and a mean internal radius *R*. The radius $R >> $ thickness *t*.



A heavy metal block of mass *m* is placed on top of the tube.

What is the approximate pressure *p* acting on the tube?

A $p = \dfrac{mg}{2\pi Rt}$

B $p = \dfrac{mg}{\pi R^2}$

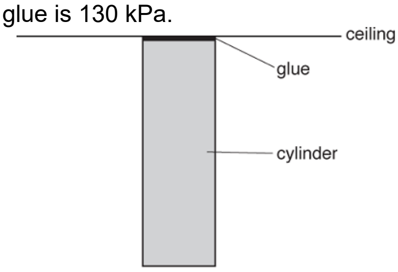
C $p = \dfrac{mg}{\pi R^2 h}$

D $p = \dfrac{mg}{\pi R^2 t}$

Your answer

[1]

28. The flat end of a uniform steel cylinder of weight 7.8 N is glued to a horizontal ceiling. The cylinder hangs vertically. The breaking stress for the glue is 130 kPa.



The glue only just holds the cylinder to the ceiling.

What is the cross-sectional area of the cylinder?

A 6.0×10^{-2} m^2

B 6.0×10^{-5} m^2

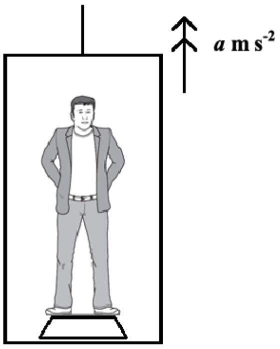
C 1.7×10^{-2} m^2

D 1.7×10^{1} m^2

Your answer

[1]

29. A man of mass *M* is standing on a set of scales in a lift. The lift is accelerating vertically upwards at a constant acceleration *a*.



The scales show the normal contact force experienced by the man.
What is the reading shown on the scales?

A. Mg
B. $M(g - a)$
C. $M(a + g)$
D. $M\frac{a}{g}$

Your answer

[1]

30. A trolley is placed on a long ramp and is released from rest from the top of the ramp. It travels to the bottom of the ramp with a constant acceleration.

A motion sensor is used to determine the velocity of the trolley at points **X** and **Y**, as shown in Fig. 21.

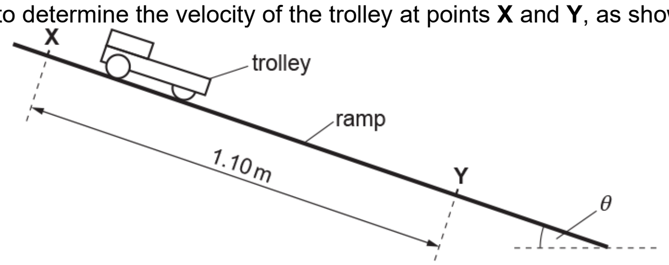


Fig. 21 (not to scale)

The distance between **X** and **Y** is 1.10 m. The trolley has velocity 1.3 ms^{-1} at **X** and velocity 2.5 ms^{-1} at **Y**.

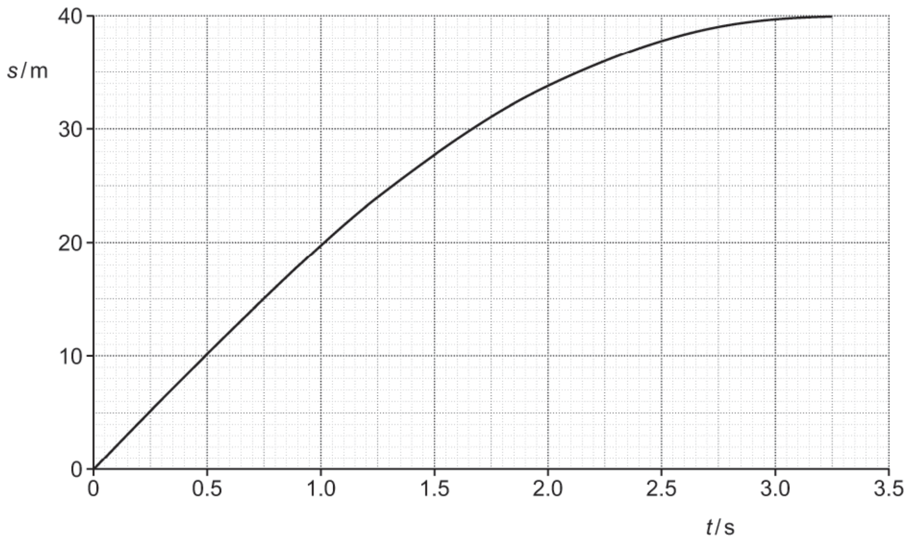
i. Calculate the acceleration *a* of the trolley.

a = ………… $m\,s^{-2}$ **[2]**

ii. The frictional forces acting on the trolley are negligible.
The acceleration of the trolley down the ramp is equal to the component of the acceleration of free fall parallel to the ramp.
Use your answer to **(i)** to calculate the angle θ between the ramp and the horizontal.

θ = ° **[2]**

31. A car is travelling at a constant speed of 20 m s^{-1} along a straight road.
The driver sees a hazard ahead in the road, applies the brakes and brings the car to a stop.
The graph below shows the displacement *s* against time *t* for the car from the time that the driver sees the hazard to when the car stops.



The braking force *F* acting on the car is constant.
The mass of the car is 950 kg.
The reaction time of the driver is 0.75 s.

Explain how you can deduce from the graph that the brakes are applied at time *t* = 0.75s.

[2]

32. A bubble of gas rises upwards through a glass of lemonade. Fig. 26.1 shows a spherical bubble accelerating vertically upwards through the lemonade.

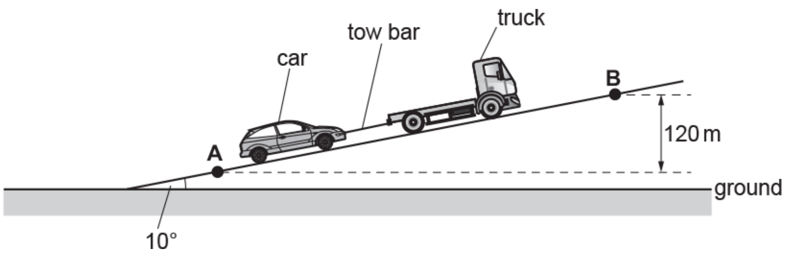
Fig. 26.1

Add arrows to show each force acting on the bubble shortly after it starts to move.

Label each arrow clearly.

[2]

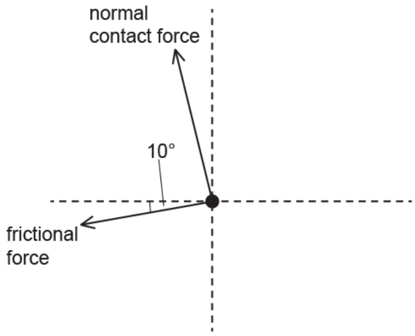
33 (a). A truck pulls a car up a slope at a **constant** speed.
The truck and the car are joined with a steel tow bar, as shown in the diagram.



The diagram is **not** drawn to scale.
The slope is 10° to the horizontal ground.
The mass of the car is 1100 kg.
The car travels from **A** to **B** . The vertical distance between **A** and **B** is 120 m.

There are four forces acting on the **car** travelling up the slope.

Complete the free-body diagram below for the car and label the missing forces.



[2]

(b). Show that the component of the weight of the car *W*s acting down the slope is about 1900 N.

[1]

(c). The total frictional force acting on the car as it travels up the slope is 300 N.

Calculate the force provided by the tow bar on the car.

force = ... N **[1]**

(d). Calculate the work done by the force provided by the tow bar as the car travels from **A** to **B** .

work done = ... J **[3]**

(e). The steel tow bar used to pull the car has length 0.50 m and diameter 1.2×10^{-2} m.
The Young modulus of steel is 2.0×10^{11} Pa.
The force on the tow bar is 2200 N.

Calculate the extension *x* of the tow bar as the car travels up the slope.

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

34. A swimming pool designer investigates the depth *d* below a water surface reached by a diver when diving from
a height *h* above the water surface.
The designer models the diver as a uniform wooden cylinder.
The experimental arrangement is shown in Fig. 18.1.

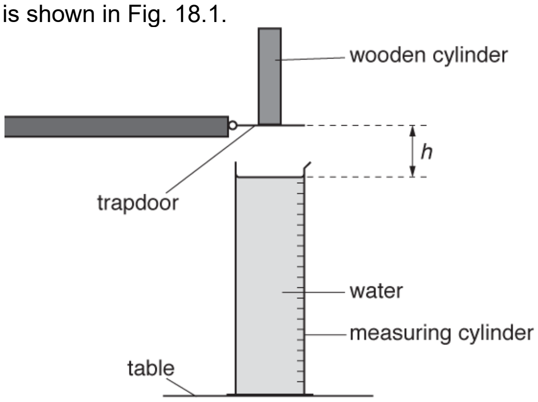


Fig. 18.1

The graph of Fig. 18.3 shows the depth *d* reached for different initial drop height *h*.

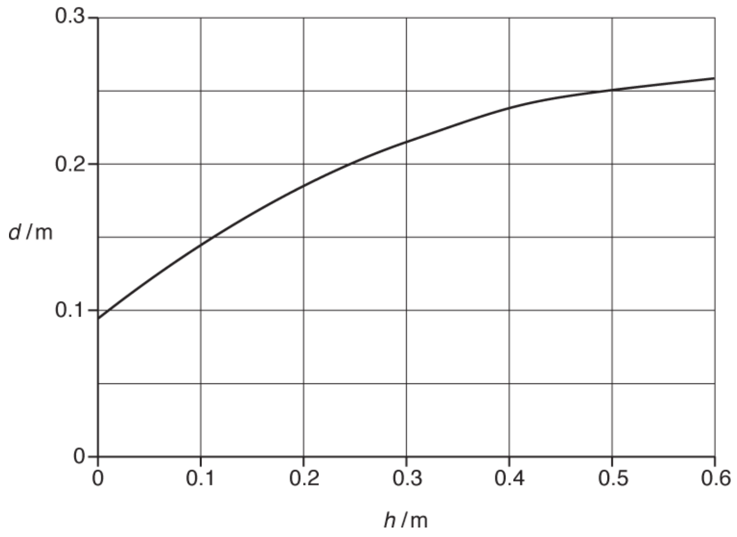


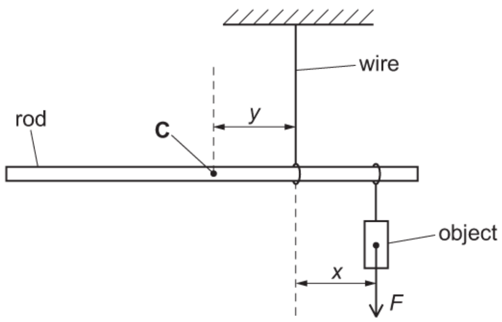
Fig. 18.3

The designer is required to double the height of a diving board for an existing swimming pool. He suggests that the depth of the pool also needs to be doubled.
Use Fig. 18.3 to explain whether you agree with this suggestion.

[3]

35 (a). A student is doing an experiment in the laboratory to determine the density of a metal rod.

A **uniform** metal rod is suspended horizontally from a wire.
The rod has an object attached to it, as shown in the diagram below.

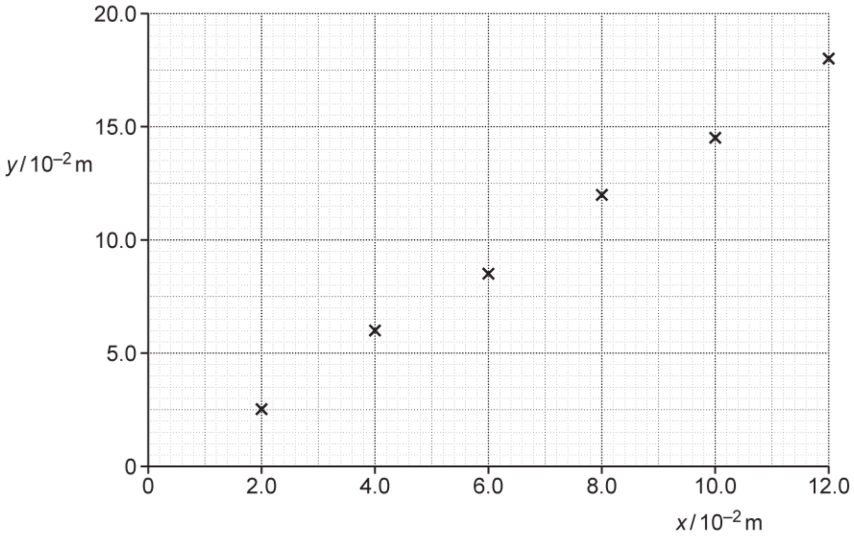


The rod is in equilibrium.
The centre of gravity **C** of the rod is a perpendicular distance *y* from the wire. The line of action of the weight *F* of the object is a perpendicular distance *x* from the wire.
The rod has length *L* and cross-sectional area *A*. The density of the metal rod is ρ.

Show that the distances *x* and *y* are given by the expression $y = \left(\frac{F}{AL\rho g}\right)x$, where *g* is the acceleration of free fall.

[2]

(b). The data points shown below are plotted by the student on a *y* against *x* grid.



i. Draw a straight line of best fit through the data points plotted by the student. Determine the gradient of the straight line of best fit.

gradient = ... **[2]**

ii. Use your answer to **(i)** and the data below to determine the density ρ of the metal.

- F = 6.8 N
- L = 0.90 m
- $A = 6.4 \times 10^{-5}\ \text{m}^2$

ρ = ... kg m^{-3} **[3]**

36. Fig. 21.1 shows a ball at **rest** on a horizontal table.

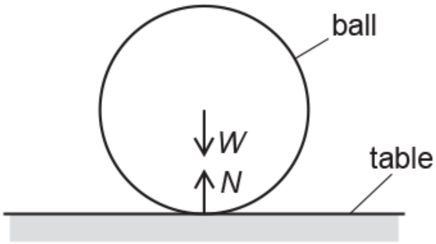


Fig. 21.1

The weight of the ball is W and the normal contact force on the ball is N.

i. According to Newton's third law of motion, W is one of the forces in a pair of equal and opposite forces.

Name the object that experiences a force of magnitude W but in the opposite direction to W.

[1]

ii. According to a student, $W = N$ is a consequence of Newton's third law of motion.

State why this is incorrect.

[1]

37. What are the correct base units for work done or energy?

A kg m
B kg m s^{-2}
C kg m^2s^{-2}
D kg m^2s^{-2}

Your answer **[1]**

38 (a). 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.

The cyclist now moves up a slope at a constant speed of $6.0\ ms^{-1}$ and continues to exert a power of 250 W on the pedals.

Fig. 17.1 represents the cyclist and bicycle as a single point **P** on the slope.

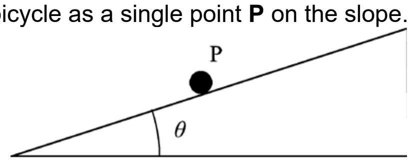


Fig. 17.1

i. Draw arrows on **Fig. 17.1** to represent the forces acting on **P**. Label each arrow with the force it represents.

[1]

ii. Calculate the angle θ of the slope to the horizontal.

θ = ... ° **[2]**

(b). The cyclist continues to move up the slope at $6.0\ ms^{-1}$ and approaches a gap of width 2.5 m as shown in **Fig. 17.2**.

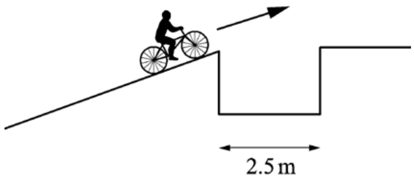


Fig. 17.2

A student has calculated that the cyclist will be able to clear the gap and land on the other side. Another student suggests that this calculation has assumed there is **no** drag and has not accounted for the effect caused by the front wheel losing contact with the slope before the rear wheel.

Without calculation, discuss how drag and the front wheel losing contact with the slope will affect the motion and explain how these might affect the size of the gap that can be crossed successfully.

[4]

39. A wooden sign is hung on a screw at point **A**.
The forces acting on the screw are shown in Fig. 22.2.

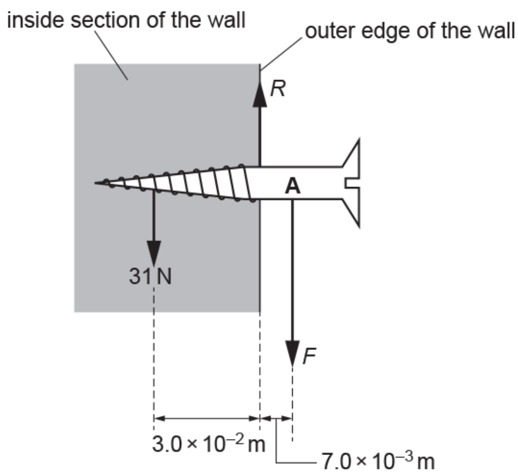


Fig. 22.2

The inside section of the wall exerts a maximum downwards force of 31 N at a distance of 3.0×10^{-2} m from the outer edge of the wall.
The hanging wooden sign exerts a force *F* at a distance 7.0×10^{-3} m from the outer edge of the wall.
There is a force R acting on the screw at the outer edge of the wall.
The mass of the screw is negligible.

Use the principle of moments to calculate the maximum mass of the wooden sign.

mass = ... kg **[3]**

40. 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.

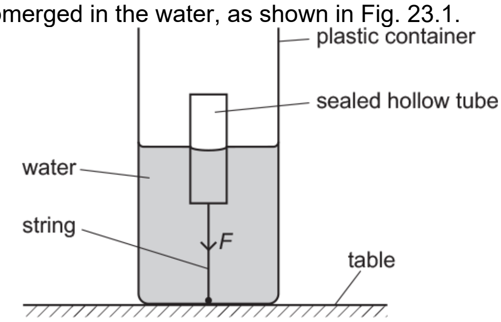


Fig. 23.1

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*.

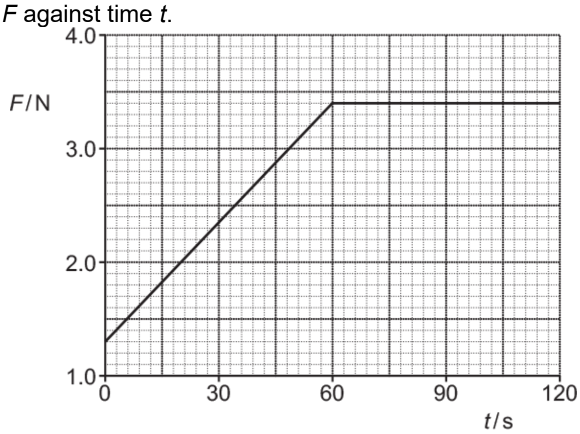


Fig. 23.2

By considering the forces acting on the tube, explain the general shape of the graph shown in Fig. 23.2.

[3]

41. The unit of potential difference is the volt.

Use the equation $W = VQ$ to show that the volt may be written in base units as kg m^2 A^{-1} s^{-3}.

[3]

42. An object is placed on a smooth horizontal surface. Two horizontal forces act on this object. **Fig. 21.3** shows the magnitudes and the directions of these two forces.

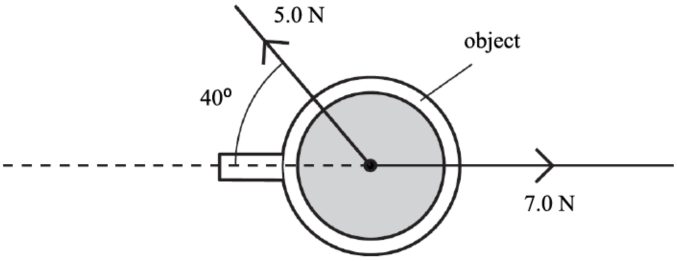


Fig. 21.3

The mass of the object is 320 g.

Calculate the magnitude of the acceleration of the object.

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

43 (a). A meteorological balloon rises through the atmosphere until it expands to a volume of $1.0 \times 10^6 \text{ m}^3$, where the pressure is $1.0 \times 10^3 \text{ Pa}$. The temperature also falls from 17 °C to − 43 °C.

The pressure of the atmosphere at the Earth's surface = 1.0×10^5 Pa.

Show that the volume of the balloon at take off is about $1.3 \times 10^4 \text{ m}^3$.

[3]

(b). The balloon is filled with helium gas of molar mass $4.0 \times 10^{-3} \text{ kg mol}^{-1}$ at 17 °C at a pressure of $1.0 \times 10^5 \text{ Pa}$.

Calculate

i. the number of moles of gas in the balloon

number of moles = ... **[2]**

ii. the mass of gas in the balloon.

mass = ... kg **[1]**

(c). The internal energy of the helium gas is equal to the random kinetic energy of all of its molecules.

When the balloon is filled at ground level at a temperature of 17 °C, the internal energy is 1900 MJ.

Estimate the internal energy of the helium when the balloon has risen to a height where the temperature is −43 °C.

internal energy = ... MJ **[1]**

(d). The acceleration of the balloon and its instruments at the Earth's surface as it is released is 27 m s^{-2}.

The density of the air at the Earth's surface is 1.3 kg m^{-3}.

Calculate the total mass *M* of the helium-filled balloon and its load.

M = ... kg **[3]**

44. A group of engineers are testing a new car. They are investigating how the braking distance *x* of the car varies with its initial speed *u* when a constant braking force is applied.
Fig. 22 shows the data points plotted on a u^2 against *x* graph. The straight line of best fit has been drawn through the data points.

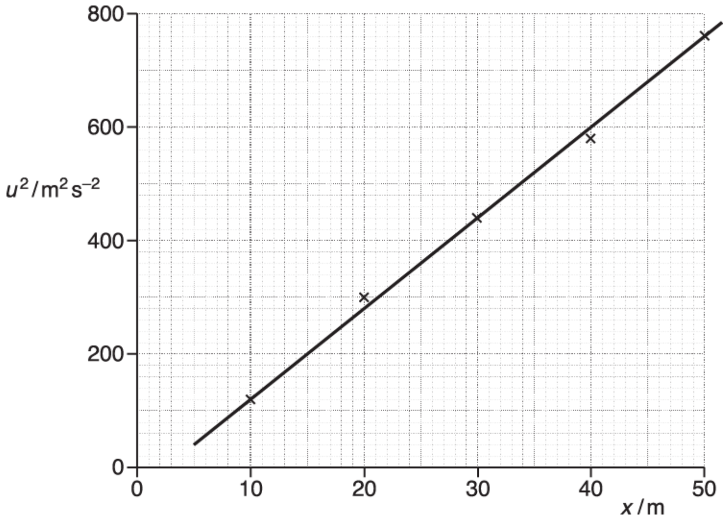


Fig. 22

The theoretical relationship between *u* and *x* for the car is

$$u^2 = 2ax$$

where *a* is the magnitude of the deceleration of the car.

The mass of the car is 920 kg.
Use the gradient of the line drawn in **Fig. 22** to determine the braking force *F* acting on the car.

F = ... N **[3]**

45 (a). A toy rocket is made from a 1.5 litre plastic bottle with fins attached for stability.

The bottle initially contains 0.30 litres of water, leaving 1.2 litres of trapped air at a temperature of 17 °C.
A pump is used to increase the pressure of the air within the plastic bottle to 2.4×10^5 Pa at the start of lift-off.

Fig. 1.1 shows the rocket at the start of lift-off.

1 litre = 10^{-3} m^3

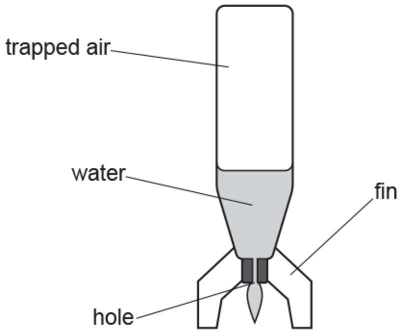


Fig. 2.1

The trapped air pushes the water downwards out of the hole, causing the rocket to rise.
The temperature of this air remains constant.

Calculate the final pressure of the trapped air just before all the water has been released.

final pressure = ...Pa **[3]**

(b). Here is some data on the toy rocket.

mass of empty bottle and fins = 0.050 kg
area of cross-section of hole = 1.1×10^{-4} m^2
initial pressure of trapped air = 2.4×10^5 Pa
atmospheric pressure = 1.0×10^5 Pa
density of water = 1.0×10^3 kg m^{-3}

i. Use the data above to show that the **upwards** force on the rocket at the start of lift-off is about 15 N.

[2]

ii. Hence calculate the initial vertical acceleration of the rocket.

initial acceleration = ... m s^{-2} **[3]**

(c). Discuss whether adding more water initially would enable the rocket to reach a greater height.

[3]

46. Fig. 21 shows the drum of a washing machine.

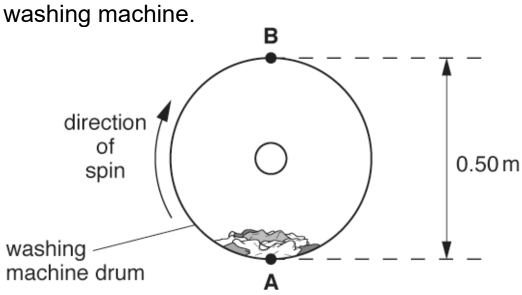


Fig. 21

The clothes inside the drum are spun in a **vertical** circular motion in a clockwise direction.

The washing machine is switched off and the speed of the drum slowly decreases. The clothes at the top of the drum at point **B** start to drop off at a certain speed *v*.

At this speed *v*, the normal contact force on the clothes is zero.

Calculate the speed *v*.

V = ms $^{-1}$ **[3]**

47. Fig. 6.1 shows a uniform metal cylinder of weight 7.0 N. The cylinder has length 100 mm and diameter 32 mm.

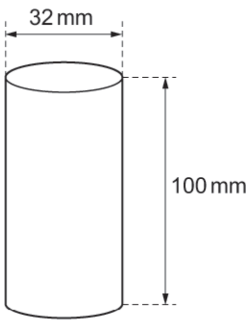


Fig. 6.1 (not to scale)

Calculate the density *ρ* of the metal.

ρ = ... kg m^{-3} **[3]**

48. Fig. 21 shows a stationary trolley on a smooth ramp.

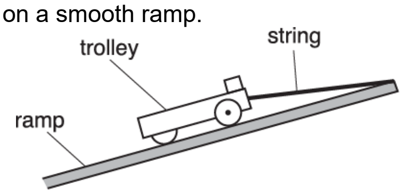


Fig. 21

A short length of string is attached between the end of the trolley and the top of the ramp.
Assume that the frictional force acting on the trolley is negligible when it is stationary or when it is moving.

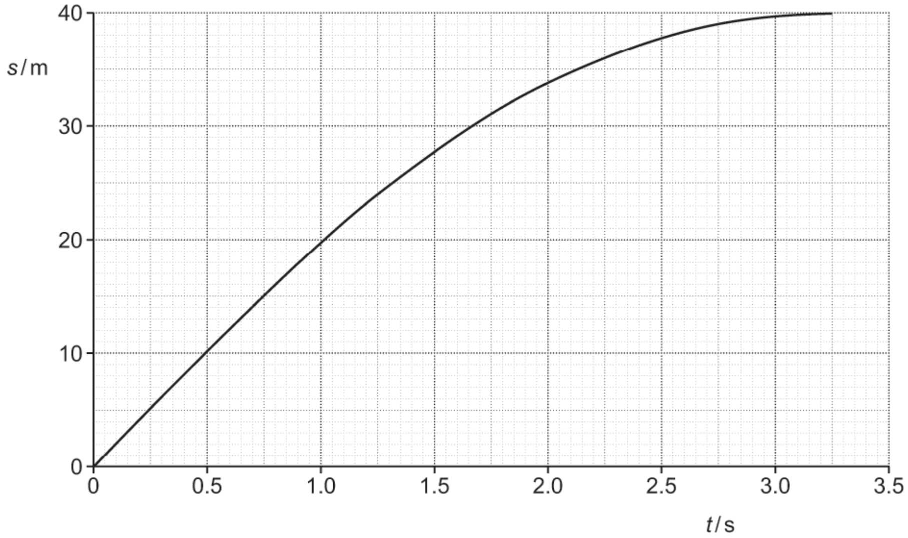
i. Other than the normal contact force, there are two other forces acting on the stationary trolley. On **Fig. 21**, draw arrows to show these two forces. You do not need to name these forces.

[1]

ii. The string is cut at time $t = 0$. The trolley travels down the ramp with a constant acceleration of 3.0 m s^{-2}.
Calculate the time t taken by the trolley to travel a distance of 0.80 m down the ramp.

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

49. A car is travelling at a constant speed of 20 m s^{-1} along a straight road.
The driver sees a hazard ahead in the road, applies the brakes and brings the car to a stop.
The graph below shows the displacement *s* against time *t* for the car from the time that the driver sees the hazard to when the car stops.



The braking force *F* acting on the car is constant.
The mass of the car is 950 kg.
The reaction time of the driver is 0.75 s.

Describe and explain the variation of the displacement with time when the same driver applies the brakes in the same car when the initial speed of the car is 10 m s^{-1}.

[3]

50 (a). Fig. 4.1 shows a uniform wooden cylinder.

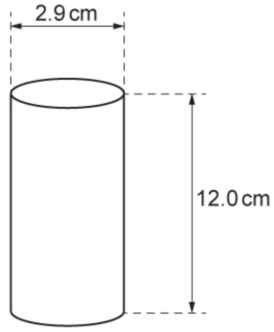


Fig. 4.1

The cylinder has height 12.0cm and diameter 2.9cm.

The density of the wood is 400kgm^{-3}.

i. Show that the cross-sectional area of the wooden cylinder is about 6.6×10^{-4} m^2.

[1]

ii. Calculate the weight *W* of the wooden cylinder.

W = ... N **[3]**

(b). A student places the wooden cylinder in a beaker of water so that it floats. The vertical distance between the water surface and the bottom of the cylinder is *y*, as shown in **Fig. 4.2**.

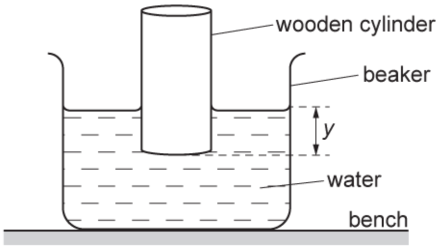


Fig. 4.2 (not to scale)

The density of water is 1000 kg m^{-3}.

Calculate the distance *y*.

y = ... m **[3]**

(c). The student repeats the experiment, but replaces the water with oil of density 900 kg m^{-3}. The cylinder will still float.

Calculate the new distance *y*. Explain your answer.

Calculation:

y = ... m

Explanation:

[4]

51. The London Eye, shown rotating anticlockwise in **Fig. 6.1**, is a giant wheel which rotates slowly at a constant speed.

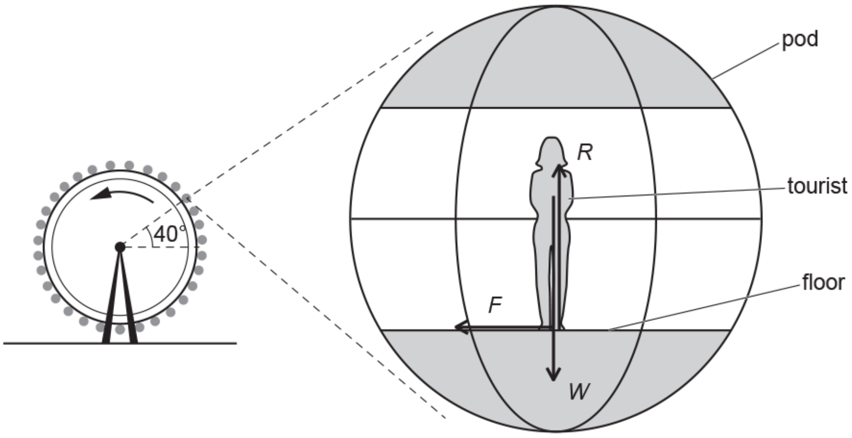


Fig. 6.1 **Fig. 6.2**

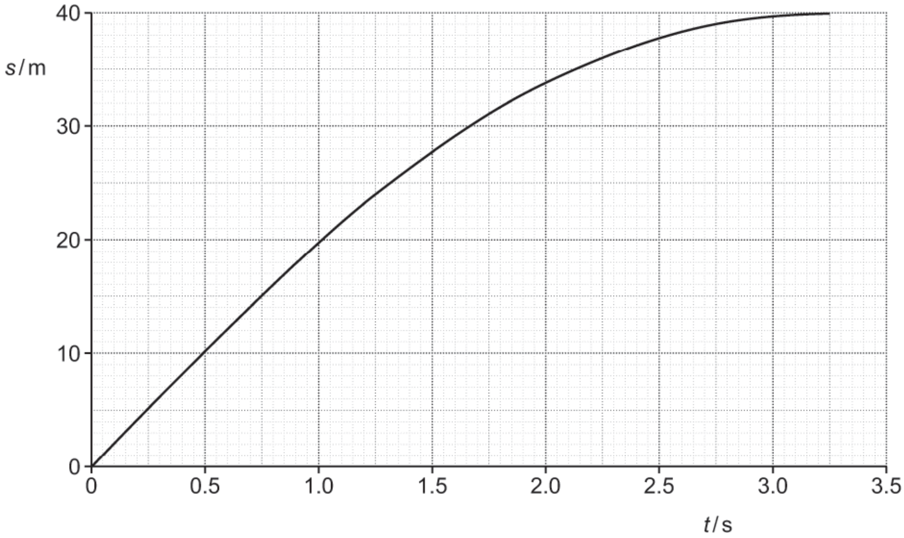
Tourists stand in pods around the circumference of the wheel.
The floor remains horizontal at all times.
At time t = 0, a tourist who has a weight W of 650 N enters a pod at the bottom of the wheel.
Fig. 6.2 shows the forces acting on the tourist at a later time, when the angle between the pod's position and the centre of the wheel is 40° above the horizontal. R is the normal contact force and F is friction.

Calculate the distance d of the centre of mass of the tourist from the centre of rotation of the London Eye.

The London Eye takes 30 minutes for one rotation.

d = ... m **[3]**

52. A car is travelling at a constant speed of 20 m s^{-1} along a straight road.
The driver sees a hazard ahead in the road, applies the brakes and brings the car to a stop.
The graph below shows the displacement *s* against time *t* for the car from the time that the driver sees the hazard to when the car stops.



The braking force *F* acting on the car is constant.
The mass of the car is 950 kg.
The reaction time of the driver is 0.75 s.

Determine the braking force *F*.
You should use information from the graph.

F = ... N **[3]**

53. Fig. 23.1 shows a metal cylinder of diameter of about 5 cm placed on a horizontal table.

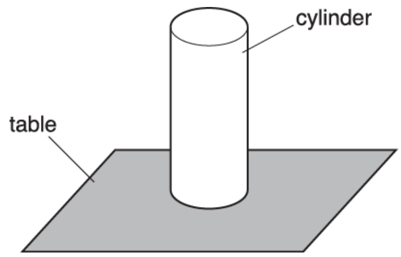


Fig. 23.1

i. State *Archimedes' principle.*

[1]

ii. Fig. 23.2 shows the metal cylinder hung from a newtonmeter.

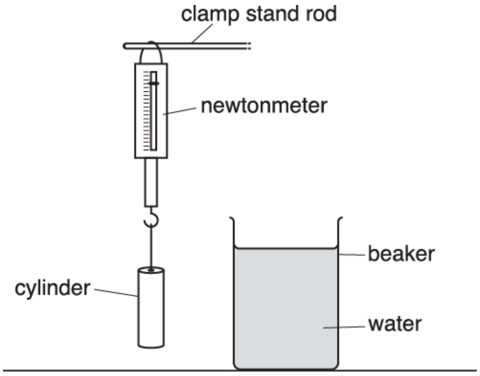


Fig. 23.2

The reading on the newtonmeter is 9.0 N.
The cylinder is slowly lowered into water in a beaker until it is completely submerged.
The cylinder does not touch the side or the bottom of the beaker. The newtonmeter reading now is 7.8 N. The density of water is 1000 kg m^{-3}.
Calculate the density ρ of the metal of the cylinder.

ρ = ... kg m^{-3} **[3]**

54 (a). A student measures the diameter of a ball in different directions.

The student's results are:

2.43 cm 2.54 cm 2.59 cm

i. State the name of a suitable measuring instrument to measure the diameter of the ball.

[1]

ii. Calculate the mean diameter d of the ball.
Include the absolute uncertainty in d.

d = ... ± .... cm **[2]**

iii. Show that the volume of the ball is about 8.4×10^{-6} m^3.

[1]

iv. The mass of the ball is 23 ± 1 g.
Determine the density ρ of the ball.
Give your answer to an appropriate number of significant figures.

ρ = ... kg m^{-3} **[2]**

v. Determine the percentage uncertainty in ρ.

percentage uncertainty = ... % **[2]**

(b). The 23 g mass ball from **(a)** is used in an experiment with a spring.

The student measures the unstretched length L_0 of a spring as shown in Fig. 3.1.

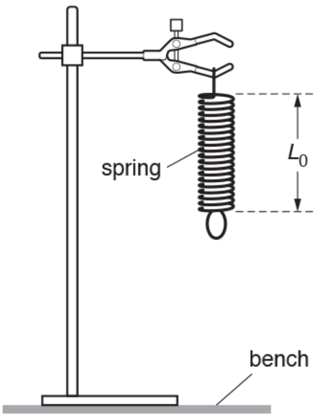


Fig. 3.1

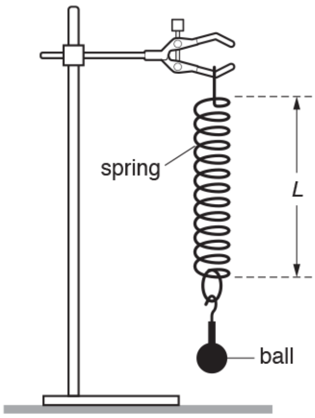


Fig. 3.2

The student then attaches the ball to the spring and measures the length L of the spring as shown in Fig. 3.2.

The student's results are:

L_0 = 0.078 m and L = 0.096 m

Calculate the force constant k of the spring.

k = ... N m^{-1} **[3]**

(c). The 23 g mass ball from **(a)** and the spring from **(b)** are now used in an experiment to investigate upthrust.

The ball attached to the spring is lowered into a beaker containing a liquid so that it is totally submerged. The student measures the new length L_N of the spring, as shown in Fig. 3.3.

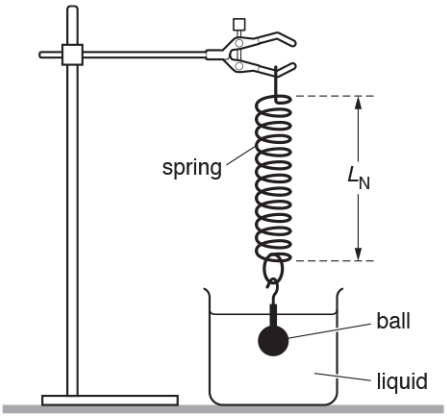


Fig. 3.3

The length L_N of the spring is now 0.088 m.

i. Calculate the upthrust on the submerged ball.

upthrust = ... N **[2]**

ii. Calculate the density of the liquid.

density of liquid = ... kg m^{-3} **[2]**

55. An engineer is investigating the tension in a steel cable supporting a uniform wooden plank as shown in Fig. 4.

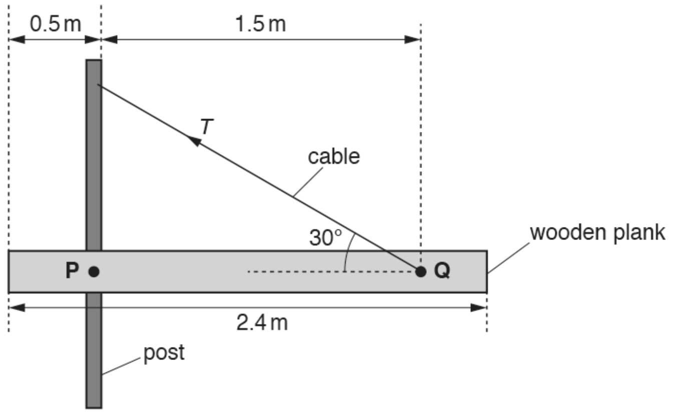


Fig. 4 (not to scale)

The plank is 2.4 m long and has a mass of 50 kg. It is pivoted at point **P** to a vertical post. The cable is fixed to the plank at point **Q** and to the vertical post as shown in Fig. 4. The cable is at an angle of 30° to the plank. The plank is in equilibrium and resting in a horizontal position.

Show that the tension *T* in the cable is about 460 N.

[4]

56. A **proton** travels from point **P** to point **Q** in a uniform electric field as shown in Fig. 21.2.

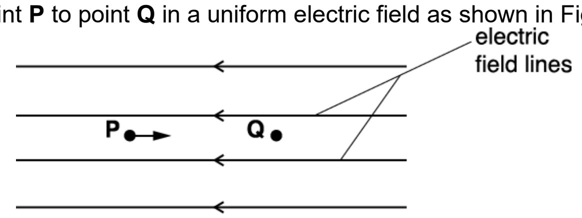


Fig. 21.2

The velocity of the proton at **P** is 7.2×10^6 m s^{-1} and the velocity at **Q** is 2.4×10^6 m s^{-1}. The distance between **P** and **Q** is 1.2 cm.

Calculate

i. the magnitude of the deceleration of the proton

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

ii. the electric field strength *E*.

E = ... N C^{-1} **[2]**

57. 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]**

58. Fig. 6.1 shows a uniform metal cylinder of weight 7.0 N. The cylinder has length 100 mm and diameter 32 mm.

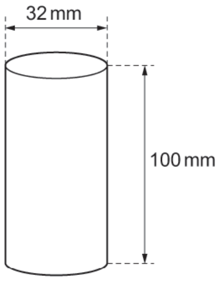


Fig. 6.1 (not to scale)

The cylinder is suspended by two cords **A** and **B**, attached to the centre of the top surface, as shown in **Fig. 6.2**.

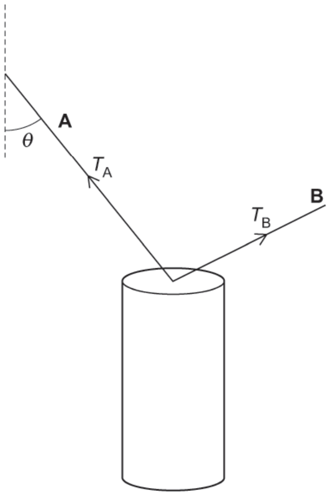


Fig. 6.2 (not to scale)

The tensions in each of the cords are T_A and T_B.

Fig. 6.3 shows T_B drawn to scale on graph paper.

Scale 1.0 cm represents 2.0 N.

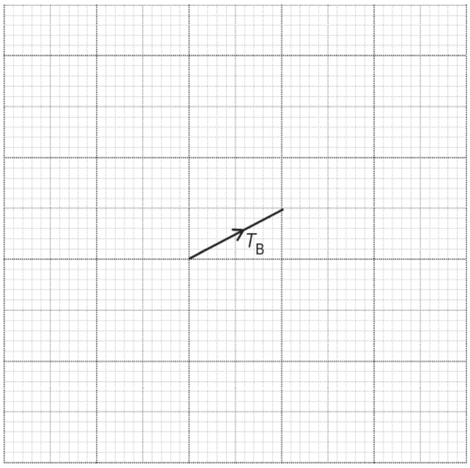


Fig. 6.3

i. Determine the magnitude of T_B.

T_B = ... N **[1]**

ii. Draw a triangle of forces on **Fig. 6.3** to represent the forces acting on the cylinder. Determine the magnitude of T_A.

T_A = ... N **[3]**

iii. Determine the angle θ in **Fig. 6. 2**.

θ = ... ° **[1]**

59. Fig. 1 shows a high-speed electric train.

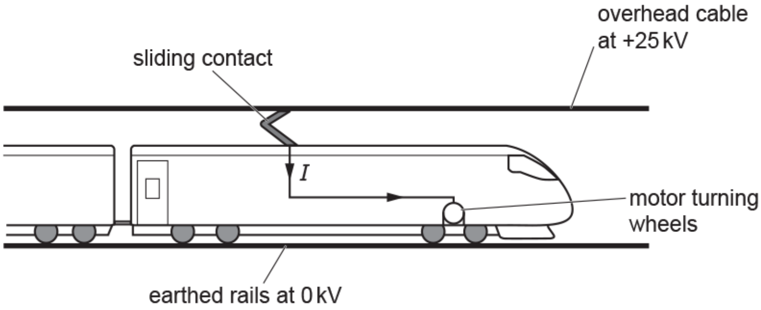


Fig. 1

The overhead cable in **Fig. 1** must be tensioned.
It is constructed from several equal lengths of wire.

Some data for one length of this wire are shown below.

- length = 1500 m
- area of cross-section = 1.1×10^{-4} m^2
- resistivity = 1.8×10^{-8} Ωm
- the Young modulus = 1.2×10^{10} Pa
- strain = 1.3%

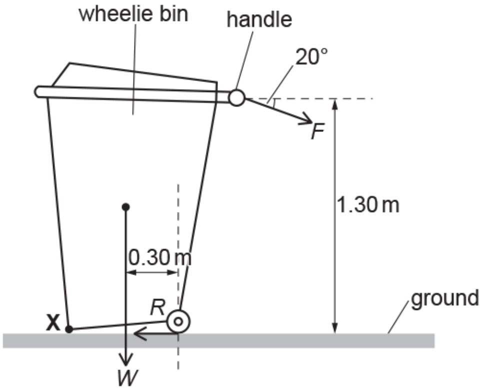
i. Calculate the resistance *R* of one length of wire.

R = ... Ω**[2]**

ii. Calculate the tension T in one length of wire.

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

60. A wheelie bin is tipped onto its wheels by applying two forces *F* and *R*.



F is applied to the handle. *F* is to the right at an angle 20° below the horizontal.
The height of the handle above the ground is 1.30 m.
R is a horizontal force applied to the left to the wheels.
The total weight of the wheelie bin and its contents is *W*.
The perpendicular distance between the line of action of the weight and the bottom of the wheels is 0.30 m.

The wheelie bin and contents have a total mass of 40 kg.

i. Show that the magnitude of the minimum force *F* which lifts the front end of the wheelie bin (point X) off the ground is 96 N.

[3]

ii. Use your answer to (i) to calculate the magnitude of the force *R* required to stop the wheelie bin from moving to the right.

R = ... N **[2]**

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

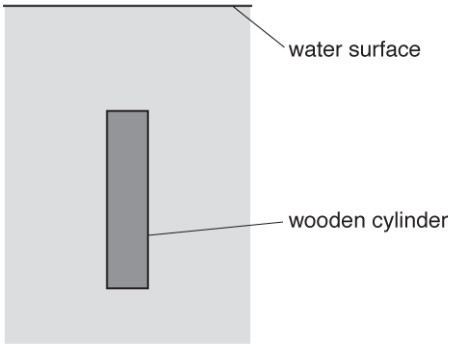


Fig. 18.2

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]

62. Fig. 18.2 shows an arrangement for lifting a car engine in a repair workshop.

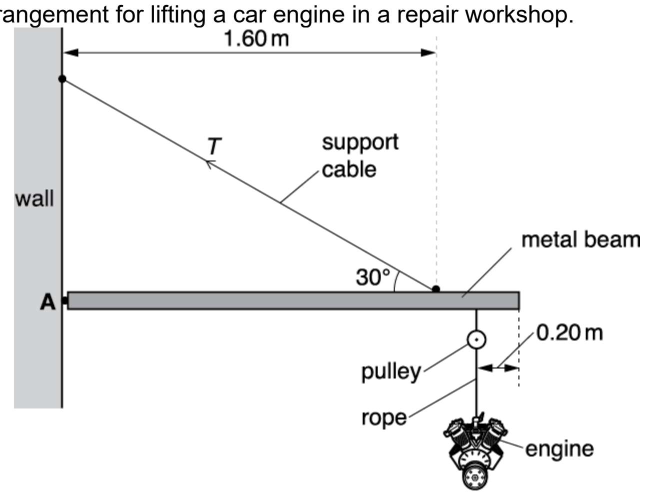


Fig. 18.2 (not to scale)

A **uniform** metal beam of length 2.00 m is hinged to a vertical wall at point **A**. The beam is held at rest in a horizontal position by a support cable of diameter of 3.0 cm. One end of this cable is fixed to the wall and the other end is fixed to the beam at a perpendicular distance of 1.60 m from the wall. The support cable makes an angle of 30° to the horizontal.
The car engine is lifted and lowered using a rope and a pulley. The pulley is fixed to the lower end of the beam at a distance of 0.20 m from the far end of the beam.
The metal beam has a mass of 120 kg and the car engine has a mass of 95 kg.

i. Calculate the tension *T* in the support cable.

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

ii. Calculate the tensile stress σ in the support cable in kPa.

σ = ... kPa **[2]**

iii. The engine is lowered using the pulley and the rope. The engine accelerates downwards. Explain briefly the effect this would have on the tension *T* in the support cable.

[1]

63 (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.

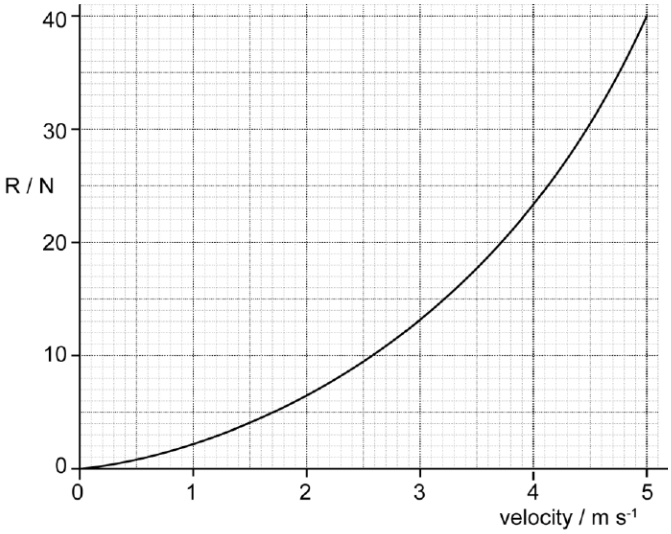


Fig.1

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

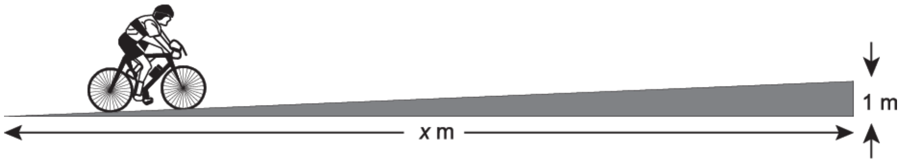
   1. the initial acceleration of the bicycle

   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]**

64. In an experiment disc **X** moving at 1.5 ms^{-1} collides elastically with two other discs **Y** and **Z** which are touching and at rest. All the discs are identical. The positions of the discs are shown in **Fig. 19.3**.

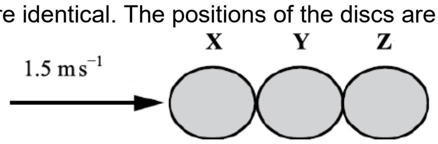


Fig. 19.3

i. Draw arrows on **Fig. 19.3** to show the relative magnitude and direction of the forces which act on disc **Y** during the collision.

[1]

ii. State the resultant force on **Y** during the collision.

[1]

iii. Show that after the elastic collision **X** is at rest and **Z** moves with a velocity of 1.5 ms^{-1}.

[4]

65 (a). Fig. 3 shows a swimmer of mass 65 kg, weight 640 N, being lifted vertically upwards from the sea by a cable of negligible mass compared to the swimmer.

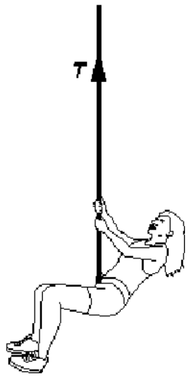


Fig. 3

The tension **T** in the cable from the time that she leaves the water at t = 0 until t = 1.5 s is 670 N.
At t = 1.5 s **T** reduces to and remains constant at 640 N.

i. Use Newton's laws to describe qualitatively the motion of the swimmer for the first 4.0 s of her ascent.

[2]

ii. Show that at t = 4.0 s her height h above the water is more than 2 m and that she is rising at about 0.7 m s^{-1}.

speed = ... m s^{-1}

h = ... m **[4]**

(b). The cable is attached to a winch rotated by an electric motor in a rescue helicopter. The electric supply to the motor has an e.m.f. of 28 V. The circuit has a total resistance of 0.11 Ω. When the swimmer is rising at 0.70 m s^{-1} the motor draws a current of 30 A from the supply.

Under these conditions calculate:

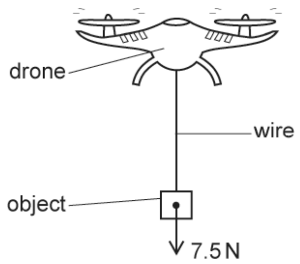
i. the power lost in the electrical circuit

power lost = ... W **[2]**

ii. the efficiency of the motor

efficiency = ... **[4]**

66. The diagram below shows an object of weight 7.5 N hung from a drone using a steel wire.



The drone is now hovering at a fixed position above the ground.

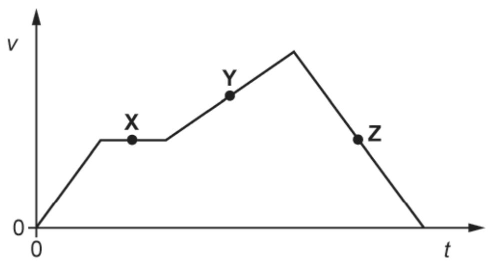
i. The wire has cross-sectional area 8.2×10^{-7} m^2 and original length 62 cm.
The Young modulus of steel is 2.0×10^{11} Pa. The wire obeys Hooke's law.

Calculate the extension x of the wire.

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

ii. The drone now moves vertically upwards.

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



The tension in the wire at **X** is 7.5 N.
Describe and explain how the tension in the wire at **Y** and **Z** compares with 7.5 N.

[3]

67. A student wishes to determine experimentally the efficiency of a small low-voltage DC motor. The motor is used to lift light loads.

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

[6]

68. Fig. 21.2 shows a model dolphin in a museum. The dolphin is held in equilibrium by two cables **A** and **B**.

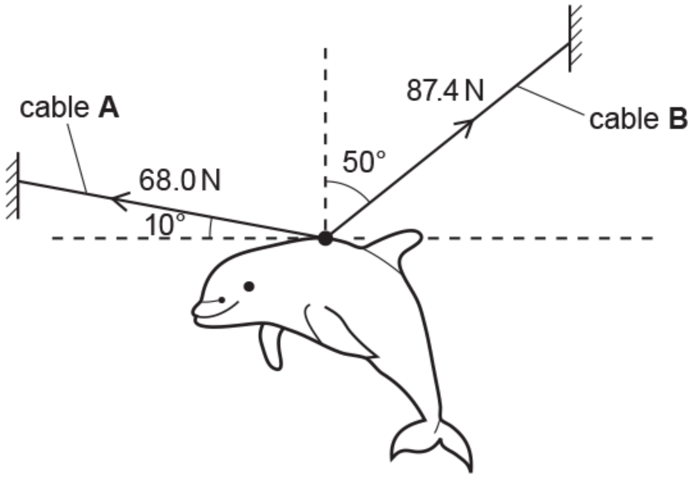


Fig. 21.2

The tension in cable **A** is 68.0 N and it makes an angle of 10° to the horizontal. The tension in cable **B** is 87.4 N and it makes an angle of 50° to the vertical.

i. Calculate the **total** vertical force F supplied by cables **A** and **B** by resolving the tensions in cables **A** and **B**.

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

ii. Use your answer from **(i)** to calculate the mass *m* of the dolphin.

m = ... kg **[2]**

iii. The cables **A** and **B** have the same length and cross-sectional area.
The material of cable **B** has Young modulus 1.29*E*, where *E* is the Young modulus of the material of cable **A**.
Both cables obey Hooke's law.

Calculate the ratio $\frac{\text{extension of cable } \mathbf{B}}{\text{extension of cable } \mathbf{A}}$.

ratio = ... **[2]**

69. Fig. 21.1 shows two identical negatively charged conducting spheres.

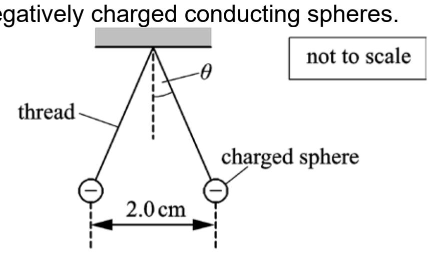


Fig. 21.1

The spheres are tiny and each is suspended from a nylon thread. Each sphere has mass 6.0×10^{-5} kg and charge -4.0×10^{-9} C. The separation between the centres of the spheres is 2.0 cm.

i. Explain why the spheres are separated as shown in **Fig. 21.1**.

[2]

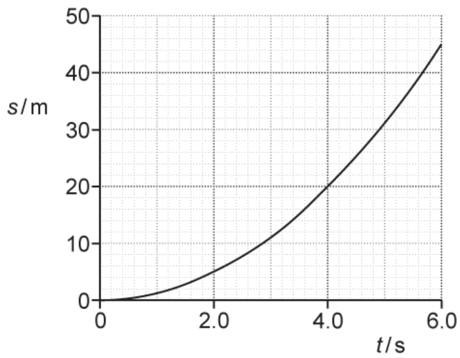
ii. Calculate the angle *θ* made by each thread with the vertical.

θ = ... ° **[4]**

70. A car starts from rest at time *t* = 0.

The car travels in a straight line with a **constant** acceleration.

The displacement *s* against time *t* graph for this car is shown below.



i. Use the graph to show that the speed of the car at *t* = 4.0s is 10ms^{-1}.

[3]

ii. The mass of the car is 1200kg.

Calculate the rate of change of momentum of the car from $t = 0$ to $t = 4.0$ s. Include an appropriate unit for your answer.

rate of change of momentum = ... unit .... **[3]**

71. The London Eye, shown rotating anticlockwise in **Fig. 6.1**, is a giant wheel which rotates slowly at a constant speed.

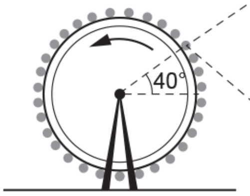


Fig. 6.1

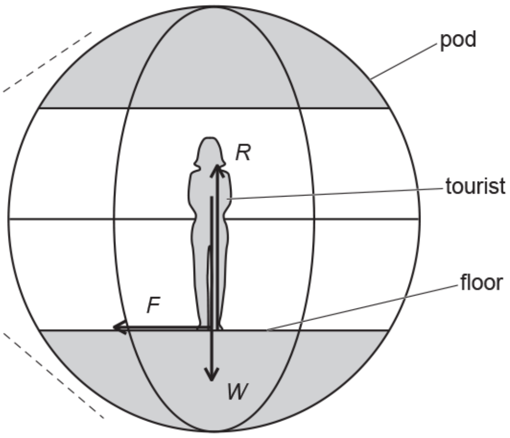


Fig. 6.2

Tourists stand in pods around the circumference of the wheel.
The floor remains horizontal at all times.
At time $t = 0$, a tourist who has a weight W of 650 N enters a pod at the bottom of the wheel.
Fig. 6.2 shows the forces acting on the tourist at a later time, when the angle between the pod's position and the centre of the wheel is 40° above the horizontal. R is the normal contact force and F is friction.

The resultant upward force ($R - W$) on the tourist changes during the 30 minutes of the rotation of the London Eye as shown in **Fig. 6.3**.

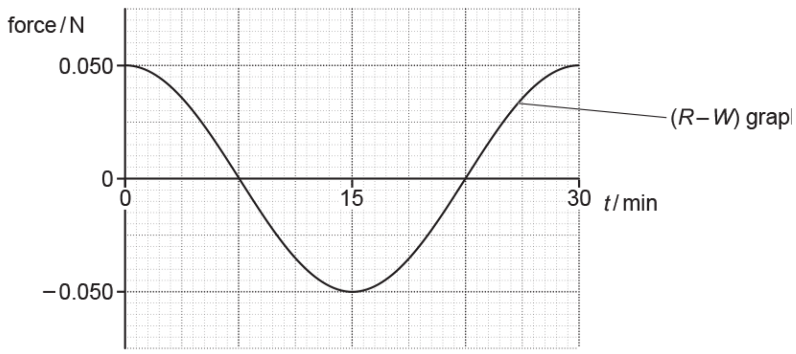


Fig. 6.3

i. Explain why the horizontal force *F* between the floor and the tourist is necessary.

[2]

ii. Draw on **Fig. 6.3** the variation of the horizontal force *F* during the 30 minutes of the anticlockwise rotation of the London Eye. Take forces to the right to be positive.

[2]

iii. Calculate the magnitude of force *F* when the pod is at the position shown in **Fig. 6.2**, at 40° above the horizontal.

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

72. Fig. 24 shows two horizontal metal plates in a vacuum.

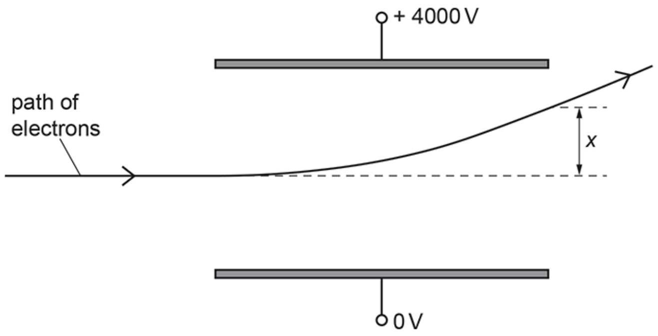


Fig. 24

The diagram is **not** drawn to scale.
Electrons travelling horizontally enter the space between the charged plates and are deflected vertically.

The potential difference between the plates is 4000 V.
The distance between the plates is 0.08 m.
The initial speed of the electrons is 6.0×10^{7} m s^{-1}.
The vertical deflection of the electrons at the far end of the plates is x.

i. Show that the vertical acceleration a of an electron between the plates is 8.8×10^{15} m s^{-2}.

[3]

ii. The length of each plate is 0.12 m.

Show that the time *t* taken by the electron to travel this length is 2.0×10^{-9} s.

[1]

iii. Calculate the vertical deflection x of the electron.

x = ... m **[2]**

73. Fig. 19 shows a crane lifting a car of mass 850 kg at constant velocity through a height of 12 m in a time of 40 s. The crane has a working efficiency of 60 %.

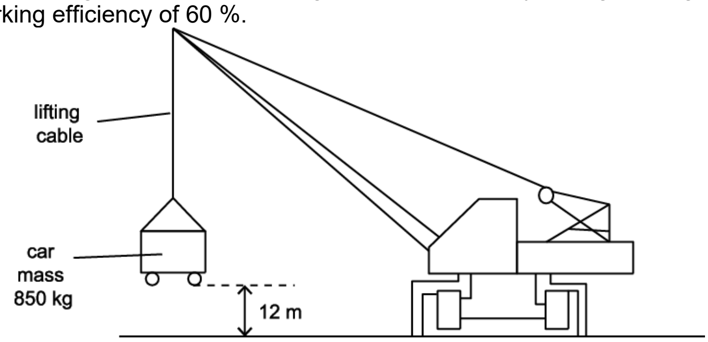


Fig. 19

i. Calculate the tension in the lifting cable.

tension = ...N **[1]**

ii. Calculate the total input power required by the crane to lift the car.

total input power = ...W **[4]**

iii. Suggest and explain **two** ways the crane can be modified to improve its efficiency.

[2]

74. Fig. 1 shows a high-speed electric train.

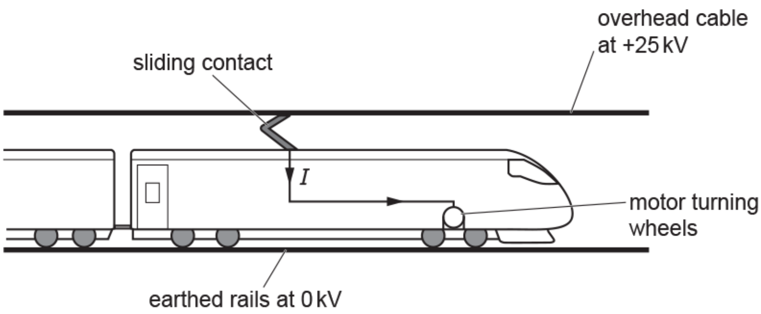


Fig. 1

The potential difference between the overhead cable and the rails on the ground is 25 kV.
The sliding contact on the top of the train constantly touches the overhead cable.
The overhead cable supplies a current I to the electric motor of the train.
The motor turns the wheels. The train experiences a **resultant** forward force *F*.

The total mass of the train is 2.1×10^5 kg.

The train accelerates from rest. The value of F is 190 kN for speeds less than 6.0 m s^{-1}.

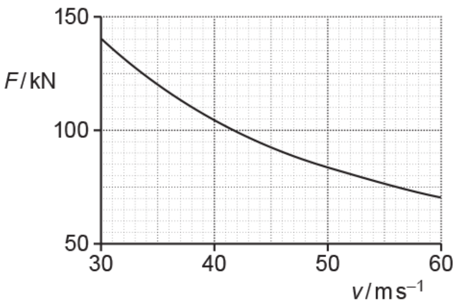
i. Show that the train's acceleration is about 1 m s^{-2}.

[1]

ii. Calculate the distance s that the train travels to reach a speed of 6.0 m s^{-1}.

s = ... m**[2]**

iii. The speed of the train is v.
During one period of its journey, the train accelerates from v = 30 m s^{-1} to v = 60 m s^{-1}.
The graph of *F* against v for this period is shown below.



1. Use the graph to show that output power of the electric motor during this period is constant at about 4 MW.

[3]

2. Calculate the current *I* in the electric motor when the train is travelling at 50 m s^{-1}.

I = ... A**[2]**

75. Fig.16 shows typical thinking, braking and stopping distances for **cars** driven at different initial speeds. The speed is shown in miles per hour (mph).

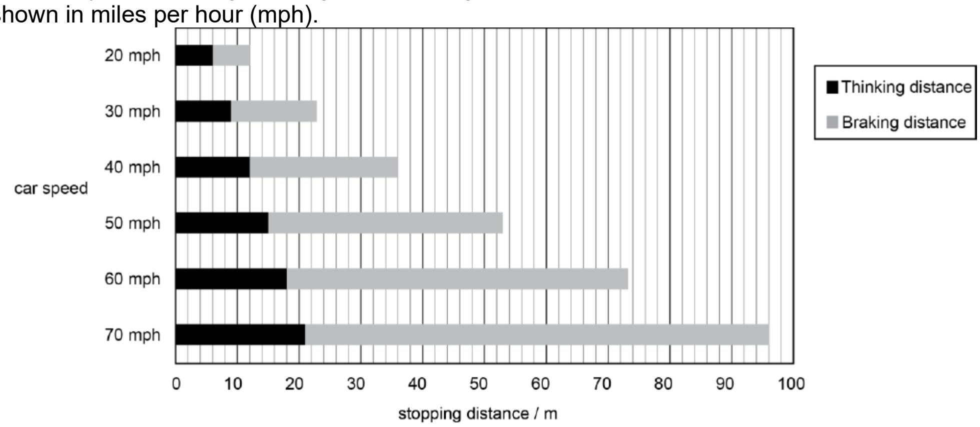


Fig. 16

A **truck** of mass 2300 kg is travelling at a constant speed of 22 m s^{-1} along a dry, level road. The driver reacts to a hazard ahead and applies the brakes to stop the truck. The reaction time of the driver is 0.97 s. The brakes exert a constant braking force of 8700 N.

i. Calculate the magnitude of the deceleration of the truck when braking.

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

ii. Show that the stopping distance of the truck is about 85 m.

[3]

iii. Show that a speed of 22 m s^{-1} is equivalent to about 50 mph (miles per hour). 1 mile = 1600 m

[1]

iv. Use Fig. 16 and your answer to (**ii**) to compare the stopping distance of the car and the truck at 50 mph. Suggest relevant factors that may have affected the stopping distance of the truck.

[4]

76. Fig. 1.1 shows a train of mass 1.9×10^5 kg travelling at 61 kmh^{-1} along a level track.

Fig. 1.1

i. Show that the train is travelling at about 17 ms^{-1}.

[1]

ii. The brakes of the train are applied and the train is brought to rest in a distance of 310 m. Calculate

1. the initial kinetic energy E_k of the train

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

2. the average deceleration a of the train

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

3. the average braking force F on the train.

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

iii. Fig. 1.2 shows a similar train travelling at 61 kmh^{-1} up an incline.

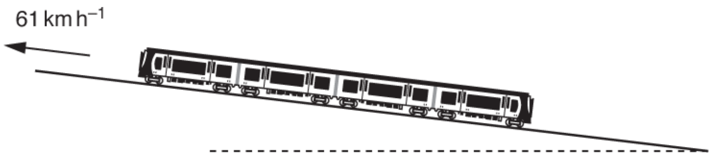


Fig. 1.2

The brakes of the train are applied with the **same** average braking force.
State and explain how the distance that the train travels, from when the brakes are applied until the train stops, compares with when the train is travelling on level track.

[2]

END OF QUESTION PAPER