OCR A Level Physics

Your notes

Dynamics

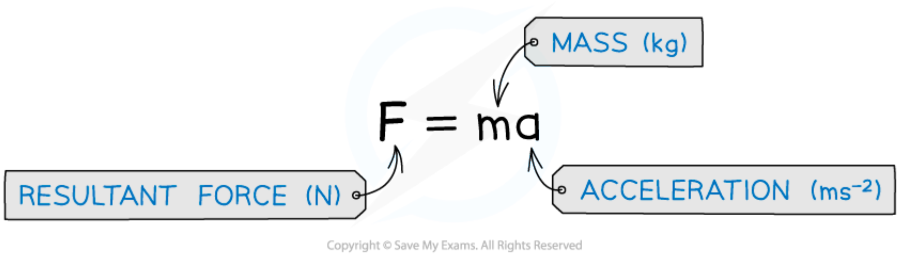
Contents

Force & Acceleration

Your notes

Force & Acceleration

- When a resultant force, *F*, acts on a body with mass, *m*, the body will speed up with acceleration, *a*
- The resultant force is related to mass and acceleration by the formula:



- This relationship means that objects will **accelerate** if there is a **resultant force** acting upon them
- An unbalanced force on a body means it experiences a resultant force
  - If the resultant force is along the direction of motion, it will speed up (**accelerate**) or slow down (**decelerate**) the body
  - If the resultant force is at an angle, it will change the direction of the body

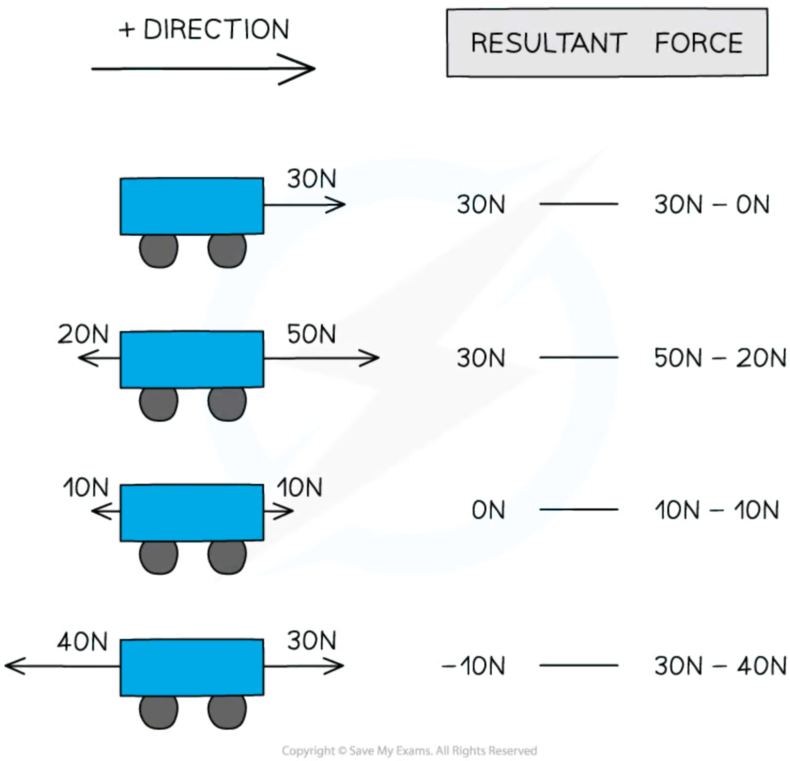
The Newton

- The Newton, N, is commonly used to measure force
- The SI unit for force is kg m s^{-2}
- One Newton is defined as:

The force that will give a mass of 1 kg an acceleration of 1 m s^{-2}

Resultant Force

- Since force is a vector, every force on a body has a magnitude and direction
- The resultant force is, therefore, the **vector sum** of all the forces acting on the body
- The direction is given by either the positive or negative direction as shown in the examples below



Resultant forces on a body can be positive or negative depending on their direction

- The resultant force could also be at an angle, in which case addition of vectors with calculation or scale drawing is used to find the magnitude and direction of the resultant force

Acceleration

- Since acceleration is a vector, it can be either positive or negative depending on the direction of the resultant force
  - If the resultant force is in the **same** direction as the motion of an object, the acceleration is **positive**
  - If the resultant force is in the **opposite** direction to the motion of an object, the acceleration is **negative**
- An object may continue in the same direction however with a resultant force in the opposite direction to its motion, it will slow down and eventually come to a stop
- If drag forces are ignored, or severely reduced, the acceleration is **independent** of the **mass** of an object

- This has been shown in experiments by astronauts who have dropped a feather and a hammer on the Moon from the same height
- Both the hammer and feather drop to the Moon's surface **at the same time**

Your notes

Worked Example

A rocket produces an upward thrust of 15 MN and has a weight of 8 MN.

a) When in flight, the force due to air resistance is 500 kN.

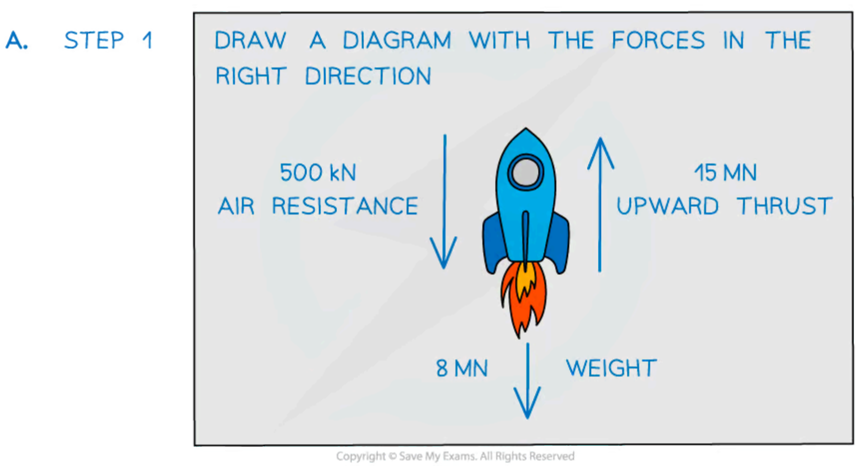
What is the resultant force on the rocket?

b) The mass of the rocket is 0.8×10^5 kg.

Calculate the acceleration of the rocket and the direction its going in.

Answer:

Part (a)



Part (b)

Your notes

STEP 2 — CALCULATE THE RESULTANT FORCE ON THE ROCKET

$$F = \underbrace{15\text{ MN}}_{\text{UPWARD FORCES}} - \underbrace{(500\text{ kN} + 8\text{ MN})}_{\text{DOWNWARD FORCES}}$$

UNIT CONVERSIONS: $1\text{ kN} = 1 \times 10^3\text{ N}$ $\quad 1\text{ MN} = 1 \times 10^6\text{ N}$

STEP 3 — CONVERT ALL VALUES TO THE SAME UNITS (NEWTONS)

$$F = 15 \times 10^6\text{ N} - (500 \times 10^3\text{ N} + 8 \times 10^6\text{ N})$$

$$F = 6.5 \times 10^6\text{ N}$$

$F = 6.5\text{ MN}$ UPWARDS

IN THE POSITIVE DIRECTION

B. STEP 1 — NEWTONS SECOND LAW

$$F = ma$$

STEP 2 — REARRANGE FOR ACCELERATION a

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

STEP 3 — SUBSTITUTE IN VALUES FOR F AND m

$$a = \frac{6.5 \times 10^6\text{ N}}{0.8 \times 10^5\text{ kg}} = 81\text{ ms}^{-2}$$ UPWARDS

ACCELERATION IS ALWAYS IN THE SAME DIRECTION AS THE RESULTANT FORCE

Examiner Tips and Tricks

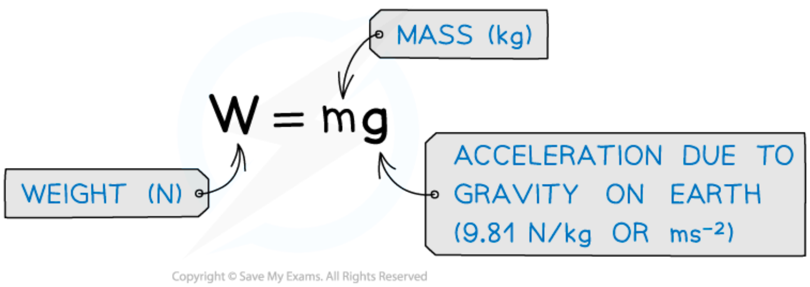
The direction you consider positive is your choice, as long as the signs of the numbers (positive or negative) are consistent throughout the question. It is a general rule to consider the direction the object is initially travelling in as positive. Therefore all vectors in the direction of motion will be positive and opposing vectors, such as drag forces, will be negative.

Your notes

Weight

Weight

- Weight is the effect of a gravitational field on a mass
- Since it is a force on an object due to the pull of gravity, it is measured in **Newtons** (N) and is a vector quantity
- The weight of a body is equal to the product of its mass (*m*) and the acceleration of free fall (*g*)



- *g* is the acceleration due to gravity or the gravitational field strength
- On Earth, this is **9.81 m s^{-2}** (or N kg^{-1})

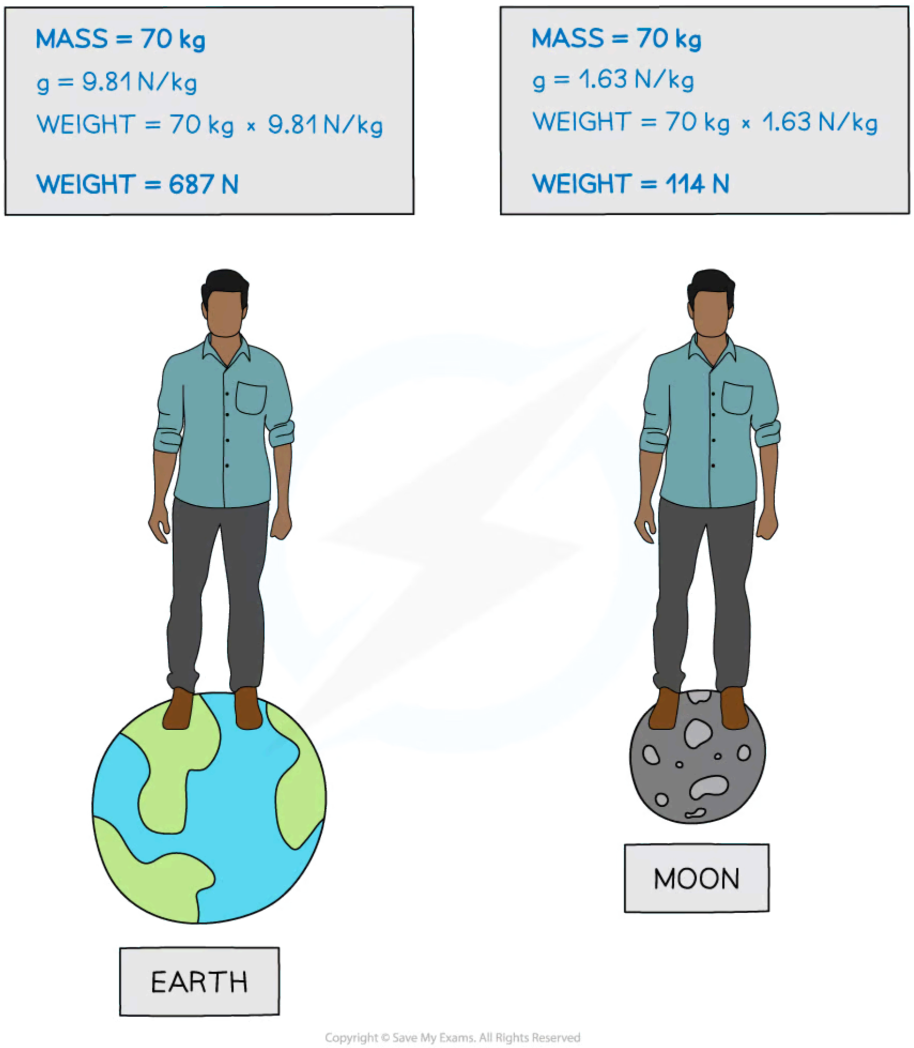
Free fall

- An object in free fall is falling solely under the influence of gravity
- On Earth, all free-falling objects accelerate towards Earth at a rate of **9.81 m s^{-2}**
- In the absence of air resistance, all bodies near the Earth fall with the same acceleration regardless of their mass

Mass v Weight

- An object's mass always remains the same, however, its weight will differ depending on the strength of the gravitational field on different planets
- For example, the gravitational field strength on the Moon is **1.63 N kg^{-1}**, meaning an object's weight will be about **6 times** less than on Earth

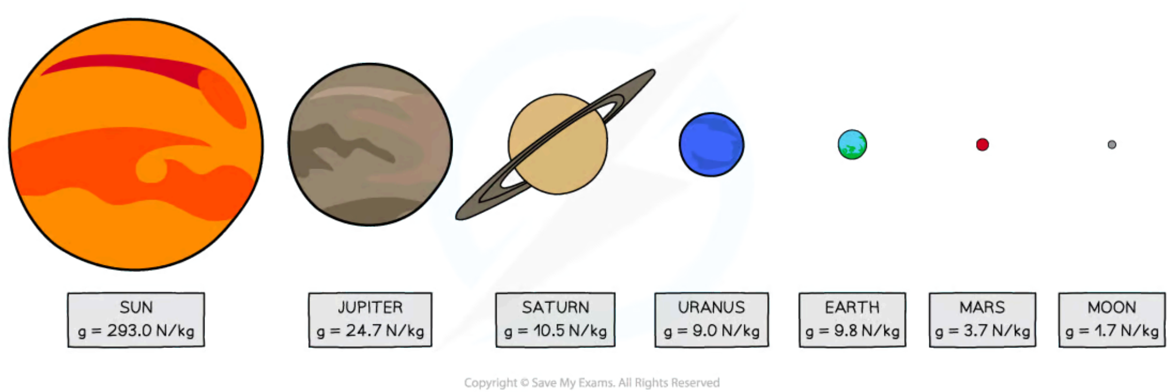
Your notes



On the moon, a person's mass will stay the same but their weight will be much lower

- The value of *g* on other planets in the solar system is given in the diagram below
  - Notice how much this varies according to the size of the planet

Your notes



Gravitational field strength of the planets in our solar system

Worked Example

The acceleration due to gravity on the moon is 1/6 of that on Earth. If the weight of a space probe on the moon is 491 N, calculate its mass.

Answer:

Your notes

STEP 1 — EQUATION FOR WEIGHT

$$W = mg$$

STEP 2 — REARRANGE FOR MASS m

$$m = \frac{W}{g} = \frac{491}{g}$$

STEP 3 — FIND g FOR THE MOON

$$g = \frac{g_{EARTH}}{6} = \frac{9.81}{6} = 1.64\ \text{Nkg}^{-1}$$

STEP 4 — SUBSTITUTE VALUE IN MASS EQUATION

$$m = \frac{491}{1.64} = 300\ \text{kg}$$

Examiner Tips and Tricks

- It is a common misconception that mass and weight are the same, but they are in fact **very different**
- Weight is the force of gravity acting upon an object
  - Weight is a **vector** quantity
- Mass is the amount of matter contained in the object
  - Mass is a **scalar** quantity

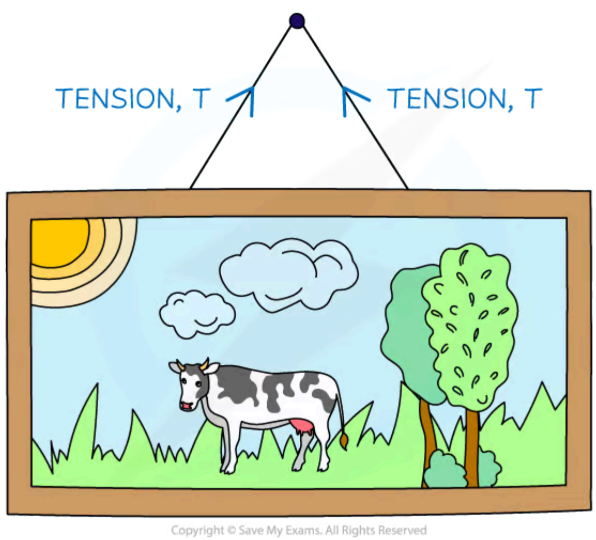
Your notes

Tension, Normal Force, Upthrust & Friction

- Tension:

  The force experienced by a cable, rope, or string when pulled, hung, rotated or supported

- This is normally labelled as *T* on free body diagrams

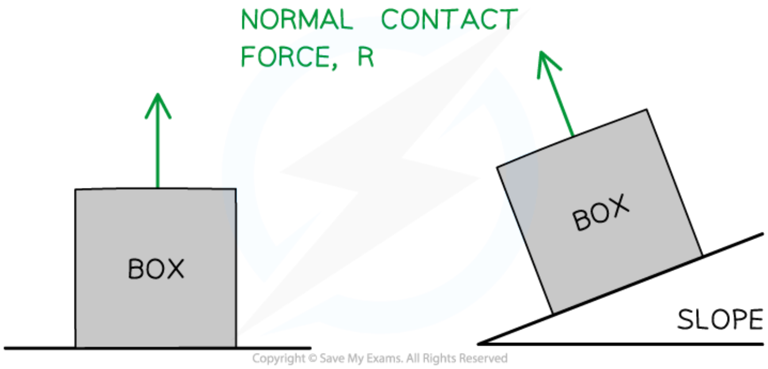


Tension always acts away from the mass

- Normal Contact Force:

  The force arising when an object rests against another object acting at a 90° angle to the plane of contact

- It is sometimes also referred to as the **reaction** force
- This is normally labelled as *N* or *R* on free body diagrams
- This force arises from Newton's Third Law

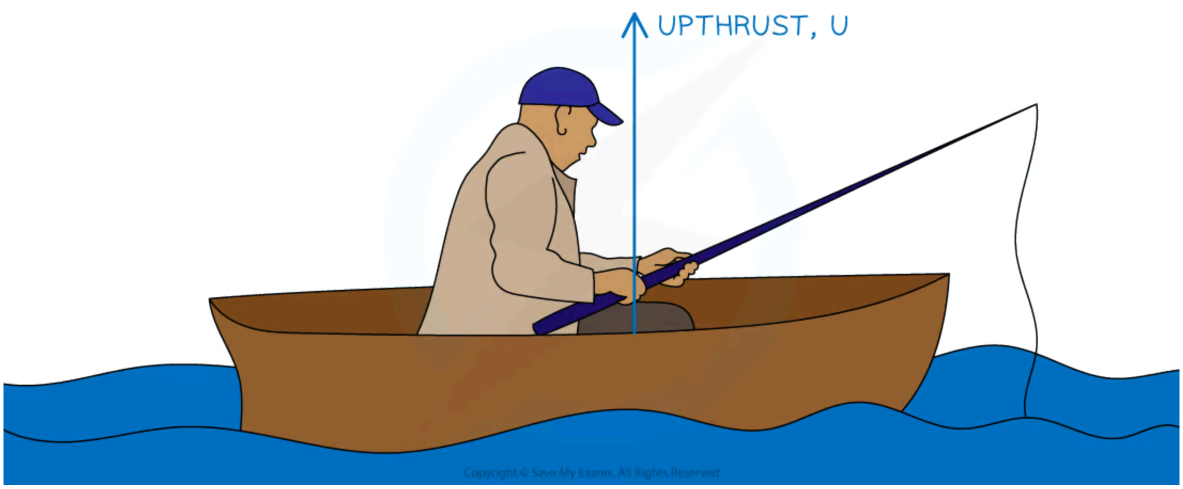


Normal contact force always acts perpendicular to the surface

- Upthrust:

  The upward buoyancy force acting on an object when it is in a fluid

- Upthrust can occur in **liquids** and **gases**



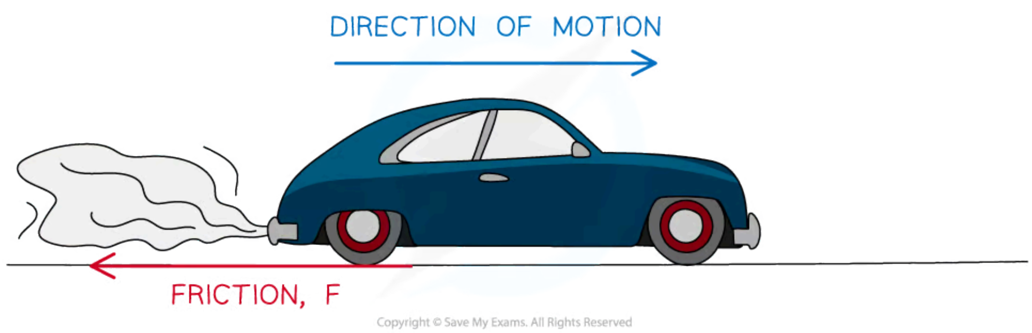
Upthrust always acts upwards

- Friction:

  The force that arises when two surfaces are in contact with each other

- Friction always **opposes** the motion
- This is normally labelled as *F* or *Fr* on free body diagrams

Your notes



Friction always acts at the point where the objects are in contact, and in the opposite direction to the direction of motion

Free-body diagrams

- Free body diagrams are useful for modelling the forces that are acting on an object
- Each force is represented as a vector arrow, where each arrow:
  - Is scaled to the magnitude of the force it represents
  - Points in the direction that the force acts
  - Is labelled with the name of the force it represents
- Free body diagrams can be used:
  - To identify which forces act in which plane
  - To resolve the net force in a particular direction
- The net force in a particular direction can be calculated by:
  - Using the labelled angles and magnitudes
  - Resolving each force into horizontal and vertical components

Worked Example

Draw free-body diagrams for the following scenarios:

a) A picture frame hanging from a nail

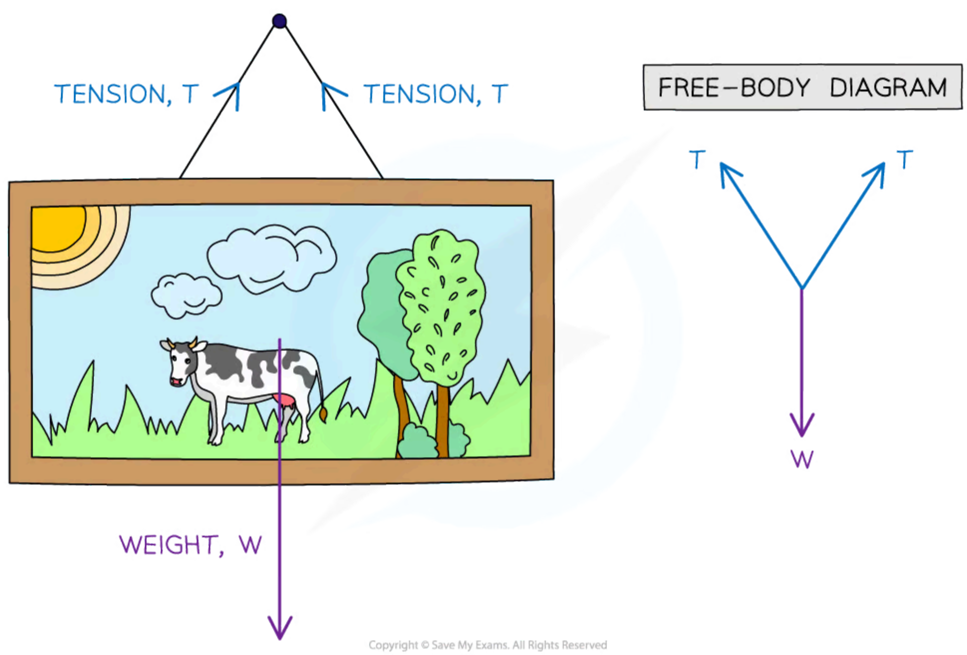
b) A box being pulled up a slope by a mass on a pulley (resolving the weight into parallel and perpendicular directions)

c) A man fishing in a stationary boat

d) A car accelerating along a road

Answer:

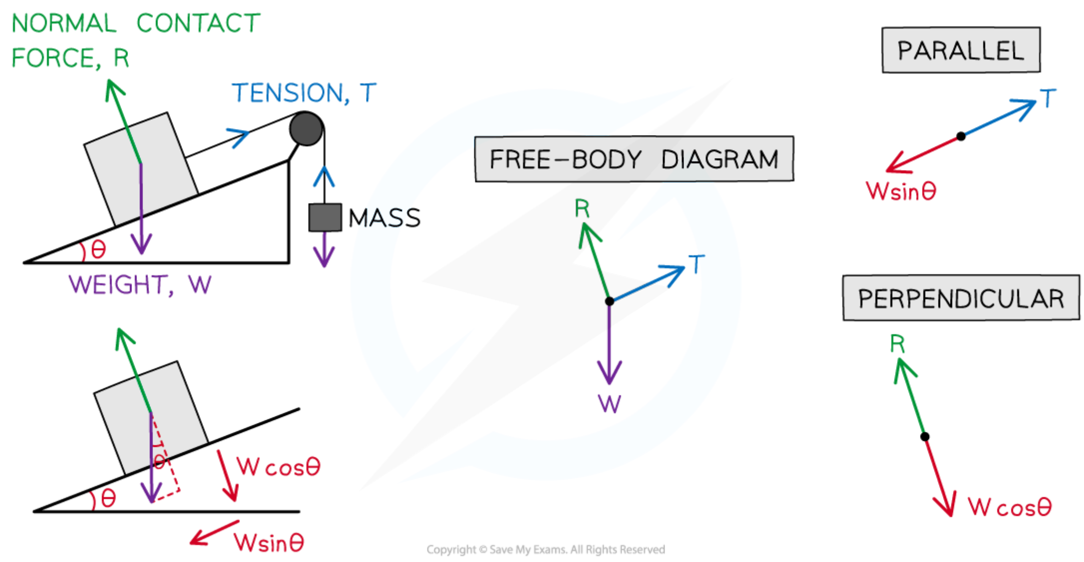
Part (a)



- The size of the arrows should be such that the 3 forces would make a closed triangle as they are in equilibrium

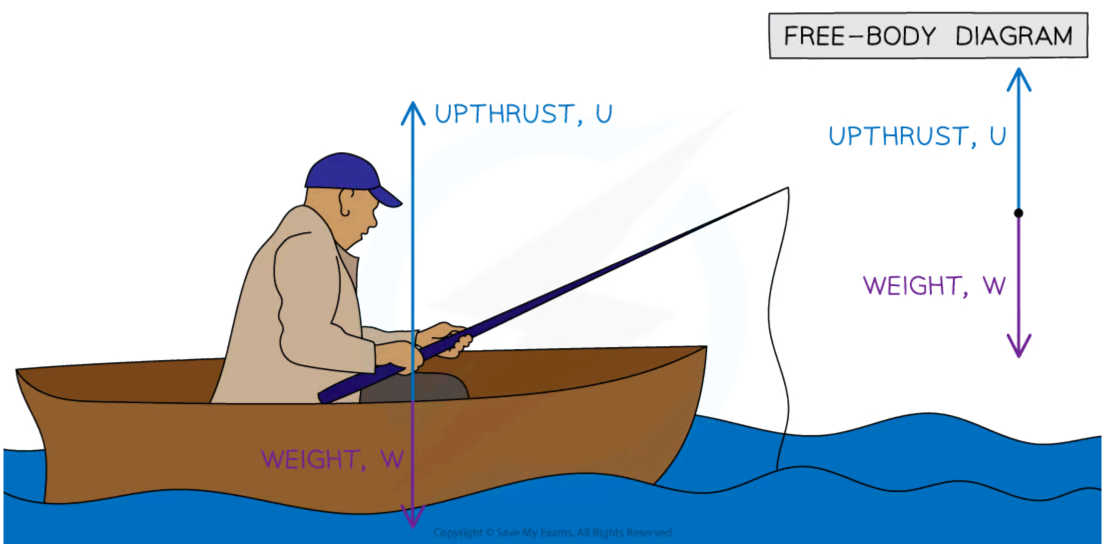
Part (b)

Your notes



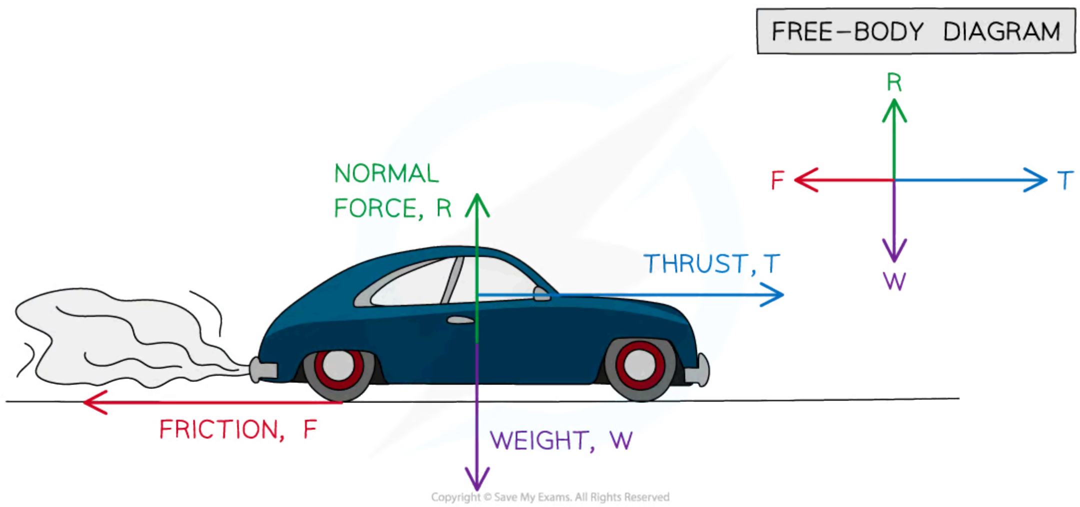
- In problems such as this, it is best to resolve the forces parallel and perpendicular to the slope
  - Usually, an angle will be given to allow calculation of the weight in these directions

Part (c)



- As the boat is not moving, the size of both arrows must be the same

Part (d)



- As the car is accelerating, the size of the thrust must be **larger** than the size of the friction force
  - As in part (c), the upwards and downwards forces must be **equal**

Examiner Tips and Tricks

If you need a reminder on how to combine and resolve vectors, take a look at the notes in '3.3 Scalars & Vectors'

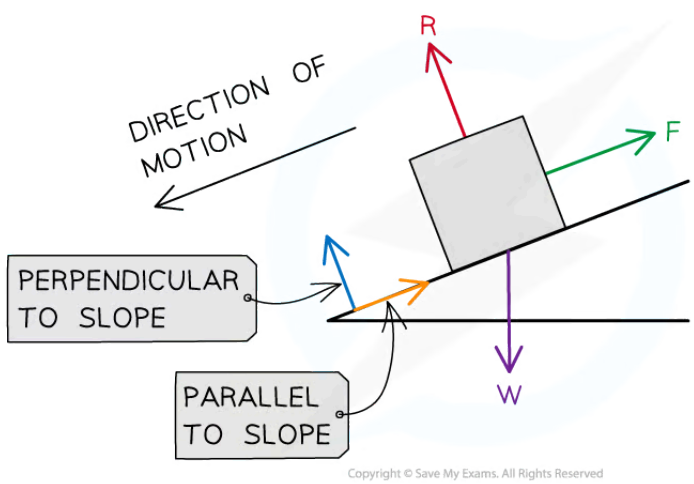
Your notes

Motion in One & Two Dimensions

Your notes

Motion in One & Two Dimensions

- If a constant force acts upon an object, then it will experience a resultant acceleration, determined using F = ma
- This motion can be investigated in one or two-dimensional planes, such as along the ground or on a slope
  - One-dimensional planes involve **just** up and down **or** left and right (on the ground)
  - Two-dimensional planes involve **both** up and down **and** left and right (on a slope)
- On a slope, it is often simpler to resolve the forces into parallel and perpendicular components, rather than horizontally and vertically:
  - The weight, *mg* of the object acts vertically down
  - The frictional force, *F* between the slope and the object acts along the plane of the slope, in the direction opposing the motion
  - The normal reaction force, *R* acts perpendicular to the plane of contact between the object and the slope

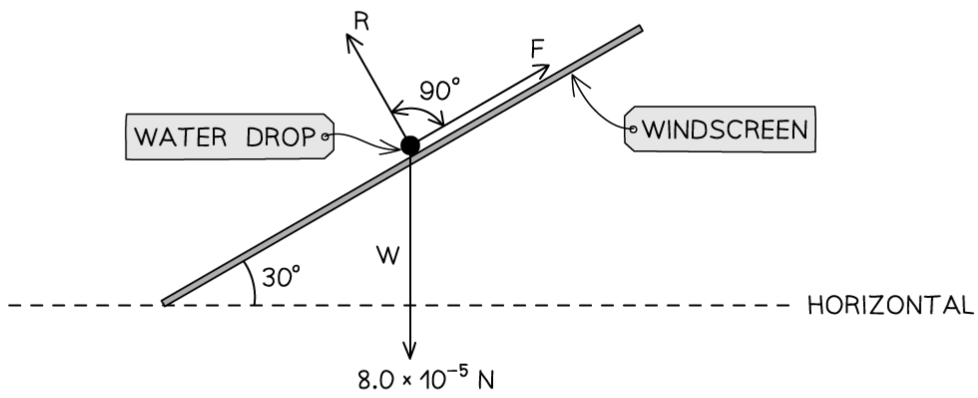


The normal reaction force R, weight W and friction F on a block moving down a slope

Your notes

Worked Example

The diagram below shows the forces acting on a water drop on the windscreen of a stationary car.



The windscreen makes an angle of 30° to the horizontal. The weight of the water drop is 8.0×10^{-5} N. The normal contact force on the water drop is *R*. There is also a force *F* acting on the water drop as shown. The water drop is stationary. Determine:

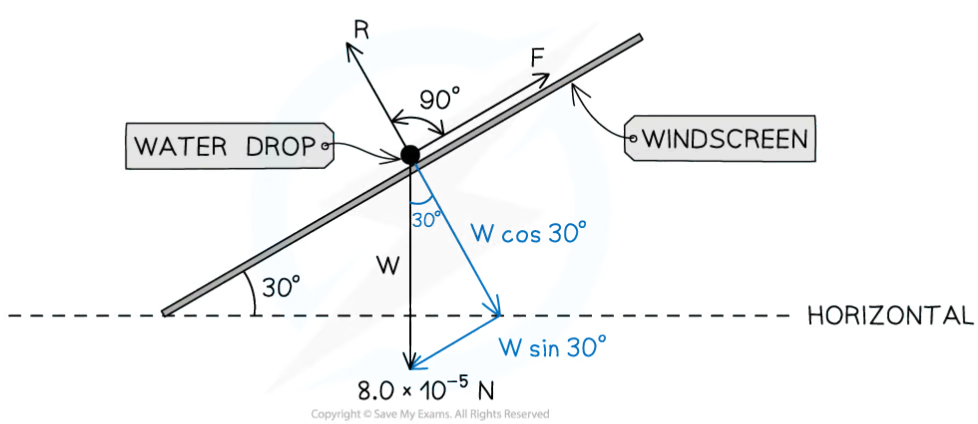
(a) The component of the weight of the water-drop perpendicular to the windscreen

(b) The component of the weight of the water-drop parallel to the windscreen

(c) The magnitude of *R*

(d) The magnitude of *F*

Answer:



Part (a)

- Perpendicular component = $W \cos 30°$
- Perpendicular component = $(8.0 \times 10^{-5}) \cos 30° = 6.9 \times 10^{-5}$ N

Part (b)

- Parallel component = $W \sin 30°$
- Parallel component = $(8.0 \times 10^{-5}) \sin 30° = 4.0 \times 10^{-5}$ N

Part (c)

- R is equal to the perpendicular component of the weight
- Perpendicular forces must be equal and opposite

$$R = 6.9 \times 10^{-5} \text{ N}$$

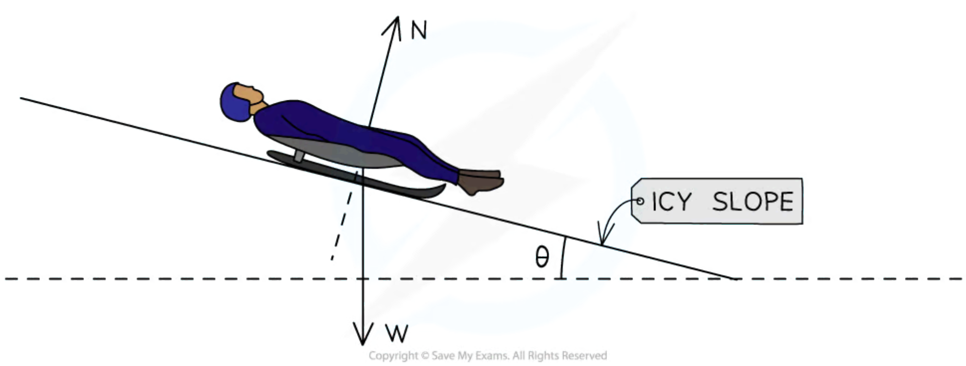
Part (d)

- F is equal to the parallel component of the weight
- Parallel forces must be equal and opposite

$$F = 4.0 \times 10^{-5} \text{ N}$$

Worked Example

The diagram below shows a rider on a sledge sliding down an icy slope. The frictional forces acting on the sledge and the rider are negligible. The normal contact force N and the total weight W of the sledge and rider are shown.

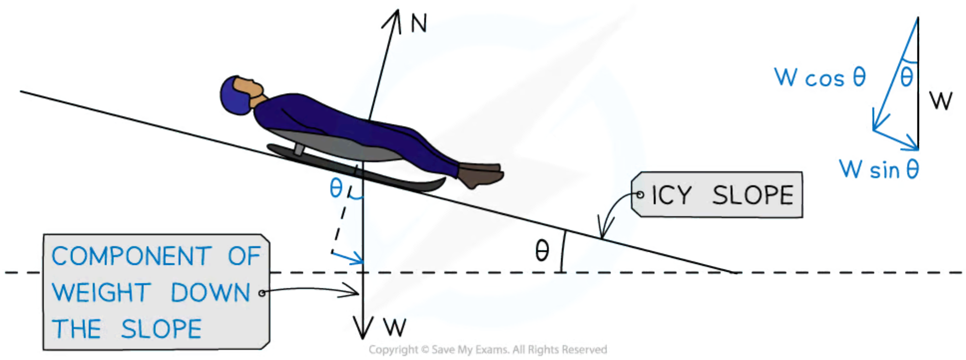


The acceleration of the sledge and rider down the slope is 2.0 m s^{-2}.Determine the angle made by the slope to the horizontal.

Answer:

Step 1: Write down the known quantities

- Acceleration, $a = 2.0$ m s^{-2}
- Weight, $W = mg$
- Component of weight parallel the slope, $F = W \sin\theta = mg \sin\theta$



Step 2: Write down the equation relating force and acceleration

$$F = ma$$

Step 3: Substitute in the component of weight down the slope

$$mg \sin\theta = ma$$

Step 4: Rearrange for sin θ and calculate the angle

$$a = g \sin\theta$$

$$\sin\theta = 2.0 / 9.81$$

$$\boldsymbol{\theta = 12°}$$

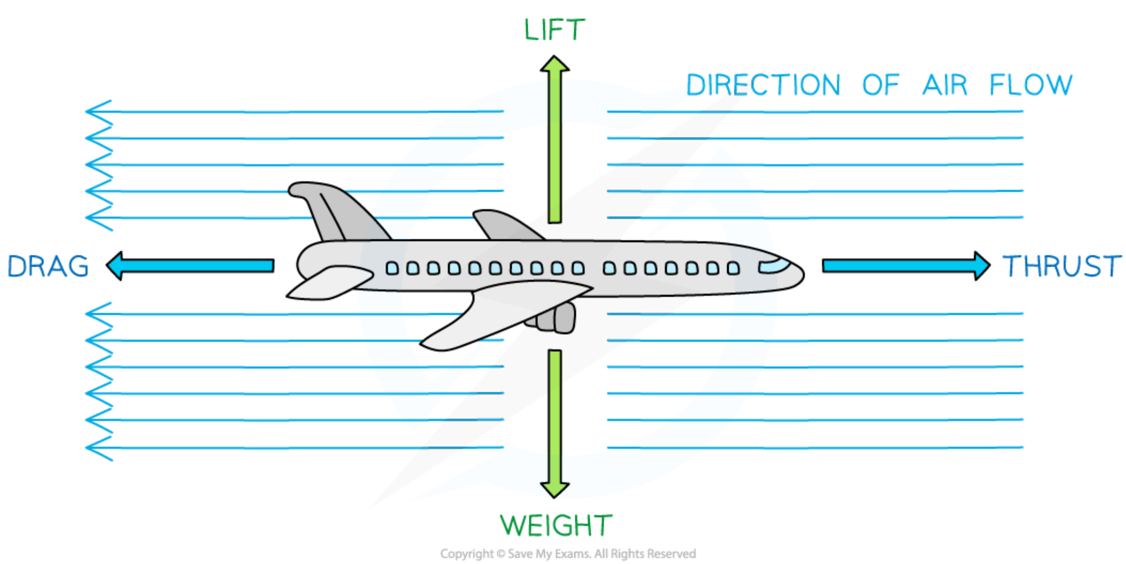
Your notes

Your notes

Drag Forces

Drag Forces

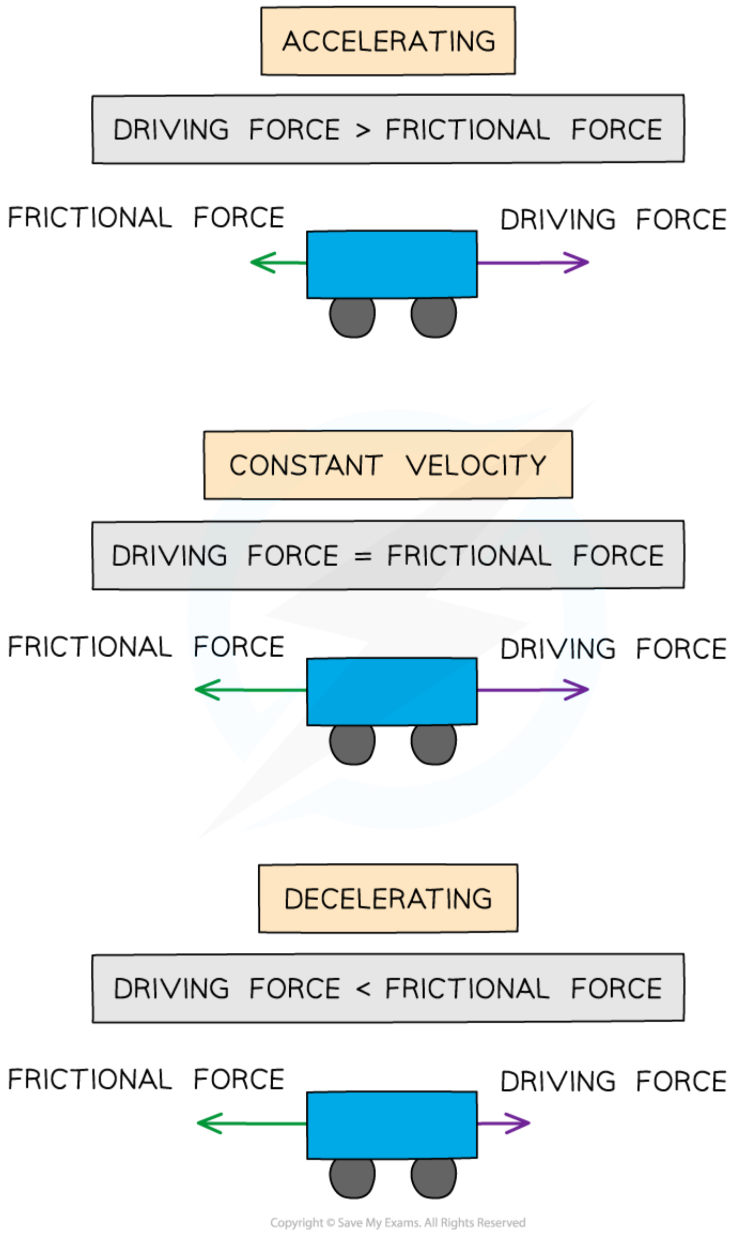
- Drag forces are forces that oppose the motion of an object moving through a fluid (gas or liquid)
- Examples of drag forces are **friction** and **air resistance**
- Drags forces:
  - Are always in the **opposite** direction to the motion of the object
  - Never speed an object up or start them moving
  - Slow down an object or keeps them moving at a constant speed
  - Convert kinetic energy into heat and sound
- Lift is an upwards force on an object moving through a fluid. It is perpendicular to the fluid flow
  - For example, as an aeroplane moves through the air, it pushes down on the air to change its direction
  - This causes an equal and opposite reaction upwards on the wings (lift) due to Newton's third law



Drag forces are always in the opposite direction to the thrust (direction of motion). Lift is always in the opposite direction to the weight

- A key component of drag forces is it increases with the speed of the object

- This is shown in the diagram below:



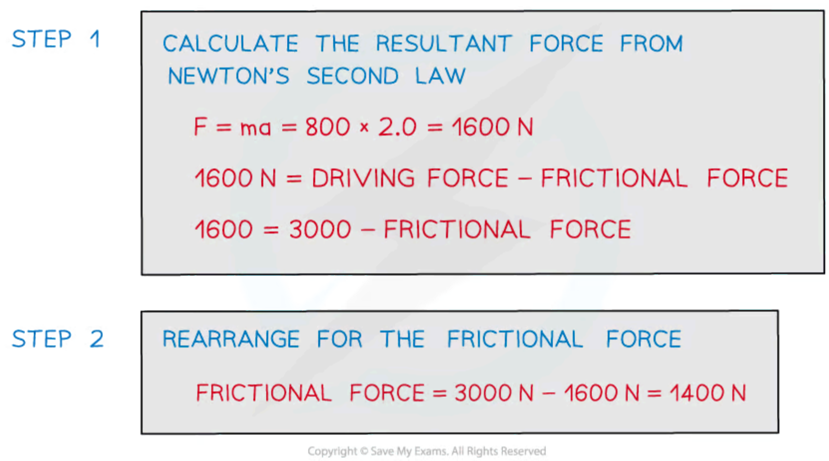
Frictional forces on a car increase with speed

Your notes

Worked Example

A car of mass 800 kg has a horizontal driving force of 3 kN acting on it.Its acceleration is 2.0 m s^{-2}.What is the frictional force acting on the car?

Answer:



Factors Affecting Drag

- The magnitude of the drag force depends on several factors, including:
  - The speed of the object
  - The object's shape and texture
  - The density of the fluid
- The two most significant factors are the **speed** of the object and the object's **cross-sectional area**

Air Resistance

- Air resistance **increases with the speed** of an object
- However, there are other factors that also affect the maximum speed, such as:
  - Cross-sectional area

Your notes

- Shape
- Altitude
- Temperature
- Humidity

Many factors such as posture, clothes and bicycle shape must be considered when trying to reduce air resistance

Examiner Tips and Tricks

If a question considers air resistance to be '**negligible**' this means in that question, air resistance is taken to be so small it will not make a difference to the motion of the body. You can take this to mean there are no drag forces acting on the body.

Objects Falling in a Uniform g Field with Drag

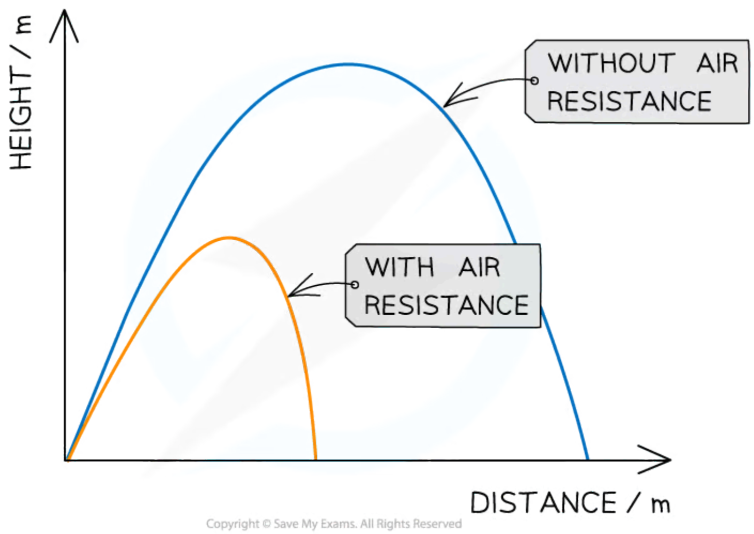
- When an object is falling vertically in a uniform gravitational field, it is usually considered to have only a constant attractive force, weight, acting on it
  - However, for a more realistic approach, the opposing drag forces should be considered

Your notes

- Opposing drag forces reduce the net force acting on an object and as a result, reduce the magnitude of the acceleration
  - The drag force will increase until it is equal in magnitude to the weight of the object
  - This leads to the object reaching a steady speed, known as its **terminal velocity**
- Because of drag, experimental values of the acceleration due to gravity, *g*, tend to be **less** than 9.81 m s^{-2}

Air Resistance & Projectile Motion

- Air resistance decreases the **horizontal** component of the velocity of a projectile
  - This means both its range and maximum height is decreased compared to no air resistance



A projectile with air resistance travels a smaller distance and has a lower maximum height than one without air resistance

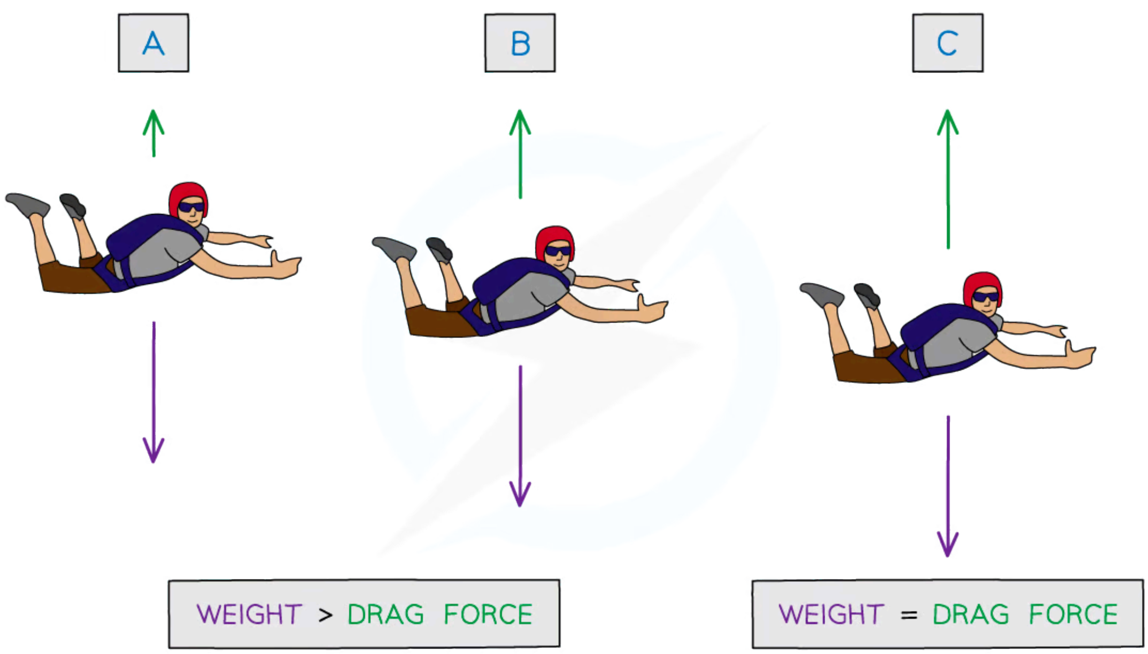
Your notes

Terminal Velocity

Your notes

Terminal Velocity

- For a body in free fall, the only force acting is its weight and its acceleration *g* is only due to gravity.
- The drag force increases as the body accelerates
    - This increase in velocity means the drag force also increases
- Due to Newton's Second Law, this means the resultant force and therefore acceleration decreases (recall ***F*** **=** ***ma***)
- When the drag force is equal to the gravitational pull on the body, the body will no longer accelerate and will fall at a constant velocity
- This velocity is called the **terminal velocity**



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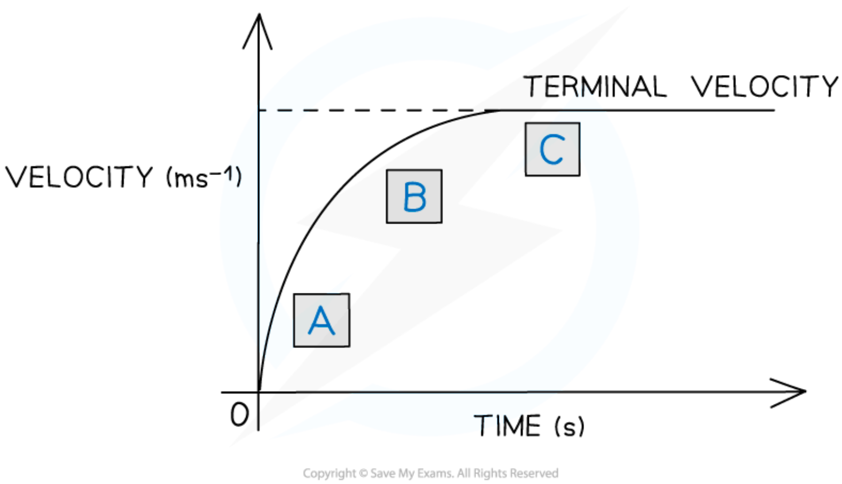
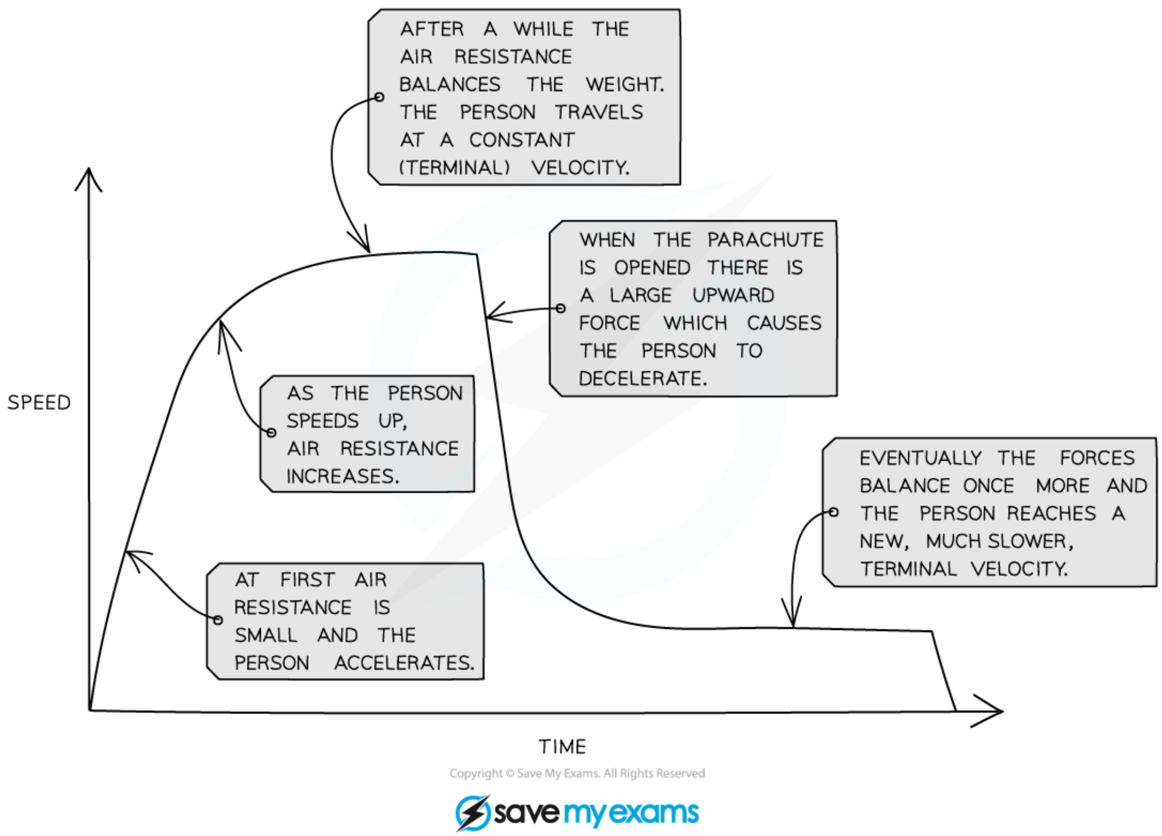


A skydiver in freefall reaching terminal velocity

- The graph shows how the velocity of the skydiver varies with time
- Since the acceleration is equal to the gradient of a velocity-time graph, the acceleration decreases and eventually becomes zero when terminal velocity is reached
- After the skydiver deploys their parachute, they decelerate to a **lower terminal velocity** to reduce the impact on landing
- This is demonstrated by the graph below:

Your notes

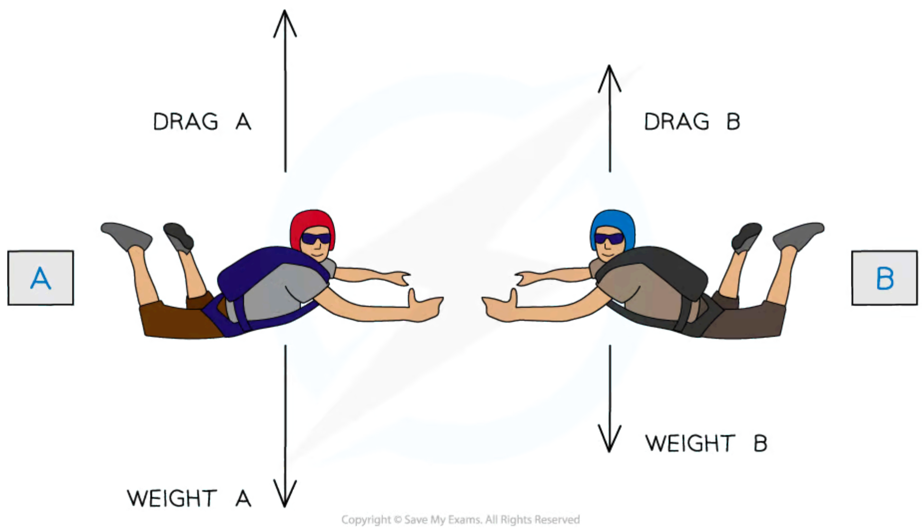


A graph showing the changes in speed of the skydiver throughout their entire journey in freefall

Worked Example

Skydivers jump out of a plane at intervals of a few seconds.

Skydivers **A** and **B** want to join up as they fall.



If **A** is heavier than **B**, who should jump first?

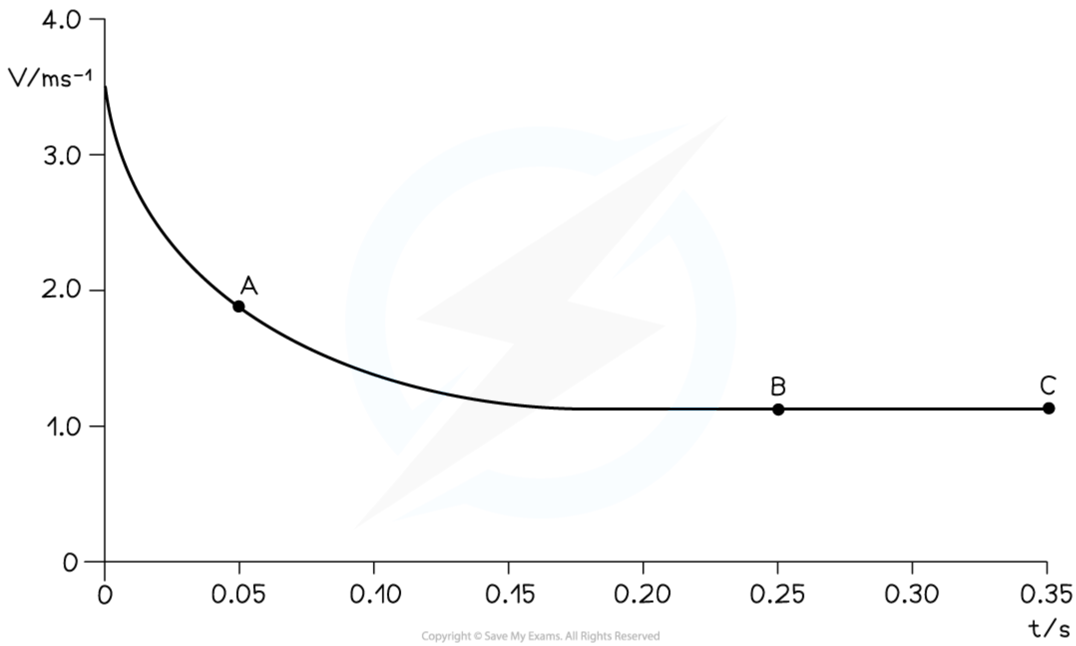
Answer:

- Skydiver **B** should jump first since he will take less time to reach terminal velocity
  - His terminal velocity will also be a lower speed than that of skydiver **A**
- This is because skydiver **A** has a higher mass, and hence, weight
  - A greater weight means a greater acceleration for **A** than **B** at every stage until terminal velocity
  - Air resistance gets larger with speed, so for air resistance to match **A**'s weight, **A** must be travelling faster than **B** at terminal velocity
- This means if **A** were to jump first, skydiver **B** would never catch up
- Skydiver **B** must jump first, then skydiver **A** can catch up

Worked Example

The diagram below shows the graph of velocity *v* against time *t* for the ball as it travels through the oil. The ball enters the oil at time *t* = 0.

Your notes



In terms of the forces acting on the ball, describe and explain its motion at

a) Point **A**

b) Point **B**

Answer:

Part (a)

At **A**:

- The drag force is **greater** than the weight of the ball
  - Therefore, the ball is decelerating

Part (b)

At **B**:

- The drag force is **equal** to the weight
  - The ball has reached terminal velocity and is no longer decelerating

Examiner Tips and Tricks

Your notes

- Exam questions about terminal velocity commonly involve the motion of skydivers as they fall
- A common misconception is that skydivers move upwards when their parachutes are deployed - however, this is not the case, they are in fact **decelerating** to a lower terminal velocity

Your notes

Investigating Terminal Velocity

Your notes

Terminal Velocity in Fluids

Aims of the Experiment

The terminal velocity of a ball bearing in a viscous fluid can be determined experimentally using a cylinder filled with a viscous liquid. The aim of this experiment is to calculate the terminal velocity of the mass as it falls through a viscous fluid.

Variables

- Independent variable = Distance between markers (m)
- Dependent variable = Time to travel between markers (s)
- Control variables
  - Use the same viscous fluid
  - Use the same ball bearing

Equipment List

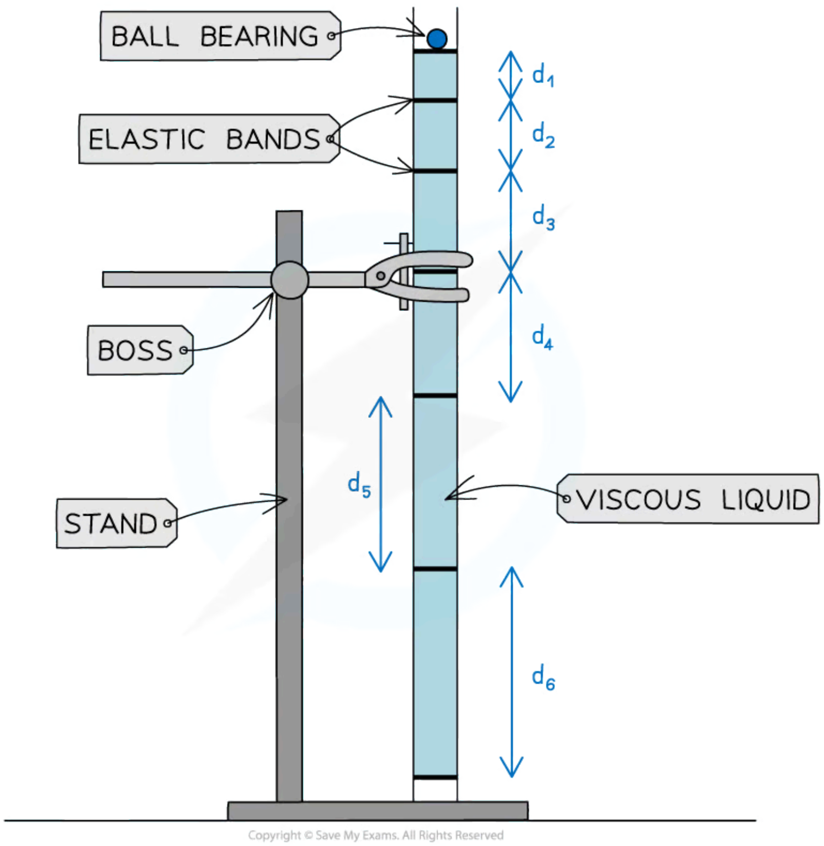
Your notes

Apparatus	Purpose
Viscous liquid such as glycerol, wallpaper paste or heavy oil	To provide a medium for the ball bearing to travel through. The more viscous the fluid, the easier the measurement of speed
Tall glass measuring cylinder	To provide a suitable container to put the viscous liquid in. The taller the container, more likely the ball will reach terminal velocity
Stand, clamp and boss	To secure the ruler and glass container
Elastic bands or marker pen	To mark set distances at which times are recorded
Metre ruler	To measure the distances between the markers
Steel ball bearings	To drop into the viscous fluid to determine the terminal velocity
Strong magnet	To enable easy removal of the ball bearing from the glass container
Stopwatch	To measure time intervals between the markers

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

Method

Your notes



Experimental set up for investigating terminal velocity in a fluid

1. Set up the equipment as shown in the diagram
2. Wrap elastic bands, or draw marks using a marker pen, around the tube of viscous liquid at set intervals measured by the ruler
3. Hold a ball bearing directly above the surface of the liquid, and then release it from rest
4. Record the time it reaches each elastic band or marker line by using the lap feature on the stopwatch
5. Calculate the time taken to travel between consecutive bands and calculate the average speed at each time
6. Repeat the procedure several times over a wide range of readings

- An example table might look like this:

Your notes

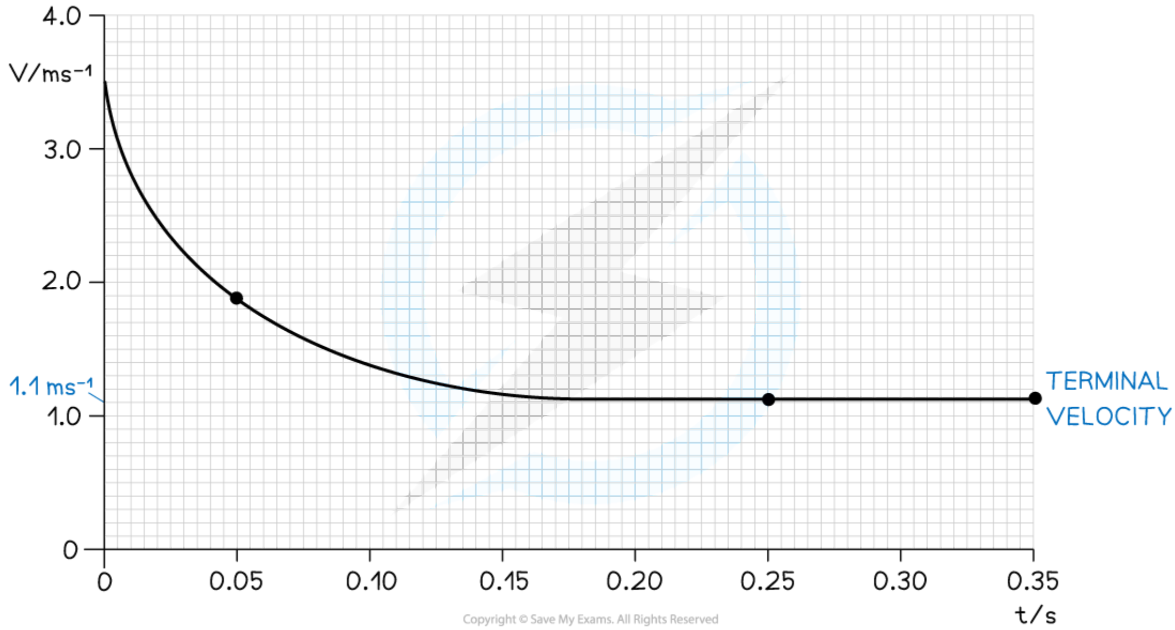
$$\text{SPEED} = \frac{\text{DISTANCE}}{\text{TIME}}$$

DISTANCE BETWEEN MARKERS (m)		TIME BETWEEN MARKERS (s)			AVERAGE TIME (s)	SPEED (ms^{-1})
		1	2	3		
d_1						
d_2						
d_3						
d_4						
d_5						
d_6						

Analysis of Results

- When the ball bearing reaches terminal velocity, the distance it has travelled between each time interval will be the same, and so its velocity can be determined
- Use the equation **speed = distance / time** to find the average velocity of the ball bearing between each set of bands or markers
- Plot a graph of velocity against time and draw a line of best fit
  - The maximum velocity is where the graph plateaus and has zero gradient
  - This is the **terminal velocity**
- An example graph of results might look like this:

Your notes



Evaluating the Experiment

Systematic Errors:

- Use a more viscous fluid to slow the ball more
  - Using a denser fluid makes the object fall slower and therefore makes determining speeds easier
- Use a tube that is as tall as possible
  - This allows the ball bearing to travel at its terminal velocity for longer
- Use larger intervals for the bands
  - This reduces the percentage uncertainty in both the distance and time between the bands

Random Errors:

- Repeat at least four times to reduce the effect of random errors
- Instead of using a stopwatch, attach the ball to some ticker tape
  - This punches holes at a set time interval so the distance between the dots can be used to find the velocities