Kinematics

Speed

- The **speed** of an object is the distance it travels per unit time
- Speed is a **scalar** quantity
  - This is because it only contains a magnitude (without a direction)
- For objects that are moving with a constant speed, use the equation below to calculate the speed:

$$\text{speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

Where:

- Speed is measured in metres per second (m/s)
- Distance traveled is measured in metres (m)
- Time taken is measured in seconds (s)

Average Speed

- In some cases, the speed of a moving object is not constant
  - For example, the object might be moving faster or slower at certain moments in time (accelerating and decelerating)
- The equation for calculating the **average speed** of an object is:

Average speed = Total distance/total time

Velocity

- The **velocity** of a moving object is similar to its speed, except it also describes the object's **direction**
  - The speed of an object only contains a magnitude - it's a **scalar** quantity
  - The velocity of an object contains both **magnitude and direction**, e.g. '15 m/s south' or '250 mph on a bearing of 030°'
- Velocity is therefore a **vector** quantity because it describes both magnitude and direction

- The equation for velocity is very similar to the equation for speed:

Velocity = displacement/time

- Where:
  - v = velocity in metres per second (m/s)
  - s = displacement, measured in metres (m)
  - t = time, measured in seconds (s)
- Velocity is a vector quantity, so it uses displacement, *s,* rather than distance which is scalar.

<u>Acceleration</u>

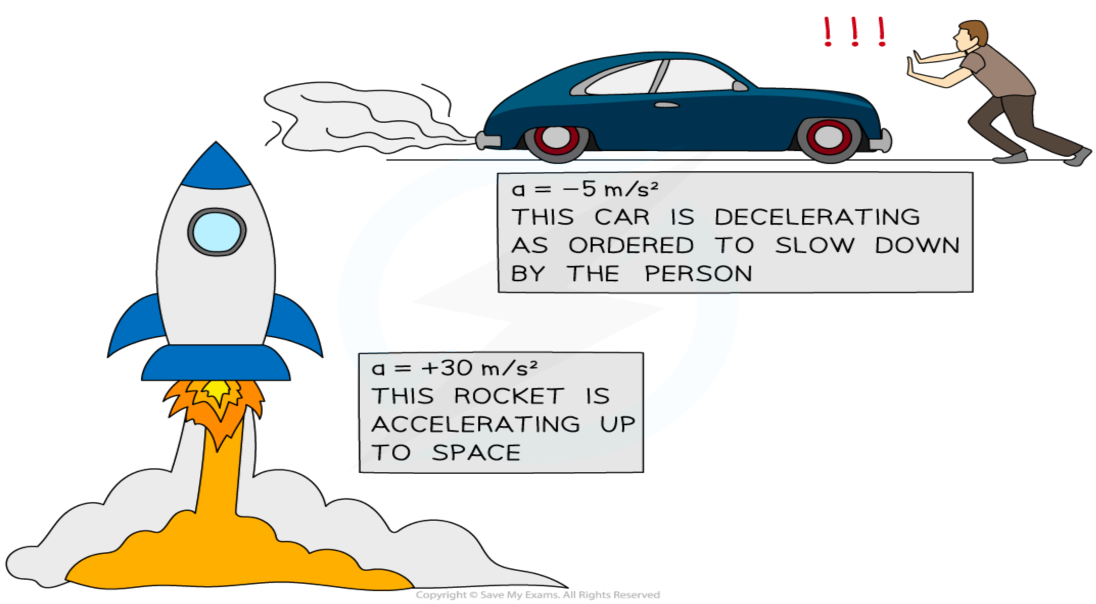
- **Acceleration** is defined as the **rate of change of velocity**
  - In other words, it describes how much an object's velocity **changes** every **second**
- The equation below is used to calculate the average acceleration of an object:

Acceleration = change in velocity/time

= (final velocity - initial velocity)/time

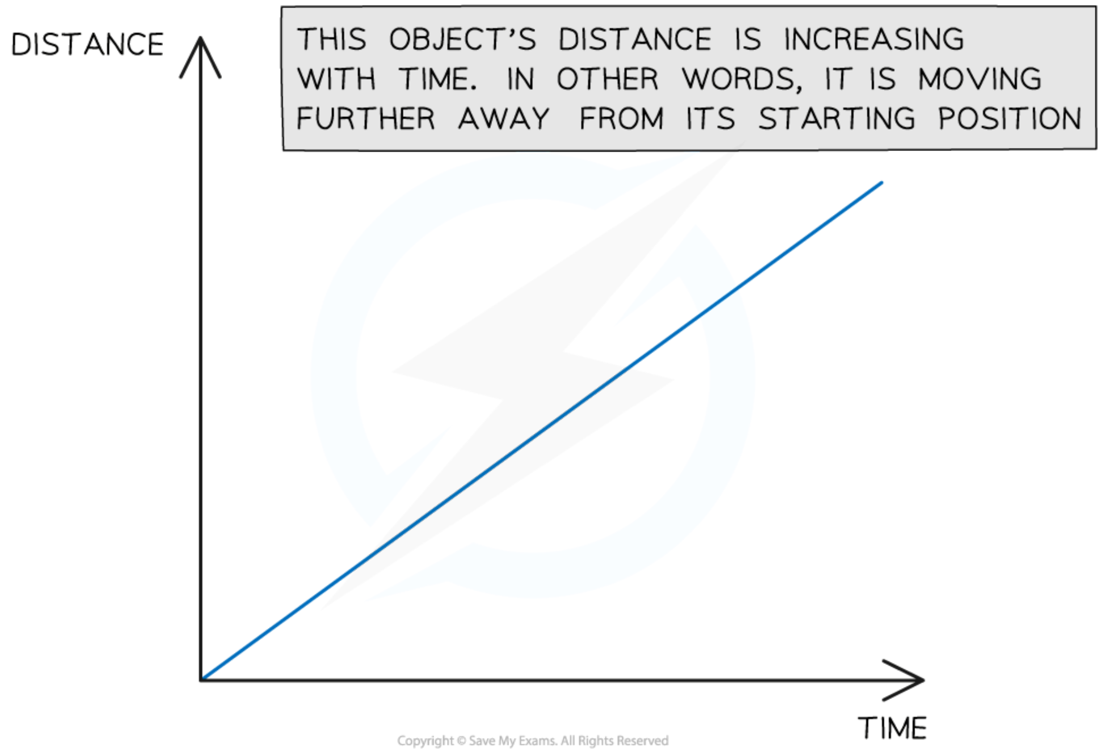
Speeding Up & Slowing Down

- An object that speeds up is **accelerating**
- An object that slows down is **decelerating**
- The **acceleration** of an object can be **positive** or **negative**, depending on whether the object is speeding up or slowing down
  - If an object is **speeding up**, its acceleration is **positive**
  - If an object is **slowing down**, its acceleration is **negative** (called **deceleration**)



Distance-Time Graphs

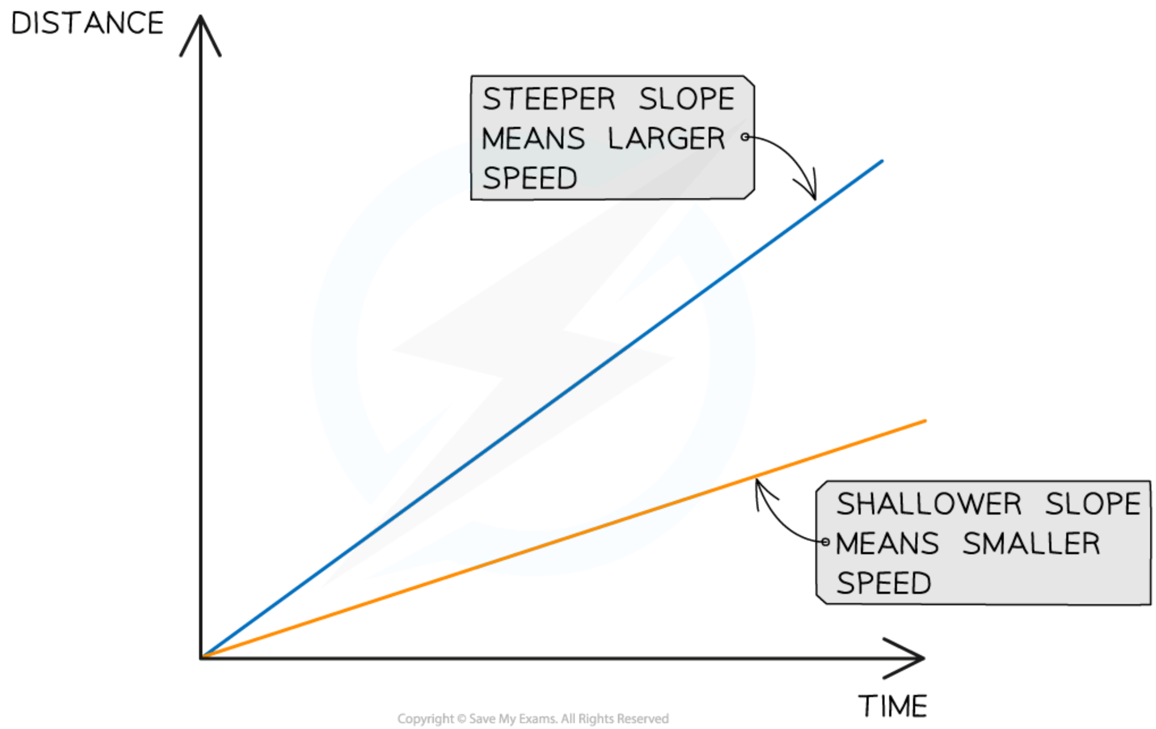
- A distance-time graph shows how the **distance** of an object moving in a straight line (from a starting position) varies over time:



This graph shows a moving object moving further away from its origin

Constant Speed on a Distance-Time Graph

- Distance-time graphs also show the following information:
    - If the object is moving at a **constant speed**
    - How **large** or **small** the speed is
- A **straight line** represents **constant speed**
- The slope of the straight line represents the **magnitude** of the speed:
    - A very **steep** slope means the object is moving at a **large** speed
    - A **shallow** slope means the object is moving at a **small** speed
    - A **flat**, **horizontal line** means the object is **stationary** (not moving)



-The gradient of a distance time graph gives us speed.

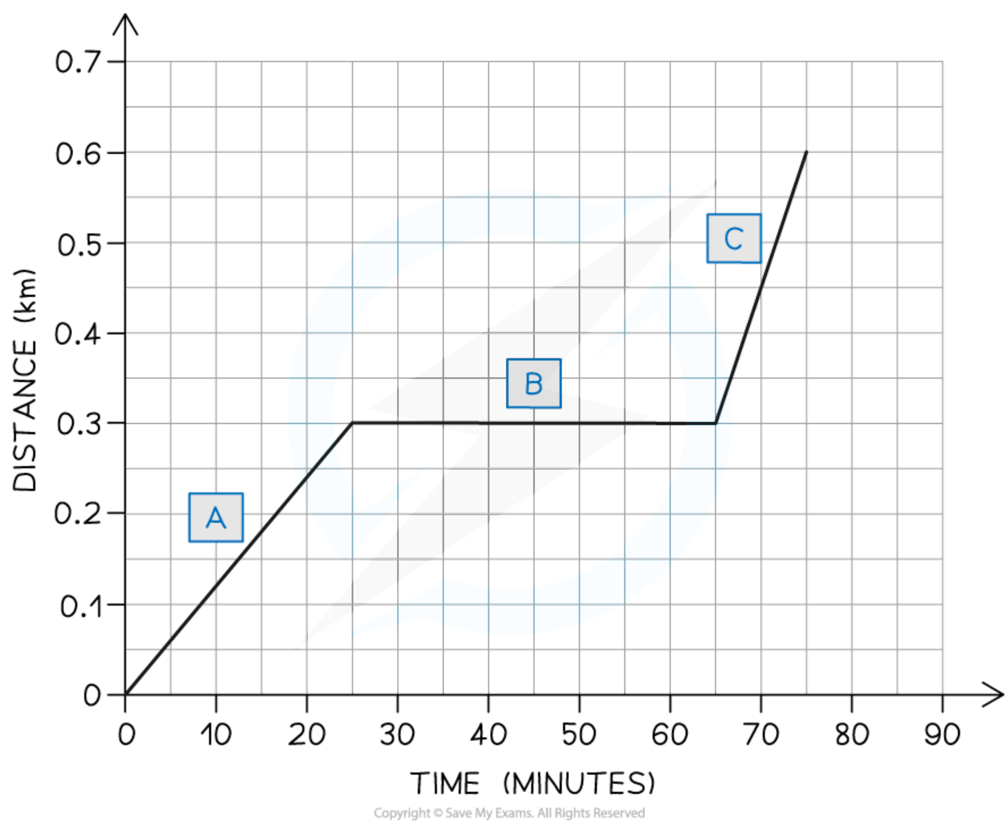
-A curve means that the speed is not constant.

Below is an example question on how to interpret distance time graphs

Example:

Ose decides to take a stroll to the park. He finds a bench in a quiet spot and takes a seat, picking up where he left off reading his book on Black Holes. After some time reading, Ose realizes he lost track of time and runs home.

A distance-time graph for his trip is drawn below.



a)How long does Ose spend reading his book?

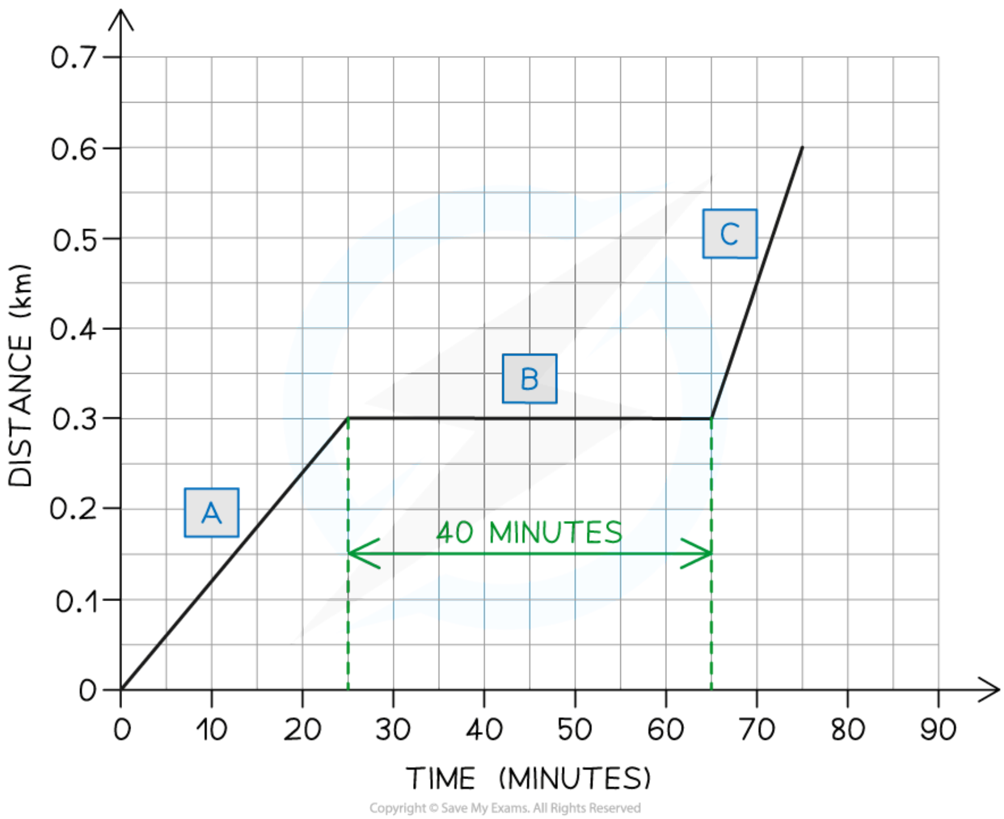
b)There are three sections labeled on the graph, A, B and C. Which section represents Ose running home?

c)What is the total distance traveled by Ose?

Solution:

Part (a)

- Ose spends **40 minutes** reading his book
- The **flat** section of the line (section B) represents an object which is **stationary** - so section B represents Ose sitting on the bench reading
- This section lasts for **40 minutes** - as shown in the graph below

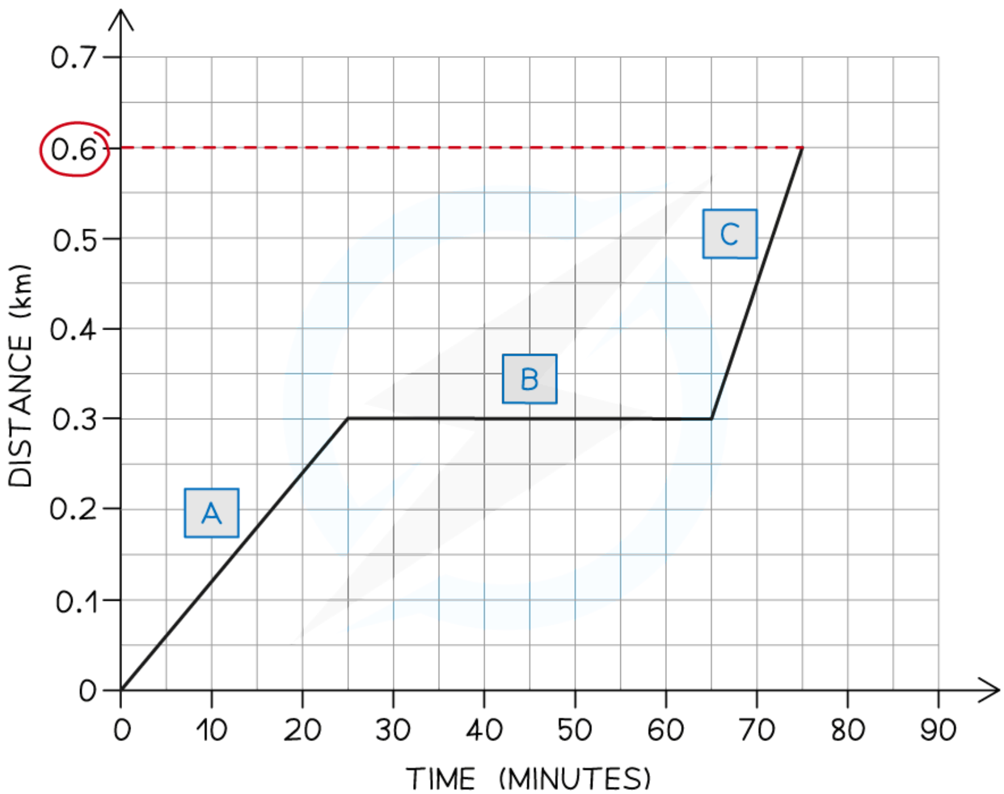


Part (b)

- **Section C** represents Ose running home
- The **slope** of the line in section C is **steeper** than the slope in section A
- This means Ose was moving with a **larger** speed (running) in section C

Part (c)

- The total distance travelled by Ose is **0.6 km**
- The total **distance** travelled by an object is given by the final point on the line - in this case, the line ends at **0.6 km** on the **distance** axis. This is shown in the image below:



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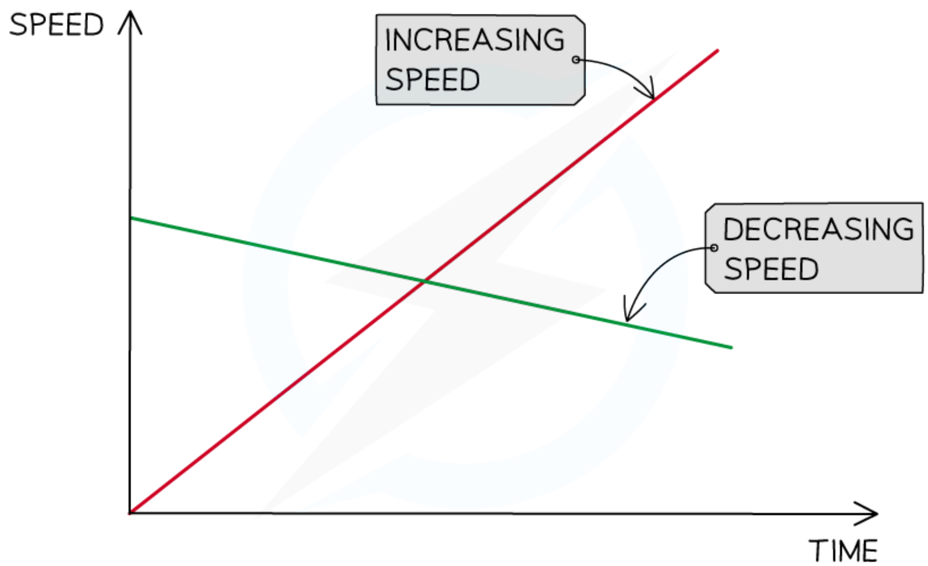
Speed-Time Graphs

A speed-time graph shows how the speed of a moving object varies with time

- The red line represents an object with **increasing** speed
- The green line represents an object with **decreasing** speed



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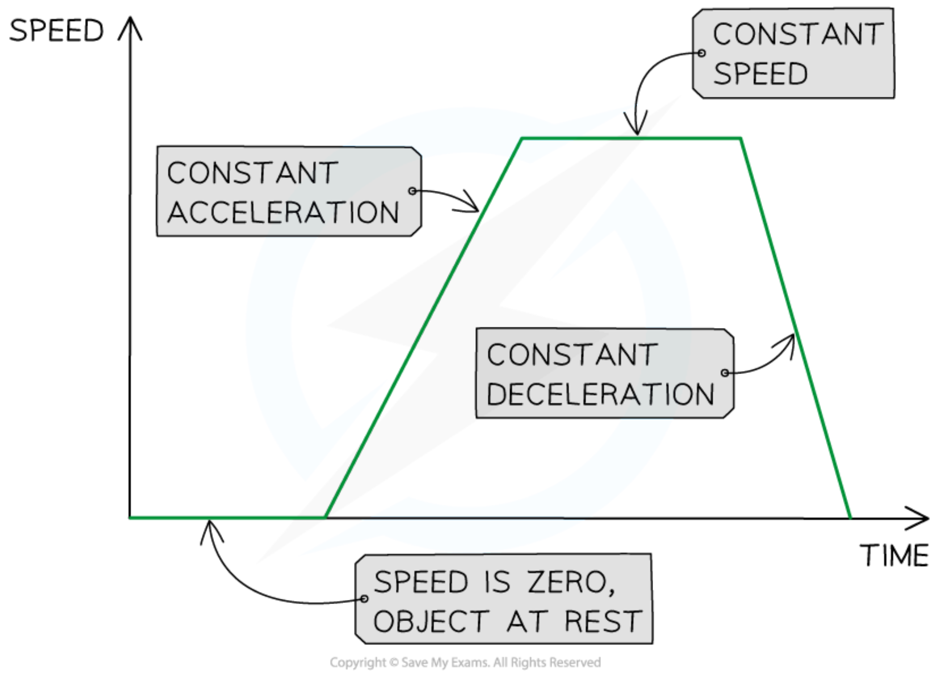
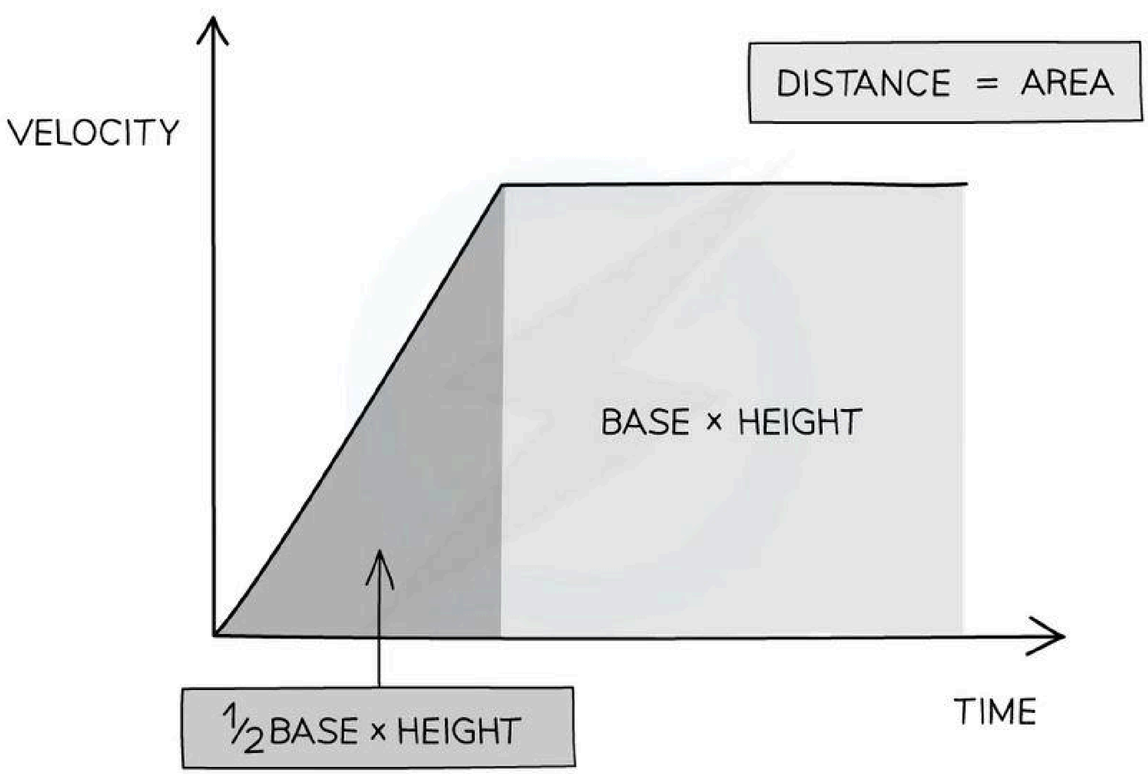
Acceleration on a Speed-Time Graph

- Speed-time graphs also show the following information:
  - If the object is moving with a **constant** acceleration or deceleration
  - The **magnitude** of the acceleration or deceleration
- A **straight line** represents **constant acceleration**
- The **slope** of the line represents the **magnitude** of acceleration
  - A **steep** slope means **large acceleration** (or deceleration) - i.e. the object's speed changes very **quickly**
  - A **gentle** slope means **small acceleration** (or deceleration) - i.e. the object's speed changes very **gradually**
  - A **flat line** means the acceleration is **zero** - i.e. the object is moving with a **constant speed**



→The **distance traveled** by an object can be found by determining the **area beneath the graph.**



- If the area beneath the graph forms a triangle (the object is accelerating or decelerating) then the area can be determined using the formula:

Area = ½ x base x height

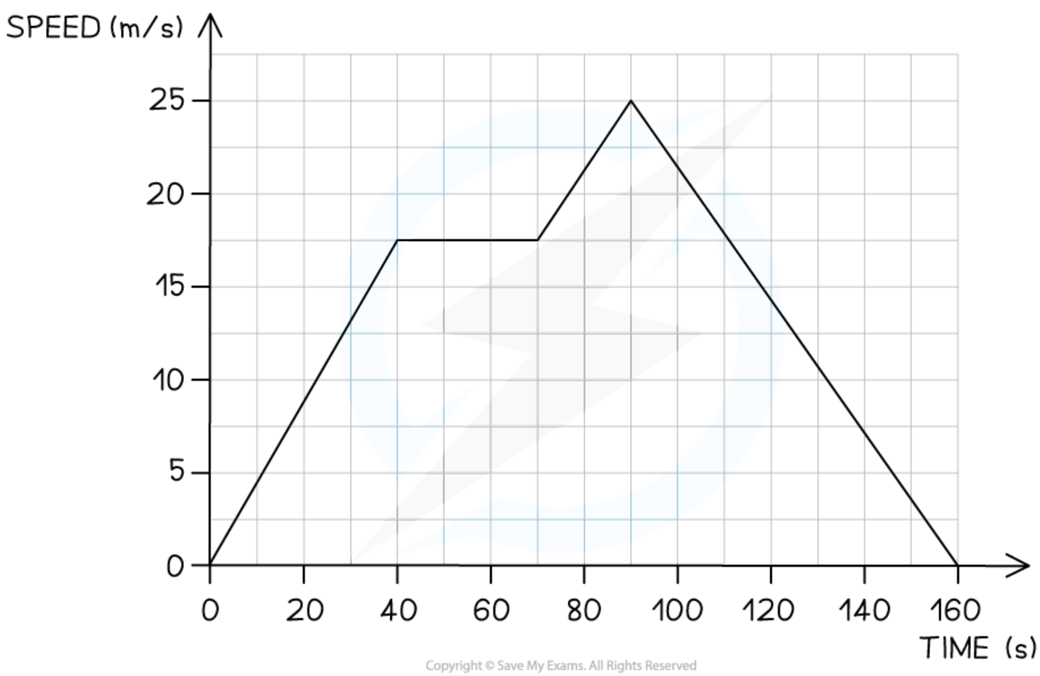
- If the area beneath the graph is a rectangle (constant velocity) then the area can be determined using the formula:

Area = base x height

Below is an example on calculating distance from a speed time graph of speed time graphs:

<u>Example 1:</u>

The speed-time graph below shows a car journey which lasts for 160 seconds.



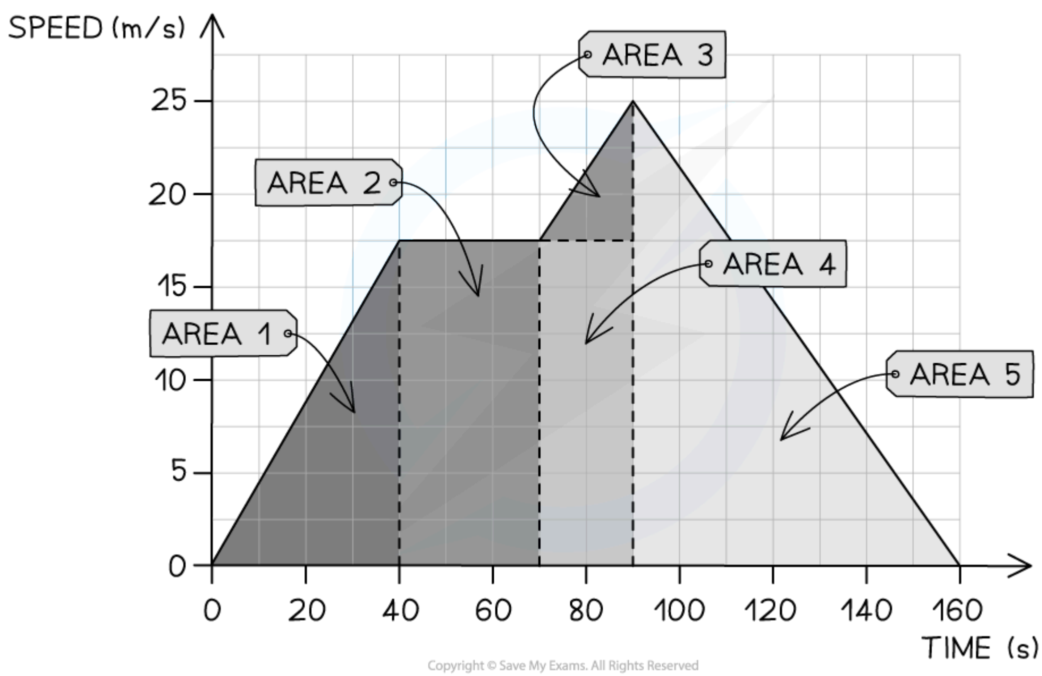
Calculate the total distance traveled by the car on this journey.

Step 1: Recall that the area under a velocity-time graph represents the distance travelled

- In order to calculate the total distance travelled, the total area underneath the line must be determined

Step 2: Identify each enclosed area

- In this example, there are five enclosed areas under the line
- These can be labelled as areas 1, 2, 3, 4 and 5, as shown in the image below:



Step 3: Calculate the area of each enclosed shape under the line

- Area 1 = area of a triangle = ½ × base × height = ½ × 40 × 17.5 = 350 m
- Area 2 = area of a rectangle = base × height = 30 × 17.5 = 525 m
- Area 3 = area of a triangle = ½ × base × height = ½ × 20 × 7.5 = 75 m
- Area 4 = area of a rectangle = base × height = 20 × 17.5 = 350 m

- Area 5 = area of a triangle = ½ × base × height = ½ × 70 × 25 = 875 m

Step 4: Calculate the total distance travelled by finding the total area under the line

- Add up each of the five areas enclosed:

total distance = 350 + 525 + 75 + 350 + 875

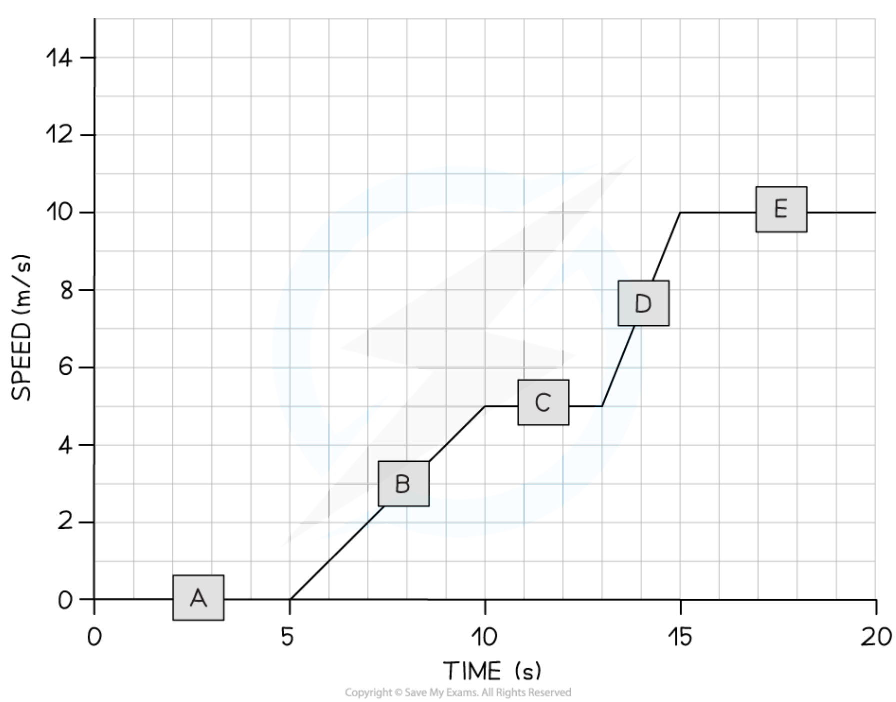
total distance = 2175 m

Below is an example on the **interpretation** of speed time graphs:

Example 2:

Tora is training for a cycling tournament.

The speed-time graph below shows her motion as she cycles along a flat, straight road.



(a) In which section (A, B, C, D, or E) of the speed-time graph is Tora's acceleration the largest?

Solution:

Part (a)

Step 1: Recall that the slope of a speed-time graph represents the magnitude of acceleration

- The slope of a speed-time graph indicates the magnitude of acceleration
  Therefore, the only sections of the graph where Tora is accelerating is section B and section D

- Sections A, C, and E are flat – in other words, Tora is moving at a constant speed (i.e. not accelerating)

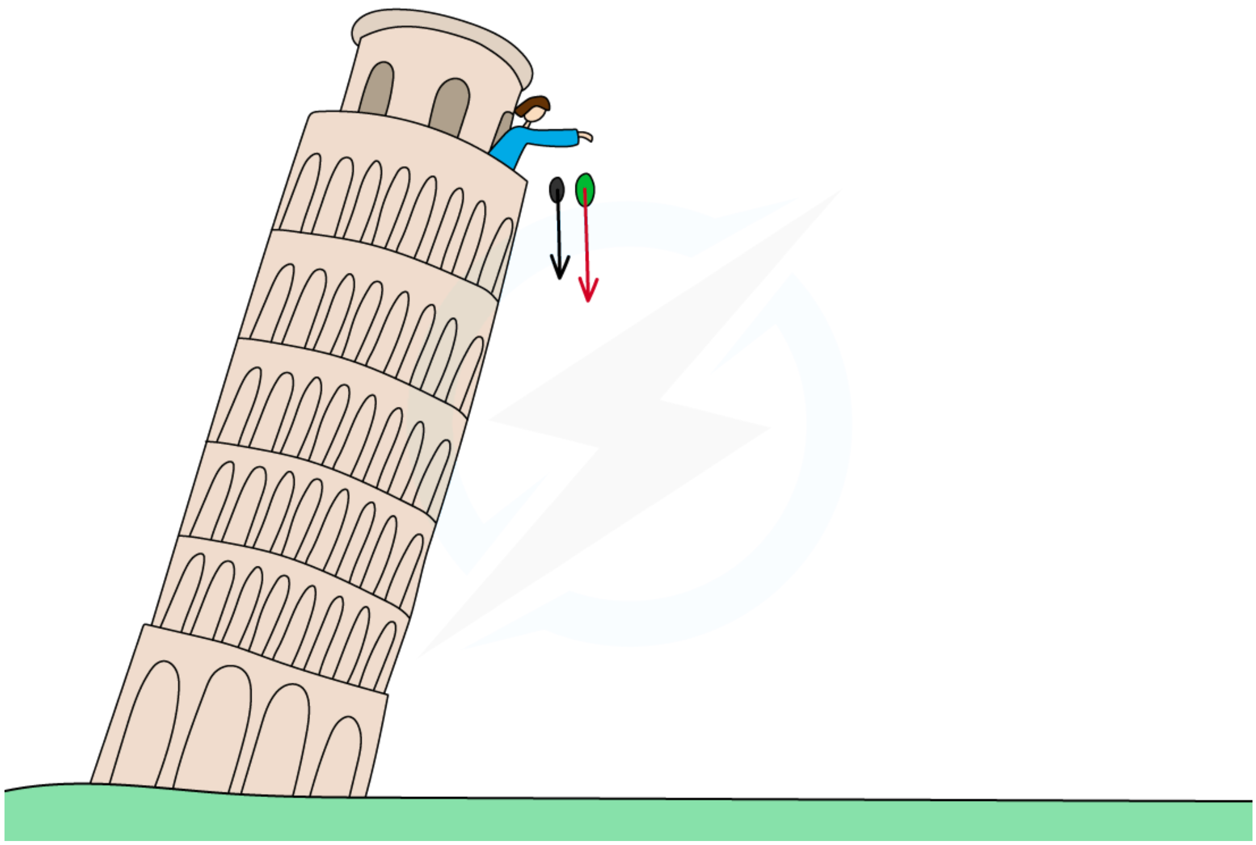
Step 2: Identify the section with the steepest slope

- Section D of the graph has the steepest slope
  Hence, the largest acceleration is shown in section D

<u>Acceleration of Free Fall</u>

- In the absence of **air resistance**, all objects fall with the **same acceleration**
- This is called the **acceleration of freefall** (this is also sometimes called acceleration due to gravity)

$$g = 10\ m/s^2$$



In the absence of air resistance, Galileo discovered that all objects (near Earth's surface) fall with an acceleration of about 9.8 m/s²

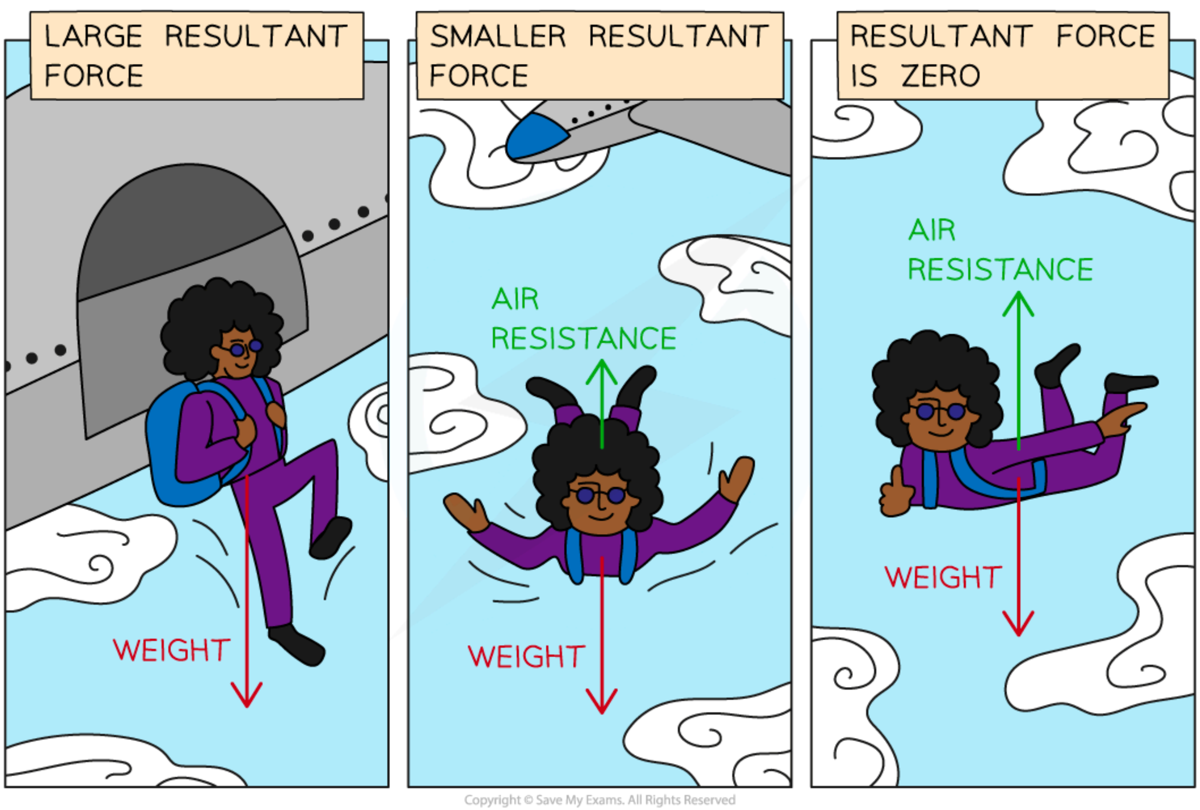
- This means that for every second an object falls, its velocity will increase by 9.8 m/s
- The symbol ***g*** also stands for the **gravitational field strength**, and can be used to calculate the weight of an object using its mass:

weight = mass × gravitational field strength

$$W = mg$$

Falling Objects with Air Resistance

- Objects falling through fluids (fluids are liquids or gases) in a uniform gravitational field, experience **two forces**:
  - **Weight** (due to gravity)
  - **Friction** (such as air resistance)
- A skydiver jumping from a plane will experience:
  - A downward acting force of weight (mass × acceleration of freefall)
  - An upward acting force of air resistance (frictional forces always oppose the direction of motion)
- The force of air resistance increases with speed. This is illustrated in the image below:



- Initially, the upwards air resistance is **very small** because the skydiver isn't falling very quickly
    - Therefore, there are **unbalanced** forces on the skydiver initially
- As the skydiver speeds up, air resistance **increases,** eventually growing large enough to **balance the downwards weight force**
- Once **air resistance equals weight,** the forces are **balanced**
    - This means there is no longer any **resultant force**
- Therefore, the skydiver's acceleration is **zero** - they now travel at a **constant** speed
- This speed is called their **terminal velocity**
- When the skydiver opens the parachute, the **air resistance increases**
    - This is due to the increased surface area of the parachute opening
- The upward force of air resistance on the skydiver increases, **slowing the acceleration** of the skydivers fall
    - The skydiver **decelerates**
- Eventually, the **forces balance** out again, and a new **slower terminal velocity** is reached