# Edexcel International A Level (IAL) Physics

Your notes

## Forces & Momentum

### Contents

# Newton's First Law of Motion

- Newton's First Law states:

  ***A body will remain at rest or move with constant velocity unless acted on by a resultant force***

- The law is used to explain why things move with a **constant** (or **uniform**) **velocity**
- If the **forces** acting on an object are **balanced**, then the **resultant force** is **zero**
  - The forces to the left = the forces to the right
  - The forces up = the forces down
- The velocity (i.e. speed and direction) **can only change** if a **resultant force** acts on the object

## Worked Example

If there are no external forces acting on the car, other than friction, and it is moving at a constant velocity, what is the value of the frictional force F?


**Answer:**

**Step 1: Identify the prompt (or 'clue') word in the question to choose which rules to apply**

- The clue in this question is 'constant velocity'
- This means that forces are perfectly balanced in every direction

**Step 2: Calculate the missing force**

- For constant velocity sum of forces,

$$\Sigma F = 0$$

$$F = D$$

**Step 3: Write the answer including units**

$$F = 6 \text{ kN}$$

# Newton's Second Law of Motion

Your notes

- Newton's Second Law states that:

  **The acceleration of an object with constant mass is directly proportional to the resultant force on it**

- An unbalanced force on a body means it experiences a resultant force
  - If the resultant force is **along the direction of motion**, the body will speed up (**accelerate**) or slow down (**decelerate**)
  - If the resultant force is at an **angle**, the body will change **direction**
- Since resultant force is being considered, the equation is often written

$$\Sigma F = ma$$

  - The use of Σ (Sigma) signifies that F is the **sum** of the forces rather than just one force acting alone

### Worked Example

An object with a mass of 750 g accelerates in a straight line at 11 m $s^{-2}$.

Determine the resultant force acting on the object.

**Answer:**

**Step 1: Write down the known quantities**

- Mass, $m$ = 750 g = 0.750 kg
- Acceleration, $a$ = 11 m $s^{-2}$.

**Step 2: Identify the equation needed and substitute in the values**

$$\Sigma F = ma = 0.75 \times 11 = 8.25$$

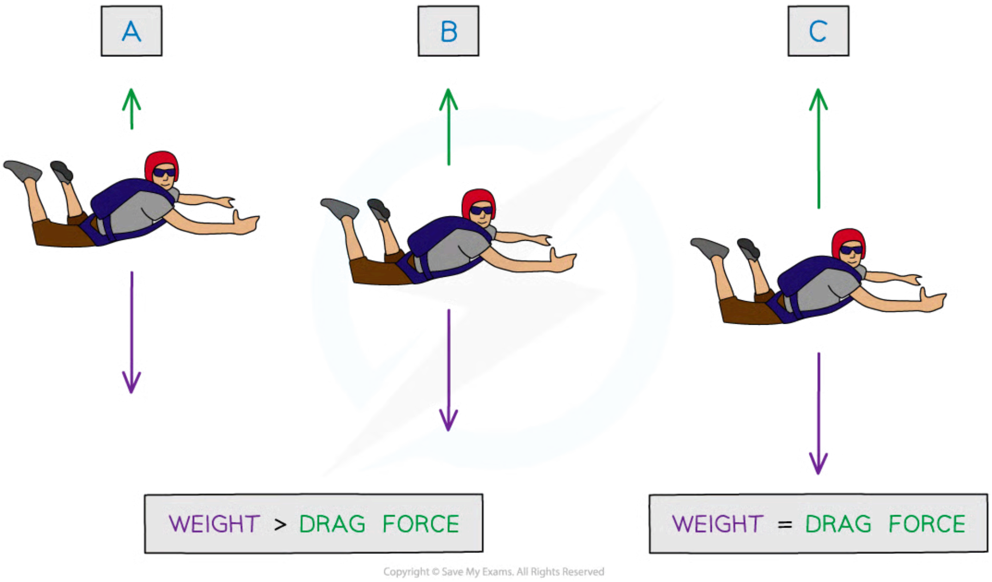
**Step 3: Write the final answer using the correct significant figures and units**

$$\Sigma F = 8.3 \text{ N}$$

# Terminal Velocity

- On Earth, moving bodies always do have **some force** acting on them, for example, due to friction caused by;
  - Movement through air or water (drag forces)
  - Movement across a surface (such as tyres on the road)
  - Moving parts within the object itself (such as the engine of a car, or the bearings in a wheel)

- When the drag forces become equal to the driving force the velocity reaches its **maximum** value and the object is said to be moving at **terminal velocity**
  - 'Terminal' means final, meaning there can be no more increases in velocity after it has been reached
- Terminal velocity is reached when the forces in the direction of motion are balanced by the forces opposing motion
  - This is often used in relation to the case of a skydiver falling in freefall, although it can apply to **any** situation where drag forces apply
- In the case of the skydiver the force in the direction of motion is their weight, which remains constant
  - As the skydiver accelerates air resistance increases, until the opposing forces balance





Your notes

Your notes

## Worked Example

Suggest two ways in which a designer could increase the maximum velocity of a car.

**Answer:**

**Step 1: Identify exactly what the question is asking for**

- The question asks about 'maximum' (terminal) velocity, this occurs when all forces are balanced
- To increase the terminal velocity the car either needs to
  - Increase the forces in the forwards direction, or
  - Decrease the forces in the backwards direction (the ones which are opposing motion)

**Step 2: Write down the forces affecting the motion**

- In the forwards direction the only force is the thrust from the engine
- The forces opposing motion include:
  - Friction between the tyres and the road
  - Air resistance
  - Friction in the moving parts of the engine
  - Friction in the moving parts of the wheel system (bearings)

**Step 3: Suggest changes the designer could make**

- Increase the forwards thrust by increasing power from the engine
- Reduce opposing forces by
  - Using tyres with less grip
  - Making the car body more streamlined
  - Reducing friction in the engine (using better oil for example)
  - Reduce friction in the moving parts with smoother surfaces or better lubricants

## Examiner Tips and Tricks

The direction you consider positive is your choice, as long as the signs of the numbers (positive or negative) are consistent throughout your answer. A clear, labelled diagram will tell both you and the Examiner which direction is positive, so nothing gets mixed up.

Having said that, there is a general rule to consider the direction the object is initially travelling in as positive. Therefore all vectors in the direction of motion will be positive and opposing vectors, such as drag forces, will be negative.

If you do get an acceleration in your answer with a negative sign, you have found that the object is slowing down. This is the Super Power of Physics equations!

# Mass, Weight & Gravitational Field Strength

## Mass

- **Mass** is the measure of the amount of matter in an object
  - Consequently, this is the property of an object that resists change in motion
- The greater the mass of a body, the smaller the change produced by an applied force
  - The SI unit for mass is the **kilogram** (kg)

## Weight

- **Weight** is the force a body experiences due to being in a gravitational field, it is given by the equation

$$W = mg$$

- Where
  - m = mass (kg)
  - g = gravitational field strength (N $kg^{-1}$)

## Gravitational Field Strength

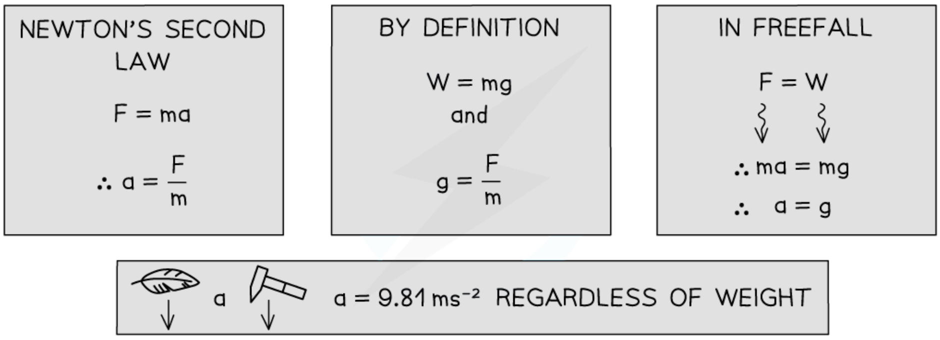
- Gravitational field strength is the force per kilogram that acts on an object, it is found using the equation

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

- Where
  - F = weight (N)
  - m = mass (kg)
- On the Earth's surface the average gravitational field strength = **9.81 N $kg^{-1}$**

## Constant Acceleration in Freefall

- **Freefall** is used to describe falling objects where the only force is weight
  - Drag forces are ignored
  - By considering freefall we can see that all objects must fall with exactly the same value for acceleration, regardless of their mass or weight


NEWTON'S SECOND LAW
F = ma
∴ a = F/m
BY DEFINITION
W = mg
and
g = F/m
IN FREEFALL
F = W
∴ ma = mg
∴ a = g
a
a = 9.81 ms⁻² REGARDLESS OF WEIGHT


Your notes

# Acceleration of Freefall Using Electromagnets & Light Gates

## Aim of the Investigations

- The overall aim of these investigations is to calculate the value of the acceleration due to gravity, *g*
- The first two experiments both use the method of dropping an object and either timing its fall, or finding the final velocity
  - Both use the SUVAT equations to produce a straight line graph
- The third experiment, using the **ramp and trolley**, is based on the inclined ramp experiment done by Galileo when he proved that all objects fall at the same rate, regardless of weight

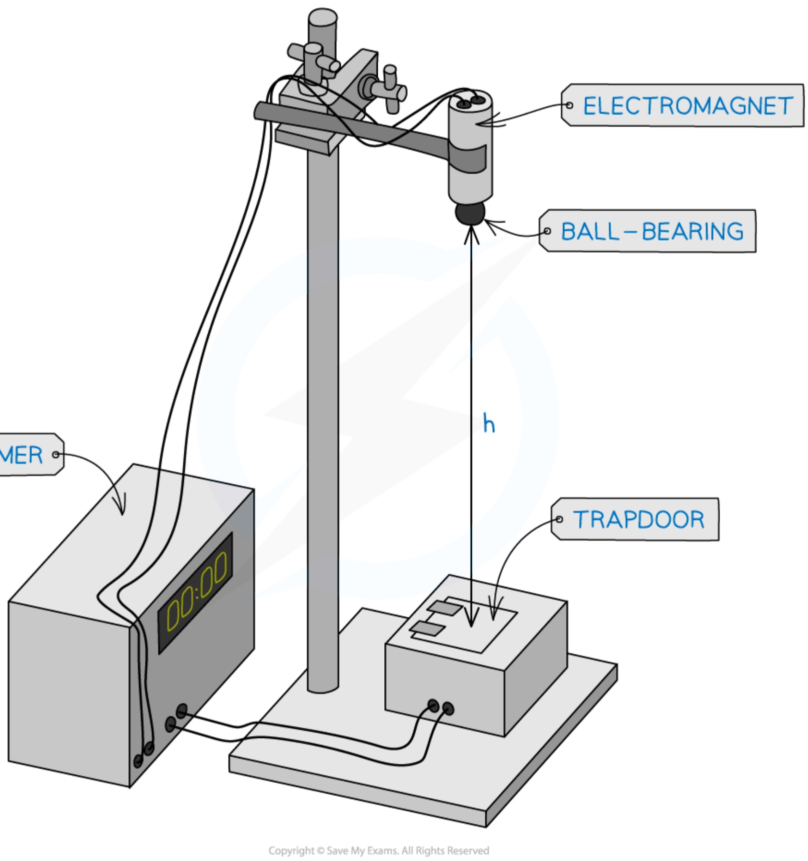
## Electromagnet Method

## Variables

- Independent variable = height, *h*
- Dependent variable = time, *t*
- Control variables:
  - Same object being dropped
  - Same electromagnet and trap door switching system

## Apparatus

- Metre rule, ball bearing, electromagnet, electronic timer, trapdoor, plumb line




***Apparatus used to measure g using the electromagnet method***

- Resolution of measuring equipment:
  - Metre ruler = 1 mm
  - Timer = 0.01 s

## Method

- By using the plumb line to find the vertical drop, position the trap door switch directly underneath the electromagnet.
- Check that the ball bearing triggers both the trap door switch and the timer when it is released.
- When the equipment is set up correctly;
  - As the current to the magnet switches off, the ball drops and the timer starts
  - When the ball hits the trapdoor, the timer stops
- The reading on the timer indicates the time it takes for the ball to fall a distance, *h*
- Measure the distance from the **bottom** of the ball bearing to the trap door switch with a metre ruler and record this distance as height, *h*

- Increase *h* (eg. by 5 cm) and repeat the experiment. At least 5 – 10 values for *h* should be used
- Repeat this method at least 3 times for each value of *h* and calculate an average *t* for each

Your notes

## Table of Results

| HEIGHT h/m | TIME $t_1$/s | TIME $t_2$/s | TIME $t_3$/s | AVERAGE TIME t/s |
|---|---|---|---|---|
| 0.10 | | | | |
| 0.15 | | | | |
| 0.20 | | | | |
| 0.25 | | | | |
| 0.30 | | | | |
| 0.35 | | | | |



## Analysis of Results

- The acceleration is found by using one of the SUVAT equations and rearranging it to create a straight line graph (y = mx + c)
- The known quantities are
- Displacement *s* = *h*
    - Time taken = *t*
    - Initial velocity = *u*
    - Acceleration *a* = *g*
- The missing SUVAT value is final velocity, *v*
- Therefore use

$$s = ut + \frac{1}{2}at^2$$

- Replace *a* with *g* and *s* with *h* and then rearrange to fit the equation of a straight line

$$h = \frac{1}{2}gt^2 \text{ (since initial velocity, u = 0)}$$

- The above equation shows that if *h* is plotted on the y-axis and $t^2$ on the x-axis the graph will produce a straight line with gradient = $\frac{1}{2}g$

## Evaluating the experiment

**Systematic Errors:**

- Residue magnetism after the electromagnet is switched off may cause *t* to be recorded as longer than it should be

**Random Errors:**

- Large uncertainty in *h* from using a metre rule with a precision of 1 mm
- Parallax error from reading *h*
- The ball may not fall accurately down the centre of the trap door
- Random errors are reduced through repeating the experiment for each value of *h* at least 3–5 times and finding an average time, *t*

## Safety Considerations

- The electromagnetic requires current
  - Care must be taken to not have any water near it
  - To reduce the risk of electrocution, only switch on the current to the electromagnet once everything is set up
- A cushion or a soft surface must be used to catch the ball-bearing so it doesn't roll off / damage the surface
- The tall clamp stand needs to be attached to a surface with a G clamp to keep it stable

## Card and Light Gates Method

## Variables

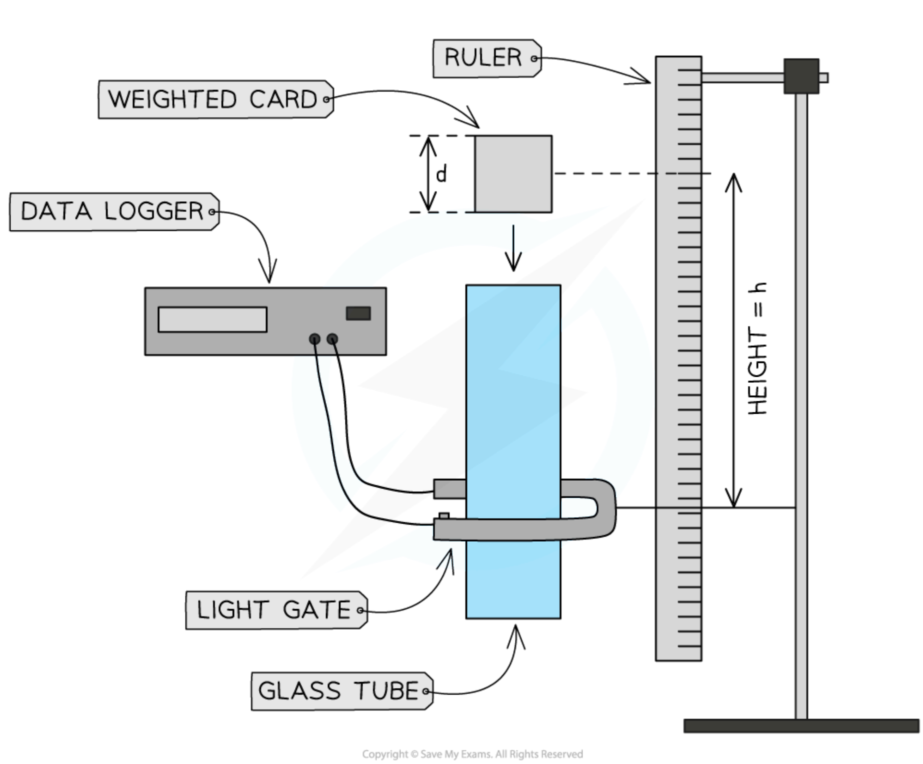
- Independent variable = height, *h*
- Dependent variable = final velocity, *v*
- Control variables:
  - Same card being dropped
  - All other equipment is the same

## Apparatus

- Metre rule, clear tube with large enough diameter for card to fall cleanly through it, card, blu-tack, light gate, data logger, plumb line

## Method

Your notes




- Clamp the clear tube vertically using the plumb line as a guide
- Attach the light gate about 20 cm above the bench
- Clamp the metre ruler vertically next to the tube so that the vertical distance from the top of the tube to the light gate can be accurately measured
- Record the distance between the light gate and the top of the tube as height, *h*
- Cut a piece of card to approximately 10 cm, measure this length precisely and enter it into the data logger as the distance
  - Weight the card slightly at one end (a large paperclip or small pieces of blu-tack can be used)
- Hold the card at the top of the tube and release it so that it falls inside the tube
  - The data logger will record velocity
- Repeat this measurement from the same height two more times
- Move the light gate up by 5 cm, record the new height, h, and drop the card three more times, recording the velocity each time
- Repeat for five more values of height

Your notes

Your notes

| $h$ / m | $V_1$ / m $s^{-1}$ | $V_2$ / m $s^{-1}$ | $V_3$ / m $s^{-1}$ | $V_{av}$ / m $s^{-1}$ |
|---|---|---|---|---|
| | | | | |



## Analysis of Results

- The acceleration is found by using one of the SUVAT equations and rearranging it to create a straight line graph (y = mx + c)
- The known quantities are
  - Displacement $s = h$
  - Initial velocity = $u$
  - Final velocity = $v$
  - Acceleration $a = g$
- The missing SUVAT value is time, $t$
- Therefore use

$$v^2 = u^2 + 2as$$

- Replace $a$ with $g$ and $s$ with $h$ and then rearrange to fit the equation of a straight line

$$v^2 = 2gh$$ (since initial velocity, u = 0)

- The above equation shows that if $v^2$ is plotted on the y-axis and $2h$ on the x-axis the graph will produce a straight line with gradient = $g$

## Evaluating the experiment

**Systematic Errors:**

- The metre ruler needs to be fixed vertically and close to the tube
- All height measurements are taken at eye level to avoid parallax errors

**Random Errors:**

- Large uncertainty in $h$ from using a metre rule with a precision of 1 mm

- Parallax error from reading *h*
- The card may fall against the sides of the tube, slowing it down
- Dropping the card from the top of the tube can introduce parallax errors
- Random errors are reduced through repeating the experiment for each value of *h* at least 3–5 times and finding an average time, *t*

Your notes

## Safety Considerations

- The tall clamp stand needs to be attached to a surface with a G clamp to keep it stable

## Ball Bearing Method

**Variables**

- Independent variable = height, *h*
- Dependent variable = time, *t*
- Control variables:
    - Same steel ball-bearing
    - Same electromagnet
    - Distance between ball-bearing and top of the glass tube

## Equipment List

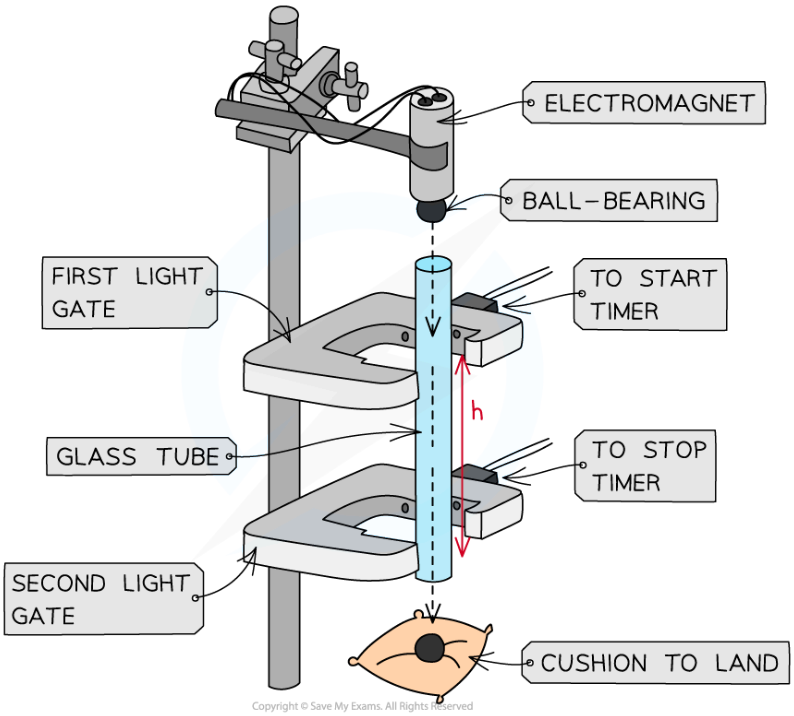
| Equipment | Purpose |
|---|---|
| **Metre ruler** | To measure the distance between the light gates |
| **Steel ball–bearing** | To measure the distance and time taken to drop. The ball must be made from a magnetic material (iron, steel etc.) |
| **Electromagnet** | To drop the ball–bearing through the glass tube at specific height every time |
| **Two light gates** | To determine the time taken to drop a certain distance |
| **Timer** | To measure the time taken for the ball to drop between the light–gates. The timer must be activated to start when the ball passes the first light gate and stop when it passes the second |
| **Tall clamp stand (retort stand)** | To hold the glass tube and electromagnet in line with each other |
| **Glass tube** | To guide the ball–bearing vertically downwards |
| **Cushion** | To stop the ball–bearing from being damaged or damaging the surface when landing |



- Resolution of measuring equipment:

- Metre ruler = 1 mm
- Timer = 0.01 s

## Method




***Apparatus set up to measure the distance and time for the ball bearing to drop***

This method is an example of the procedure for varying the height the ball-bearing falls and determining the time taken – this is just one possible relationship that can be tested

1. Set up the apparatus by attaching the electromagnet to the top of a tall clamp stand. Do not switch on the current till everything is set up
2. Place the glass tube directly underneath the electromagnet, leaving space for the ball-bearing. Make sure it faces directly downwards and not at an angle
3. Attach both light gates around the glass tube at a starting distance of around 10 cm
4. Measure this distance between the two light gates as the height, *h* with a metre ruler
5. Place the cushion directly underneath the end of the glass tube to catch the ball-bearing when it falls through
6. Switch the current on the electromagnet and place the ball-bearing directly underneath so it is attracted to it
7. Turn the current to the electromagnet off. The ball should drop
8. When the ball drops through the first light gate, the timer starts
9. When the ball drops through the second light gate, the timer stops

Your notes

10. Read the time on the timer and record this as time, *t*

11. Increase *h* (eg. by 5 cm) and repeat the experiment. At least 5 – 10 values for *h* should be used

12. Repeat this method at least 3 times for each value of *h* and calculate an average *t* for each

- An example of a table with some possible heights would look like this:

**Example Table of Results**

| HEIGHT h/m | TIME $t_1$/s | TIME $t_2$/s | TIME $t_3$/s | AVERAGE TIME t/s |
|---|---|---|---|---|
| 0.10 | | | | |
| 0.15 | | | | |
| 0.20 | | | | |
| 0.25 | | | | |
| 0.30 | | | | |
| 0.35 | | | | |



## Analysis of Results

- The acceleration is found by using one of the SUVAT equations
- The known quantities are
  - Displacement s = *h*
  - Time taken = *t*
  - Initial velocity *u* = *u*
  - Acceleration *a* = *g*
- The following SUVAT equation can be rearranged:

$$s = ut + \frac{1}{2}at^2$$

$$2s = 2ut + at^2$$

$$\frac{2s}{t} = 2u + at$$

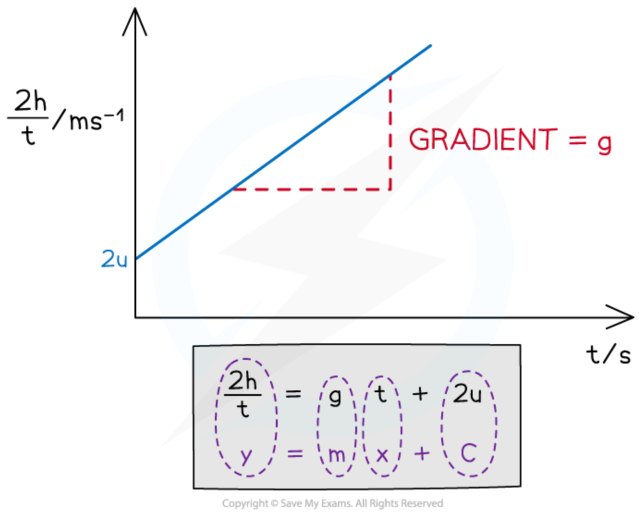
- Substituting in the values and rearranging it as a straight line equation gives:

Your notes

$$\frac{2h}{t} = gt + 2u$$

- Comparing this to the equation of a straight line: y = mx + c
  - y = 2h/*t* (m $s^{-1}$)
  - x = *t*
  - Gradient, m = a = *g* (m $s^{-2}$)
  - y-intercept = 2*u*

1. Plot a graph of the 2*h*/*t* against *t*
2. Draw a line of best fit
3. Calculate the gradient - this is the acceleration due to gravity *g*
4. Assess the uncertainties in the measurements of *h* and *t*. Carry out any calculations needed to determine the uncertainty in g due to these




***The graph of 2h/t against t produces a straight-line graph where the acceleration is the gradient***

## Evaluating the Experiment

**Systematic Errors:**

- Residue magnetism after the electromagnet is switched off may cause *t* to be recorded as longer than it should be

**Random Errors:**

- Large uncertainty in *h* from using a metre rule with a precision of 1 mm
- Parallax error from reading *h*

- The ball may not fall accurately down the centre of each light gate
- Random errors are reduced through repeating the experiment for each value of *h* at least 3–5 times and finding an average time, *t*

## Safety Considerations

- The electromagnetic requires current
  - Care must be taken to not have any water near it
  - To reduce the risk of electrocution, only switch on the current to the electromagnet once everything is set up
- A cushion or a soft surface must be used to catch the ball-bearing so it doesn't roll off / damage the surface
- The tall clamp stand needs to be attached to a surface with a G clamp so it stays rigid

# Acceleration of Freefall Using a Ramp & Trolley

- This method of finding acceleration due to freefall uses the SUVAT equations, but applies them to a trolley rolling down an inclined ramp.

## Variables

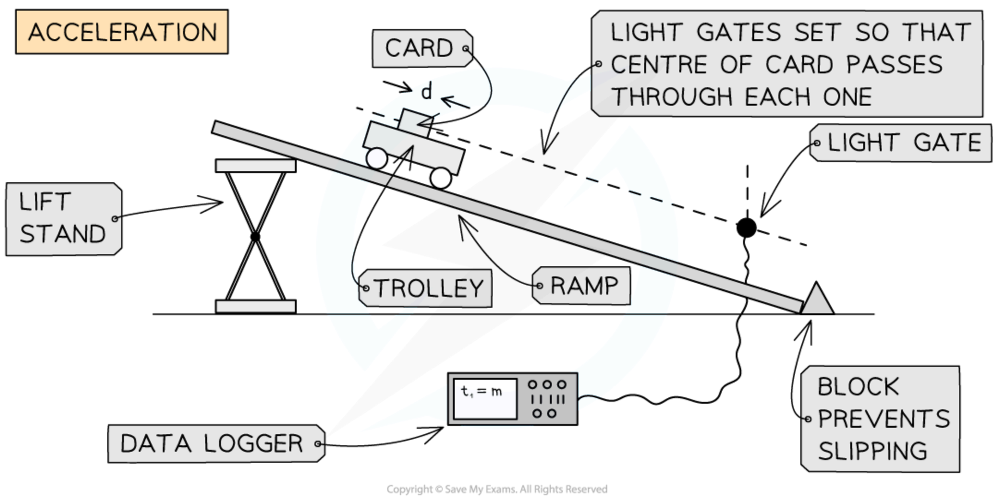
- Independent variable = velocity of the trolley, *v*
- Dependent variable = time, *t*
- Control variables:
  - Height of ramp must be constant
  - Same trolley being used

## Apparatus

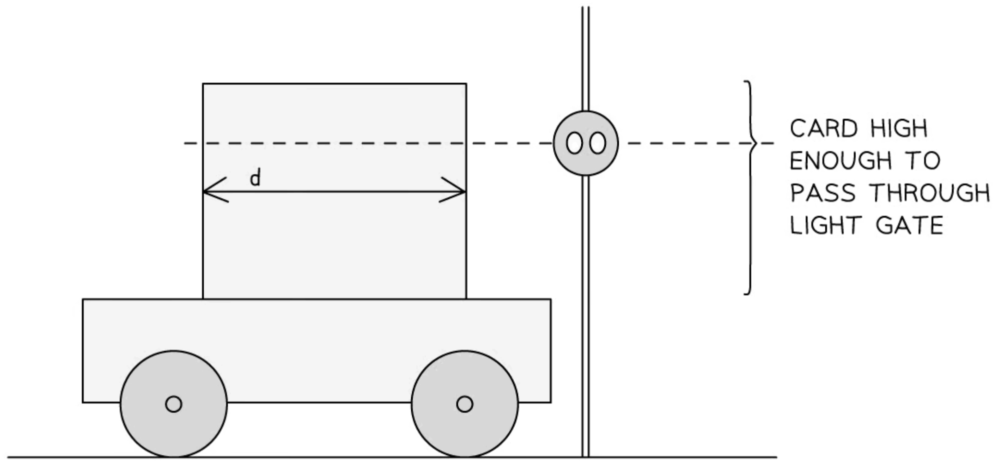
- Inclined ramp
- Trolley with ≅10 cm card attached
- Light gate and computer or datalogger
- Stopwatch
- Block to prevent slipping

## Method

Your notes




- Carefully cut a piece of card so that it is between 5 – 10 cm in length, and has a height which can break the beam of a light gate as the trolley passes through.
- Measure and record the length, d, of the card
  - Record this in the datalogging software
- Attach the card to the trolley and roll the trolley past the light gate checking the beam is broken by the card
  - Adjust the height of the light gate as needed.




- Start the timing on the software, making sure it is set to record instantaneous velocity
- Release the trolley and simultaneously start the stopwatch.
- As the card passes the light gate stops the stopwatch
  - record the time, *t*
- Repeat procedure 3 times, discard anomalies and calculate mean *t*

Your notes

- This reduces errors
- Repeat the procedure at least 5 times, varying the height the trolley is dropped from for each reading
  - This causes a variation in v which is recorded by the light gate, and t which is recorded using the stopwatch.

Your notes

AS RECORDED BY THE LIGHT GATE AND DATA LOGGING SOFTWARE

| VELOCITY / m $s^{-1}$ | TIME $t_1$/s | TIME $t_2$/s | TIME $t_3$/s | AVERAGE TIME t/s |
|---|---|---|---|---|
| | | | | |



## Analysis of Results

- The acceleration is found by using one of the SUVAT equations and rearranging it to create a straight line graph (y = mx + c)
- The known quantities are
  - Time taken, *t* = average *t*
  - Initial velocity, *u* = 0 (the trolley starts from rest)
  - Final velocity *v* = *v* (recorded by the light-gate)
  - Acceleration *a* = *g*
- The missing SUVAT value is displacement, *s*
  - Therefore use

$$v = u + at$$

- This matches the equation of a straight line
  - y = velocity, *v*
  - x = average time, *t*
  - gradient = acceleration, *a*

- y-intercept = initial velocity, *u*
- Plot a graph of v against average t
  - The gradient will be the acceleration
  - This acceleration is provided by gravity, and so will give a value for *g*

## Evaluating the experiment

**Systematic Errors:**

- Make sure for each repeat reading the trolley is released from the same point
- The card should be measured carefully so value *d* is accurate

**Random Errors:**

- Large uncertainty in *d* from using a ruler with a precision of 1 mm
- Reaction time when starting and stopping the stopwatch
  - Random errors are reduced through repeating the experiment for each value of *v* at least 3 times and finding an average time, *t*
- The card may hit the light gate
  - Discard a result where this occurs
- They trolley may not travel straight down the ramp
  - Discard a result where this occurs

## Safety Considerations

- The trolley may fly off the end of the ramp
  - Use a block or tray at the bottom of the ramp to prevent this

### Examiner Tips and Tricks

This experiment can be modified by using the light gate to record time through the gate.

You can then use the time from the light gate to calculate the velocity, *v* of the trolley by calculating with $v = d/t$ where d is the length of the card and the time is the time on the light gate.

However, most light-gate software should allow you to eliminate this step.

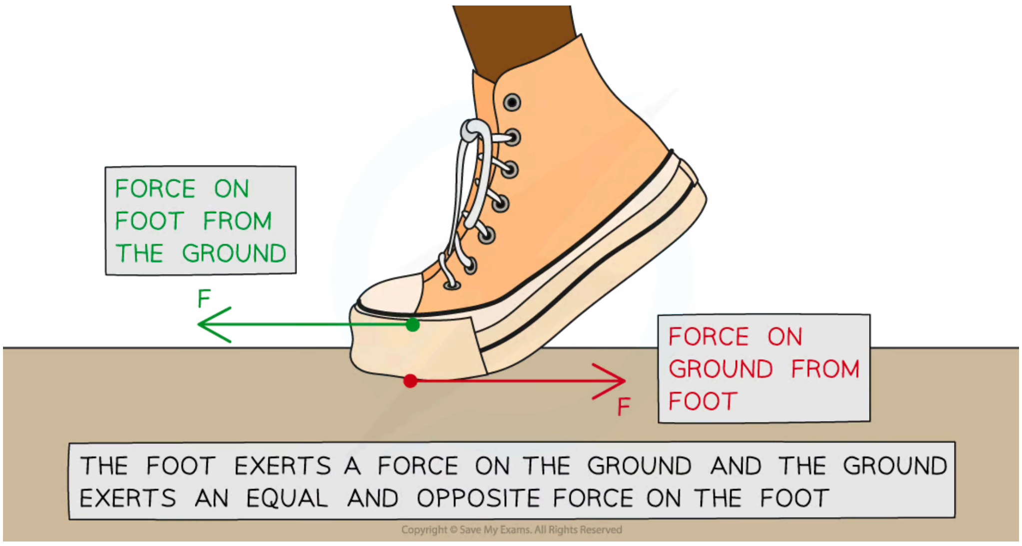
Your notes

# Newton's Third Law of Motion

- Newton's **third law of motion** states:

  **Whenever two bodies interact, the forces they exert on each other are equal in size, act in opposite directions, and are of the same type**

- Newton's third law explains the following important principles about forces:
  - All forces arise in **pairs** – if object A exerts a force on object B, then object B exerts an **equal** and **opposite** force on object A
  - Force pairs are of the **same type** – for example, if object A exerts a **gravitational force** on object B, then object B exerts an equal and opposite **gravitational force** on object A
- Newton's third law explains the forces that enable someone to walk
- The image below shows an example of a pair of equal and opposite forces acting on two objects (the ground and a foot):




***Newton's Third Law: The foot pushes the ground backwards, and the ground pushes the foot forwards***

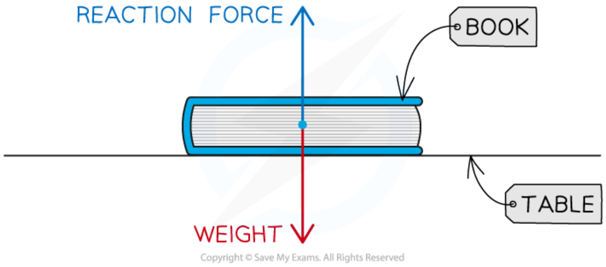
- One force is from the foot that pushes the ground backwards
- The other is an **equal and opposite** force from the ground that pushes the foot forwards

## Worked Example

A physics textbook is at rest on a dining room table.

Your notes

Eugene draws a free body force diagram for the book and labels the forces acting on it.




Eugene says the diagram is an example of Newton's third law of motion. William disagrees with Eugene and says the diagram is an example of Newton's first law of motion.

By referring to the free-body force diagram, state and explain who is correct.

**Answer:**

**Step 1: State Newton's first law of motion**

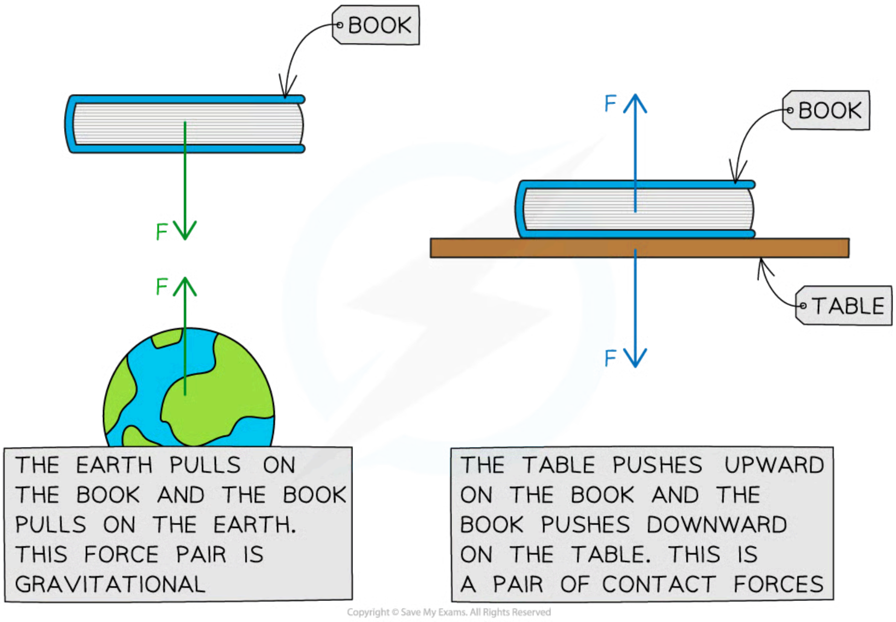
- Objects will remain at rest, or move with a constant velocity unless acted on by a resultant force

**Step 2: State Newton's third law of motion**

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

**Step 3: Check if the diagram satisfies the two conditions for identifying Newton's third law**

- In each case, Newton's third law identifies pairs of equal and opposite forces, of the same type, acting on two different objects
- The diagram only involves **one object**
- Furthermore, the forces acting on the object are different types of force - one is a **contact force** (from the table) and the other is a **gravitational force** on the book (from the Earth) - its **weight**
- The image below shows how to apply Newton's third law correctly in this case, considering the pairs of forces acting:




**Step 4: Conclude which person is correct**

- In this case, **William is correct**
- The free-body force diagram in the question is an example of **Newton's first law**
- The book is **at rest** because the two forces acting on it are **balanced** - i.e. there is no **resultant force**

## Examiner Tips and Tricks

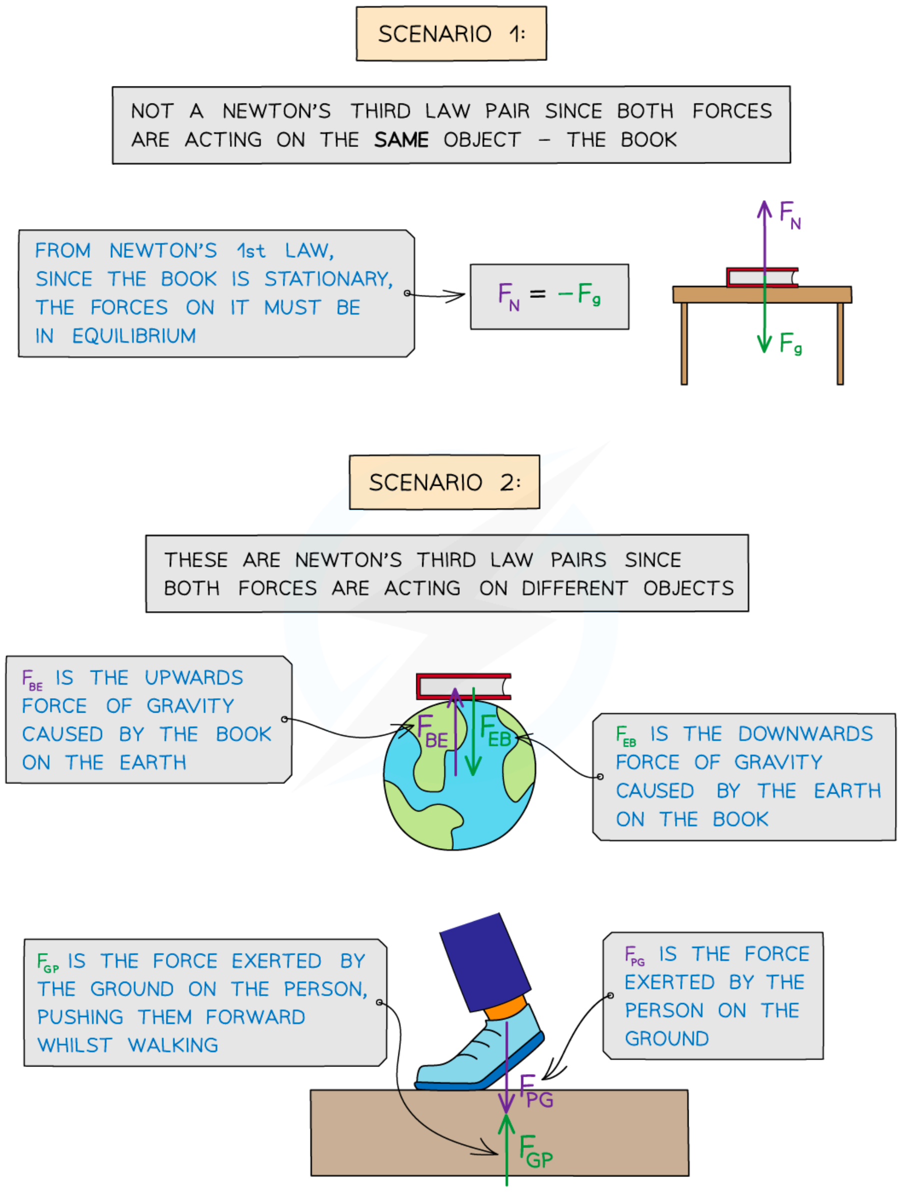
Remember that pairs of equal and opposite forces in Newton's third law act on **two different objects.** It's a really common mistake to confuse Newton's third law with Newton's first law. That also means it's a really common exam question, which often uses a version of the example below.

Applying this check will help you distinguish between them.

Newton's first law involves forces acting on a **single** object.

These differences are shown in Scenario 1 (Newton's first law) vs. Scenario 2 (Newton's third law)

Your notes


SCENARIO 1:
NOT A NEWTON'S THIRD LAW PAIR SINCE BOTH FORCES ARE ACTING ON THE SAME OBJECT – THE BOOK
FROM NEWTON'S 1st LAW, SINCE THE BOOK IS STATIONARY, THE FORCES ON IT MUST BE IN EQUILIBRIUM
$F_N = -F_g$
$F_N$
$F_g$
SCENARIO 2:
THESE ARE NEWTON'S THIRD LAW PAIRS SINCE BOTH FORCES ARE ACTING ON DIFFERENT OBJECTS
$F_{BE}$ IS THE UPWARDS FORCE OF GRAVITY CAUSED BY THE BOOK ON THE EARTH
$F_{BE}$
$F_{EB}$
$F_{EB}$ IS THE DOWNWARDS FORCE OF GRAVITY CAUSED BY THE EARTH ON THE BOOK
$F_{GP}$ IS THE FORCE EXERTED BY THE GROUND ON THE PERSON, PUSHING THEM FORWARD WHILST WALKING
$F_{PG}$ IS THE FORCE EXERTED BY THE PERSON ON THE GROUND
$F_{PG}$
$F_{GP}$

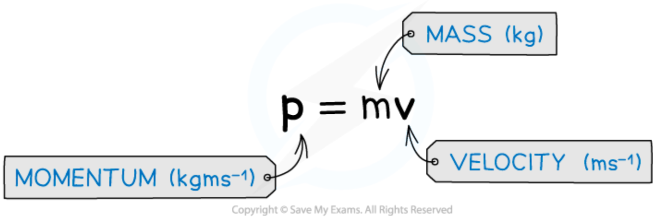


Your notes

Your notes

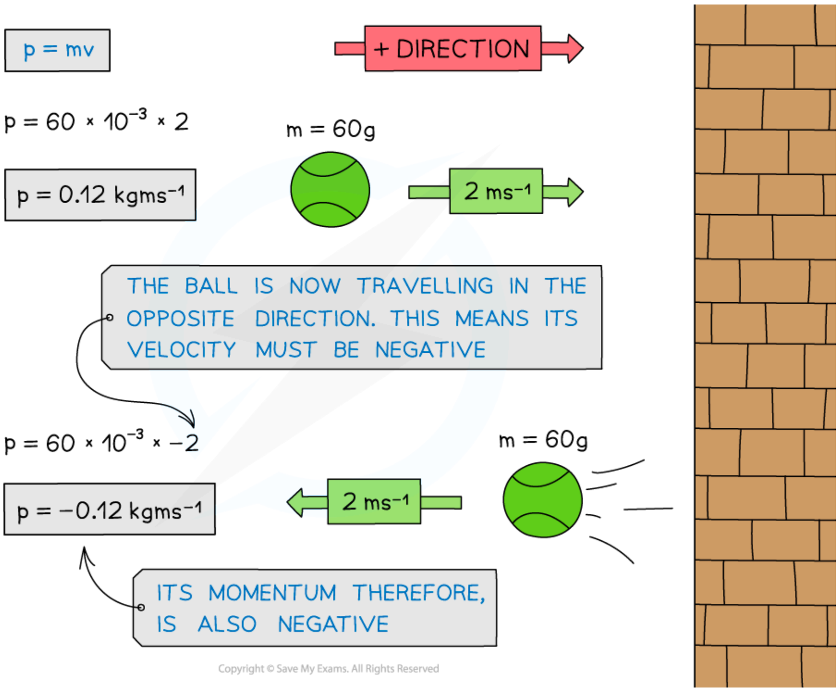
# Defining Momentum

- Linear momentum (*p*) is defined as the product of mass and velocity




***Momentum is the product of mass and velocity***

- Momentum is a vector quantity - it has both a magnitude and a direction
- This means it can have a negative or positive value
  - If an object travelling to the right has positive momentum, an object travelling to the left (in the opposite direction) has a negative momentum
- The SI unit for momentum is **kg m s$^{-1}$**

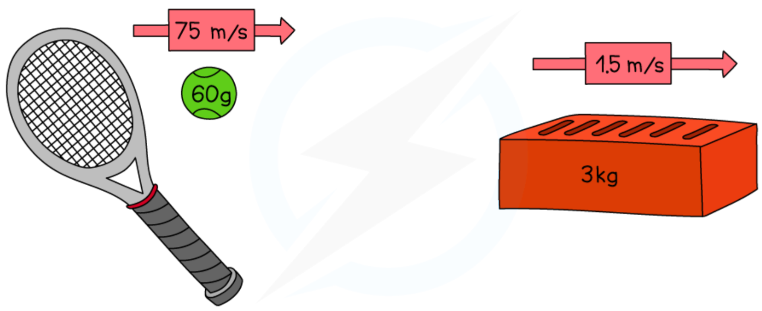



***When the ball is travelling in the opposite direction, its velocity is negative. Since momentum = mass × velocity, its momentum is also negative***

Your notes

## Worked Example

Which object has the most momentum?






**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

Since momentum is in **kg m s$^{-1}$**:

- If the mass is given in grams, make sure to convert to kg by dividing the value by 1000.
- If the velocity is given in km s$^{-1}$, make sure to convert to m s$^{-1}$ by multiplying the value by 1000

The direction you consider positive is your choice, as long the signs of the numbers (positive or negative) are consistent throughout the question.

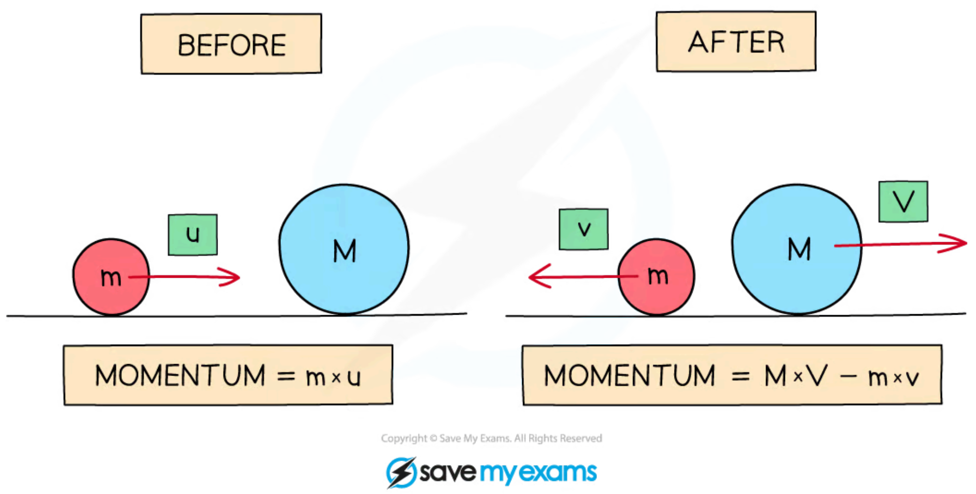
Sketching a diagram **which includes the signs on positive and negative values** will help you avoid mistakes when calculating

# The Principle of Conservation of Linear Momentum

- 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
- Momentum is **always** conserved in collisions where no external forces act
- This is usually written as:

**Total momentum before a collision = Total momentum after a collision**

- Since momentum is a **vector** quantity, a system of objects moving in opposite directions can have an overall momentum of 0
  - This applies to objects moving towards each other or away from each other
- The diagram below shows two masses *m* with velocity *u* and *M* at rest (M has 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 $m \times u$
- 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 $\mathbf{(M \times V) - (m \times v)}$

Your notes

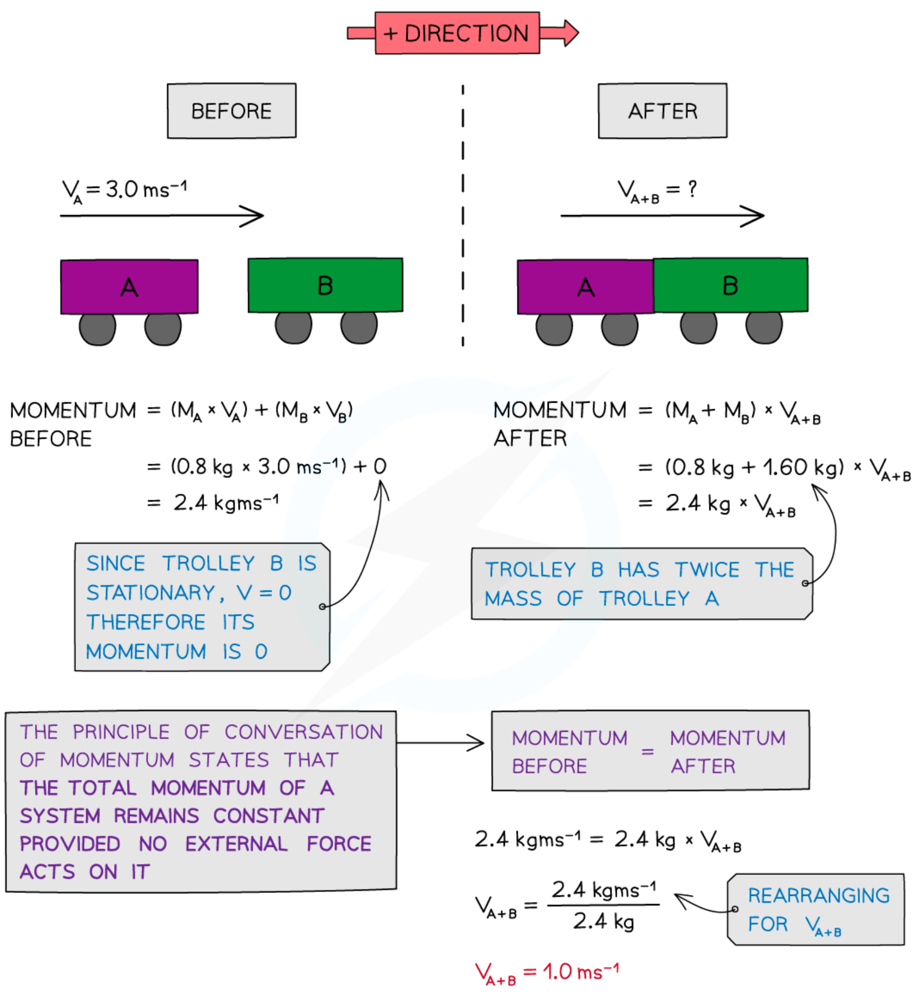
### Worked Example

Trolley **A** of mass 0.80 kg collides head-on with stationary trolley **B** whilst travelling at

3.0 m s$^{-1}$. Trolley **B** has twice the mass of trolley **A**. On impact, the trolleys stick together.

Using the conversation of momentum, calculate the common velocity of both trolleys after the collision.

**Answer:**



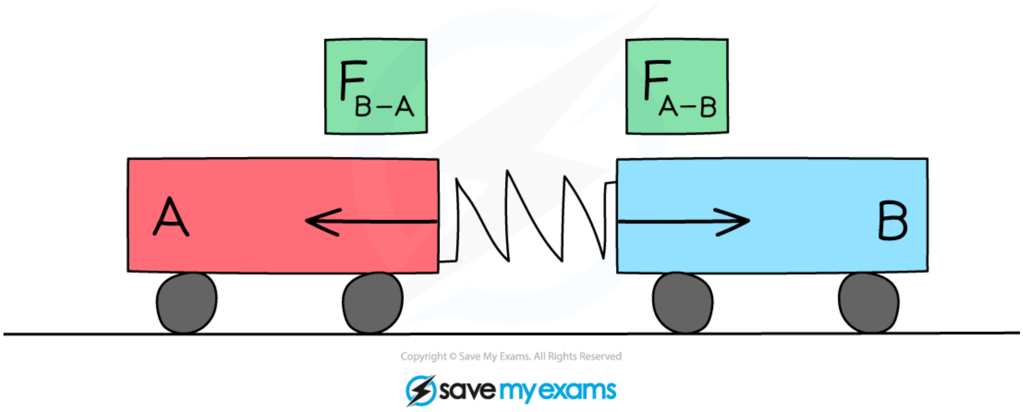
# Conservation of Linear Momentum & Newton's Third Law

Your notes

- Newton's third law of motion states:

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

- This means:
  - 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*

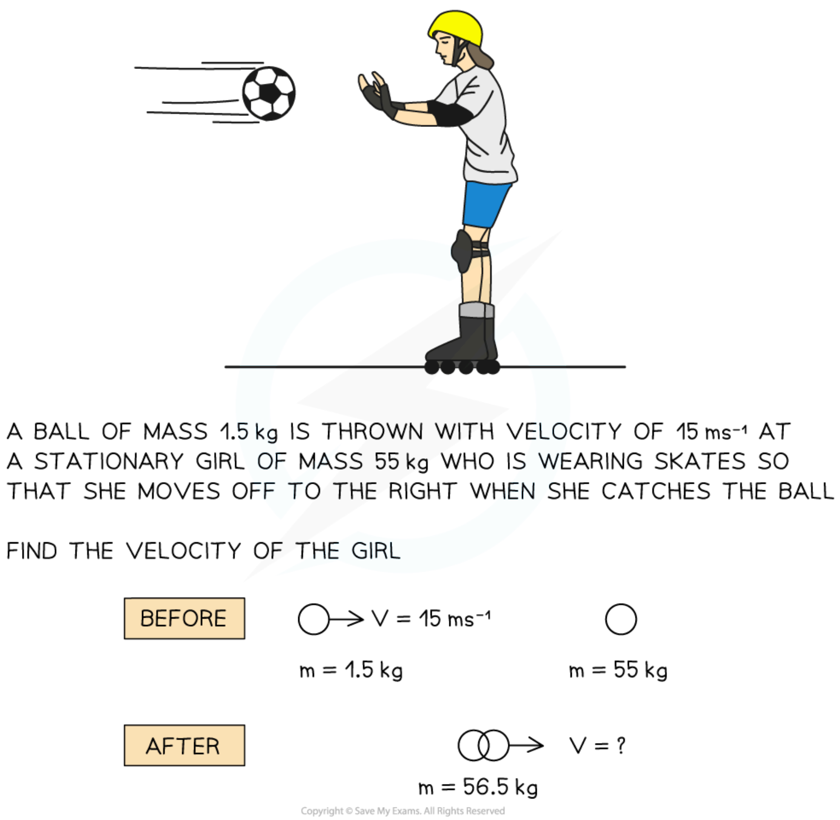
- Consider the collision between two trolleys, **A** and **B**:
  - When trolley **A** exerts a force on trolley **B**, trolley **B** will exert an equal force on trolley **A** in the opposite direction
- In this case:

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

- 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

Momentum questions are often very long and wordy. Even if you are given a diagram, make a quick sketch representing all the bodies as point masses. Mark the velocities with arrows and include positive and negative signs.




The Maths of momentum is straightforward, so as long as you have your vector directions clear in your mind, nothing can go wrong!

Your notes