OCR A Level Physics

Your notes

Moments

Contents

Moments

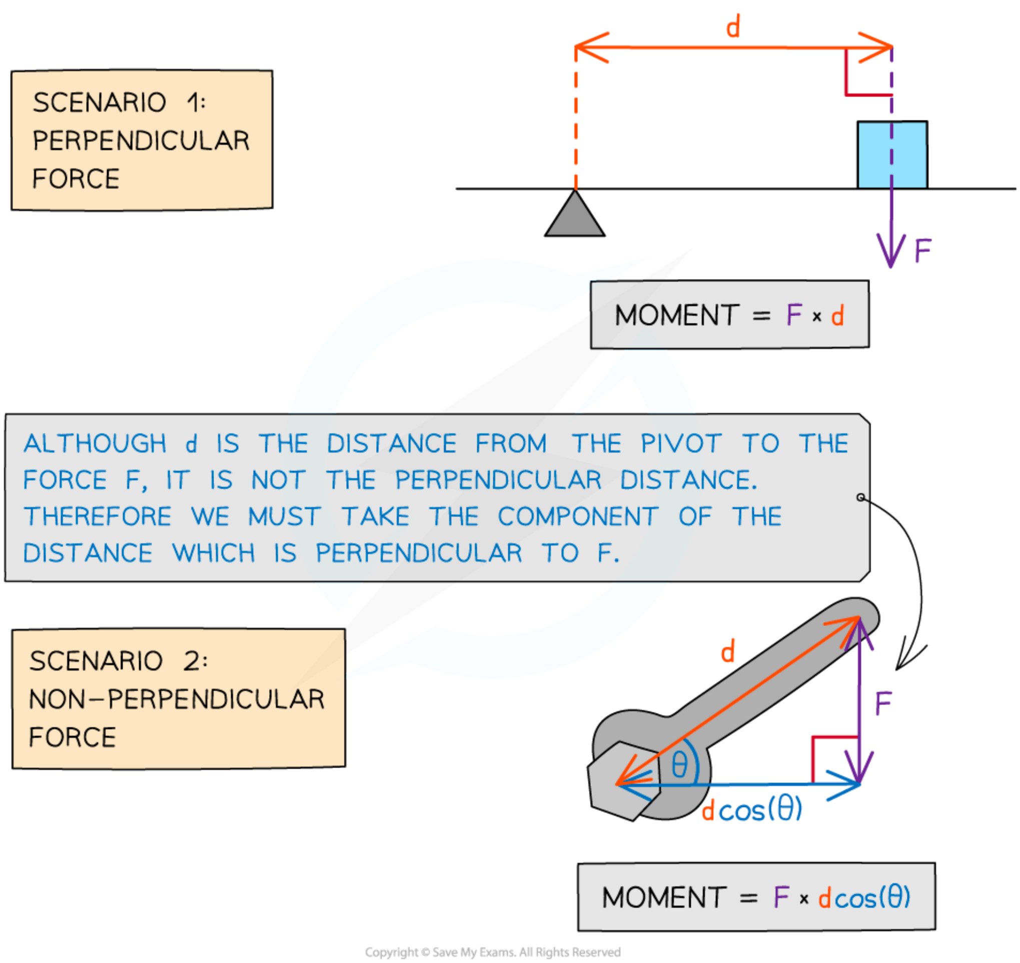
Your notes

What is a Moment?

- A moment is the **turning effect of a force**
- Moments occur when forces cause objects to **rotate** about some pivot
- The moment of a force is given by

Moment (**N m**) = Force (**N**) × perpendicular distance from the pivot (**m**)

- The SI unit for the moment is Newton metres (**N m**). This may also be Newton centimetres (**N cm**) depending on the units given for the distance



The force might not always be perpendicular to the distance

- An example of moments in everyday life is opening a door
- The door handle is placed on the other side of the door to the hinge (the pivot) to **maximise** the distance for a given force and therefore provide a greater moment (turning force)
  - This makes it easier to push or pull it

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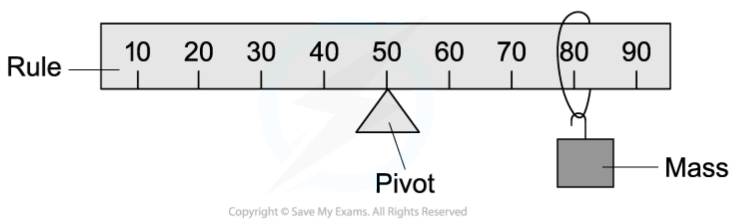
Worked Example

A uniform metre rule is pivoted at the 50 cm mark.

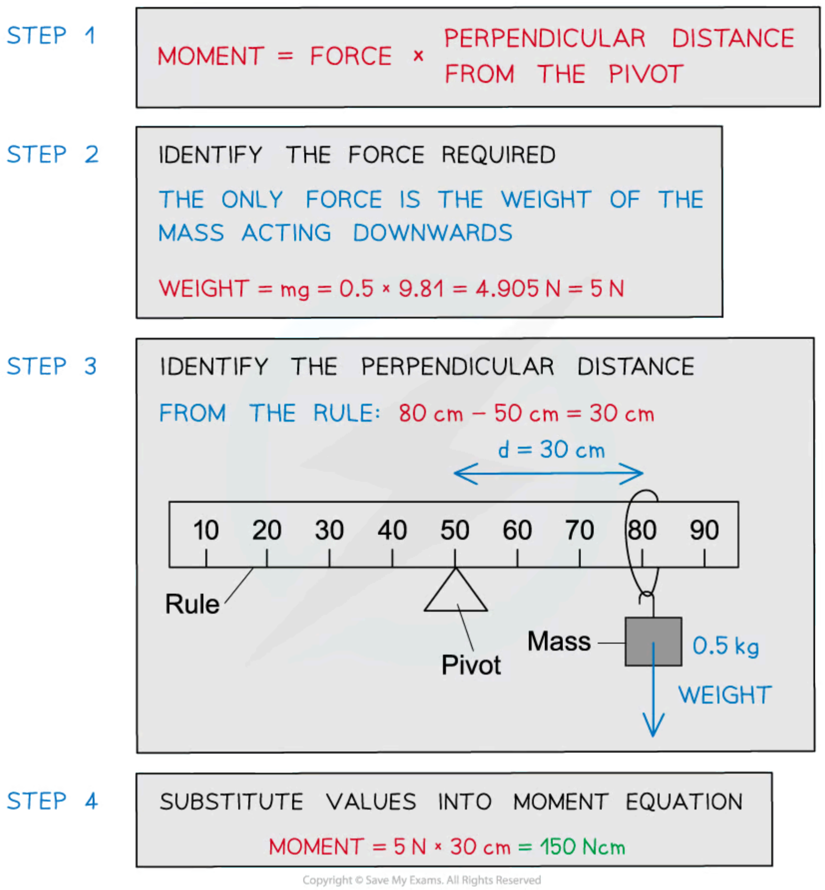
A 0.5 kg weight is suspended at the 80 cm mark, causing the rule to rotate about the pivot.

Assuming the weight of the rule is negligible, what is the turning moment about the pivot?



Answer:

Your notes



Examiner Tips and Tricks

If not already given, drawing all the forces on an object in the diagram will help you see which ones are perpendicular to the distance from the pivot. Not all the forces will provide a turning effect and it is not unusual for a question to provide more forces than required to throw you off!

The Principle of Moments

- The principle of moments states:

For a system to be in equilibrium, the sum of clockwise moments about a point must be equal to the sum of the anticlockwise moments (about the same point)

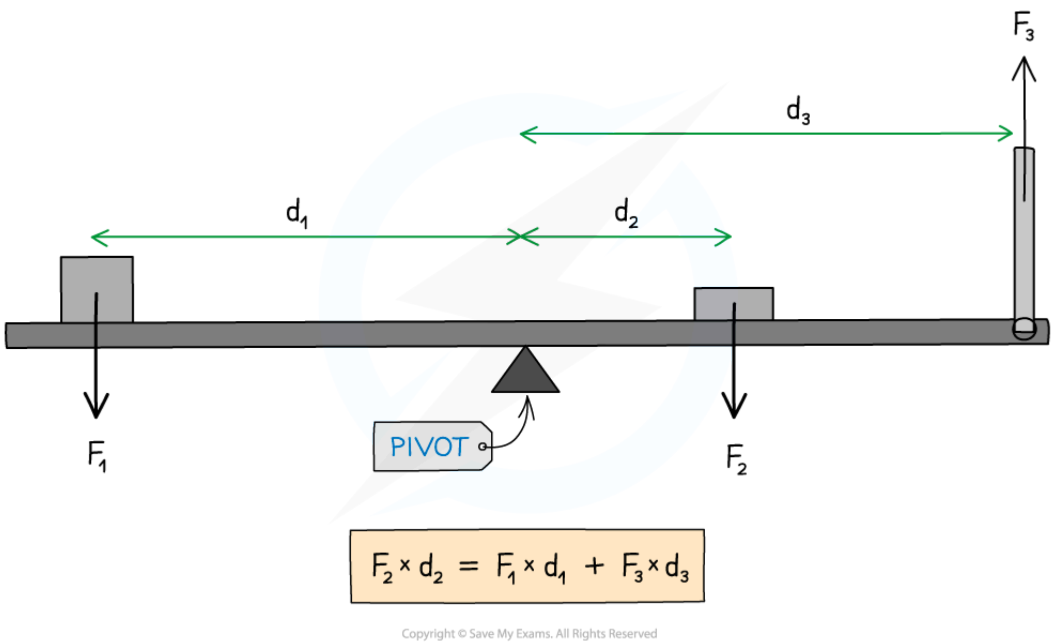


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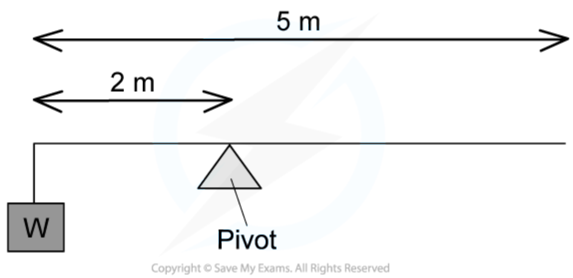
Diagram showing the moments acting on a balanced beam

- In the above diagram:
  - Force F_2 is supplying a clockwise moment;
  - Forces F_1 and F_3 are supplying anticlockwise moments
- Hence: $F_2 \times d_2 = (F_1 \times d_1) + (F_3 \times d_3)$

Worked Example

A uniform beam of weight 40 N is 5 m long and is supported by a pivot situated 2 m from one end. When a load of weight W is hung from that end, the beam is in equilibrium as shown in the diagram.



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What is the value of W?

A. 10 N

B. 50 N

C. 25 N

D. 30 N

Answer:

ANSWER: A

STEP 1

PRINCIPLE OF MOMENTS STATES THAT

CLOCKWISE MOMENTS = ANTICLOCKWISE MOMENTS

STEP 2

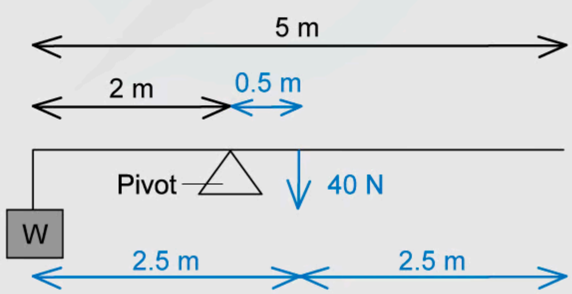
CALCULATE THE CLOCKWISE MOMENT

SINCE THE BEAM IS UNIFORM, ITS WEIGHT WILL ACT AT ITS CENTRE OF GRAVITY (THE MIDDLE)

THIS IS $5 \div 2 = 2.5$ m FROM THE END

SINCE THE PIVOT IS 2m FROM THE END, THIS FORCE IS 0.5 m FROM THE PIVOT

CLOCKWISE MOMENT = 40 N × 0.5 m = 20 Nm



STEP 3

CALCULATE THE ANTICLOCKWISE MOMENT

ANTICLOCKWISE MOMENT = W × 2m

STEP 4

EQUATE BOTH THESE MOMENTS

20 Nm = W × 2m

STEP 5

REARRANGE FOR W

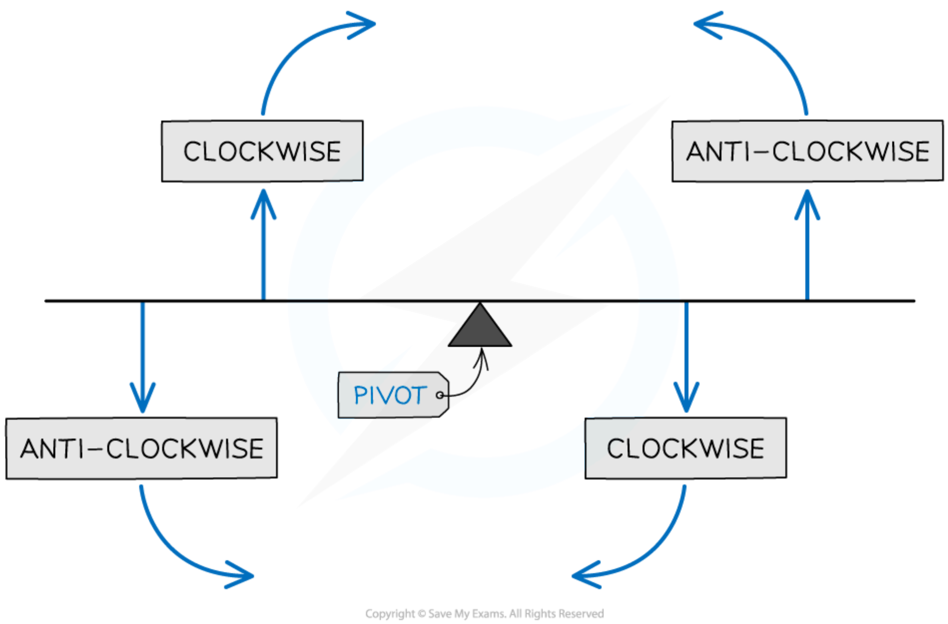
$$W = \frac{20 \text{ Nm}}{2\text{m}} = 10 \text{ N}$$

Your notes

Your notes

Examiner Tips and Tricks

Make sure that all the distances are in the same units and you're considering the correct forces as clockwise or anticlockwise, as seen in the diagram below



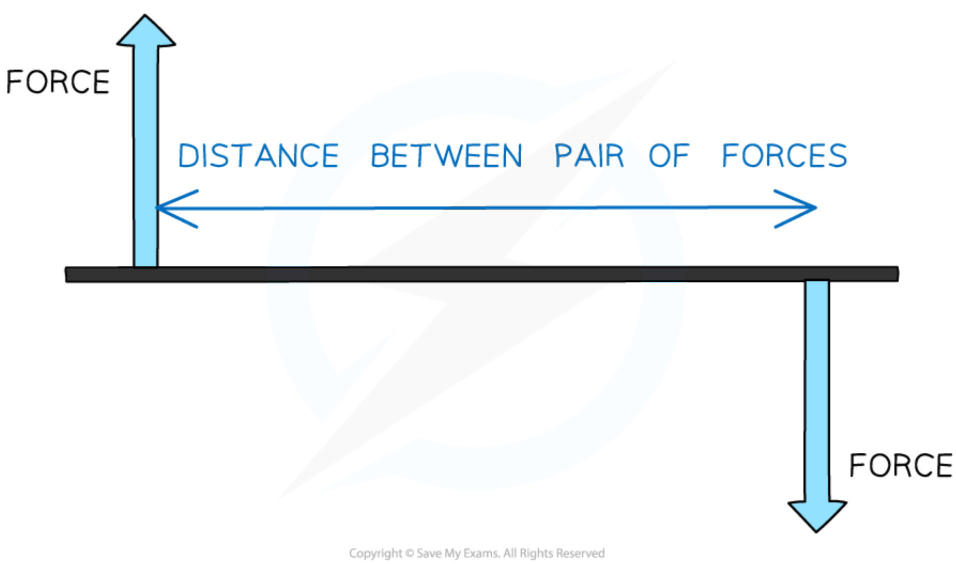
Couples & Torque

Your notes

Couples & Torque

Couples

- A couple is a **pair** of equal and opposite coplanar forces that acts to produce **rotation** only
- A couple consists of a pair of forces that are:
    - Equal in magnitude
    - Opposite in direction
    - Perpendicular to the distance between them



A couple must consist of two equal and opposite forces separated by a perpendicular distance

- Couples produce a resultant force of **zero**, so, due to Newton's Second law (**F** = **ma**), the object does **not** accelerate
    - The size of this turning effect is given by its **torque**
- Unlike moments of a single force, the moment of a couple doesn't depend on a pivot
- The moment of a couple is equal to:

Your notes

Force × Perpendicular distance between the lines of action of the forces

Torque

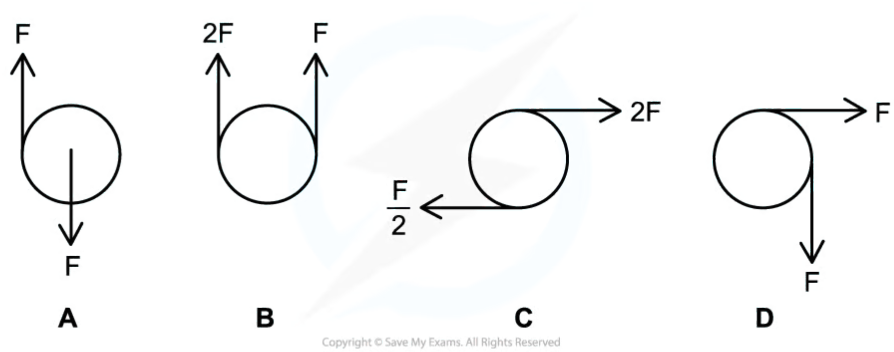
- The moment of a couple is known as a **torque**
- The torque of a couple can be calculated with the following equation

$$\tau = Fd$$

- Where:
  - τ = torque (N m)
  - F = one of the forces (N)
  - d = perpendicular distance between the forces (m)

Worked Example

Which pair of forces act as a couple on the circular object?



Answer: A

- In diagram **A**, the forces are:
  - Equal in size
  - In opposite directions
  - Perpendicular to the distance between them
- **B** is incorrect as the forces are in the same direction
- **C** is incorrect as the forces are different in size
- **D** is incorrect as the distance between the forces is not perpendicular

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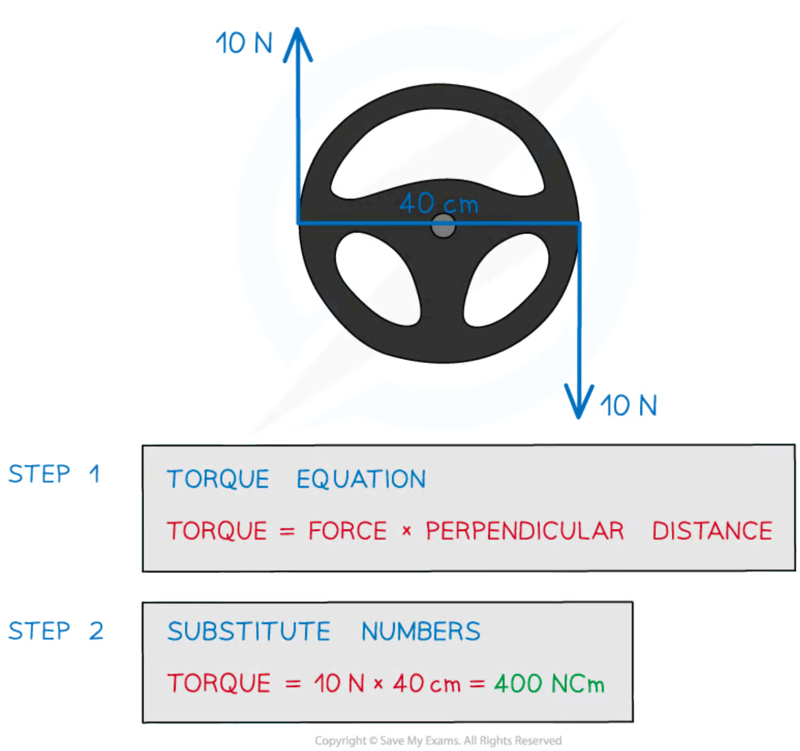
Worked Example

A steering wheel of diameter 40 cm and the force of the couple needed to turn it is 10 N. Calculate the torque on the steering wheel.

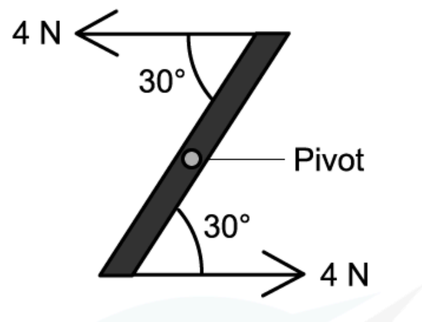
Answer:



Worked Example

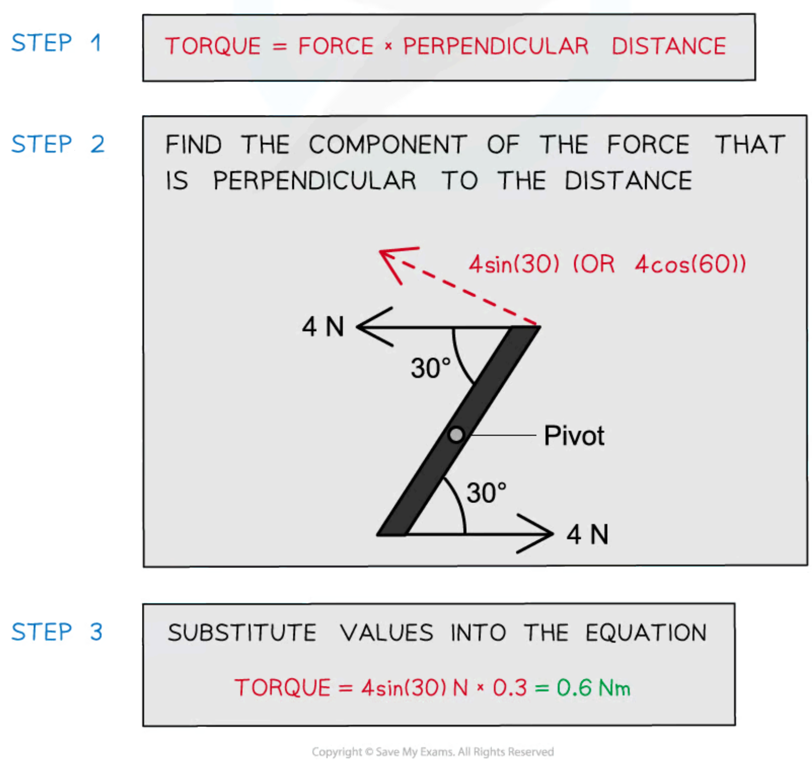
A rule of length 0.3 m is pivoted at its centre. Equal and opposite forces of magnitude 4.0 N are applied to the ends of the ruler, created a couple as shown below.

Your notes



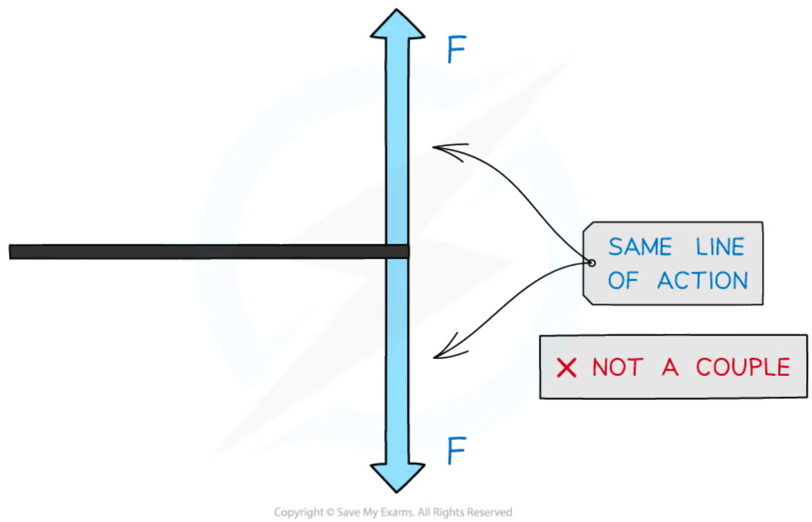
What is the magnitude of the torque of the couple on the ruler when it is at the position shown?

Answer:



Examiner Tips and Tricks

The forces given might not always be perpendicular to the distance between them. In this case, remember to find the component of the force vector that **is** perpendicular by resolving the force vector. The forces that make up a couple cannot share the same line of action which is the line through the point at which the force is applied. An example of this is shown in the diagram below:



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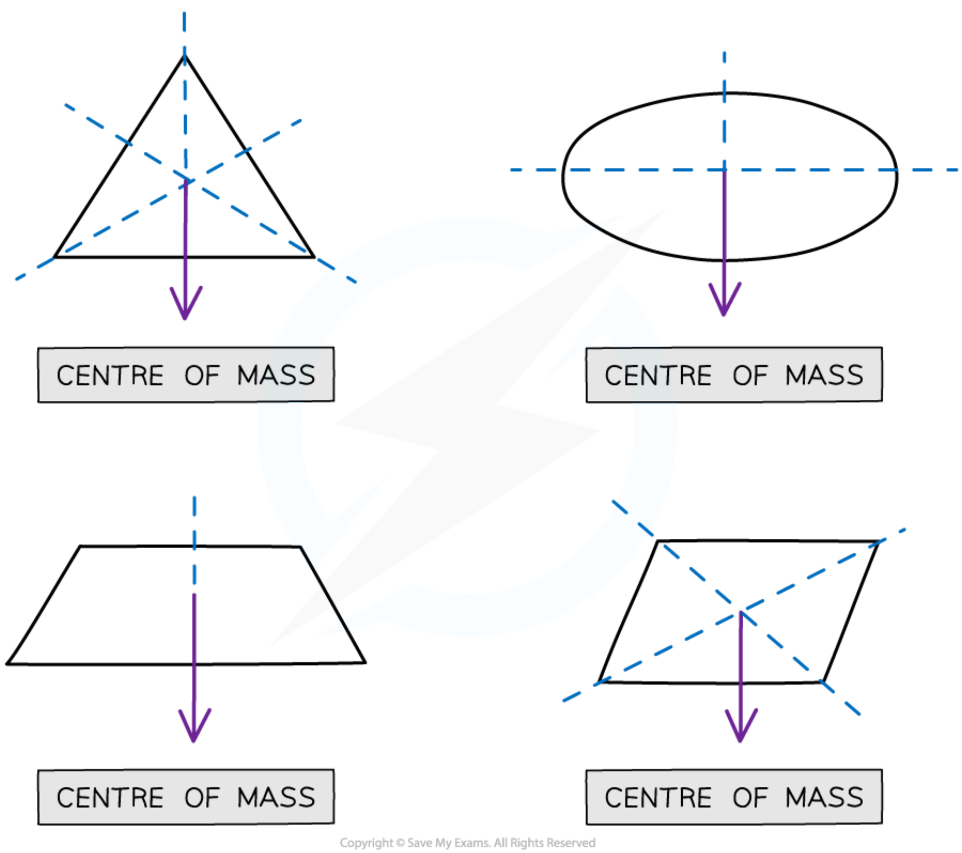
Centre of Mass

Centre of Mass

- The centre of mass of an object is **the point at which the weight of the object may be considered to act**
- The position of the centre of mass of uniform regular solid is at its centre
  - For example, for a person standing upright, their centre of mass is roughly in the middle of the body behind the navel, and for a sphere, it is at the centre
- For symmetrical objects with uniform density, the centre of mass is located at the **point of symmetry**



The centre of mass of a shape can be found by symmetry

Stability

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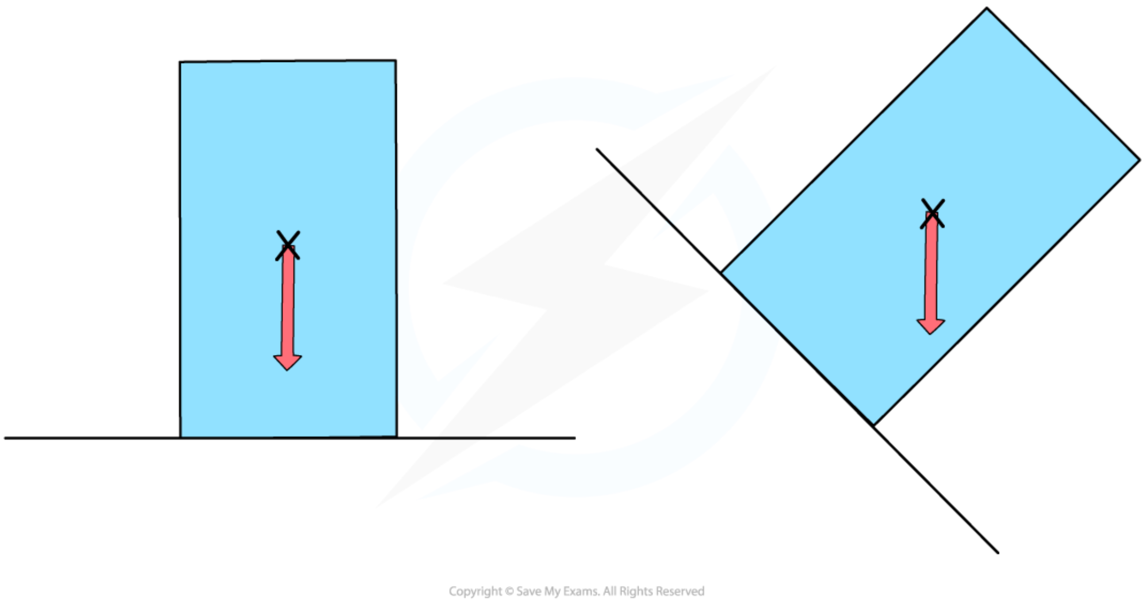
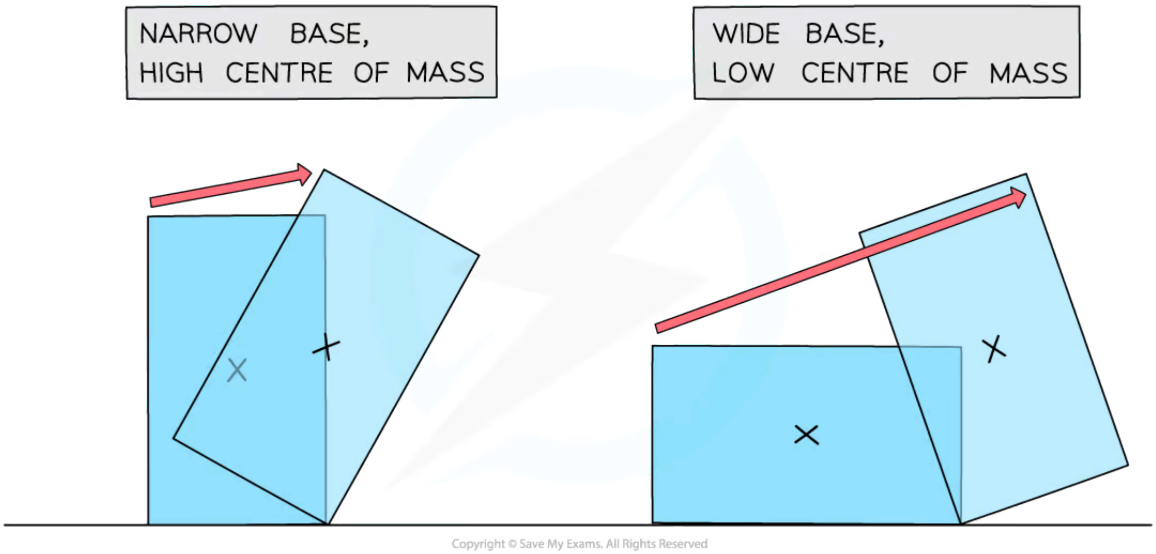
- The position of the centre of mass of an object affects its stability
- An object is stable when its centre of mass lies above its base



The object on the right will topple, as its centre of mass is no longer over its base

- The **wider** base an object has, the **lower** its centre of mass and it is more **stable**
- The **narrower** base an object has, the **higher** its centre of mass and the object is more likely to topple over if pushed



The most stable objects have wide bases and low centres of mass

Finding the Centre of Mass

- When an object is suspended from a point, the object will always settle so that its centre of mass comes to rest **below the pivoting point**
- This can be used to find the centre of mass of an irregular shape:

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Your notes

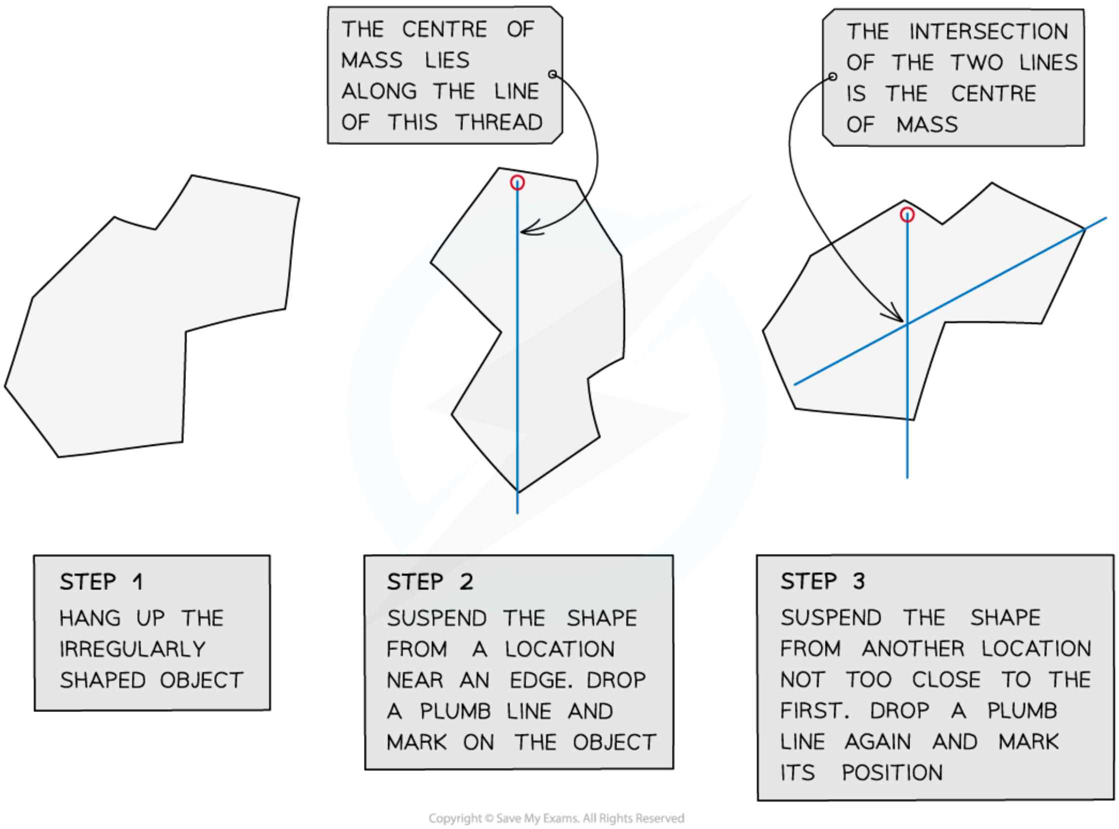

Diagram showing an experiment to find the centre of mass of an irregular shape

- The irregular shape (a plane laminar) is suspended from a pivot and allowed to settle
- A plumb line (a lead weight) is then held next to the pivot and a pencil is used to draw a vertical line from the pivot
  - The centre of mass **must** be somewhere on this line
- The process is then repeated, suspending the shape from two or three different points
- The centre of mass is located at the point where **all three lines cross**

Centre of gravity v Centre of mass

- In a uniform gravitational field, the centre of gravity is **identical** to the centre of mass
- The centre of mass does **not** depend on the gravitational field
- Since weight = mass × acceleration due to gravity, the centre of gravity **does** depend on the gravitational field

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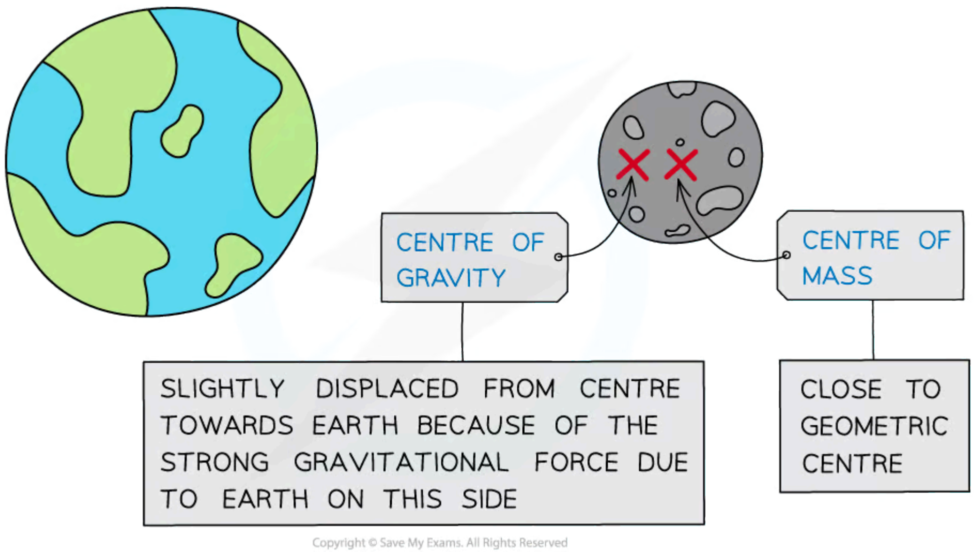
- When an object is in space, its centre of gravity will be more towards the object with the larger gravitational field
  - For example, the Earth's gravitational field on the Moon:



The Earth's stronger gravitational field pushes the Moons centre of gravity closer to Earth

Examiner Tips and Tricks

Since the centre of mass is a hypothetical point, it can lie inside or outside of a body. The centre of mass will constantly shift depending on the shape of a body. For example, a human body's centre of mass is lower when leaning forward than upright

Equilibrium

Your notes

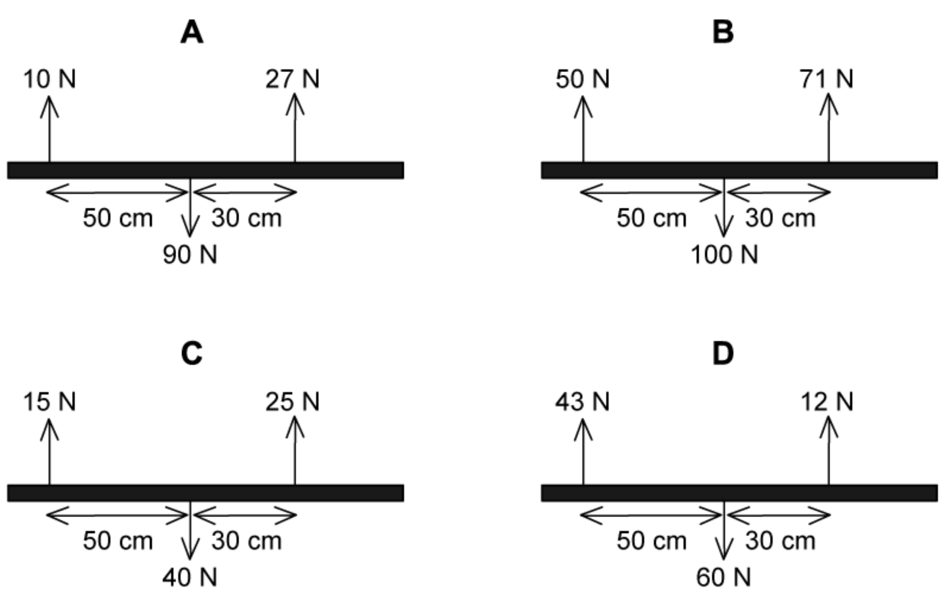
Equilibrium

- A system is in equilibrium when all the forces are balanced. This means:
  - There is **no** resultant force
  - There is **no** resultant torque
- An object in equilibrium will therefore remain at rest, or at a constant velocity, and not rotate
- The system is in an equilibrium state when applying **the principle of moments**

Worked Example

Four beams of the same length each have three forces acting on them.

Which beam has both zero resultant force and zero resultant torque acting?



ANSWER: C

STEP 1

ZERO RESULTANT FORCE AND RESULTANT TORQUE MEANS THE BEAM IS IN EQULIBRIUM

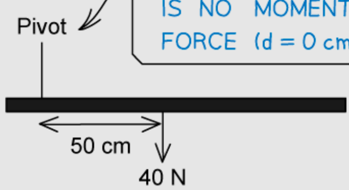
IN EQUILIBRIUM, THE CLOCKWISE MOMENTS = ANTICLOCKWISE MOMENTS (FROM PRINCIPLE OF MOMENTS)

STEP 2

CALCULATE THE CLOCKWISE MOMENTS

40 N × 50 cm = 2000 Ncm

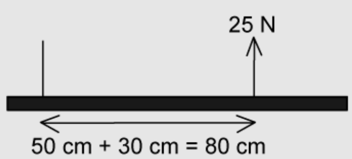
YOU CAN TAKE MOMENTS ABOUT ANY POINT OF YOUR CHOICE. TAKING THE MOMENTS FROM HERE MEANS THERE IS NO MOMENT CAUSED BY THE 15 N FORCE (d = 0 cm)



STEP 3

CALCULATE THE ANTICLOCKWISE MOMENTS

25 N × 80 cm = 2000 Ncm



STEP 4

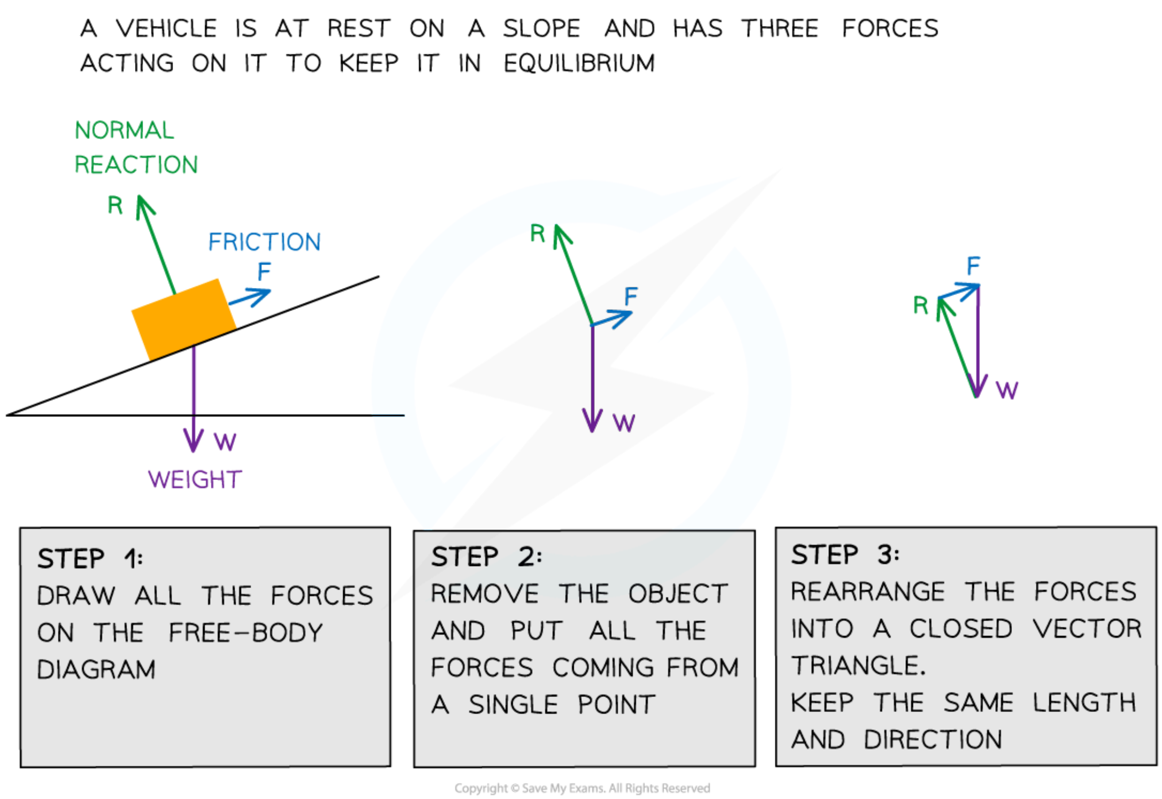
CLOCKWISE MOMENTS (2000 Ncm) = ANTICLOCKWISE MOMENT (2000 Ncm) THEREFORE THIS BEAM IS IN EQUILIBRIUM

Conditions for Equilibrium

- **Coplanar forces** can be represented by vector triangles
- Forces are in equilibrium if an object is either

Your notes

  - At rest
  - Moving at **constant** velocity
- In equilibrium, coplanar forces are represented by **closed** vector triangles
  - The vectors, when joined together, form a closed path
- The most common forces on objects are
  - Weight
  - Normal reaction force
  - Tension (from cords and strings)
  - Friction
- The forces on a body in equilibrium are demonstrated below:



Three forces on an object in equilibrium form a closed vector triangle

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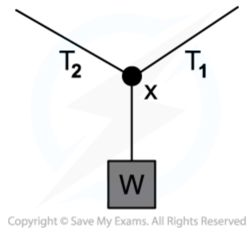
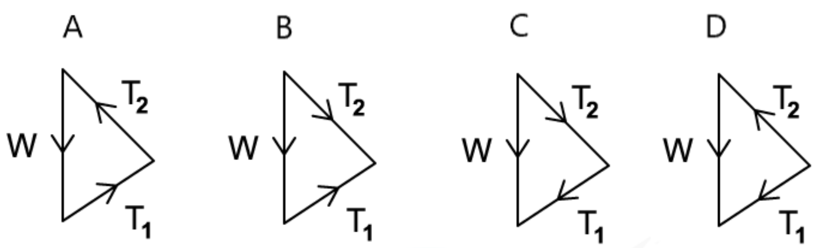
Worked Example

A weight hangs in equilibrium from a cable at point **X**. The tensions in the cables are T_1 and T_2 as shown.



Which diagram correctly represents the forces acting at point **X**?



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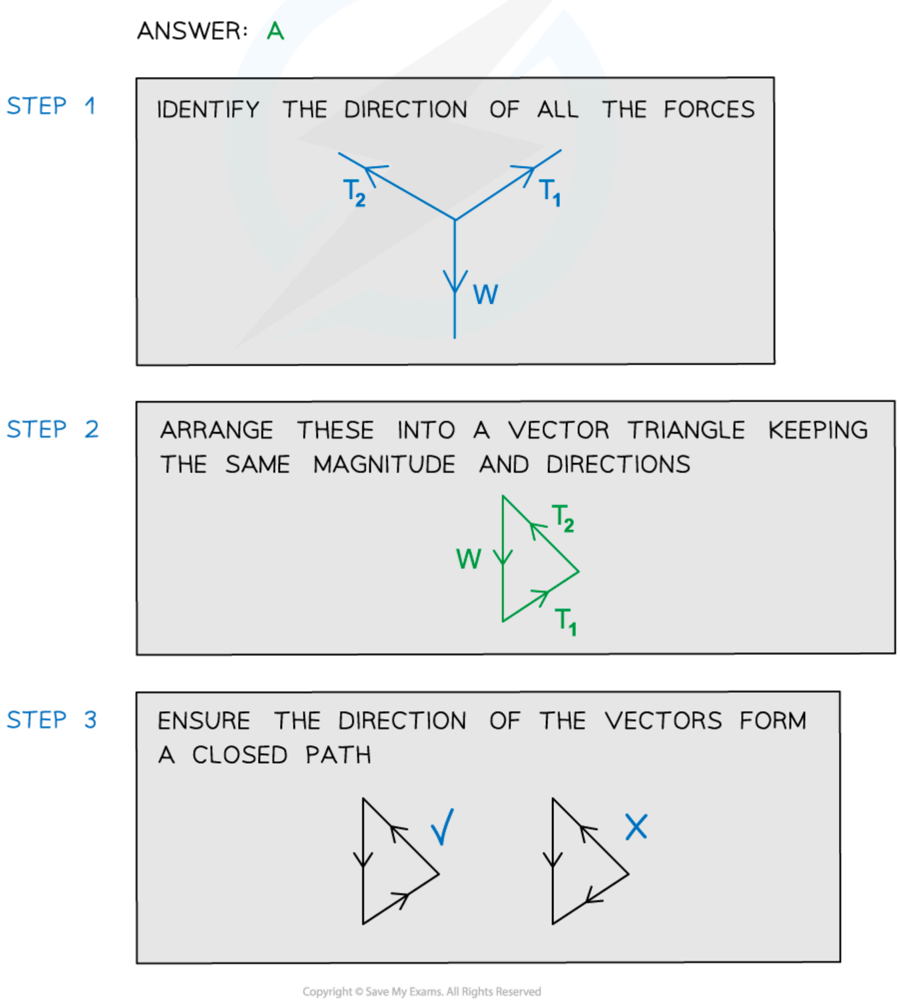

Examiner Tips and Tricks

The diagrams in exam questions about this topic tend to be drawn to scale, so make sure you have a ruler handy!