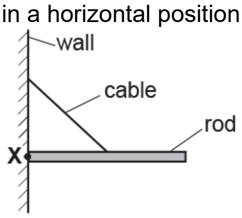
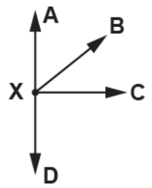
Forces in Action Equilibrium

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



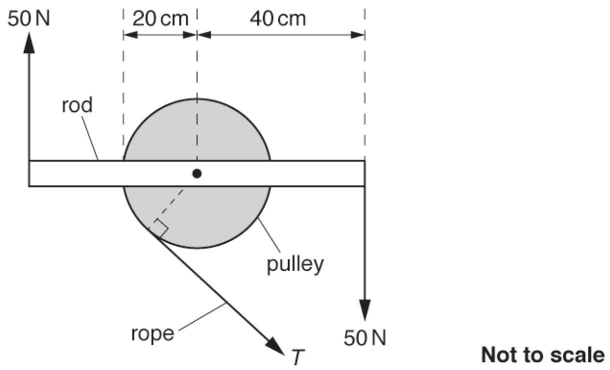
The rod is hinged at point **X**. A cable is attached to a vertical wall and the midpoint of the rod.

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



Your answer [1]

2. The centre of a rod is fixed to a pulley. Two 50 N forces are applied to the ends of the rod as shown. The tension in the rope attached to the pulley is *T*. The system is in equilibrium.



What is the moment of the tension *T* about the centre of the pulley?

A 10 N m
B 20 N m
C 30 N m
D 40 N m

Your answer [1]

3. State the *principle of moments*.

____

____ **[1]**

4. State the *principle of moments*.

____

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____ **[1]**

5. Explain how Newton's law of gravitation is applied between two non-spherical asteroids.

____

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____ **[1]**

6. A screw is used to hang a wooden sign on a wall. It is screwed into the wall using a screwdriver.

The width of the screwdriver blade is 5.0×10^{-3} m from end to end.
The ends of the blade exert equal and opposite forces on the screw.
The magnitude of each force is 350 N, as shown in Fig. 22.1.

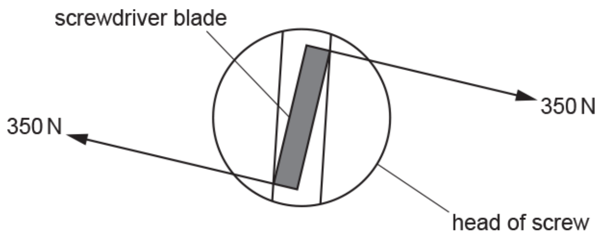


Fig. 22.1

Calculate the magnitude of the torque of the couple produced by the forces at each end of the screwdriver blade.

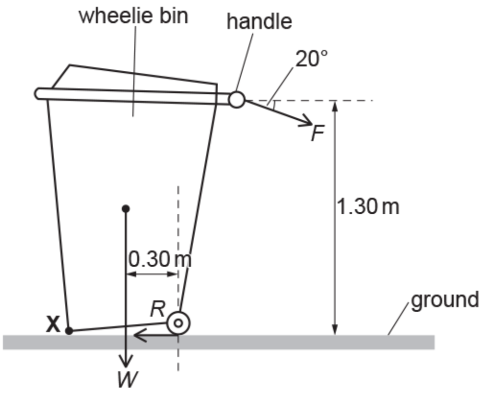
torque = ... N m **[1]**

7. For a system to be in equilibrium, the resultant force must be zero.

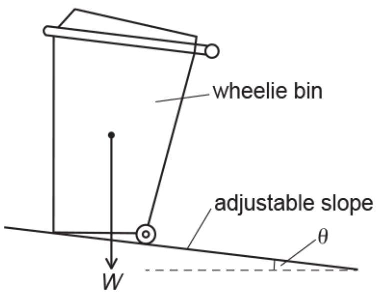
State another condition that must be satisfied for the system to be in equilibrium.

---**[1]**

8 (a). A wheelie bin is tipped onto its wheels by applying two forces *F* and *R*.



The wheelie bin in now placed on an adjustable slope. The wheels are now fixed so they cannot move.



The angle *θ* made by the slope with the horizontal is steadily increased from zero.

Explain, without calculation, at what angle *θ* the wheelie bin starts to topple clockwise.

---**[1]**

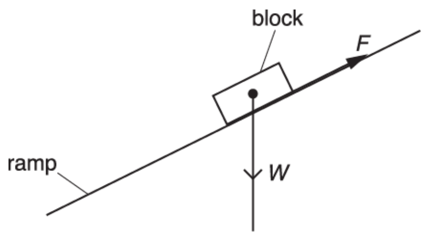
(b). *F* is applied to the handle. *F* is to the right at an angle 20° below the horizontal.
The height of the handle above the ground is 1.30 m.
R is a horizontal force applied to the left to the wheels.
The total weight of the wheelie bin and its contents is *W*.
The perpendicular distance between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

State the **principle of moments**.

-- [1]

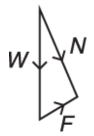
9. A block of wood is at rest on a ramp.
The weight of the block is *W* and the frictional force on the block is *F*.



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?

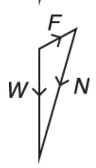
A



B

C

D

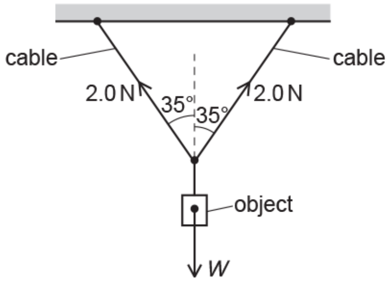


Your answer

[1]

10. An object of weight W is suspended from two identical cables.

The tension in each cable is 2.0 N. Each cable makes an angle of 35° to the vertical.

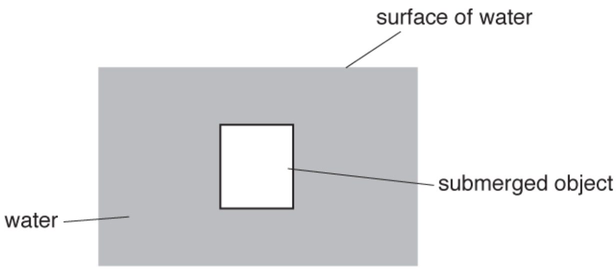


What is the weight *W* of the object?

A 1.6 N
B 2.3 N
C 2.8 N
D 3.3 N

Your answer [1]

11. The diagram below shows an object submerged in water.



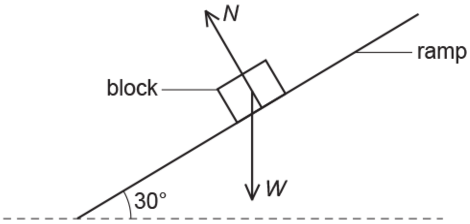
The object is stationary in the water.

Which statement about the upthrust acting on the object is correct?

A It is zero.
B It is equal to the mass of the object.
C It is equal to the weight of the object.
D It is equal to the volume of the water displaced.

Your answer [1]

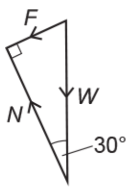
12. A wooden block is **stationary** on a ramp.

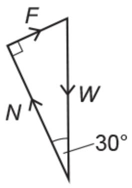


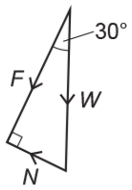
The diagram is **not** drawn to scale.

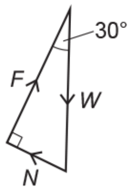
The block has weight *W*. The normal contact force on the block is *N*. The frictional force *F* on the block is not shown on the diagram.

Which triangle of forces diagram is correct?

A


B


C


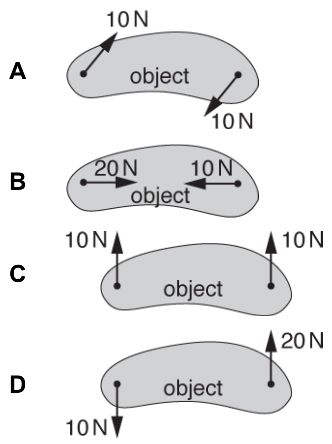
D


Your answer

[1]

13. Two forces act on an object in the same plane.

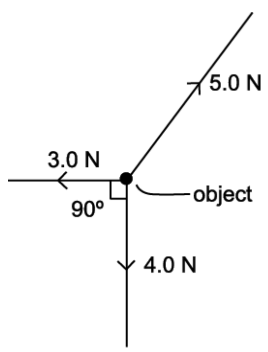
Which diagram shows a couple?



Your answer

[1]

14. The diagram below shows three forces acting on an object.



The object is **stationary.** All the forces lie in the vertical plane. The weight of the object is 4.0 N.

Which statement is **not** correct?

A. The resultant force on the object is zero.
B. The magnitude of the resultant force of 3.0 N and 4.0 N forces is 5.0 N.
C. The magnitude of the vertical component of the 5.0 N force is 4.0 N.
D. The resultant force in the horizontal direction is 3.0 N.

Your answer

[1]

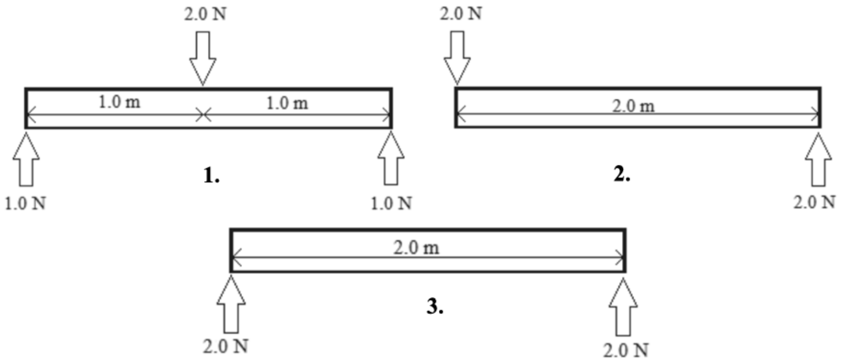
15. Which physical quantity has the same base units as energy?

A. moment
B. momentum
C. force
D. pressure

Your answer

[1]

16. A 2.0 m rigid rod with negligible weight is subject to forces in three different ways as shown in diagrams **1-3** below.



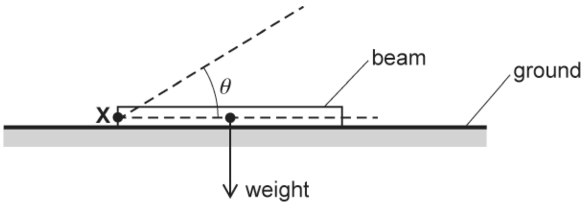
For the rod to be in equilibrium which of the diagrams above is / are correct?

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

Your answer

[1]

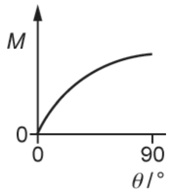
17. A uniform beam is initially lying on horizontal ground, as shown below.



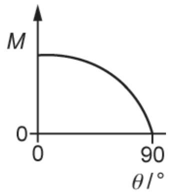
The end **X** of the beam is hinged.
The beam is tilted from angle $\theta = 0$ to $\theta = 90°$.
The moment of the weight of the beam about point **X** is M.

Which M against θ graph is correct?

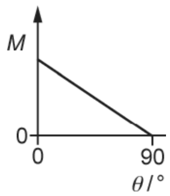
A



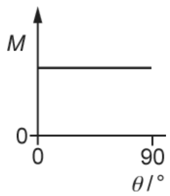
B



C

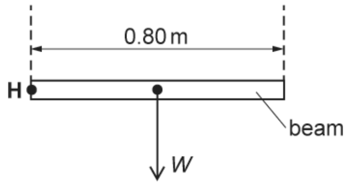


D



Your answer ☐ **[1]**

18. A uniform beam has length 0.80 m and weight W.
The beam is hinged at point **H**.
A cable is attached to the beam at a distance x from **H**. The vertical upwards force in the cable is 0.75 W. **The cable is not shown in the diagram.**
The beam is at rest in the horizontal position.

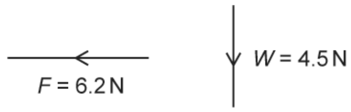


Which condition is correct?

A $x < 0.40$ m
B $x = 0.40$ m
C 0.40 m $< x < 0.80$ m
D $x = 0.80$ m

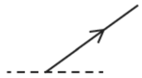
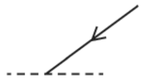
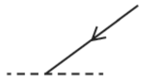
Your answer ☐ **[1]**

19. An object is in equilibrium under the action of three coplanar forces *F*, *R* and *W*. The diagram below shows the forces *F* and *W*.



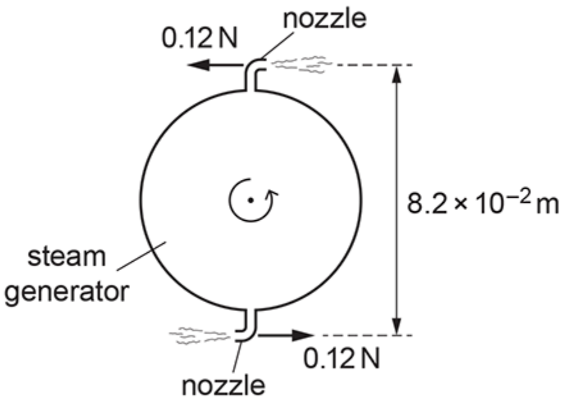
The angle between *F* and *W* is 90°.

Which row shows the correct magnitude of *R* and the approximate direction of *R*?

	Magnitude of *R* / N	Direction of *R*
A	7.7	
B	7.7	
C	10.7	
D	10.7	

Your answer [1]

20. The diagram below shows a rotating steam generator.



The steam ejected from the nozzles provides a couple. The force at each nozzle is 0.12 N. The perpendicular distance between the nozzles is 8.2×10^{-2} m.

What is the work done by the forces as the steam generator completes one revolution?

A 0 J
B 9.8×10^{-3} J
C 3.1×10^{-2} J
D 6.2×10^{-2} J

Your answer [1]

21 (a). Fig. 22 shows two identical springs supporting an object.

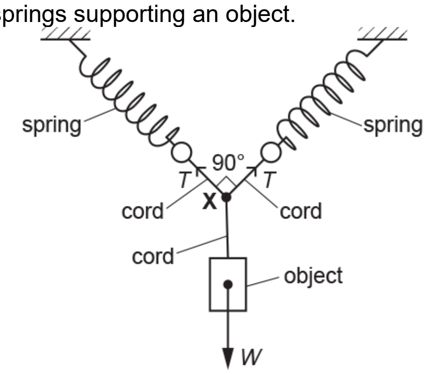


Fig. 22

Three short lengths of cord are tied together at point **X**. The other ends of the cords are attached to the ends of the springs and the object as shown in Fig. 22. The angle between the central axes of the springs is 90°.
The tension in each spring is the same and equal to *T*. The weight *W* of the object is 4.8 N.
The point **X** is in equilibrium.

Sketch a **labelled** triangle of forces diagram for the three forces acting at point **X**. You do not need to draw this diagram to scale.

[2]

(b). Show that the tension *T* in each extended spring is 3.4 N.

[2]

(c). The force constant of each spring is 24 N m^{-1}.
Calculate the energy stored in each spring.

energy = ______________________ J **[2]**

22.

i. Define the moment of a force about a point.

____ **[1]**

ii. State the principle of moments as a condition for equilibrium.

____

____ **[1]**

23. Fig. 22 shows a uniform platform secured to a wall and resting on a vertical concrete pillar.

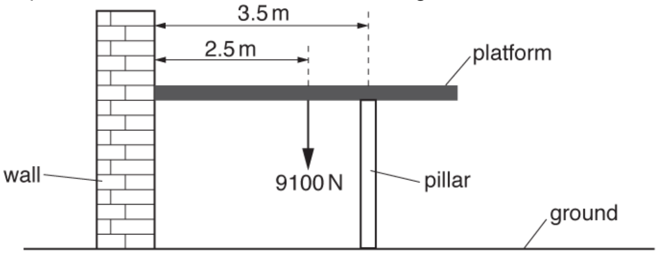


Fig. 22

The platform is in a horizontal position.
The weight of the platform is 9100 N and it has length 5.0 m. The centre of the pillar is 3.5 m from the wall.

Use the principle of moments and the information provided in Fig. 22 to calculate the vertical force *F* exerted by the pillar on the platform.

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

24. Fig. 1.1 shows a sign hanging from a rod fixed to a vertical wall. A metal wire attached between the rod and the wall holds the rod horizontal.

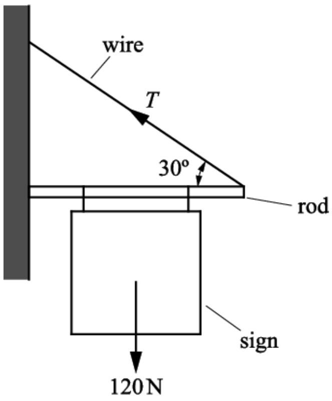


Fig.1.1

The weight *W* of the sign and rod act through the centre point of the rod. The value *W* is 120 N. The angle between wire and rod is 30°.

i. Draw an arrow on **Fig. 1.1** to show the direction of the force exerted on the rod by the wall.

-- **[1]**

ii. State how you chose this direction.

-- **[1]**

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

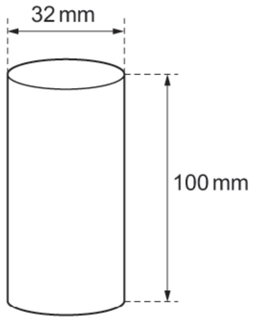


Fig. 6.1 (not to scale)

Fig. 6.4 shows the same cylinder at rest on a bench.
A horizontal force *F* is applied to the cylinder so that it can rotate about point **X**.

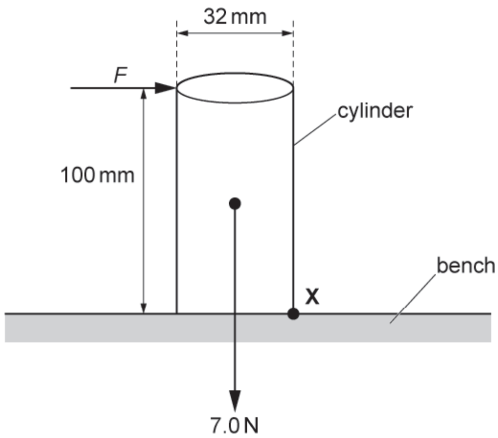


Fig. 6.4 (not to scale)

Calculate the minimum value of *F* to just topple the cylinder about **X**.

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

26. Fig. 22 shows two identical springs supporting an object.

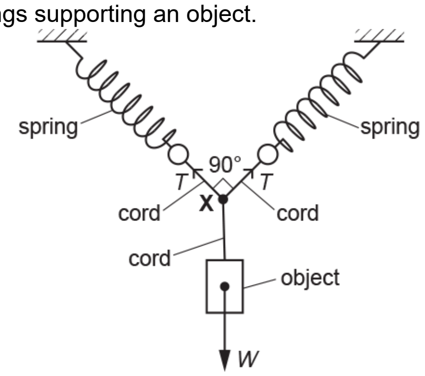


Fig. 22

Three short lengths of cord are tied together at point **X**. The other ends of the cords are attached to the ends of the springs and the object as shown in Fig. 22. The angle between the central axes of the springs is 90°.
The tension in each spring is the same and equal to *T*. The weight *W* of the object is 4.8 N.
The point **X** is in equilibrium.

State and explain the magnitude and the direction of the resultant force at **X** due to the two forces exerted by the extended springs.

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____ **[2]**

27. Fig. 1.1 shows a sign hanging from a rod fixed to a vertical wall. A metal wire attached between the rod and the wall holds the rod horizontal.

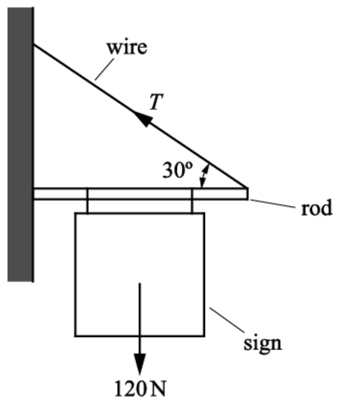


Fig.1.1

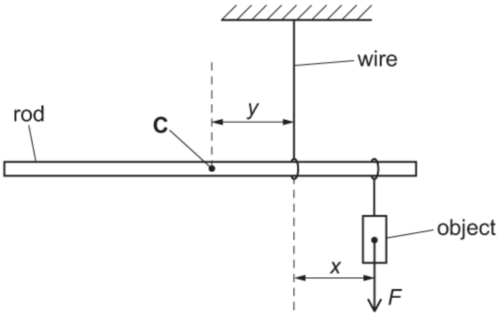
The weight *W* of the sign and rod act through the centre point of the rod. The value *W* is 120 N. The angle between wire and rod is 30°.

Explain why the vertical force exerted on the rod by the wire is 60 N.

--- **[2]**

28 (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.

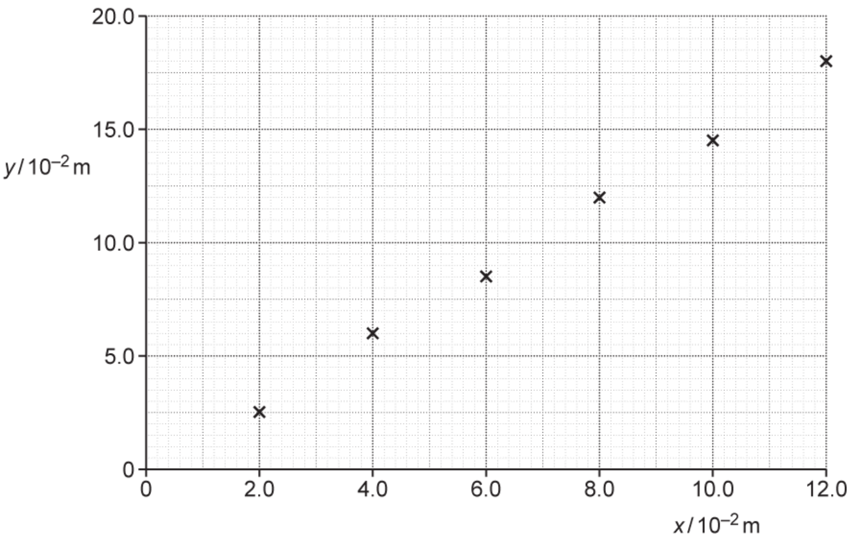


The rod is in equilibrium.
The centre of gravity **C** of the rod is a perpendicular distance *y* from the wire. The line of action of the weight *F* of the object is a perpendicular distance *x* from the wire.
The rod has length *L* and cross-sectional area *A*. The density of the metal rod is ρ.

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 × 10^{-5} m^2

ρ = ... kg m^{-3} **[3]**

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

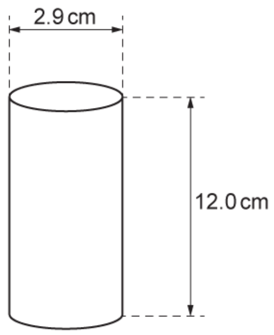


Fig. 4.1

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**.

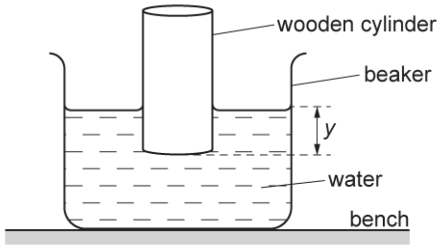


Fig. 4.2 (not to scale)

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]**

30. 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.

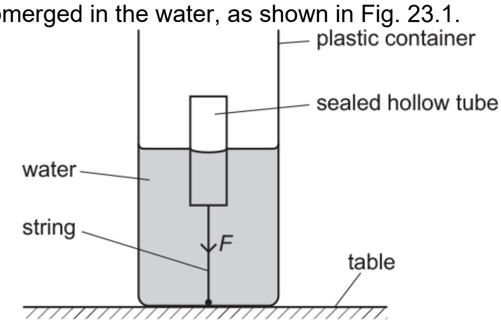


Fig. 23.1

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*.

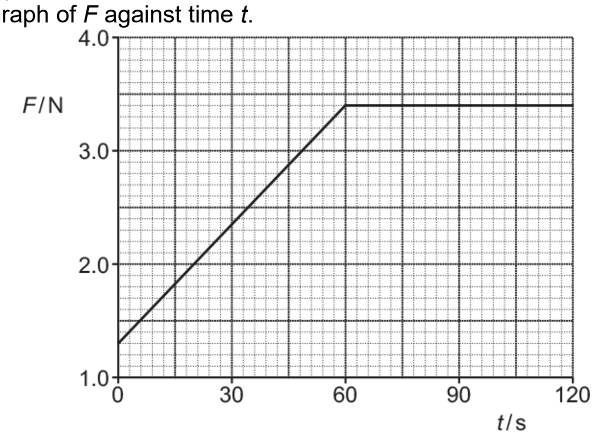


Fig. 23.2

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

____

____

____

____

____

____

____ **[3]**

31 (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.

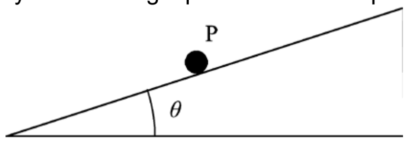


Fig. 17.1

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**.

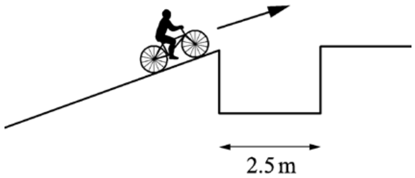


Fig. 17.2

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]**

32 (a). Fig. 1 shows the top of a crane which has an arm **AC** of mass 1800 kg. The centre of mass of the arm is at **D**.

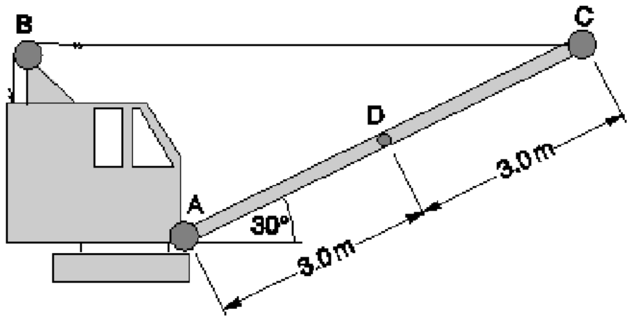


Fig. 1

The arm can rotate about the pivot at **A**. It is supported by a horizontal cable **BC**. The dimensions are as shown on the diagram.

i. The arm is in equilibrium. Draw and label three arrows on **Fig. 1** to represent the three forces acting on the arm.

[3]

ii. Calculate the tension in the cable **BC**.

tension = ... kN **[3]**

(b). The arm is rotated about **A** by shortening the cable **BC**. The cable is no longer horizontal. Explain whether the tension in the cable has increased or decreased.

---**[3]**

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

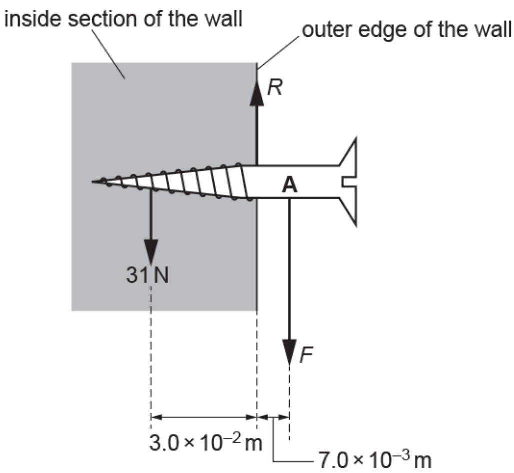


Fig. 22.2

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]**

34. A cylinder head gasket is a thin sheet of material used in a car engine.
A car manufacturer wants to locate the centre of gravity of the gasket shown in Fig. 18.1.

Fig. 18.1

Describe how the centre of gravity of the gasket can be determined using equipment from a laboratory.

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____ **[4]**

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

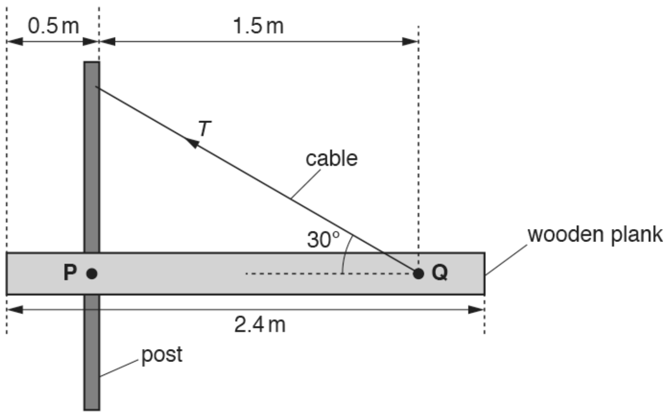


Fig. 4 (not to scale)

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.

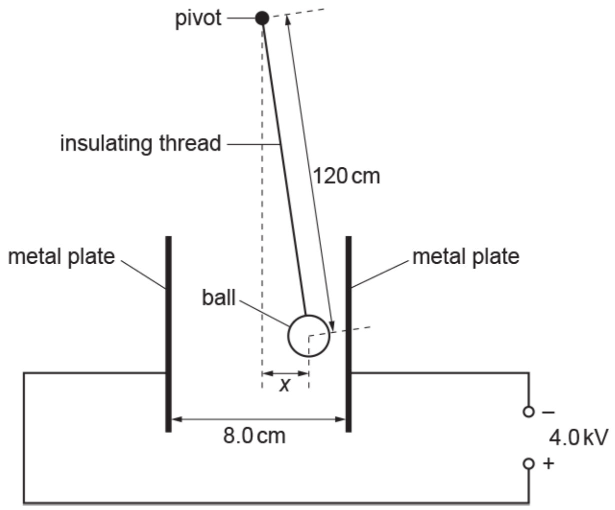
Show that the tension *T* in the cable is about 460 N.

[4]

36(a). A ball coated with conducting paint has weight 0.030 N and radius 1.0 cm. The ball is suspended from an insulating thread. The distance between the pivot and the centre of the ball is 120 cm.

The ball is placed between two vertical metal plates. The separation between the plates is 8.0 cm. The plates are connected to a 4.0 kV power supply.

The ball receives a positive charge of 9.0 nC when it is made to touch the positive plate. It then repels from the positive plate and hangs in equilibrium at a displacement *x* from the vertical, as shown below. The diagram is **not** drawn to scale.



i. Show that the electric force acting on the charged ball is 4.5×10^{-4} N.

[2]

ii. Draw, on the diagram above, arrows which represent the **three** forces acting on the ball.
Label each arrow with the name of the force it represents.

[2]

iii. By taking moments about the pivot, or otherwise, show that x = 1.8 cm.

[2]

(b). The ball is still positively charged.

The plates are now moved slowly towards each other whilst still connected to the 4.0 kV power supply. The plates are stopped when the separation is 5.0 cm.

Explain the effect that this has on the deflection of the ball and explain why the ball eventually starts to oscillate between the plates.

[4]

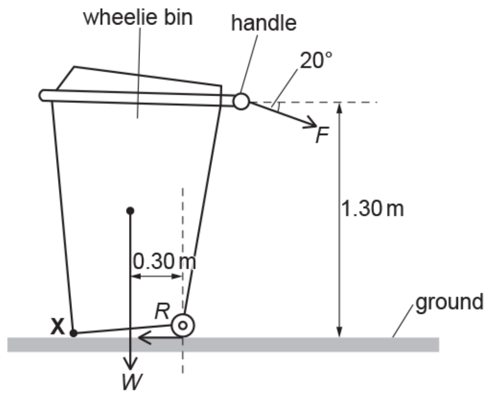
(c). When the ball oscillates between the plates, the current in the external circuit is 3.2×10^{-8} A.

A charge of 9.0 nC moves across the gap between the plates each time the ball makes one complete oscillation.

Calculate the frequency *f* of the oscillations of the ball.

f = ... Hz **[2]**

37. 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]**

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

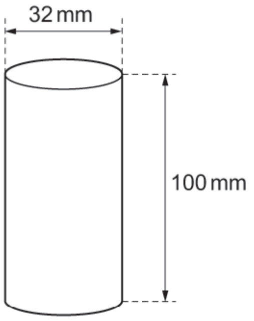


Fig. 6.1 (not to scale)

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

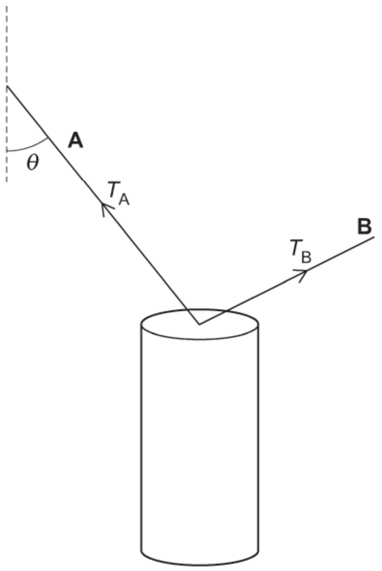


Fig. 6.2 (not to scale)

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.

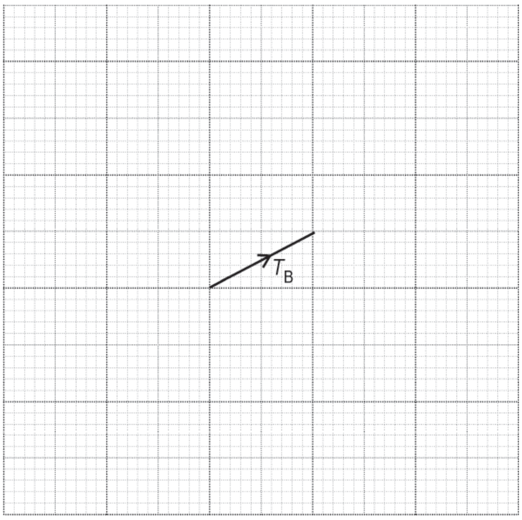


Fig. 6.3

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]**

39. A gymnast hangs from the rings apparatus shown in Fig. 17.1. He raises his legs from a vertical to a horizontal position. Fig. 17.2 shows a simple model to demonstrate the forces exerted on his legs in the horizontal position. The total weight *W* of the legs is 260 N and acts at a point 40 cm from the pivot **P** in the hip. A force *T* is supplied by his hip flexor muscles which are attached to a point in the bone 3.0 cm from the pivot **P.** When horizontal, force *T* makes an angle of 50° with his legs.

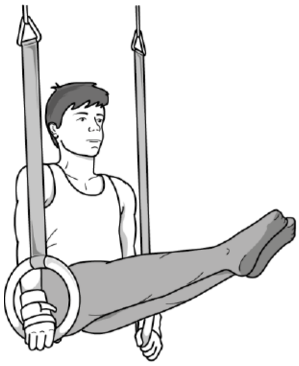


Fig. 17.1

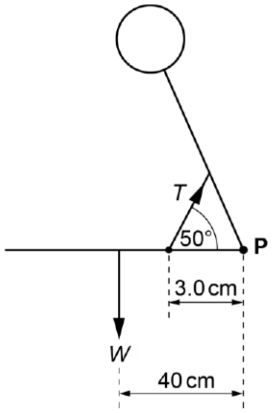


Fig. 17.2

i. Take moments about **P** to calculate the force *T* needed to keep his legs horizontal.

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

ii. Describe and explain the change in the force *T*, if any, as his legs are lowered from the horizontal position to vertical position.

--- **[2]**

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

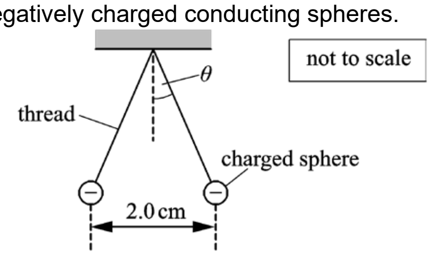


Fig. 21.1

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]**

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

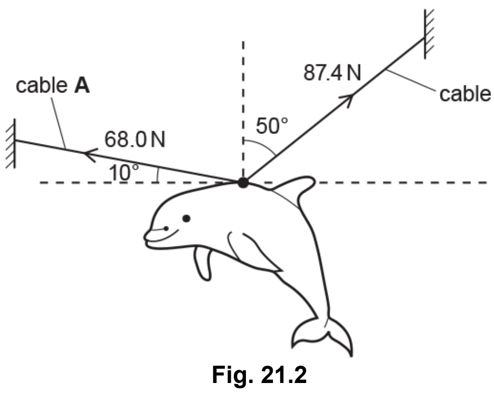


Fig. 21.2

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]**

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

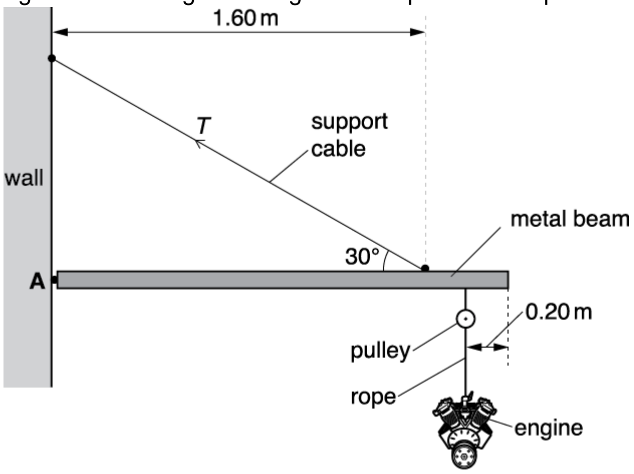


Fig. 18.2 (not to scale)

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]**

43. A binary star is a pair of stars which move in circular orbits around their common centre of mass.

In this question consider the stars to be point masses situated at their centres.

Fig. 3.1 shows a binary star where the mass of each star is *m*. The stars move in the same circular orbit.

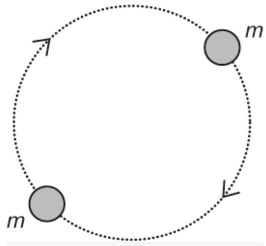


Fig. 3.1

i. Explain why the stars of equal mass must always be diametrically opposite as they travel in the circular orbit.

--- **[2]**

ii. The centres of the two stars are separated by a distance of 2*R* equal to 3.6×10^{10} m, where *R* is the radius of the orbit. The stars have an orbital period *T* of 20.5 days. The mass of each star is given by the equation

$$m = \frac{16\pi^2 R^3}{GT^2}$$

where *G* is the gravitational constant.

Calculate the mass *m* of each star in terms of the mass $M_\odot$ of the Sun.

1 day = 86400 s

$M_\odot = 2.0 \times 10^{30}$ kg

m = -- $M_\odot$ **[3]**

iii. The stars are viewed from Earth in the plane of rotation.
The stars are observed using light that has wavelength of 656 nm in the laboratory.
The observed light from the stars is Doppler shifted.

Calculate the maximum change in the observed wavelength $\Delta\lambda$ of this light from the orbiting stars. Give your answer in nm.

$\Delta\lambda$ = ____________________________________ nm **[2]**

44. 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.

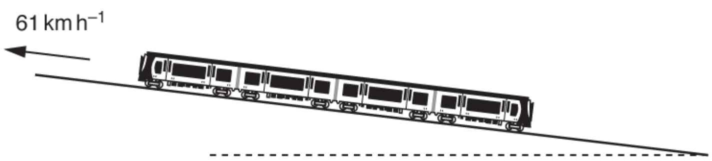


Fig. 1.2

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.

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____ **[2]**

END OF QUESTION PAPER