Edexcel GCSE Physics

Your notes

Momentum

Contents

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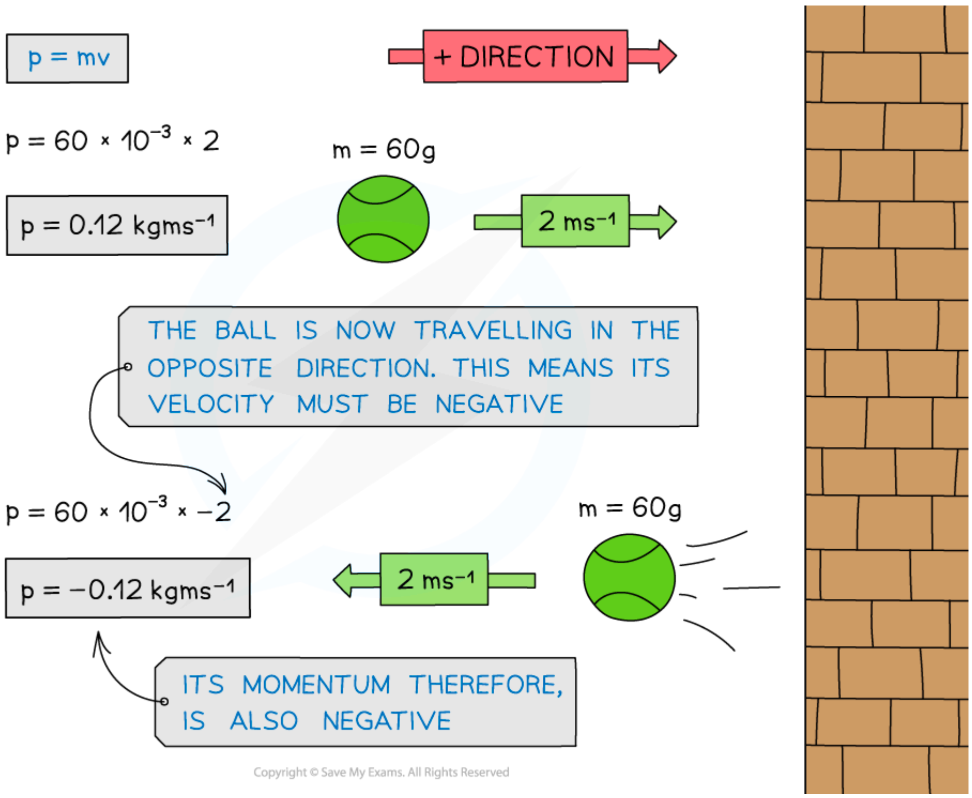
Momentum

Higher Tier Only

- A moving object has **momentum** which is defined by the equation:

$$p = mv$$

- Where:
  - p = momentum in kilogram metre per second (kg m/s)
  - m = mass in kilograms (kg)
  - v = velocity in metres per second (m/s)
- This means that an object at rest (i.e v = 0) has **no** momentum
- Momentum keeps an object moving in the same direction, making it difficult to change the direction of an object with a large momentum
- Since velocity is a vector this means that the momentum of an object also depends on its **direction** of travel
- This means that momentum can be either **positive** or **negative**
  - If an object travelling to the right has positive momentum, an object travelling in the opposite direction (to the left) will have negative momentum



The tennis ball's momentum is negative when it moves in the opposite direction to which it initially was travelling in

- Therefore, the momentum of an object will change if:
  - The object **accelerates** (speeds up) or **decelerates** (slows down)
  - Changes **direction**
  - Its **mass** changes

Worked Example

Which object has the most momentum?

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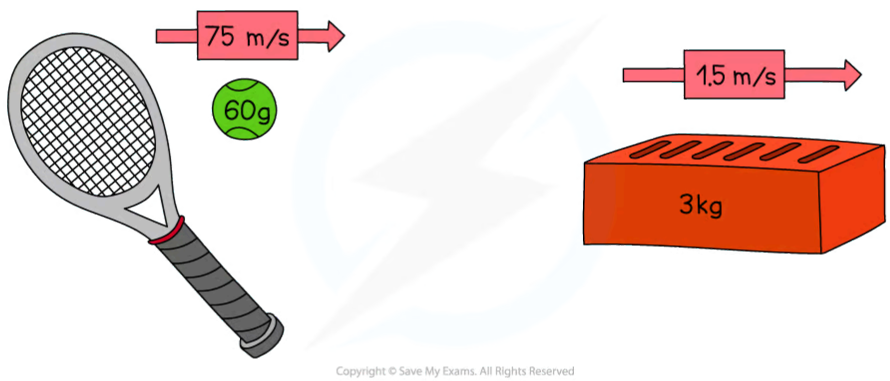

Answer:

MOMENTUM = MASS × VELOCITY

MOMENTUM = 0.06 kg × 75 m/s
= 4.5 kg m/s

MOMENTUM = MASS × VELOCITY

MOMENTUM = 3 kg × 1.5 m/s
= 4.5 kg m/s

- Both the tennis ball and the brick have the same momentum
- Even though the brick is much heavier than the ball, the ball is travelling much faster than the brick
- This means that on impact, they would both exert a similar force (depending on the time it takes for each to come to rest)

Examiner Tips and Tricks

Remember the units of momentum as **kg m/s** which is the product of the units of mass (kg) and velocity (m/s).Which direction is taken as positive is completely up to you in the exam. In general, the right and upwards are taken as positive, and down or to the left as negative.

Examples of Momentum

Higher Tier Only

- Examples of momentum in an event are **collisions**
- Objects will either:

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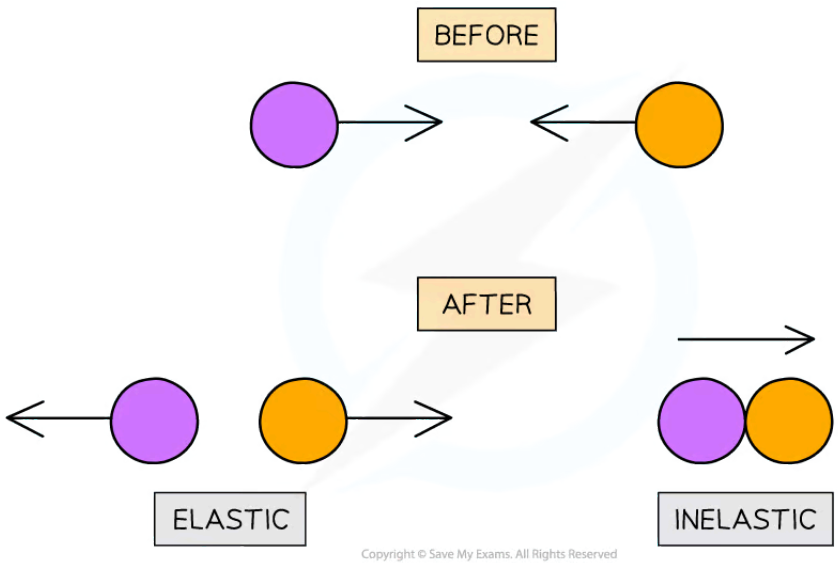
- Collide and move in **opposite** directions - this is an **elastic** colision
- Collide and move in the **same** direction together - this is an **inelastic** collision
- When the objects move in opposite directions:
  - Each object will have a **different** velocity depending on its mass and initial momentum of the system
- When the objects move in the same direction together:
  - They will have a **combined** mass and velocity
- Momentum is always **conserved** in a collision



The difference between elastic and inelastic collisions

Examiner Tips and Tricks

If an exam question asks you to **analyse** a collision, follow these tips for full marks:

- Always consider the motion **before** and **after** the collision and state:
  - The velocities of each object
  - The direction each object moves
- State whether the collision was **elastic** or **inelastic** and explain your reasoning
  - In a perfectly elastic collision, the kinetic energy is the same before and after

- In a perfectly inelastic collision, the two objects stick together after colliding
- Describe any energy transfers that occur if kinetic energy is not conserved
    - For example, it may be converted into heat, sound, elastic potential energy etc

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Conservation of Momentum

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Conservation of Momentum

Higher Tier Only

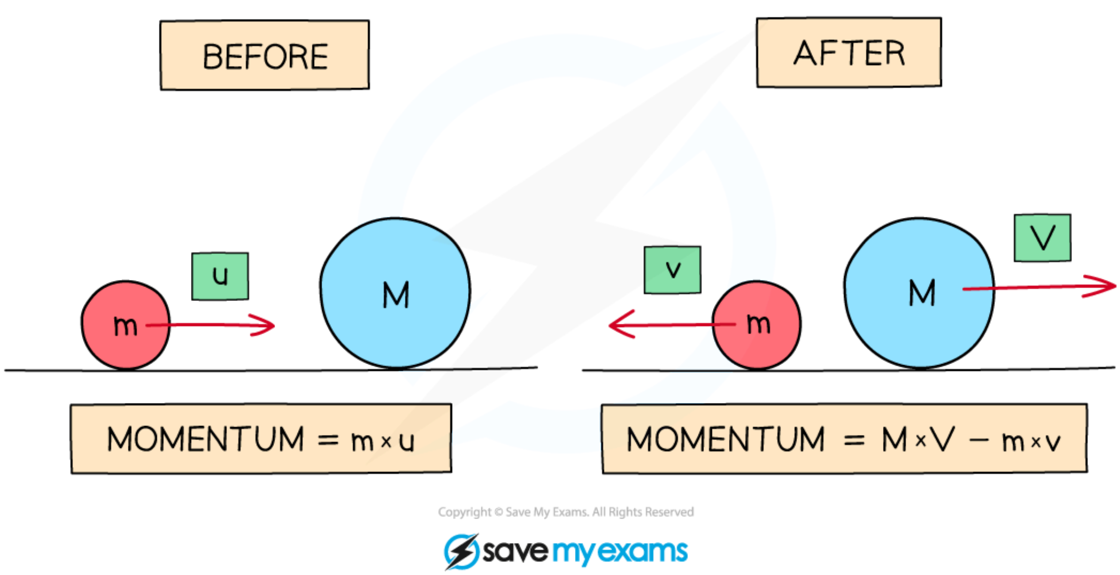
- The principle of conservation of momentum states that:

  In a closed system, the total momentum before an event is equal to the total momentum after the event

- A closed system means the energy within the system is constant and there is an absence of external forces (e.g. friction)
- In other words:

  The total momentum before a collision = The total momentum after a collision

- A system is a certain number of objects under consideration
  - This can be just one object or multiple objects
- Since momentum is a **vector** quantity, a system of objects moving in opposite directions (e.g. towards each other) at the same speed will have an overall momentum of 0 since they will cancel out
  - Momentum is **always conserved** over time
- The diagram below shows two masses *m* with velocity *u* and *M* at rest (ie. zero velocity)



The momentum of a system before and after a collision

- Before the collision:
  - The momentum is only of mass *m* which is moving
  - If the right is taken as the positive direction, the total momentum of the system is $\boldsymbol{m \times u}$
- After the collision:
  - Mass *M* also now has momentum
  - The velocity of *m* is now -*v* (since it is now travelling to the left) and the velocity of *M* is *V*
  - The total momentum is now the momentum of *M* + momentum of *m*
  - This is $(M \times V) + (m \times -v)$ or $\boldsymbol{(M \times V) - (m \times v)}$

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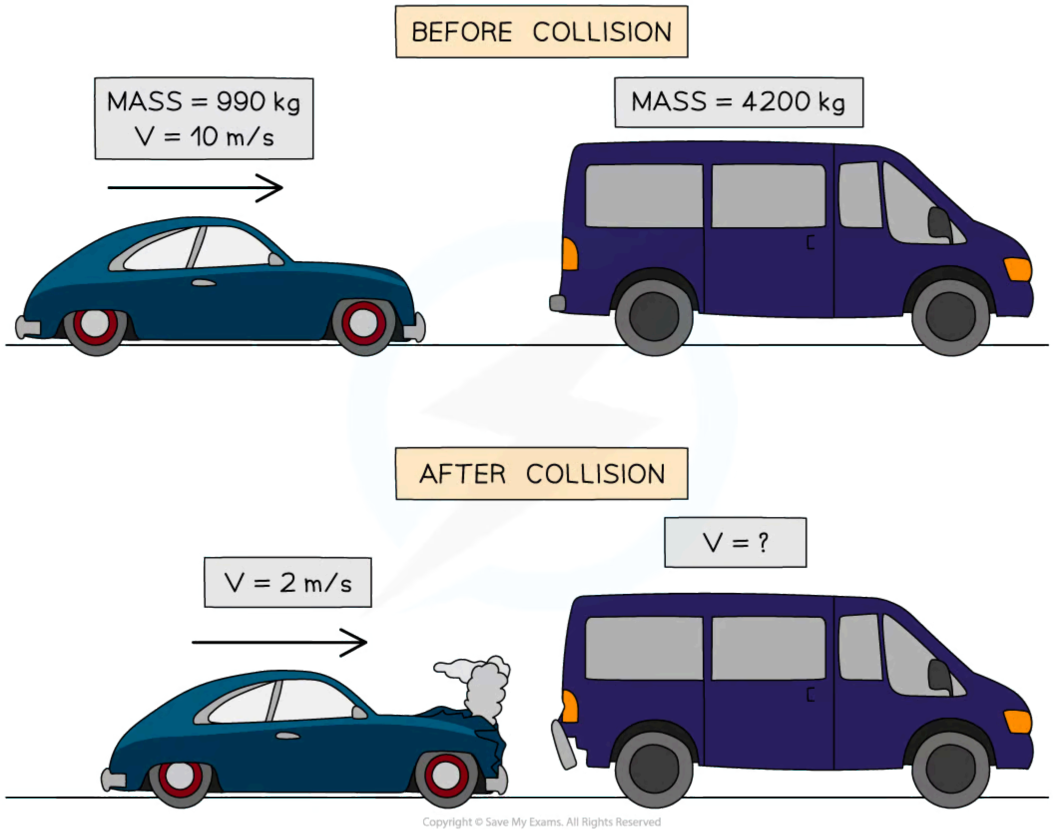
Worked Example

The diagram shows a car and a van, just before and just after the car collided with the van, which is initially at rest.



Use the idea of conservation of momentum to calculate the velocity of the van when it is pushed forward by the collision.

Answer:

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Step 1: State the principle of conversation of momentum

- In a closed system, the total momentum before an event is equal to the total momentum after the event

Step 2: Calculate total momentum before the collision

$$p = mv$$

- Momentum of the car:

$$p = 990 \times 10 = 9900 \text{ kg m/s}$$

- Momentum of the van:

The van is at rest, therefore v = 0 m/s and p = 0 kg m/s

- Total momentum before:

$$p_{before} = 9900 + 0 = 9900 \text{ kg m/s}$$

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Step 3: Calculate the momentum after the collision

- Momentum of the car:

$$p = 990 \times 2 = 1980 \text{ kg m/s}$$

- Momentum of the van:

$$p = 4200 \times v$$

- Total momentum after

$$p_{after} = 1980 + 4200v \text{ kg m/s}$$

Step 4: Rearrange the conversation of momentum equation for the velocity of the van

$$p_{before} = p_{after}$$

$$9900 = 1980 + 4200v$$

$$9900 - 1980 = 4200v$$

$$v = \frac{9900\text{-}1980}{4200} = 1.9 \text{ m/s}$$

Examiner Tips and Tricks

If it is not given in the question already, drawing a diagram of before and after helps keep track of all the masses and velocities (and directions) in the conversation of momentum questions.

Newton's Third Law & Momentum

Higher Tier Only

- Newton's third law of motion states:

  Whenever two bodies interact, the forces they exert on each other are equal and opposite

- This means:

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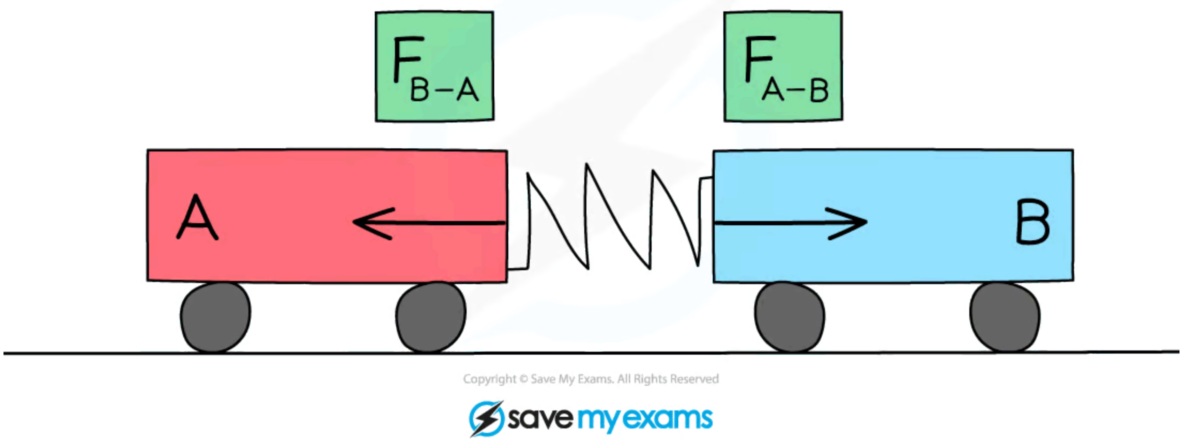
- When one object exerts a force on another object, the second object will exert an equal force on the first object in the opposite direction
- When two objects collide, both objects will react, generally causing one object to speed up (gain momentum) and the other object to slow down (lose momentum)



Newton's third law can be applied to collisions

- Consider the collision between two trolleys, **A** and **B**:
  - When trolley **A** exerts a force on trolley **B**, trolley **B** will exert an equal force on trolley **A** in the opposite direction
- In this case:

$$F_{B-A} = -F_{A-B}$$

- While the forces are equal in magnitude and opposite in direction, the accelerations of the objects are not necessarily equal in magnitude
- From Newton's second law, acceleration depends upon both force and mass, this means:
  - For objects of equal mass, they will have equal accelerations
  - For objects of unequal mass, they will have unequal accelerations

Examiner Tips and Tricks

Remember in Newton's Third law that the two forces should always be from **different** objects.

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Force & Momentum

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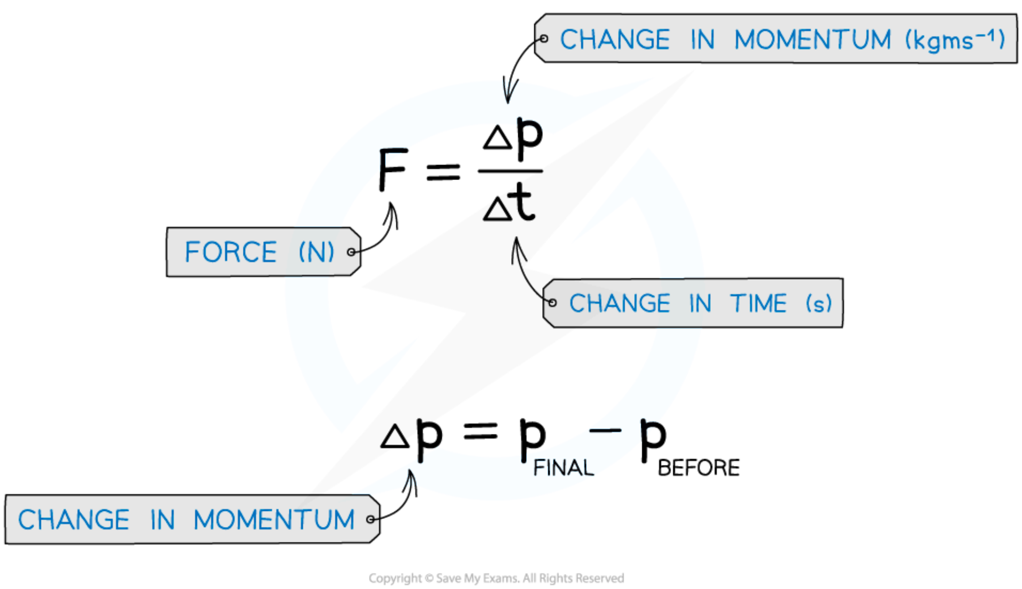
Force & Momentum

Higher Tier Only

- When a force acts on an object that is moving, or able to move, the object will accelerate (or decelerate)
  - This causes a **change in momentum**
- More specifically, the force is the **rate of change in momentum**



- Δt is the **change** in time, or the time taken for the force to change
- Where the change in momentum is defined as

Final momentum – Initial momentum

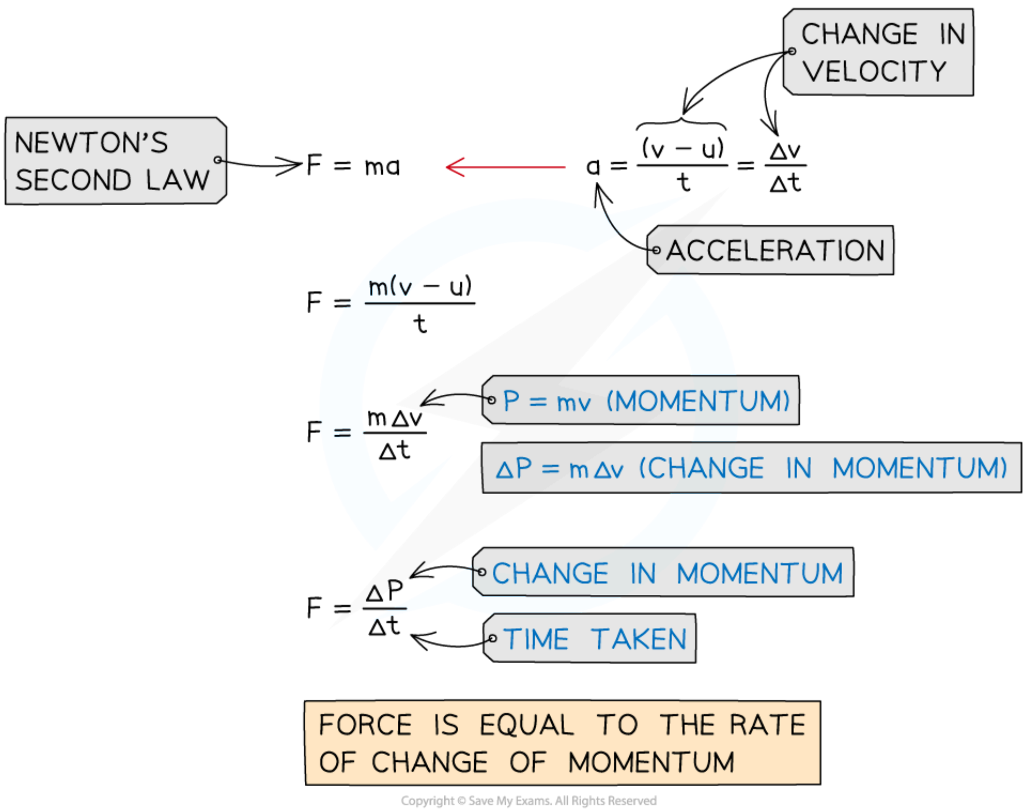
$$\Delta p = mv - mu$$

- Where:
  - m = mass in kilograms (kg)
  - v = final velocity in metres per second (m/s)

    - u = initial velocity in metres per second (m/s)
- Force and momentum are **vectors** so they can be either positive or negative values

Deriving the Force & Momentum Equation

- The force and momentum equation can be derived from Newton's Second law and the definition of acceleration



Worked Example

A tennis ball hits a racket with a change in momentum of 0.5 kg m/s. For the different contact times, which tennis racket experiences more force from the tennis ball?

Answer:

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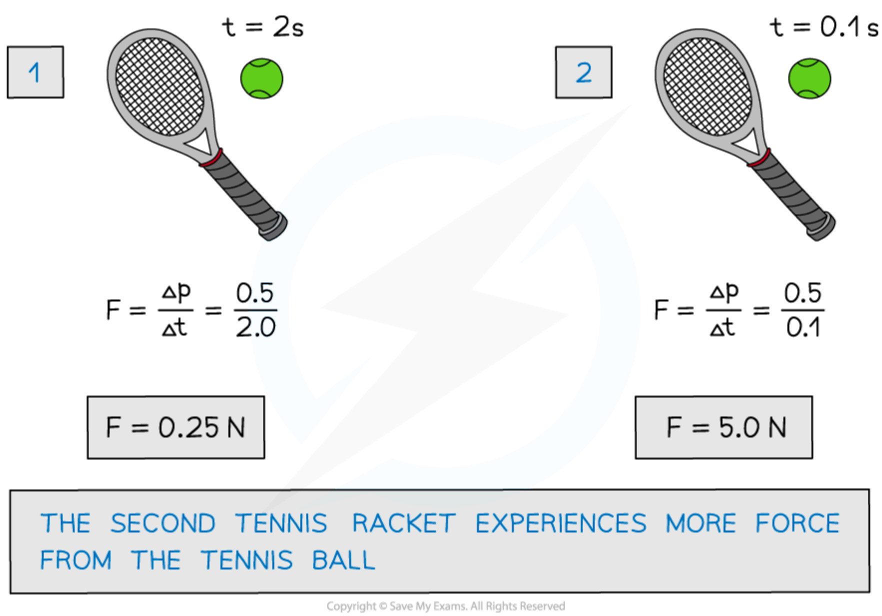

Examiner Tips and Tricks

Maths Tip: Remember 'rate of change' describes how one variable changes with respect to another. In maths, how fast something changes with **time** is represented as dividing by ***Δt*** (e.g. acceleration is the rate of change in velocity)More specifically, ***Δt*** is used for finite and quantifiable changes such as the difference in time between two events

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Mass & Inertia

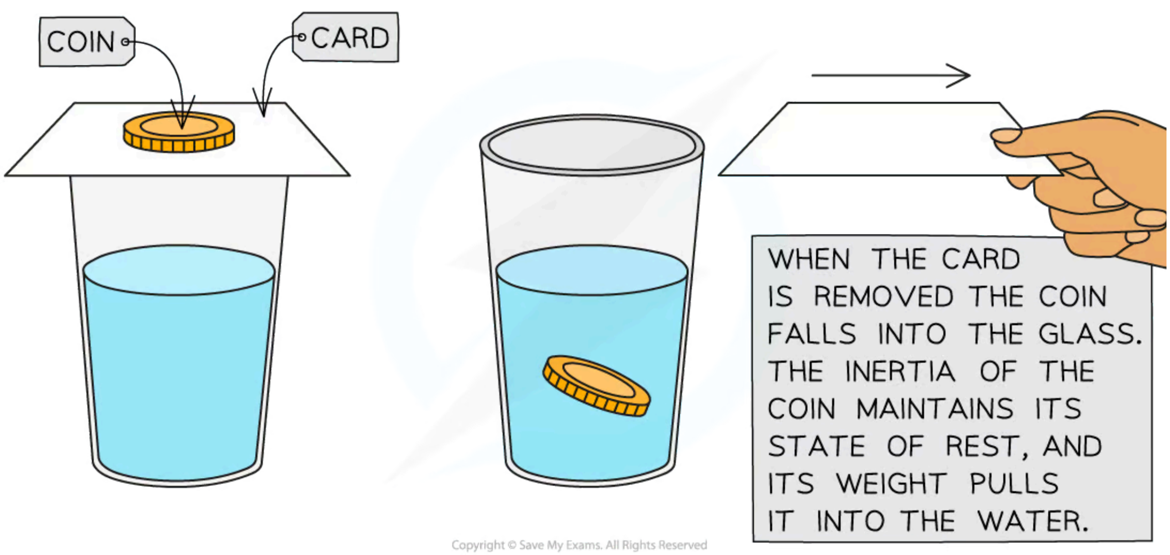
Mass & Inertia

Higher Tier Only

- The concept of **inertia** is closely related to motion, it is defined as:

  The tendency of an object to continue in its state of rest, or in uniform motion unless acted upon by an external force

- In other words, inertia is an object's **resistance** to a **change in motion**
  - If an object is **at rest**, it will tend to **remain at rest**
  - If an object is moving at a **constant velocity** (constant speed in a straight line), it will **continue** to do so
- The image below illustrates the concept of inertia using a coin and a cup of water:



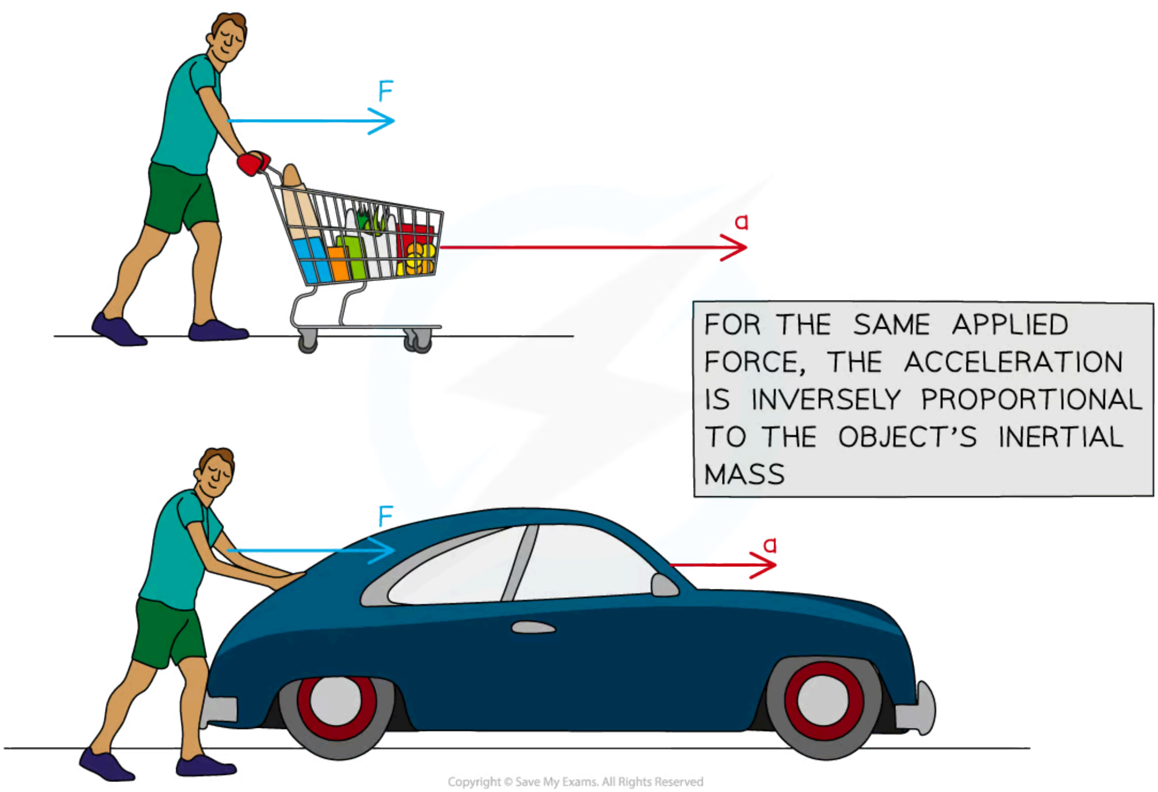
Demonstrating the inertia of a small coin

- **Inertial mass** is the property of an object which describes how **difficult** it is to **change its velocity**
- It is defined as the **ratio** between the **force** applied to it and the **acceleration** it experiences:

$$\text{inertial mass} = \frac{\text{force}}{\text{acceleration}}$$

$$m = \frac{F}{a}$$

- Where:
  - m = inertial mass in kilograms (kg)
  - F = force in newtons (N)
  - a = acceleration in metres per second squared (m/s^2)
- This equation shows that for a **given force**, inertial mass is **inversely proportional** to acceleration
  - **Larger inertial masses** will experience **small accelerations**
  - **Smaller inertial masses** will experience **large accelerations**



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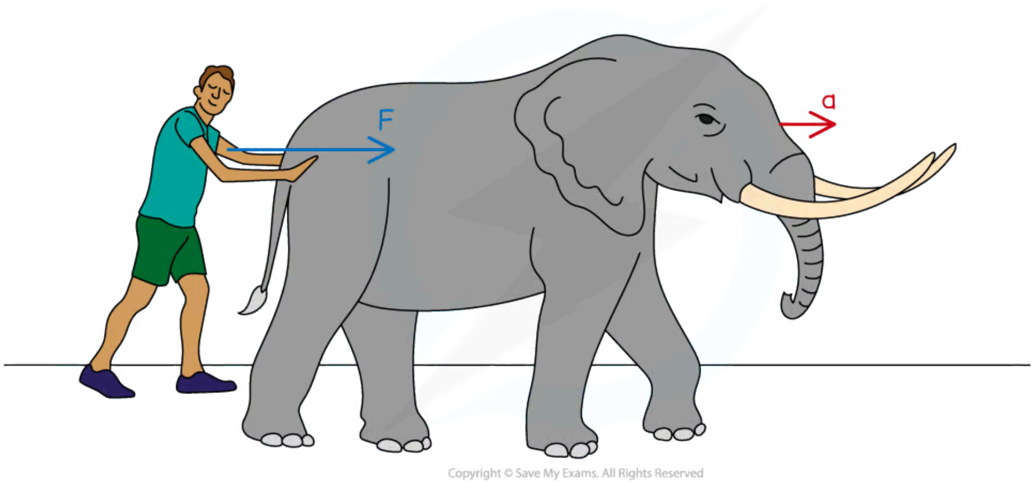

This collection of objects have a variety of inertial masses. For the same applied force, their accelerations are inversely proportional to their mass

Worked Example

Three objects are used by a physics technician to demonstrate the concept of inertial mass.She applies the same force to each of the three objects and notes that:

- Object **A** accelerates at 1.5 m/s^2
- Object **B** accelerates at 0.7 m/s^2
- Object **C** accelerates at 2.0 m/s^2

Which object has the largest inertial mass?

Answer:

Step 1: State the definition of inertial mass

- Inertial mass is defined as the ratio of force to acceleration

Step 2: Apply the definition to each of the objects in the question

- Because each object experiences the same force, inertial mass is **inversely proportional** to acceleration
- This means that the object with the **largest inertial mass** will experience the **smallest acceleration**
- **Object B** has the smallest acceleration, so it has the largest inertial mass

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Examiner Tips and Tricks

The definition of inertial mass as a **ratio** between **force** and **acceleration** should look similar to **Newton's second law.** That's because when you calculate the mass of an object using Newton's second law, you are in fact calculating its inertial mass.