Cambridge (CIE) IGCSE Physics

Your notes

Moments

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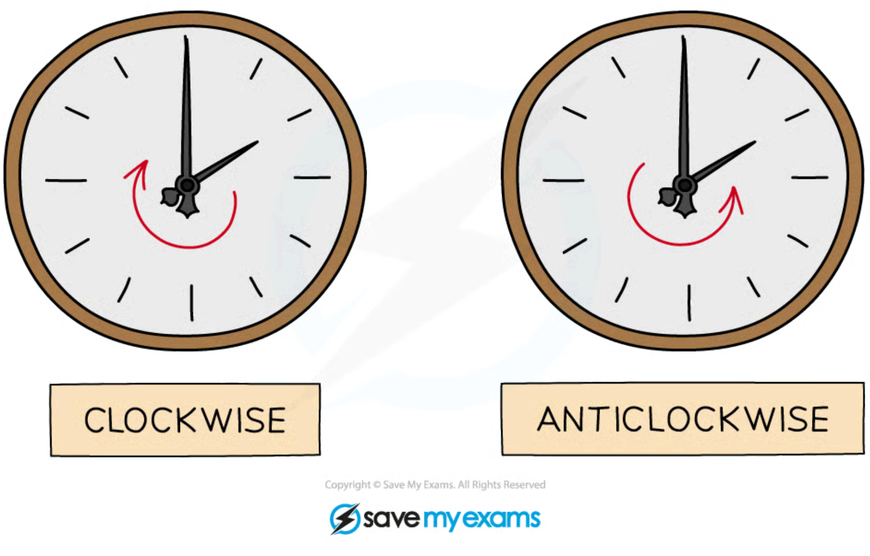
- Investigating Centre of Gravity

Moments

- The **moment** of a force is the **turning effect** produced when a force is exerted on an object
- Examples of the turning effect of a force are:
  - A child on a see-saw
  - Turning the handle of a spanner
  - A door opening and closing
  - Using a crane to move building supplies
  - Using a screwdriver to open a tin of paint
  - Turning a tap on and off
  - Picking up a wheelbarrow
  - Using scissors
- Forces can cause the **rotation** of an object about a fixed **pivot**
- This rotation can be **clockwise** or **anticlockwise**

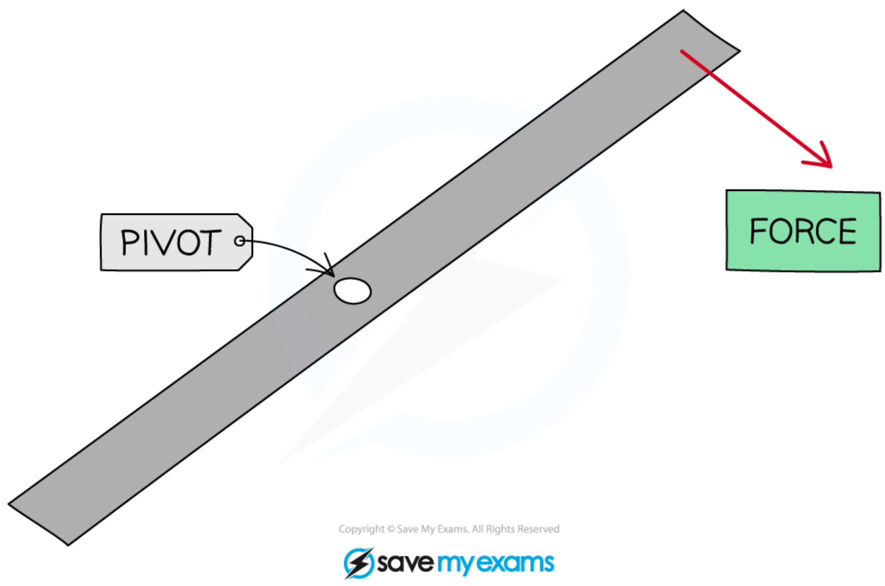
Clockwise and anti-clockwise rotation



Consider the hands of a clock when deciding if an object will rotate in a clockwise or anti-clockwise direction

- A force applied on one side of the pivot will cause the object to rotate

Turning effect of a force about a pivot



The force applied will cause the object to rotate clockwise about the pivot

The moment equation

- A **moment** is defined as:

The turning effect of a force about a pivot

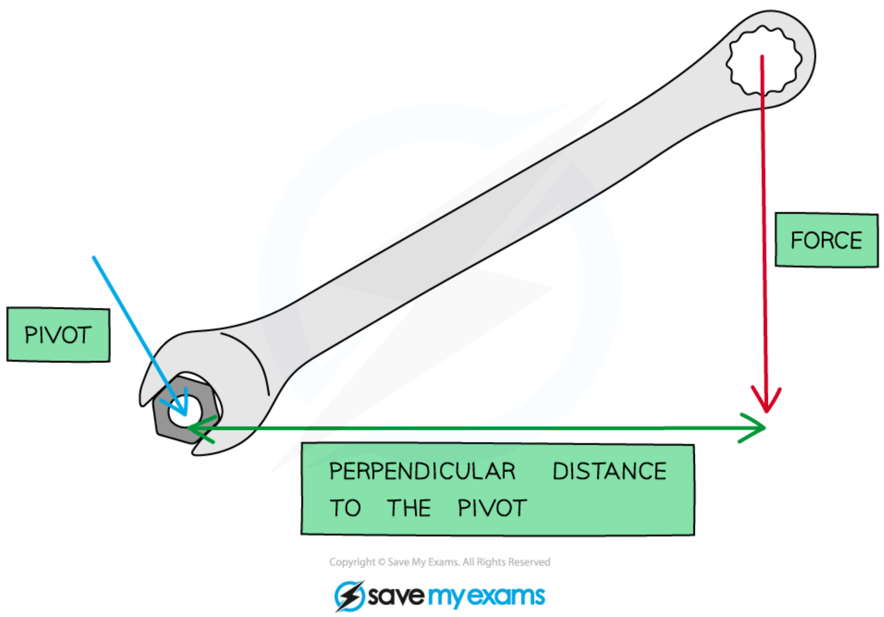
- The size of a moment is defined by the equation:

$$\text{moment} = \text{force} \times \text{perpendicular distance from pivot}$$

- The forces should be **perpendicular** to the distance from the pivot
  - For example, on a horizontal beam, the forces which will cause a moment are those directed upwards or downwards

The turning effect of a force exerted on a spanner

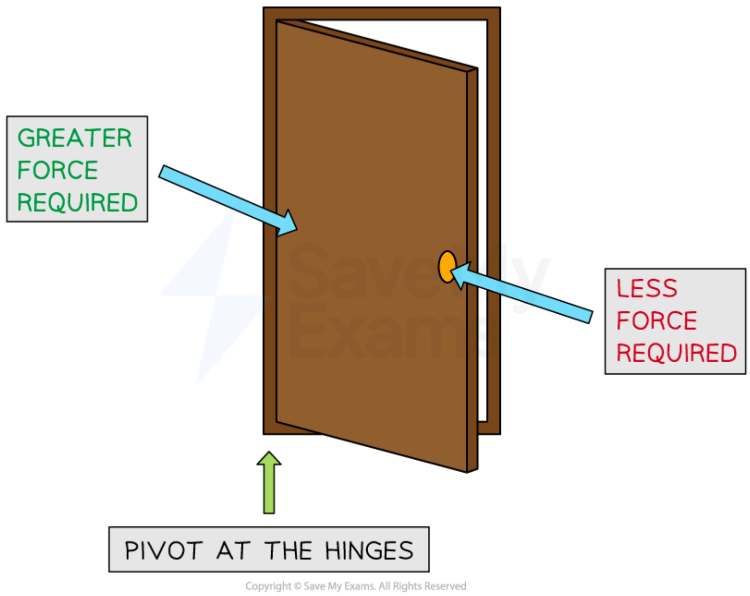
Your notes



The moment depends on the force and perpendicular distance to the pivot

- **Increasing** the **distance** at which a force is applied from a pivot **decreases** the **force** required
  - If you try to push open a door right next to the hinge, it is very difficult, as it requires a lot of force
  - If you push the door open at the side furthest from the hinge, then it is much easier, as less force is required

Forces required to open a door



A greater force is required to push open a door next to the hinges than at the door handle

Your notes

Worked Example

A carpenter attempts to loosen a bolt that has rusted. To turn the bolt, they exert a force of 22 N using a spanner of length 20 cm. The force is exerted 5 cm from the end of the spanner.

Calculate the turning effect of the force.

Answer:

Step 1: List the known quantities

- Force, $F = 22\ \text{N}$
- Length of spanner, $= 20\ \text{cm}$

Step 2: Determine the distance from the pivot

- The force is exerted 5 cm from the end of the spanner
- Therefore, the distance from the force to the pivot is

$$s = 20 - 5$$

$$s = 15\ \text{cm}$$

- Convert cm to m

$$s = \frac{15}{100}$$

$$s = 0.15\ \text{m}$$

Step 3: Write out the equation for moments

$$\text{moment} = \text{force} \times \text{perpendicular distance from pivot}$$

$$M = Fs$$

Step 4: Substitute in the known values to calculate

$$M = 22 \times 0.15$$

$$M = 3.3\ \text{N m}$$

Examiner Tips and Tricks

The moment of a force is measured in newton metres (N m), but can also be newton centimetres (N cm) if the distance is measured in cm instead.

Your notes

If your IGCSE moments exam question doesn't ask for a specific unit, always convert the distance into **metres**

Principle of moments (core)

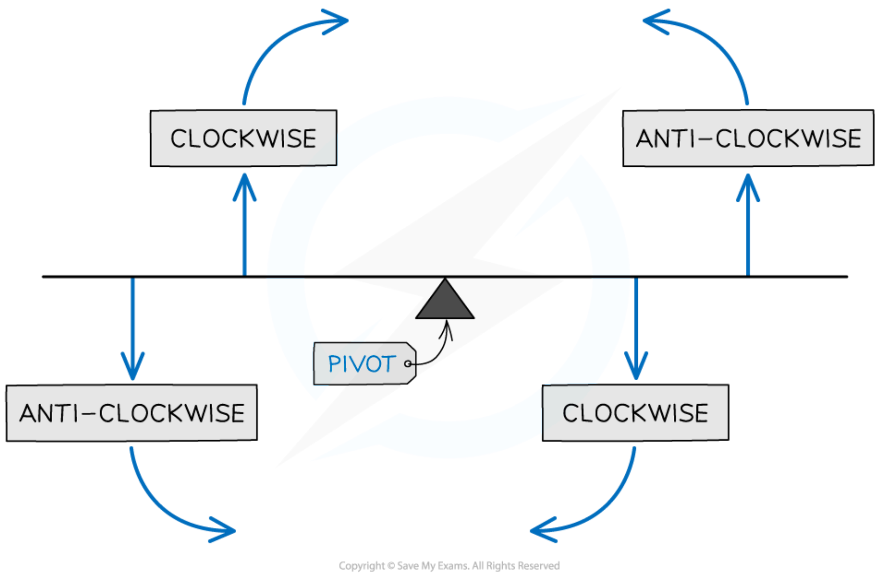
- The **principle of moments** states that:

If an object is balanced, the total clockwise moment about a pivot equals the total anticlockwise moment about that pivot

- The principle of moments means that for a balanced object, the moments on both sides of the pivot are **equal**

clockwise moment = anticlockwise moment

Principle of moments



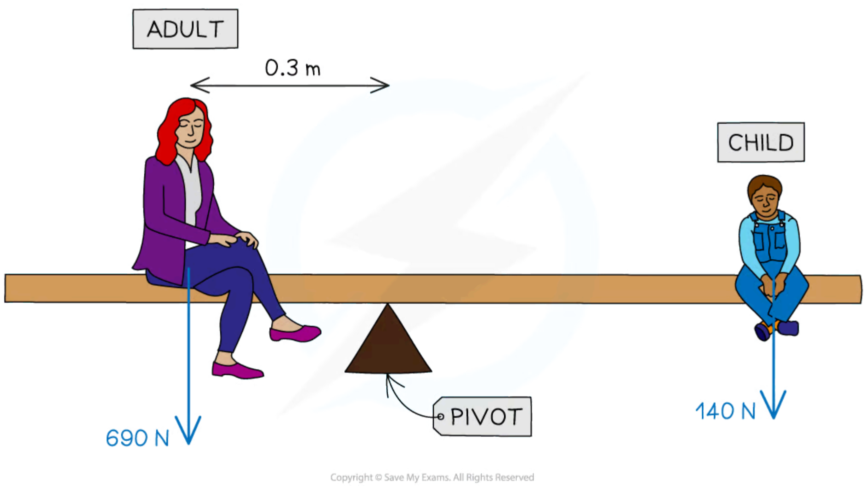
Imagine holding the beam about the pivot and applying just one of the forces. If the beam moves clockwise then the force applied is clockwise. This is the principle of moments

Worked Example

A parent and child are at opposite ends of a playground see-saw.

The weight force acting on the parent is 690 N and the weight force acting on the child is 140 N.

The adult sits at a distance of 0.3 m from the pivot.



Your notes

Calculate the distance the child must sit from the pivot for the see-saw to be balanced.

Use the principle of moments in your calculation.

Answer:

Step 1: List the known quantities

- Clockwise force (child), $F_{child} = 140 \text{ N}$
- Anticlockwise force (adult), $F_{adult} = 690 \text{ N}$
- Distance of adult from the pivot, $s_{adult} = 0.3 \text{ m}$

Step 2: Write down the moment equation and the principle of moments

- Moment equation:

$$\text{moment} = \text{force} \times \text{perpendicular distance from pivot}$$

$$M = Fs$$

- Principle of moments:

$$\text{total clockwise moments} = \text{total anticlockwise moments}$$

Step 3: Calculate the total clockwise moments

- The clockwise moment is from the child

$$M_{child} = F_{child} \times s_{child}$$

$$M_{child} = 140 \times s_{child}$$

Step 4: Calculate the total anticlockwise moments

- The anticlockwise moment is from the adult

$$M_{adult} = F_{adult} \times s_{adult}$$

$$M_{adult} = 690 \times 0.3$$

$$M_{adult} = 207 \text{ N m}$$

Step 5: Substitute into the principle of moments equation

$$\text{total clockwise moments} = \text{total anticlockwise moments}$$

$$M_{child} = M_{adult}$$

$$140 \times s_{child} = 207$$

Step 6: Rearrange for the distance of the child from the pivot

$$s_{child} = \frac{207}{140}$$

$$s_{child} = 1.5 \text{ m}$$

- The child must sit **1.5 m** from the pivot to balance the see-saw

Examiner Tips and Tricks

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

If you are studying the core tier for IGCSE Physics, you will only be expected to apply the principle of moments to a situation where one force acts on either side of the pivot

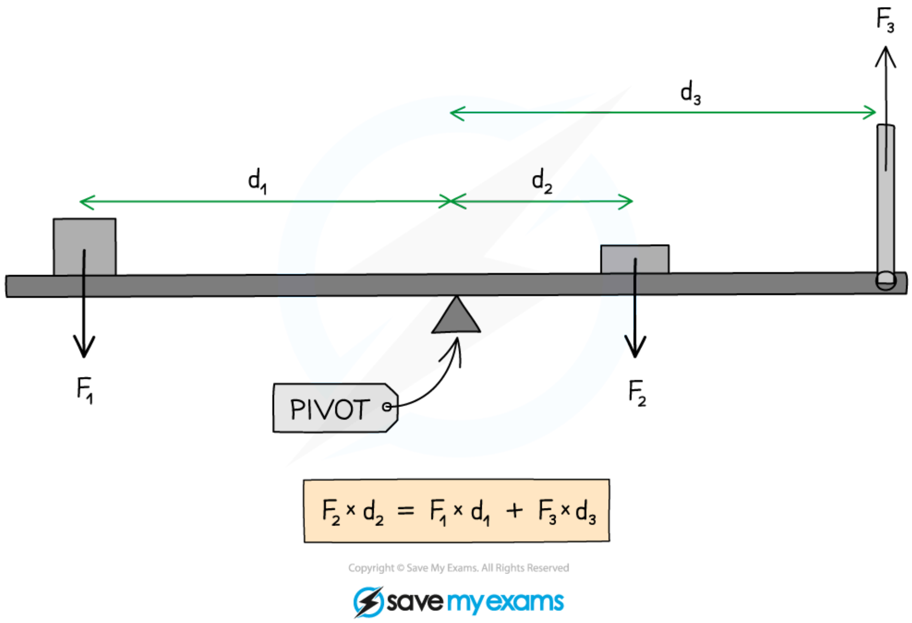
Principle of moments (extended)

Extended tier only

- In the example below, the forces and distances of the objects on the beam are different, but they are arranged in a way that **balances** the whole system

Using the principle of moments

Your notes



***The clockwise and anticlockwise moments acting on a beam* are balanced**

- In the above diagram:
  - Force F_1 causes an **anticlockwise** moment of $F_1 \times d_1$ about the pivot
  - Force F_2 causes a **clockwise** moment of $F_2 \times d_2$ about the pivot
  - Force F_3 causes an **anticlockwise** moment of $F_3 \times d_3$ about the pivot
- Collecting the clockwise and anticlockwise moments:
  - Sum of the clockwise moments = $F_2 \times d_2$
  - Sum of the anticlockwise moments = $(F_1 \times d_1) + (F_3 \times d_3)$
- Using the principle of moments, the beam is balanced when:

sum of the clockwise moments = sum of the anticlockwise moments

$$F_2 \times d_2 = (F_1 \times d_1) + (F_3 \times d_3)$$

Your notes

Equilibrium

- In physics, the term **equilibrium** means:

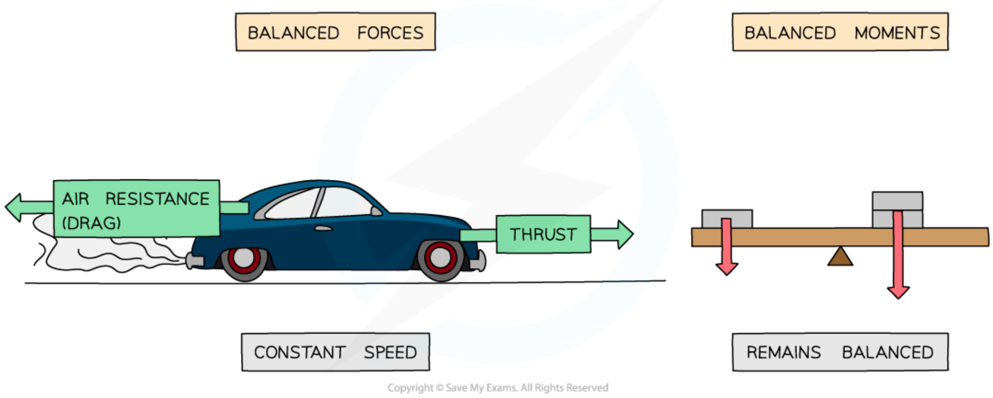
A state of balance or stability

- In other words, a system in equilibrium keeps doing what it's doing without any change

Conditions for equilibrium

- For objects in equilibrium:
  - The **forces** on the object must be **balanced**
    - There must be no **resultant force**
  - The **sum of clockwise moments** on the object must **equal** the **sum of anticlockwise moments**
    - There must be no **resultant moment**

Examples of systems in equilibrium



When the forces and moments on an object are balanced, the object will remain in equilibrium

Demonstrating equilibrium

Extended tier only

Aim of the experiment

- This experiment aims to demonstrate that there is no resultant moment for an object in equilibrium

Your notes

Variables

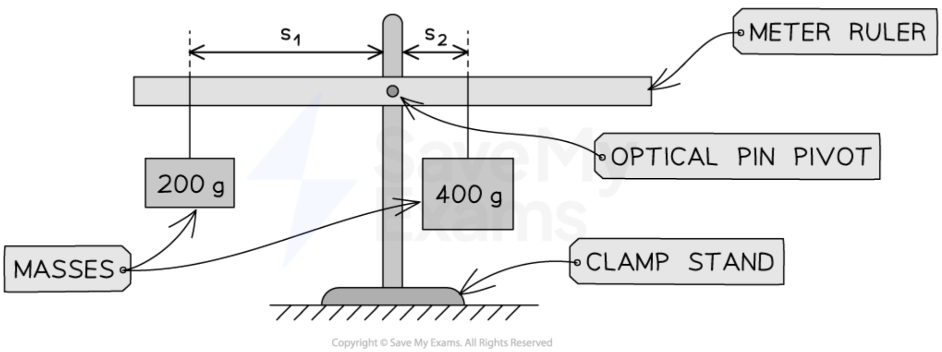
- **Independent variable** = force, F, and distance, s
- **Dependent variable** = moment, M
- Control variables:
  - The length of the cotton loops should be equal on each side of the beam

Equipment

Equipment list

Equipment	Purpose
Metre ruler with a small hole at the centre	To provide the beam on which to add masses
2 × 100 g mass hangers	To attach the masses to the ruler
8 × 100 g masses	To add the mass at different points along the ruler
Clamp stand, boss & clamp	To secure the pivot in place
Optical pin and cork	To act as the pivot
Small piece of plasticine	To ensure the ruler is balanced at the start
2 loops of cotton	To attach the mass hangers to the metre ruler

Example set up of equipment to demonstrate equilibrium



The ruler acts as the beam with the pin as the pivot. Unequal masses are added at different distances until the beam is balanced and equilibrium is reached

Your notes

Method

1. Hang unequal loads on either side of the pivot; one person holds the beam while the other person hangs the loads
2. Adjust the distances of mass 1, m_1, and mass 2, m_2, until the beam is balanced
3. Adjust further to ensure the beam is perfectly horizontal with no resultant moment
4. Record the distance from the pivot of masses m_1 and m_2
5. Repeat the process for different sized loads

Example results table

m_1 (g)	F_1 (N)	s_1 (cm)	m_2 (g)	F_2 (N)	s_2 (cm)	Anticlockwise moment M_1 (N m)	Clockwise moment M_2 (N m)

A results table should contain spaces for all the measurements taken and any calculations required

Analysis of results

- Force 1, F_1, is providing the anticlockwise moment, M_1
  - Where:
    - $F_1 = m_1 g$
    - $M_1 = F_1 s_1$
- Force 2, F_2, is providing the clockwise moment, M_2
  - Where:
    - $F_2 = m_2 g$

- $M_2 = F_2 s_2$

- Remember to convert **g to kg** and **cm to m** for the calculations to give units of **Nm** for the moments
- The results should show that for all the systems tested, the anticlockwise moment is equal to the clockwise moment
  - Therefore, there is no resultant moment when the system is in equilibrium

Evaluating the experiment

Systematic errors

- The cotton loops should be added to the ruler when viewed straight on to avoid a **parallax error**
- The cotton loops should be measured to ensure they are equal in length
- The experiment should be checked to ensure there is no friction between the metre ruler and the optical pin pivot so the ruler is balanced, only because of the added masses

Random errors

- The **precision** of the experiment is improved by:
  - ensuring the experiment is done in a space with **no draft** or breeze, as this could affect the motion or position of the hanging masses
  - using an **electronic system** or a spirit level that identifies the angle of the beam would improve the experiment, or using a flat rod with masses placed on top
- The **accuracy** of the experiment is improved by:
  - taking **more than five** readings for each mass and position and then calculating the **mean**
- It is assumed that the mass of the cotton loops is negligible (zero)
- It is assumed that the mass of each mass and hanger is 100 g, this should be verified in advance using an electronic balance

Safety considerations

- Safety **goggles** should be worn because the cotton loops could snap and hit someone in the eye
- Use a **G clamp** to secure the clamp stand to the bench so it does not topple over and cause injury
- **Stand up** to carry out this experiment so you do not fall over when looking level with the metre ruler
- Place a **mat** or a soft material below the metre ruler to cushion any masses that may fall to the ground and to keep the area clear of feet and hands

Your notes

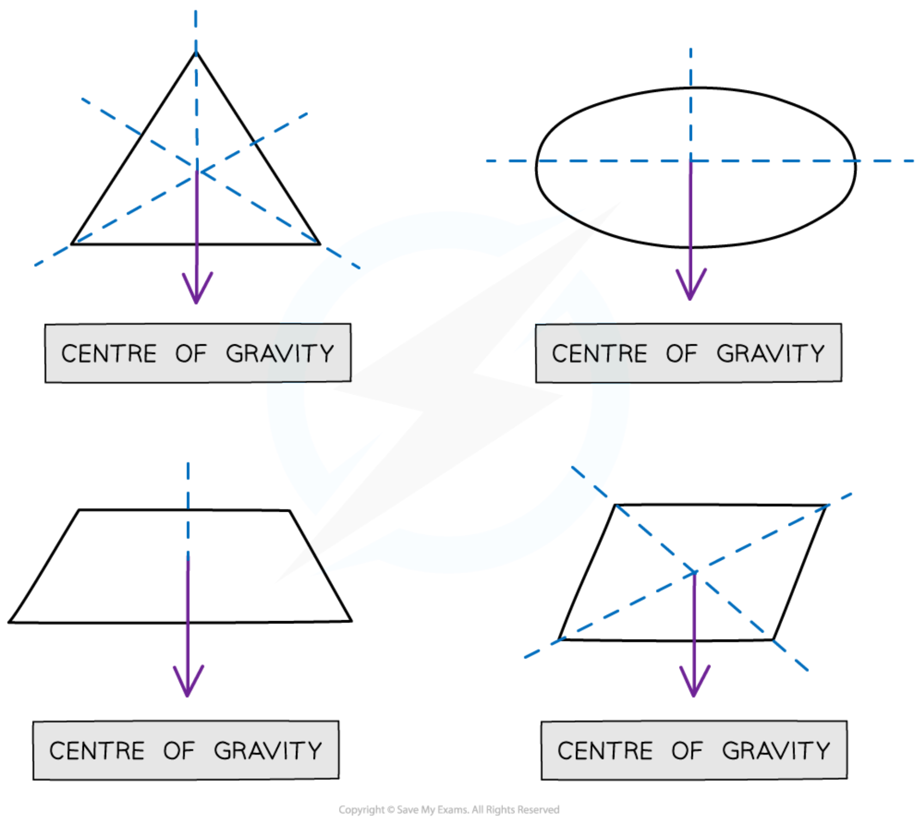
Centre of gravity

- The **centre of gravity** of an object is defined as:

The point through which the weight of an object acts

- For a symmetrical object of uniform density, the **centre of gravity is located at the point of symmetry**
  - For example, the centre of gravity of a sphere is at the centre

Finding the centre of gravity of symmetrical objects



The centre of gravity of a regular shaped object can be found using symmetry

Examiner Tips and Tricks

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

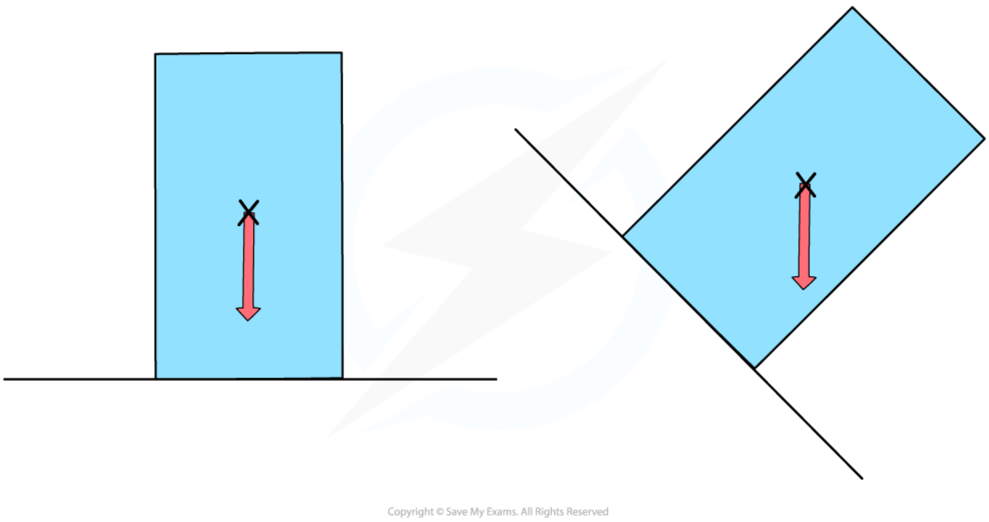
However, when you are drawing force diagrams, always draw the weight force as if it were acting from the centre of gravity of the object!

Your notes

Stability

- The **centre of gravity** of a symmetrical object is along the **axis of symmetry**
- The **position** of the centre of gravity affects the **stability** of an object
- An object is **stable** when its centre of gravity lies above its **base**

Centre of gravity of an object in different positions



The object will topple, when its centre of gravity is no longer over its base

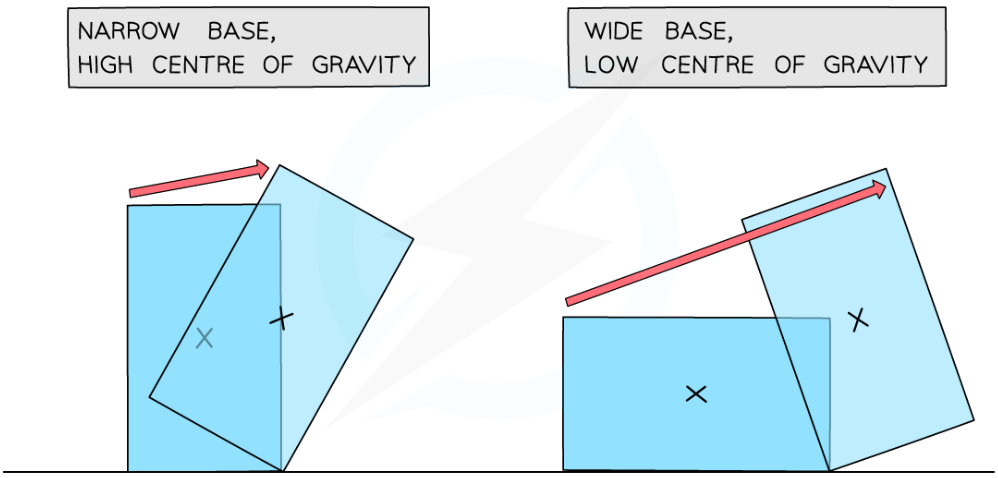
- If the centre of gravity does not lie above its base, then an object will **topple** over
- The most stable objects have a **low** centre of gravity and a **wide** base

Low centre of gravity of a car

Cars are stable because they have a low centre of gravity and a wide base

- Taller objects with a narrow base have a higher centre of gravity and are less stable
- This is why lorries and buses are advised not to use motorways and bridges on very windy days

Stability of object in different positions

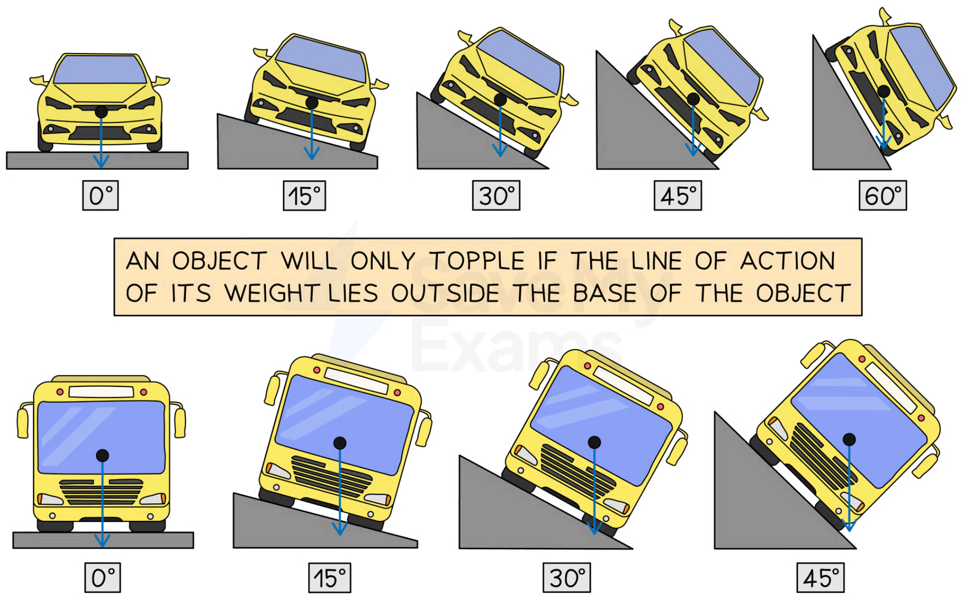


When the object is positioned on its narrow base, it is less stable because its centre of gravity is higher

Moments and stability

- If the line of action of the **weight** force lies outside the base of the object, there will be a **resultant moment,** and the body will topple

Car and bus on varying inclines



The car can be titled to 60° without toppling, but the bus will topple at 45°

- Tall objects with a narrow base will topple easily
  - Ten-pin bowling pins are designed specifically to topple easily

Your notes

- The stability of objects can be increased by widening the base
  - High chairs are designed with a wide base so that they do not topple
  - Bunsen burners have a wide base to ensure they do not topple

Your notes

Examiner Tips and Tricks

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

Investigating centre of gravity

Aim of the experiment

- This experiment aims to determine the position of the centre of gravity of an irregularly shaped **plane lamina**
- **Independent variable** = shape of plane lamina
- **Dependent variable** = position of centre of gravity
- Control variables:
  - Punching the holes in the plane lamina before determining the line of action of the weight force

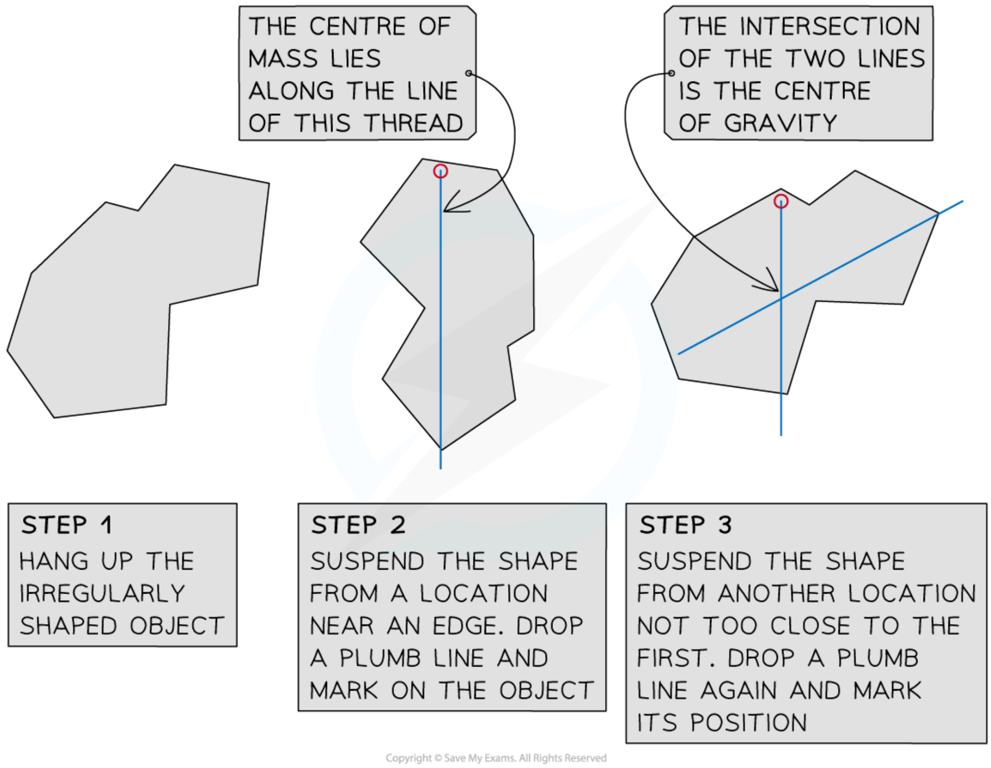
Equipment

Equipment list

Equipment	Purpose
Irregularly shaped plane lamina	To find the position of the centre of gravity of
Hole punch	To create a hole in the plane lamina to tie the thread to
Thread	To hang the plane lamina from the clamp
Thread and mass or sticky tack	To form the plumb line
Pencil and ruler	To draw the line of action of the weight force
Clamp stand, boss & clamp	To hang the plane lamina from

Method

Determining the centre of gravity of an irregularly shaped plane lamina



For irregularly shaped objects, the centre of gravity can be found using the suspension method

1. Punch 3 holes near the outer edges of the plane lamina in different locations
2. Create a loop of thread and hang the plane lamina from the clamp
3. Use a plumb line (a weighted thread) aligned with the hanging thread to show the line of action of the weight force
4. Use a ruler and pencil to mark the line of action of the weight force onto the plane lamina
5. Repeat the process until 3 lines have been drawn
6. The point at which the lines cross is the position of the centre of gravity

Analysis of results

- Each plane lamina is an irregularly shaped object
- When an object is suspended from a point, it will always settle with its centre of gravity directly below the point of suspension

Evaluating the experiment

Systematic errors

- The plumb line should be viewed straight on to avoid a **parallax error**

Your notes

- Dots should be made on the plane lamina whilst in position and then a ruled line should be made after the lamina has been removed from the clamp

Random errors

- The plane lamina should be allowed to settle before determining the action line of the weight force
- The holes should be punched in the plane lamina before determining the action line of the weight force, because punching the holes after can affect the position of the centre of gravity

Your notes