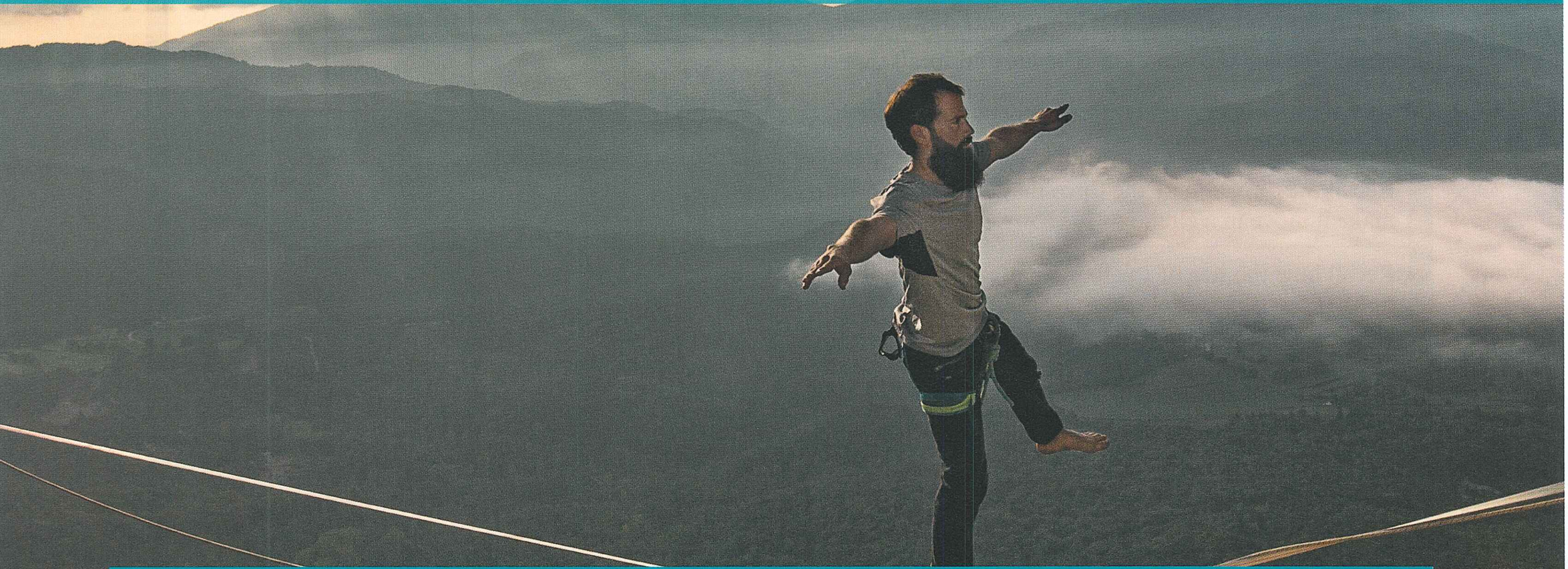
Chapter 4
Turning effects



IN THIS CHAPTER YOU WILL:

- describe and calculate the turning force
- investigate and apply the principle of moments
- describe the conditions needed for an object to be in equilibrium
- describe how the centre of gravity of an object affects its stability

> apply the principle of moments when there is more than one moment on each side of a pivot.

GETTING STARTED

Spend 60 seconds thinking on your own, have 30 seconds of discussion with a partner and then be prepared to share your answers to the following questions with the class. You might find it helpful to draw sketches.

Explain how the street performer pictured in Figure 4.1a appears to levitate (float in space above the ground) and the performer shown in Figure 4.1b appears to defy the force of gravity.

Explain how lifeboats (see Figure 4.1c) can be self-righting (turn the right way up after capsizing).

Figure 4.1a: A street performer appears to levitate. **b:** A street performer appears to defy the force of gravity. **c:** An engraving of a self-righting lifeboat from the 19th century.

MEET THE WOLF OF WAR

It is a sad fact that war creates opportunities for advances in technology. China invented the trebuchet in the 5th century and it was an effective siege weapon until the invention of gunpowder. A trebuchet is a catapult that has a swinging arm to fire a projectile (a thrown object).

The trebuchet is made from a long beam that pivots on an axle. The attacking soldiers attach a sling containing the projectile to the end of the longer section. They attach a counterweight to the shorter end. To fire the trebuchet, the soldiers allow the counterweight to fall which applies a turning force or moment on the beam. Because the projectile is further from the axle (or pivot), the projectile moves much faster than the counterweight and the sling at the end extends the effective length of the beam, making the projectile move even faster. The trebuchet uses energy transfers as well as turning forces. The largest trebuchets had a 15 metre beam, a 9000 kg counterweight and could hurl a 140 kg stone block to a range of almost 300 metres. Loup de Guerre (or Wolf of War) was the biggest trebuchet ever built, by Edward I, who was king of England in the late 13th century. He refused the surrender of Scottish defenders so that he could use it against Stirling Castle.

Discussion questions

1 Try explaining how a trebuchet works. Describe how the performance of the trebuchet would change if the projectile and counterweight swapped positions. Hint: Think about the relative speeds of the two ends of the beam. Draw a sketch if it helps.

2 A trebuchet uses energy transfers as well as turning forces. Can you think of other ideas in physics that need more than one topic to explain it?

3 What do you think would have done more damage to the walls of Stirling Castle – a projectile that is twice as massive or twice as fast? (If you have already met the equation for kinetic energy, see if you can work it out.)

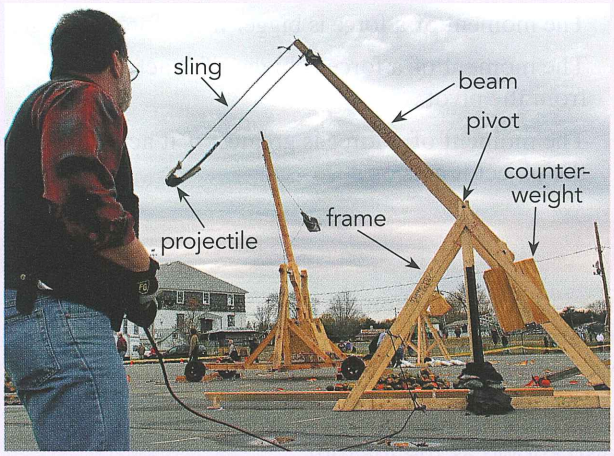


Figure 4.2: Trebuchets are not a part of modern warfare. Here, an enthusiast uses his trebuchet to throw a pumpkin during a recent North American Pumpkin Launch.

4.1 The moment of a force

Figure 4.3 shows a boy who is trying to open a heavy door by pushing on it. He must make the **turning effect** of his force as big as possible. How should he push?

Figure 4.3: Opening a door – how can the boy have a big turning effect?

First of all, look for the **pivot** – the fixed point about which the door will turn. This is the hinge of the door. To open the door, the person must push with as big a force as possible, and as far as possible from the pivot – at the other edge of the door. (That is why the door handle is fitted there.) To have a big turning effect, the person must push hard at right angles to the door. Pushing at a different angle gives a smaller turning effect.

The quantity that tells us the turning effect of a force about a pivot is its **moment**.

- The moment of a force is bigger if the force is bigger.
- The moment of a force is bigger if it acts further from the pivot.
- The moment of a force is greatest if it acts at 90° to the object it acts on.

KEY WORDS

turning effect: when a force causes an object to rotate or would make the object rotate if there were no resistive forces

pivot: the fixed point about which a lever turns; also known as the fulcrum

moment: the turning effect of a force about a pivot, given by force × perpendicular distance from the pivot

Making use of turning effects

Figure 4.4 shows how understanding moments can be useful.

When using a crowbar to lift a heavy rock, pull near the end of the bar, and at 90°, to have the biggest possible turning effect.

When lifting a load in a wheelbarrow, the long handles help to increase the moment of the lifting force.

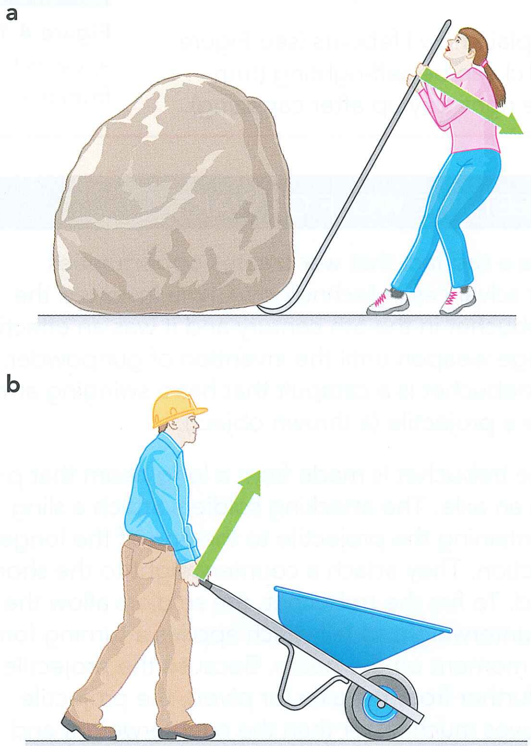


Figure 4.4: Understanding moments can help in some difficult tasks.

Balancing a beam

Figure 4.5 shows a small child sitting on the left-hand end of a see-saw. Her weight causes the see-saw to tip down on the left. Her father presses down on the other end. If he can press with a force greater than her weight, the see-saw will tip to the right and she will come up in the air.

Now, suppose the father presses down closer to the pivot. He will have to press with a greater force if the turning effect of his force is to overcome the turning effect of his daughter's weight. If he presses at half the distance from the pivot, he will need to press with twice the force to balance her weight.

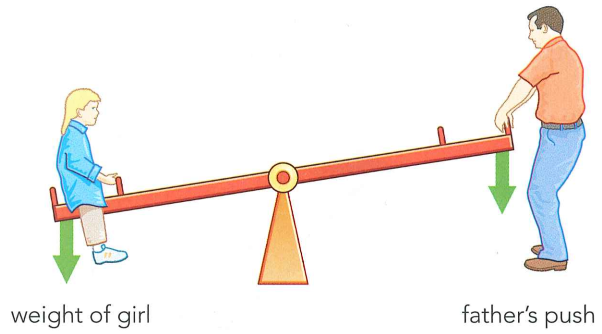


Figure 4.5: Two forces are causing this see-saw to tip. The girl's weight causes it to tip to the left, while her father provides a force to tip it to the right. He can increase the turning effect of his force by increasing the force, or by pushing down at a greater distance from the pivot.

A see-saw is an example of a beam, a long, rigid object that is pivoted at a point. The girl's weight is making the beam tip one way. The father's push is making it tip the other way. If the beam is to be balanced, the moments of the two forces must cancel each other out.

Equilibrium

In science and in other subjects, you will often hear about things that are in equilibrium. This always means that two or more things are balanced. When a beam is balanced, we say that it is in **equilibrium**. When an object is in equilibrium:

- the forces on it must be balanced (no resultant force)
- the turning effects of the forces on it must also be balanced (no resultant turning effect).

When a resultant force acts on an object, it will start to move off in the direction of the resultant force. If there is a resultant turning effect, it will start to rotate.

KEY WORD

equilibrium: when no net force and no net moment act on a body

Questions

1 Choose the correct option in the following statements.
   a The moment of a force is bigger if the force is {smaller / bigger}.
   b The moment of a force is bigger if it acts {closer / further} from the pivot.
   c The moment of a force is greatest if it acts at {0°/ 45°/ 90°} to the object it acts on.

2 Three different forces are pulling on a heavy trapdoor (Figure 4.6). Which force will have the biggest turning effect? Explain your answer.

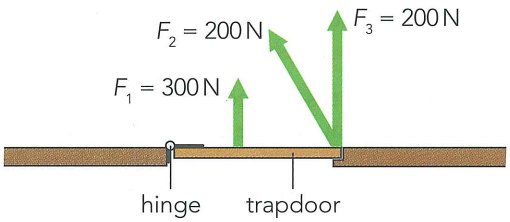


Figure 4.6

3 Explain why somebody would use a spanner with a longer handle if they needed to undo a tight bolt.

4 a Explain why a tree is more likely to be blown over in a stronger wind.
   b Explain why a taller tree is more likely to be blown over than a shorter tree.

4.2 Calculating moments

We have seen that, the greater a force and the further it acts from the pivot, the greater is its moment. We can write an equation for calculating the moment of a force like this:

KEY EQUATION

moment of a force = force × perpendicular distance from the pivot

Now let us consider the unit of moment. Since moment is a force (N) multiplied by a distance (m), its unit is simply the newton metre (Nm). There is no special name for this unit in the SI system. Take care: if distances are given in cm, the unit of moment will be Ncm. Take care not to mix these different units (Nm and Ncm) in a single calculation.

Figure 4.7 shows an example. The 40 N force is 2.0 metres from the pivot, so:

$$\text{moment of force} = 40\,\text{N} \times 2.0\,\text{m} = 80\,\text{Nm}$$

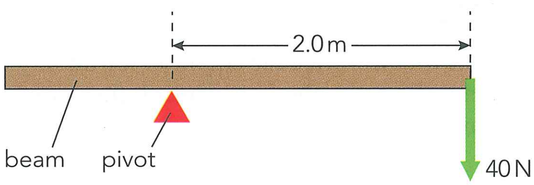


Figure 4.7: Calculating the moment of a force.

Balancing moments

Look back at Figure 4.5, where a father and his daughter are playing on a see-saw. On her own, she would make the see-saw turn **anticlockwise**; her weight has an anticlockwise moment. To make the see-saw balance, her father needs to push down on the right-hand end of the see-saw, applying a **clockwise** moment.

The idea that an object is balanced when clockwise and anticlockwise moments are equal is known as the **principle of moments**. We can use this principle to find the value of an unknown force or distance, as shown in Worked Example 4.1.

WORKED EXAMPLE 4.1

The daughter in Figure 4.5 has a weight of 500 N and is sitting 2.0 metres to the left of the pivot. Her father has a weight of 800 N. How far to the right of the pivot should he sit so that the see-saw is balanced?

Step 1: Write down what you know and what you want to find out.

anti-clockwise force = 500 N
distance = 2.0 m

clockwise force = 800 N; distance = ?

Step 2: Since the see-saw has to be in equilibrium, we can write:

total anticlockwise moment = total clockwise moment

Step 3: Substitute in the values from Step 1, and solve.

500 N × 2.0 m = 800 N × perpendicular distance

1000 Nm = 800 N × perpendicular distance

$$\text{perpendicular distance} = \frac{1000\text{ Nm}}{800\text{ N}} = 1.25\text{ m}$$

Answer

The father needs to sit 1.25 m to the right of the pivot so that the see-saw is balanced.

Questions

5 Write down, in words, the equation for finding the moment of a force about a point, stating carefully the units for each quantity.

6 A bolt is tightened by applying a turning force of 30 N to the end of the spanner (Figure 4.8).

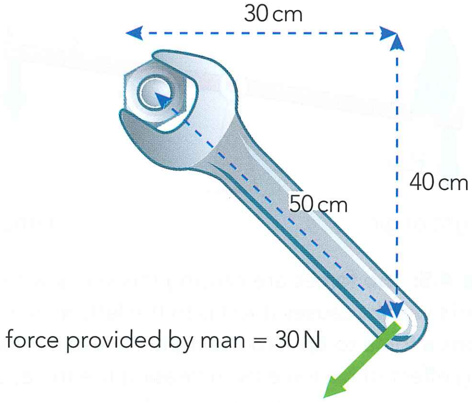


Figure 4.8

a Which of the three distance measurements should you use?

b Use this distance to calculate the moment.

7 A uniform metre ruler is balanced at its midpoint (Figure 4.9).

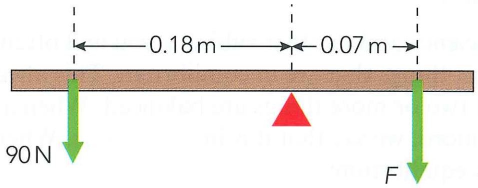


Figure 4.9

Calculate the unknown force *F*.

8 A boy of mass 60 kg, and his sister of mass 49 kg, play on a see-saw pivoted at its centre. If the boy sits 2.7 metres from the pivot of the see-saw, calculate the distance from the other side of the pivot the girl must sit to make the see-saw balanced.

KEY WORDS

anticlockwise: turning in the opposite direction from the hands on a clock

clockwise: turning in the same direction as the hands on a clock

principle of moments: when an object is in equilibrium, the sum of anticlockwise moments about any point equals the sum of clockwise moments about the same point

ACTIVITY 4.1

Moving fingers along a metre ruler

Work with a partner. Take it in turns to balance a metre ruler (or a pair of round pencils) across your index fingers with your hands wide apart but at different distances from the ends of the ruler. Slowly bring your hands together. Discuss what you observe with your partner. As part of your discussions, you both need to describe and explain what you observe.

Now work independently to write a description and an explanation. Your description should include a diagram of what was happening. You can label the diagram as part of your explanation, which needs to include the following words: moments, centre of gravity, and friction.

When you have both finished writing, swap your work and decide who has written the better explanation and why it is better. For example, is it clearer or more scientifically accurate? Update your own work with any improvements.

Now try the same thing with a 100 g mass taped somewhere to the ruler (or use a pool cue if available). What do you observe this time? Can you explain what is happening?

You need to describe and explain as you did before.

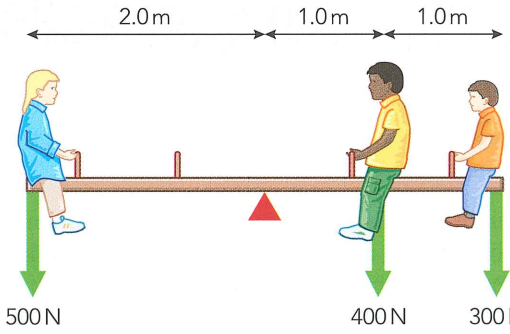


Figure 4.10: A balanced see-saw. On her own, the child on the left would make the see-saw turn anticlockwise; her weight has an anticlockwise moment. The weight of each child on the right has a clockwise moment. Since the see-saw is balanced, the sum of the clockwise moments must equal the anticlockwise moment.

More balancing moments

The three children in Figure 4.10 have balanced their see-saw – it is in equilibrium. The weight of the child on the left is tending to turn the see-saw anticlockwise. So the weight of the child on the left has an anticlockwise moment. The weights of the two children on the right have clockwise moments. From the data in Figure 4.10, we can calculate these moments:

$$\text{anticlockwise moment} = 500\,\text{N} \times 2.0\,\text{m} = 1000\,\text{Nm}$$

$$\begin{aligned}\text{clockwise moments} &= (300\,\text{N} \times 2.0\,\text{m}) + (400\,\text{N} \times 1.0\,\text{m})\\ &= 600\,\text{Nm} + 400\,\text{Nm}\\ &= 1000\,\text{Nm}\end{aligned}$$

The brackets are included as a reminder to perform the multiplications before the addition.

We can see that, in this situation:

total clockwise moment = total anticlockwise moment

So, the see-saw in Figure 4.10 is balanced.

WORKED EXAMPLE 4.2

The beam shown in Figure 4.11 is 2.0 metres long and has a weight of 20 N. It is pivoted as shown. A force of 10 N acts downwards at one end. What force, F must be applied downwards at the other end to balance the beam?

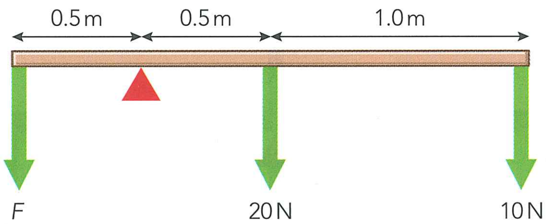


Figure 4.11: Balancing a beam.

Step 1: Identify the clockwise and anticlockwise forces. Two forces act clockwise: 20 N at a distance of 0.5 m, and 10 N at 1.5 m. One force acts anticlockwise: the force F at 0.5 m.

Step 2: Since the beam is in equilibrium, we can write total clockwise moment = total anticlockwise moment

Step 3: Substitute in the values from Step 1, and solve.

$$\begin{aligned}(20\,\text{N} \times 0.5\,\text{m}) + (10\,\text{N} \times 1.5\,\text{m}) &= F \times 0.5\,\text{m}\\ 10\,\text{Nm} + 15\,\text{Nm} &= F \times 0.5\,\text{m}\\ 25\,\text{Nm} &= F \times 0.5\,\text{m}\\ F &= \frac{25\,\text{Nm}}{0.5\,\text{m}}\\ &= 50\,\text{N}\end{aligned}$$

CONTINUED

Answer

A force of 50 N must be applied downwards at the other end to balance the beam.

You might have been able to work this out in your head, by looking at the diagram. The 20 N weight requires 20 N to balance it, and the 10 N at 1.5 m needs 30 N at 0.5 m to balance it. So the total force needed is 50 N.

In equilibrium

In Figure 4.10, three forces are shown acting downwards. There is also the weight of the see-saw itself, 200 N, to consider, which also acts downwards, through its midpoint. If these were the only forces acting, they would make the see-saw accelerate downwards. Another force acts to prevent this from happening. There is an upward contact force where the see-saw sits on the pivot. Figure 4.12 shows all five forces.

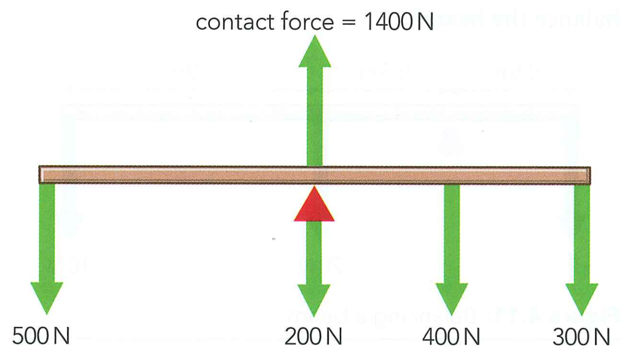


Figure 4.12: A force diagram for the see-saw shown in Figure 4.10. The upward contact force of the pivot on the see-saw balances the downward forces of the children's weights and the weight of the see-saw itself. The contact force has no moment about the pivot because it acts through the pivot. The weight of the see-saw is another force that acts through the pivot, so it also has no moment about the pivot.

Because the see-saw is in equilibrium, we can calculate this contact force. It must balance the four downward forces, so its value is (500 + 200 + 400 + 300) N = 1400 N, upwards. This force has no turning effect because it acts through the pivot. Its distance from the pivot is zero, so its moment is zero.

Now we have satisfied the two conditions that must be met if an object is to be in equilibrium:

- there must be no resultant force acting on it
- total clockwise moment = total anticlockwise moment.

You can use these two rules to solve problems concerning the forces acting on objects in equilibrium.

Sometimes we know that the forces and moments acting on an object are balanced. Then we can say that it is in equilibrium. Sometimes we know the reverse, namely, that an object is in equilibrium. Then we can say that there is no resultant force on it, and no resultant moment.

Questions

9 A uniform metre ruler is balanced at its centre (Figure 4.13).

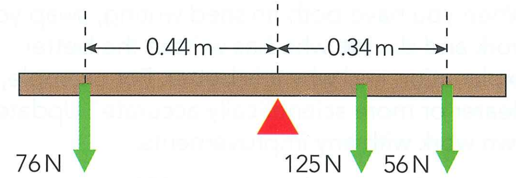


Figure 4.13: Balanced uniform metre ruler.

a Calculate the distance to the right of the pivot that the 125 N load needs to be placed for the ruler to be balanced.

b Calculate the contact force acting at the pivot.

10 A beam is balanced on a pivot 0.33 metres from its left-hand side (Figure 4.14).

The beam balances when a weight of 0.47 N is suspended 0.13 metres from the same end.

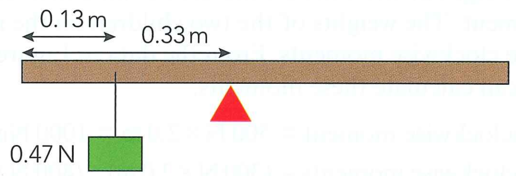


Figure 4.14: Balanced beam.

a Calculate the anticlockwise moment of the 0.47 N force.

b What is the moment due to the weight of the rod?

c The weight of the rod is 0.79 N. Calculate the position of its centre of gravity to the right of the pivot.

EXPERIMENTAL SKILLS 4.1

A question of balance

Engineers need to design structures that do not fall down when the forces on them change location or magnitude (size). For example, a building needs to stay standing when wind blows against it with different strengths or from different directions. Bridges should not bend or collapse when vehicles cross them. You will test whether there is a resultant moment on an object that is in equilibrium. You will test the moment of a force and the principle of moments in this experiment.

You will need:

- a metre ruler
- two 10 N spring balances
- set of 100 g masses
- two clamp-stands with clamps and bosses
- three cotton loops

Safety: Take care not to drop the masses on your feet.

Getting started

- What is meant by equilibrium?
- What is the moment of a force?
- What is the principle of moments?
- Where would you expect the centre of gravity to be for a metre ruler?
- Figure 4.15 shows a lorry about to be driven across a bridge supported by columns A and B. Describe the force at column A as the lorry travels between A and B and then beyond column B.

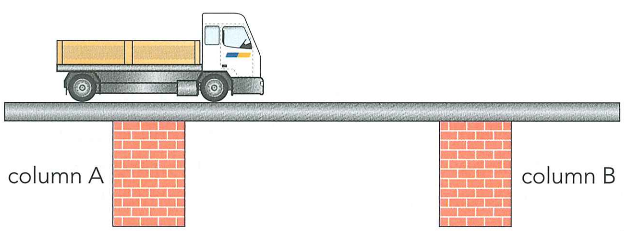


Figure 4.15: Lorry on a bridge.

Method

1 Set up the apparatus as shown in Figure 4.16 with the loops for the spring balances about 5 cm from each end of the ruler. You are going to move the load to different positions along the ruler. Make sure that the ruler is horizontal before you take each measurement by moving the clamps holding one of the spring balances up or down its clamp-stand.

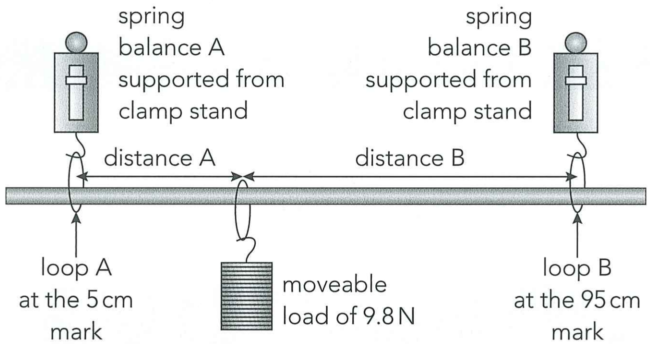


Figure 4.16: Apparatus for investigation.

2 Hang the 9.8 N from the ruler so that distance A = 10 cm and distance B = 80 cm.

3 Note down the readings on both of the spring balances, F_A and F_B, and calculate ($F_A + F_B$). Record all the values in a copy of the table below:

Distance from A / m	F_A / N	F_B / N	$F_A + F_B$ / N
0.1			

4 Move the load about 10 cm along the ruler towards B. Make sure the ruler is horizontal and then record all the measurements required to complete the next row of the table.

5 Repeat this process until the load is at a distance of 0.8 m from A.

6 On the same axes, plot line graphs of F_A, F_B and $F_A + F_B$ on the vertical axis against the distance from A on the horizontal axis.

CONTINUED

Questions

1 Why did you have to make sure that the ruler was horizontal before each measurement was made?

2 Calculate the mean of your ($F_A + F_B$) values. This should be more than the load of 9.81 N hanging from the ruler. Can you explain why?

3 Measure the mass of the ruler and work out its weight. Does this account for the difference in the last question?

4 Instead of doing the experiment, it can be solved mathematically by taking moments about either spring balance. For example, the force at spring balance A, F_A, can be solved by taking moments about B (and taking into account of the ruler to get a more accurate result).

ACTIVITY 4.2

Understanding the shadoof

The Ancient Egyptians used the shadoof to lift water and irrigate the land. It is still in use today (see Figure 4.17).

Figure 4.17: A Sudanese man irrigates his land using a shadoof.

The shadoof has a counterweight at the short end and a bucket at the long end of a beam. It takes as much effort to move the bucket down as it does to pull it up.

Unless your teacher gives you a time, spend one minute thinking on your own, one minute of discussion with your neighbour and then be prepared to share your answers to question 1 with the class.

1 a What is the advantage of making it take as much effort to push the bucket down as it does to pull it up?

b Explain how the shadoof does this.

2 Draw a diagram of the shadoof and include the pivot, the counterweight and the forces acting on it. You could estimate the lengths of the beam and assume that the counterweight has a weight of 150 N.

If you are given time and the equipment, make a working model.

REFLECTION

Did you understand the physics in Activities 4.1 and 4.2? A good test of your understanding is whether you can explain it clearly. Are you able to support your explanations with clear and correct force diagrams? If you are still unsure, ask a classmate to explain it.

4.3 Stability and centre of gravity

People are tall and thin, like a pencil standing on end. Unlike a pencil, we do not topple over when touched by the slightest push. We are able to remain upright, and to walk, because we make continual adjustments to the positions of our limbs and body. We need considerable brain power to control our muscles for this. The advantage is that, with our eyes about a metre higher than if we were on all-fours, we can see much more of the world.

Circus artistes such as tightrope walkers and high-wire artistes (Figure 4.18) have developed the skill of remaining upright to a high degree. They use items such as poles or parasols to help them maintain their balance. The idea of moments can help us to understand why some objects are **stable** while others are more likely to topple over.

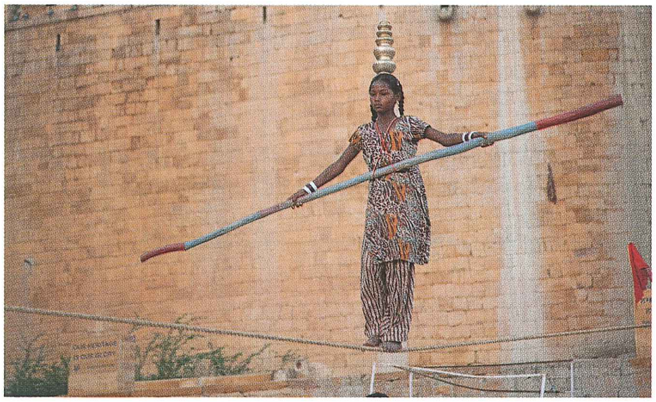


Figure 4.18: This high-wire artiste is using a long pole to maintain her stability on the wire. If she senses that her weight is slightly too far to the left, she can redress the balance by moving the pole to the right. Frequent, small adjustments allow her to walk smoothly along the wire.

A tall glass can be knocked over easily – it is **unstable**. Figure 4.19 shows what happens if the glass is tilted.

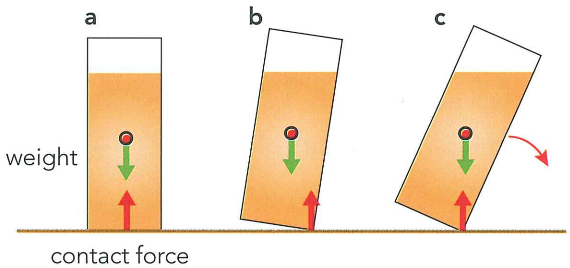


Figure 4.19: A tall glass is easily toppled. Once the line of action of its weight is beyond the edge of the base the glass tips right over.

In Figure 4.19a, the glass is upright. Its weight acts downwards and the contact force of the table acts upwards. The two forces are in line, and the glass is in equilibrium.

In Figure 4.19b, the glass is tilted slightly to the right, and the forces are no longer in line. There is a pivot at the point where the base of the glass is in contact with the table. The line of the glass's weight is to the left of this pivot, so it has an anticlockwise moment, which tends to tip the glass back to its upright position.

In Figure 4.19c, the glass is tipped further. Its weight acts to the right of the pivot, and has a clockwise moment, which makes the glass tip right over.

Centre of gravity

In Figure 4.19, the weight of the glass is represented by an arrow starting at a point inside the liquid. Why is this? The reason is that the glass behaves as if all of its mass were concentrated at this point, known as the **centre of gravity**. The force of gravity acts on the mass of the glass – each bit of the glass is pulled by the Earth's gravity. However, rather than drawing lots of weight arrows, one for each bit of the glass, it is simpler to draw a single arrow acting through the centre of gravity. (Because we can think of the weight of the glass acting at this point, it is sometimes known as the centre of gravity.)

KEY WORDS

stable: an object that is unlikely to topple over, often because it has a low centre of gravity and a wide base

unstable: an object that is likely to topple over, often because it has a high centre of gravity and a narrow base

centre of gravity: all the mass of an object could be located here and the object would behave the same (when ignoring any spin)

Figure 4.20 shows the position of the centre of gravity for several objects. A person is fairly symmetrical, so their centre of gravity must lie somewhere on the axis of symmetry. (This is because half of their mass is on one side of the axis, and half on the other.) The centre of gravity is in the middle of the body, roughly level with the navel. A ball is much more symmetrical, and its centre of gravity is at its centre.

For an object to be stable, it should have a low centre of gravity and a wide base. The pyramid in Figure 4.20 is an example of this. The high-wire artiste shown in Figure 4.18 has to adjust her position so that her centre of gravity remains above her base, which is the point where her feet make contact with the wire.

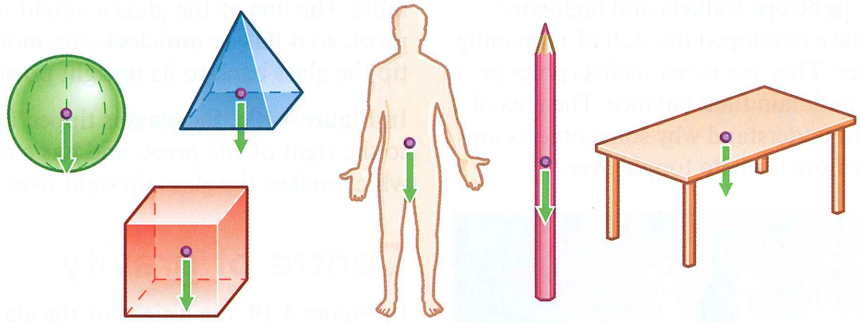


Figure 4.20: The weight of an object acts through its centre of gravity. Symmetry can help to judge where the centre of gravity lies. An object's weight can be considered to act through this point. Note that, for the table, its centre of gravity is in the air below the table top.

Finding the centre of gravity

Balancing is the clue to finding an object's centre of gravity. A metre ruler balances at its midpoint, so that is where its centre of gravity must lie.

The procedure for finding the centre of gravity of a more irregularly shaped object is shown in Figure 4.21. In this case, the object is a piece of card, described as a plane **lamina**. The card is suspended from a pin. If it is free to move, it hangs with its centre of gravity below the point of suspension. This is because its weight pulls it round until the weight and the contact force at the pin are lined up. Then there is no moment about the pin. A plumb-line is used to mark a vertical line below the pin. The centre of gravity must lie on this line.

The process is repeated for two more pinholes. Now there are three lines on the card, and the centre of gravity must lie on all of them, that is, at the point where they intersect. Two lines might have been enough, but it is advisable to use at least three points to reveal any inaccuracies.

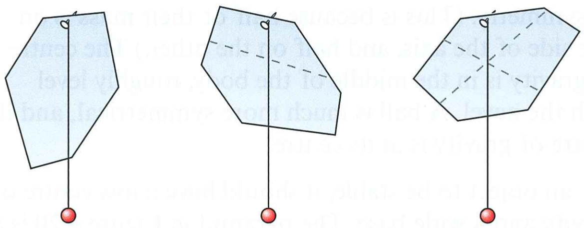


Figure 4.21: Finding the centre of gravity of an irregularly shaped piece of card. The card hangs freely from the pin. The centre of gravity must lie on the line indicated by the plumb-line hanging from the pin. Three lines are enough to find the centre of gravity.

KEY WORD

lamina: flat two-dimensional shape

EXPERIMENTAL SKILLS 4.2

Centre of gravity of a plane lamina

You will investigate a technique for finding the centre of gravity of a piece of rectangular card. Once you gain confidence that the technique works, you will apply it to an irregular shape, perhaps the map of your country. Locating the centre of gravity of a body is important when considering its stability.

You will need:

- at least two pieces of card
- a hole punch
- a pencil
- a pair of scissors
- a ruler
- a clamp stand and boss
- a pin (or short thin metal rod)
- a length of string with a weight (plumb bob) attached.

Safety: The pin and the scissors should be handled with care to avoid cutting someone. Wear eye protection if using a pin (as opposed to a thin metal rod). Ensure that the pin is not at eye height and is pointing away from the edge of the bench.

CONTINUED

Getting started

- Predict where the centre of gravity is located on the rectangular lamina.
- Predict where the centre of gravity is located on the shape you propose.
- Can you suggest shapes where the centre of gravity would not be on the card?

Method: Part 1

Find the centre of gravity of a rectangular sheet of card. This is your lamina.

1 Use the hole punch to make three holes far apart around the edge of the lamina.
2 Fix the pin horizontally in the clamp.
3 Using one hole, hang the lamina from the pin. Make sure that it can swing freely.
4 Hang the string from the pin so that the weight makes it hang vertically. Mark two points on the lamina along the length of the string.
5 Repeat steps 3 and 4 using the other two holes.
6 Lay the lamina on the bench and, using a ruler, draw lines joining each pair of points. Where the lines cross is the centre of gravity of the lamina. It should be where the lines of symmetry coincide but, if the three lines cross exactly at a point, you have done well!

Method: Part 2

Repeat part 1 after you have cut a shape out of the lamina. See if you can get a map of your country printed on the card so that you can find its centre of gravity.

Questions

1 Did the three lines you drew intersect at the same point?
2 If the three lines did not intersect at the same point, how did you decide where the centre of gravity is located?
3 If the three lines did not intersect at the same point, how much confidence do you have in the location you have chosen?
4 Suggest a way of checking that you have located (found) the centre of gravity?
5 Explain why the centre of gravity of the lamina lies on a vertical line below the pin (pivot).

PEER ASSESSMENT

Swap your work with a partner for Experimental skills 4.2.

Give them a smiley face for the following:

- three neatly drawn and closely intersecting lines on their rectangular lamina (as this shows careful experimental technique)
- three closely intersecting lines on their irregular shape
- correct answer to the Getting Started questions
- a clear and correct explanation of why the centre of gravity is vertically below the pivot.

Finally, discuss anything that you can learn from each other.

Questions

11 On a copy of the shapes below, mark the centre of gravity for each with an X. Where possible, show lines that helped you locate the centre of gravity.

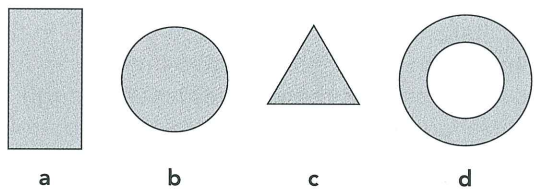


Figure 4.22: Laminar shapes.

12 Buses and other vehicles have to be tilt-tested to an angle of at least 28 degrees from the vertical before they can carry passengers.

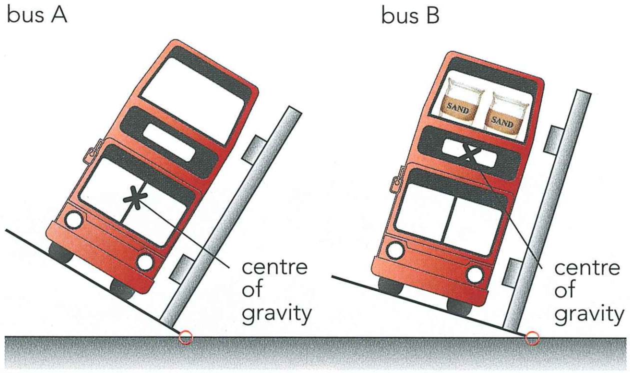


Figure 4.23: Both of these double-decker buses would topple over if tilted any further.

a Use the ideas of stability and centre of gravity to explain why either bus in Figure 4.23 would topple over if tilted any further. You can draw on copies of the diagrams to help with your explanation.

b Explain how the stability of the bus would be affected by having more passengers on the upper deck.

c Explain why bags of sand are only put on the top deck of bus B and not the lower deck.

13 Figure 4.24 shows the forces acting on a cyclist.

a Explain how you can tell that the cyclist shown in Figure 4.24a is in equilibrium.

b Are the forces on the cyclist in Figure 4.24b balanced now? How can you tell?

c Would you describe the cyclist as stable or unstable? Explain your answer.

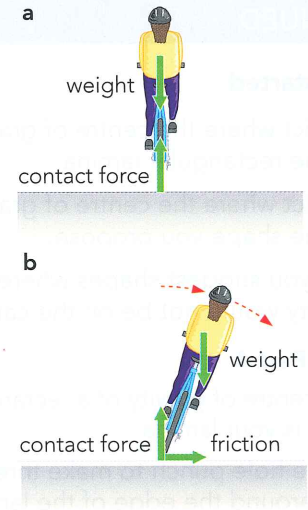


Figure 4.24: Forces acting on a cyclist.

PROJECT

The Italian Job

The Italian Job was a film made in 1969. In this film a gang steals gold worth $4 million in Turin, northern Italy. As the gang escapes through Switzerland on a bus, the driver loses control. The bus ends up with its rear half hanging over the edge of a vertical drop. Any attempt to reach the gold at the back of the coach risks sending the bus, the men and the gold crashing into the valley below. The film finishes with Croker saying: 'Hang on a minute lads, I've got a great idea'. The film is available online but only the last five minutes are important from a physics viewpoint.

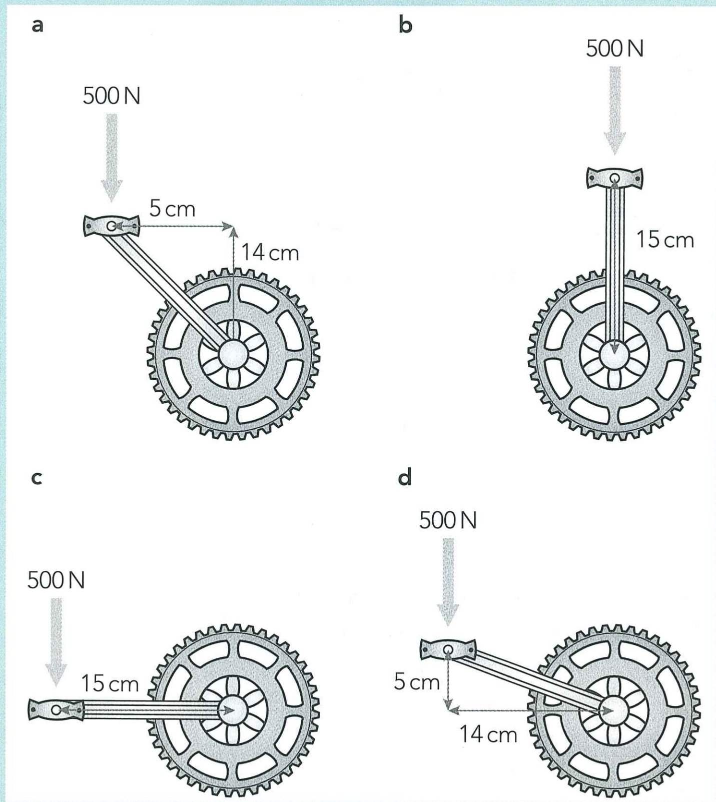
- You need to suggest what Croker's 'great idea' might have been to save the gold and get off the coach safely. You should work in groups of three.
- Start by describing the problem using correct scientific terms like 'pivot', 'centre of gravity', 'equilibrium', 'moment' and 'the principle of moments'.
- Make a storyboard of your solution and include it as part of a two-minute pitch for a sequel to the film.
- Select the best pitch (with correct or corrected physics) from three or four groups of three to present to the rest of the class.

SUMMARY

The moment of a force is a measure of its turning effect.
Increasing force or distance from the pivot increases the moment of a force.
Moment of a force = force × perpendicular distance from the pivot.
An object is in equilibrium when the forces on it are balanced (no resultant force) and the turning effects of the forces on it are balanced (no resultant turning effect).
The centre of gravity is the point at which the weight of an object appears to be concentrated.
The location of the centre of gravity affects stability.

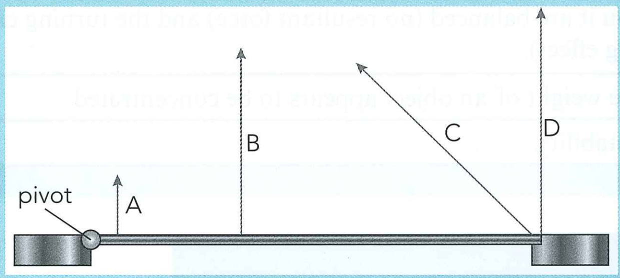
EXAM-STYLE QUESTIONS

1 The pictures show different positions of a bicycle pedal.
Which position would result in the biggest turning force? **[1]**

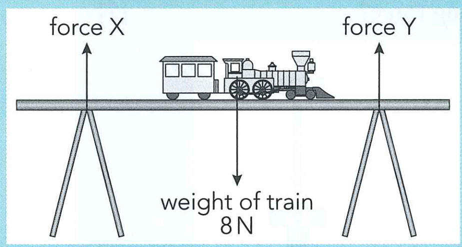


CONTINUED

2 This is a plan view of a gate that will swing open about the pivot shown. Also shown are the positions for a motor and the direction they will move the gate. The length of the arrows indicates the size of the force. Choose the arrow that will swing the gate open the quickest. **[1]**



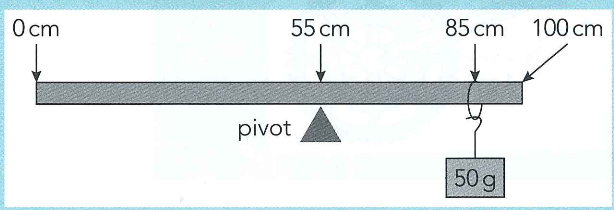
3 A toy train is crossing a bridge.



The centre of gravity of the train is mid-way between the supports. Which row of the table shows the correct values of the contact forces at X and Y? **[1]**

	Force X/N	Force Y/N
a	8	0
b	0	8
c	4	4
d	8	8

4 A 1.0 metre wooden ruler is damaged and no longer uniform. The mass of the ruler is 11.5 g. The ruler is balanced on a pivot with a 50 g mass as shown.



Where is the centre of gravity of the ruler? **[1]**

A at the 13 cm mark
B at the 42 cm mark
C at the 60 cm mark
D at the 68 cm mark

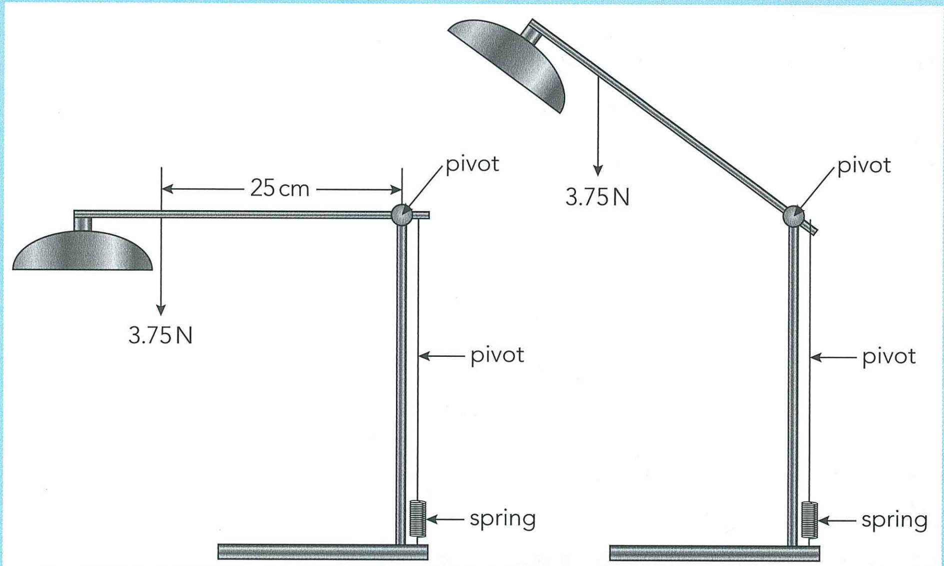
CONTINUED

5 **State** two ways that the turning force can be increased. [2]

6 State two pieces of evidence that would tell you that a body is not in equilibrium. [2]

7 The diagram shows an angle-poise lamp. The light is at the end of an arm. The arm can be moved about the pivot. The cord passes vertically down to a stretched spring.

The weight of the lamp and arm is 3.75 N and acts at a distance of 25 cm from the pivot.



a Write down the equation used to calculate the moment of a force. [1]

b **Calculate** the moment of the 3.75 N force about the pivot when the arm is horizontal. [2]

c The arm is raised as shown in the diagram.

i **Explain** what has happened to the moment of the 3.75 N force about the pivot. [1]

ii Explain what has happened to the clockwise moment produced by the spring. [1]

[Total: 5]

COMMAND WORDS

state: command term not supplied

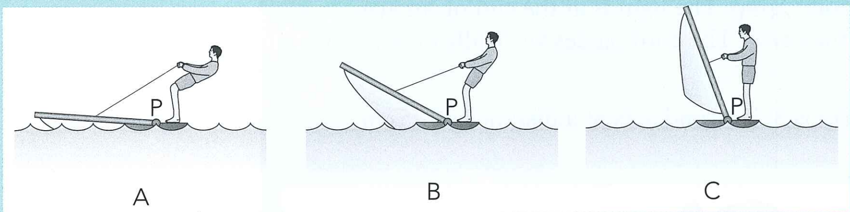
calculate: work out from given facts, figures or information

explain: set out purposes or reasons; make the relationships between things evident; provide why and/or how and support with relevant evidence

CONTINUED

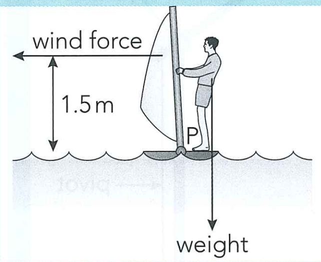
8 The diagrams show a windsurfer pulling up the sail of a sailboard. The sail pivots where it joins with the board at point P.

a As the sail is pulled up from A to C, how does the force needed vary? Explain your answer. **[2]**



The windsurfer and the sailboard shown in the diagram below are in equilibrium.

b What does equilibrium mean? **[1]**



The windsurfer weighs 900 N. The wind is blowing with a force of 300 N. The windsurfer maintains equilibrium.

c Calculate how far to the right of the pivot the windsurfer has to move his centre of gravity. **[2]**

d What would the windsurfer need to do if the force of the wind decreased? Explain your answer. **[2]**

[Total: 7]

SELF-EVALUATION CHECKLIST

After studying this chapter, think about how confident you are with the different topics. This will help you to see any gaps in your knowledge and help you to learn more effectively.

I can	See Topic...	Needs more work	Almost there	Confident to move on
Give everyday examples of a turning force.	4.1			
Understand that increasing force or distance from the pivot increases the moment of a force.	4.1			
Calculate the moment using the product force × perpendicular distance from the pivot.	4.2			
Apply the principle of moments to balancing a beam.	4.2			
Apply the principle of moments to different situations, including when there is more than one moment on either side of the pivot.	4.2			
Perform an experiment to find the centre of gravity of a piece of card.	4.3			
Describe how the location of the centre gravity affects stability.	4.3			