WJEC GCSE Physics: Combined Science

Your notes

Distance, Speed & Acceleration

Contents

Describing Motion

Your notes

Describing Motion

Speed & Velocity

- **Speed** is a measure of how fast or slow an object is moving
- It is a **scalar** quantity
  - Because it only contains a magnitude (without a direction)
- The **velocity** of a moving object is similar to its speed, except it also describes the object's **direction**
- Velocity is a **vector** 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°'

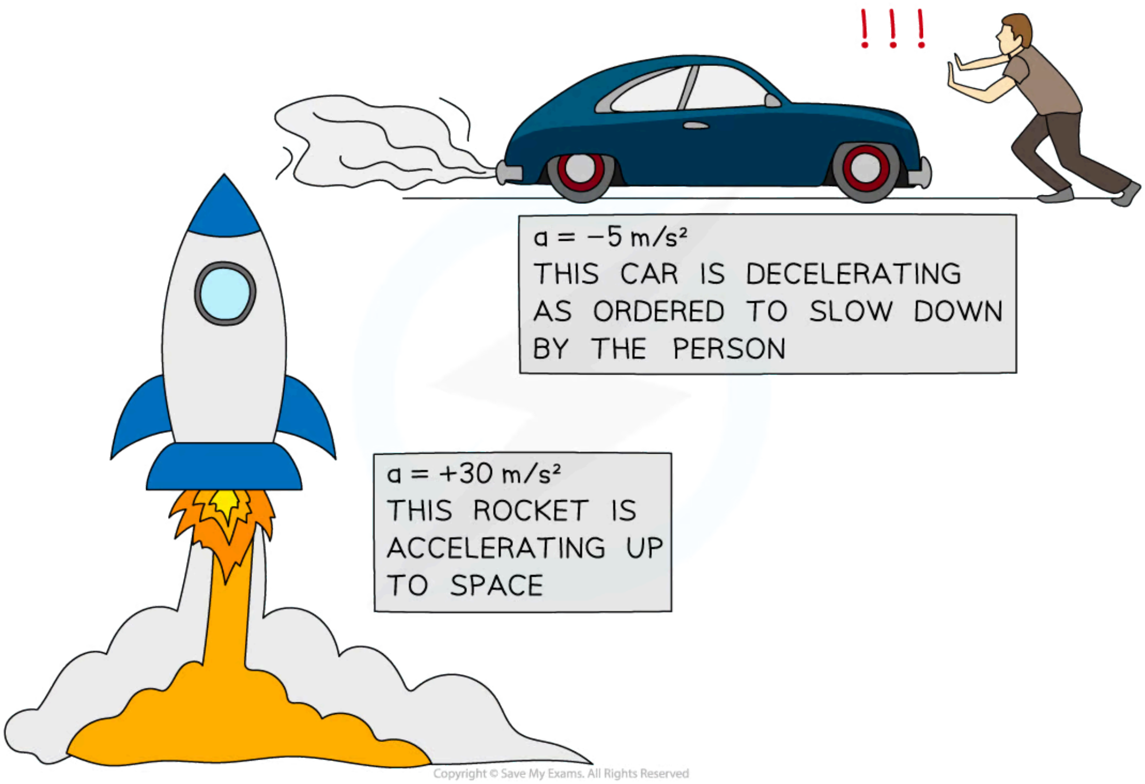
Comparing Speed and Velocity

The cars in the diagram above have the same speed (a scalar quantity) but different velocities (a vector quantity). Fear not, they are in different lanes!

Acceleration

- **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 **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** (sometimes called **deceleration**)

Positive and Negative Acceleration



A rocket speeding up (accelerating) and a car slowing down (decelerating)

Your notes

Calculating Speed & Acceleration

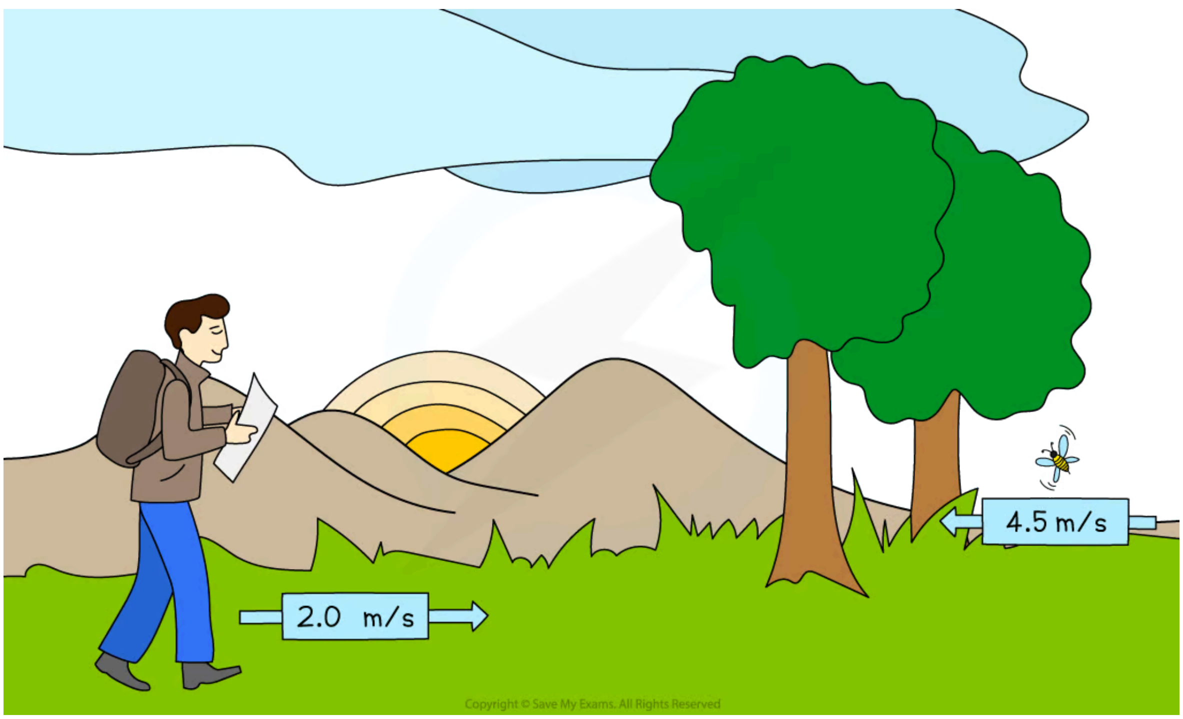
Calculating Speed

- For objects that are moving with a **constant speed**, use the equation below to calculate the speed:

$$\text{Speed} = \frac{\text{distance}}{\text{time}}$$

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

The Speed of Different Objects



A hiker might have a speed of 2.0 m/s, whereas a particularly excited bumble bee can have a speed of up to 4.5 m/s

Calculating Acceleration

- The equation below is used to calculate the average acceleration of an object:

Your notes

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{change in time}}$$

$$a = \frac{\Delta v}{\Delta t}$$

- Where:
  - a = acceleration in metres per second squared (m/s^2)
  - Δv = change in velocity in metres per second (m/s)
  - Δt = time taken in seconds (s)

Worked example

Planes fly at typical speeds of around 250 m/s. Calculate the total distance travelled by a plane moving at this average speed for 2 hours.

Answer:

Step 1: List the known quantities

- Average speed = 250 m/s
- Time taken = 2 hours

Step 2: Write the relevant equation

$$\text{Speed} = \frac{\text{distance}}{\text{time}}$$

Step 3: Rearrange for the total distance

$$\text{total distance} = \text{average speed} \times \text{time taken}$$

Step 4: Convert any units

- The time given in the question is not in standard units
- Convert 2 hours into seconds:

$$2 \text{ hours} = 2 \times 60 \times 60 = 7200 \text{ s}$$

Step 5: Substitute the values for average speed and time taken

$$\text{total distance} = 250 \times 7200$$

$$\text{total distance} = 1\,800\,000 \text{ m}$$

Your notes

Worked example

A Japanese bullet train decelerates at a constant rate in a straight line. The velocity of the train decreases from 50 m/s to 42 m/s in 30 seconds.

(a) Calculate the change in velocity of the train.

(b) Calculate the deceleration of the train, and explain how your answer shows the train is slowing down.

Answer:

Part (a)

Step 1: List the known quantities

- Initial velocity = 50 m/s
- Final velocity = 42 m/s

Step 2: Write the relevant equation

change in velocity = final velocity – initial velocity

Step 3: Substitute values for final and initial velocity

change in velocity = 42 – 50

change in velocity = –8 m/s

Part (b)

Step 1: List the known quantities

- Change in velocity, Δv = – 8 m/s
- Time taken, t = 30 s

Step 2: Write the relevant equation

$$a = \frac{\Delta v}{\Delta t}$$

Step 3: Substitute the values for change in velocity and time

a = –8 ÷ 30

a = –0.27 m/s

Step 4: Interpret the value for deceleration

- The answer is **negative**, which indicates the train is **slowing down**

Examiner Tip

Remember the units for acceleration are **metres per second squared**, m/s^2. In other words, acceleration measures how much the velocity (in m/s) changes every second, m/s/s.

Your notes

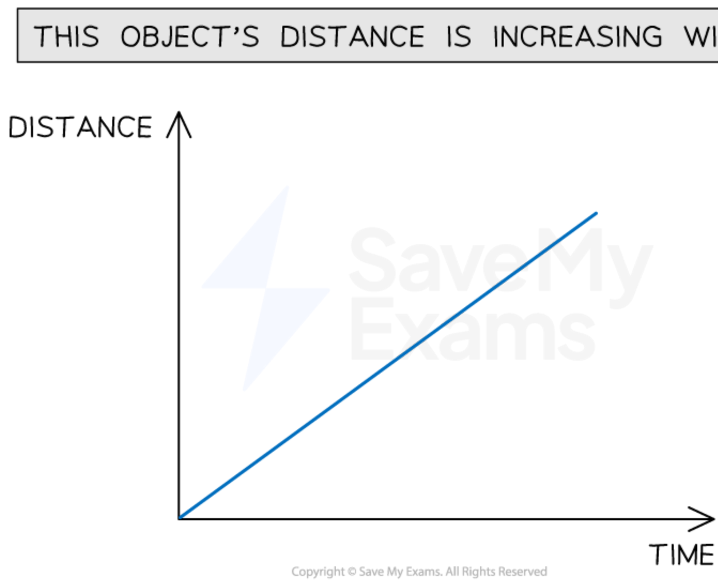
Your notes

Distance-Time Graphs

Distance-Time Graphs

- A **distance-time graph** is used to describe the motion of an object and calculate its speed

A Distance-Time Graph of an Object Moving Away from the Starting Position



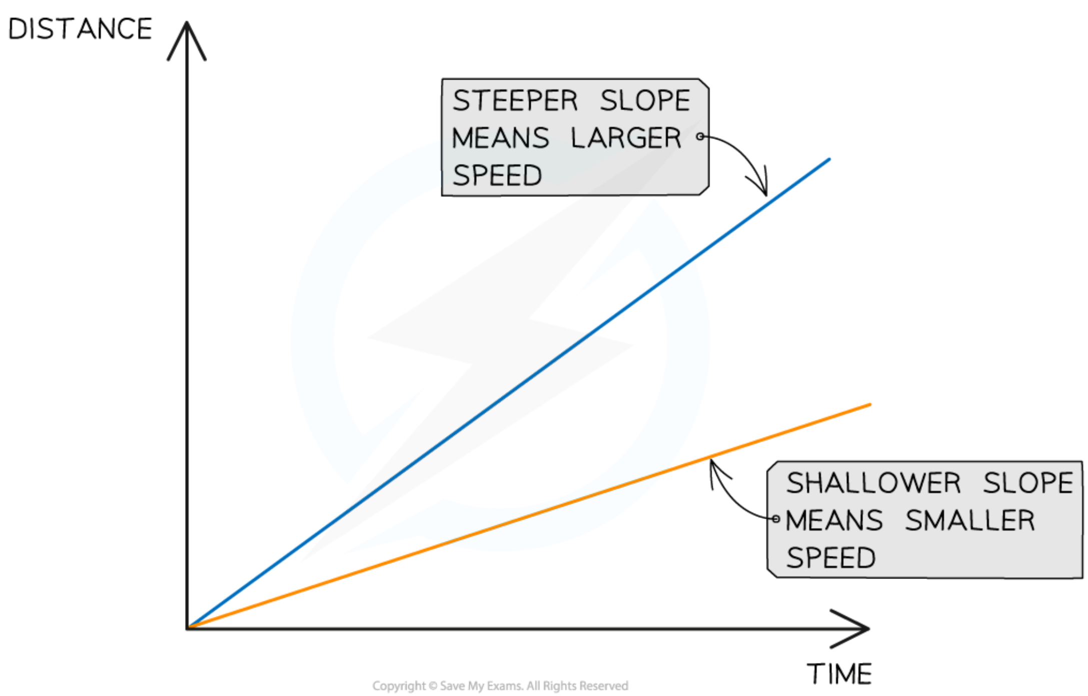
This graph shows a moving object moving further away from its origin

Constant Speed on a Distance-Time Graph

- Distance-time graphs show the following information:
  - If the object is moving at a **constant speed**
  - How **fast** or **slow** 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 **fast** speed
  - A **shallow** slope means the object is moving at a **slower** speed
  - A **flat**, **horizontal line** means the object is **stationary** (not moving)

The Gradient of a Distance-Time Graph

Your notes



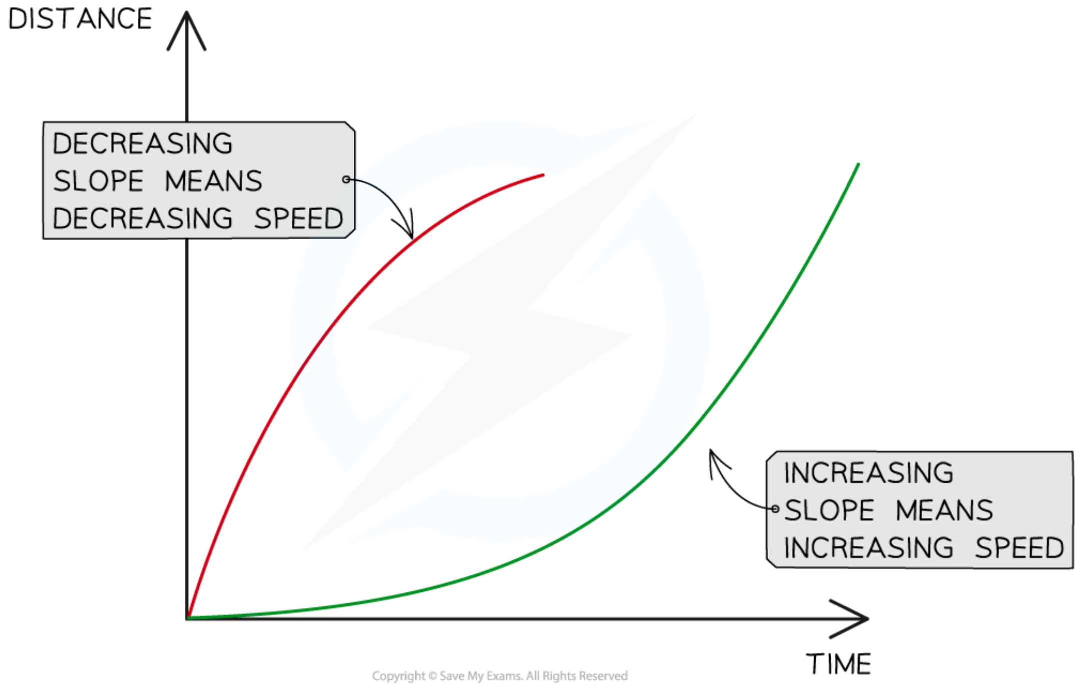
This graph shows how the slope of a line is used to interpret the speed of moving objects. Both of these objects are moving with a constant speed because the lines are straight.

Changing Speed on a Distance-Time Graph

- Objects might be moving at a **changing speed**
  - This is represented by a **curve**
- In this case, the slope of the line will be changing
  - If the slope is **increasing**, the **speed** is **increasing** (accelerating)
  - If the slope is **decreasing**, the **speed** is **decreasing** (decelerating)
- The image below shows two different objects moving with changing speeds

Acceleration and Deceleration on a Distance-Time Graph

Your notes



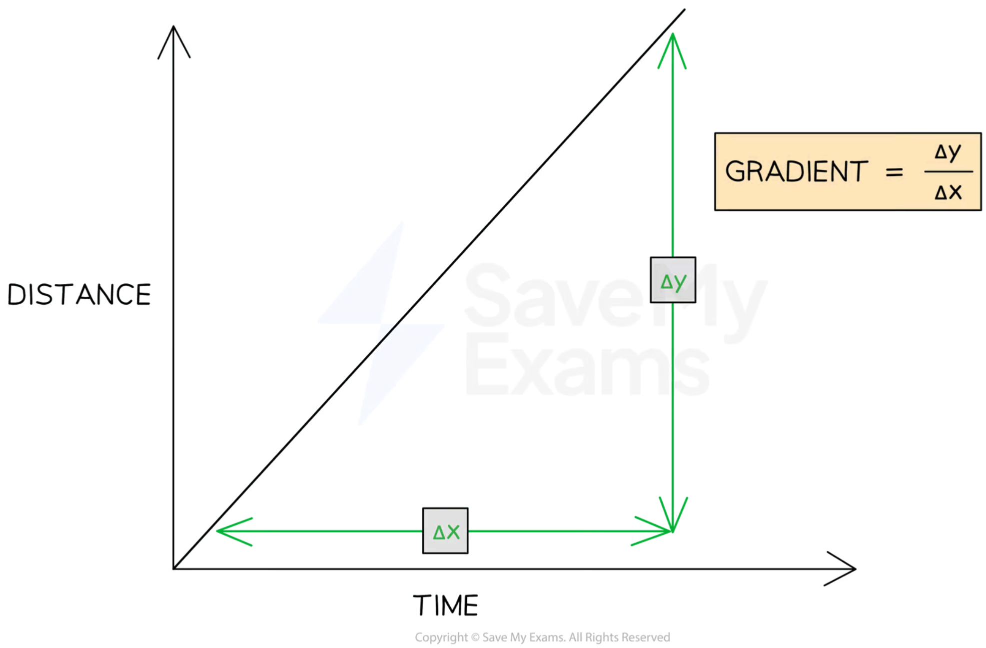
Changing speeds are represented by changing slopes. The red line represents an object slowing down and the green line represents an object speeding up.

Calculating Speed on a Distance-Time Graph

- The **speed** of a moving object can be calculated from the **gradient** of the line on a **distance-time** graph:

$$\text{speed} = \text{gradient} = \frac{\Delta y}{\Delta x}$$

Calculating the Gradient of a Straight Line



Your notes

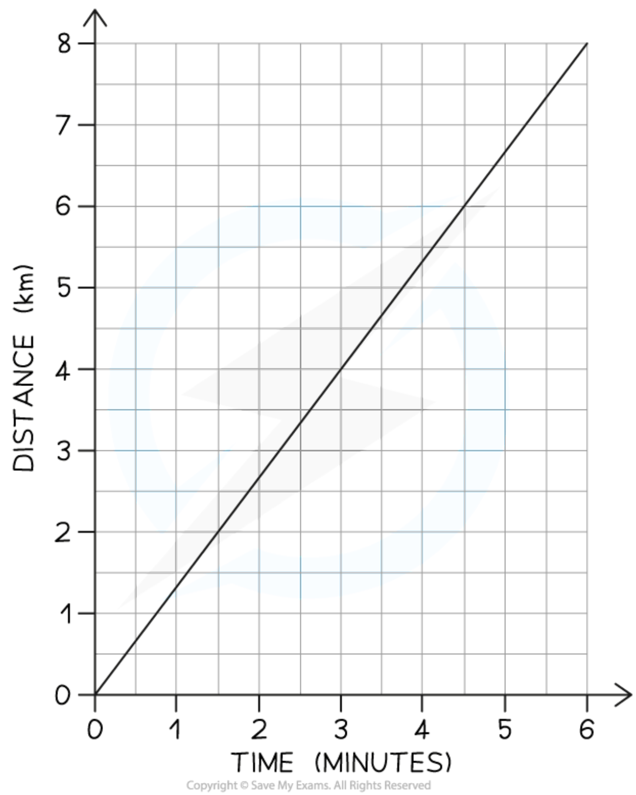
The speed of an object can be found by calculating the gradient of a distance-time graph

- Δy is the **change** in y (distance) values
- Δx is the **change** in x (time) values

Your notes

Worked example

A distance-time graph is drawn below for part of a train journey. The train is travelling at a constant speed.



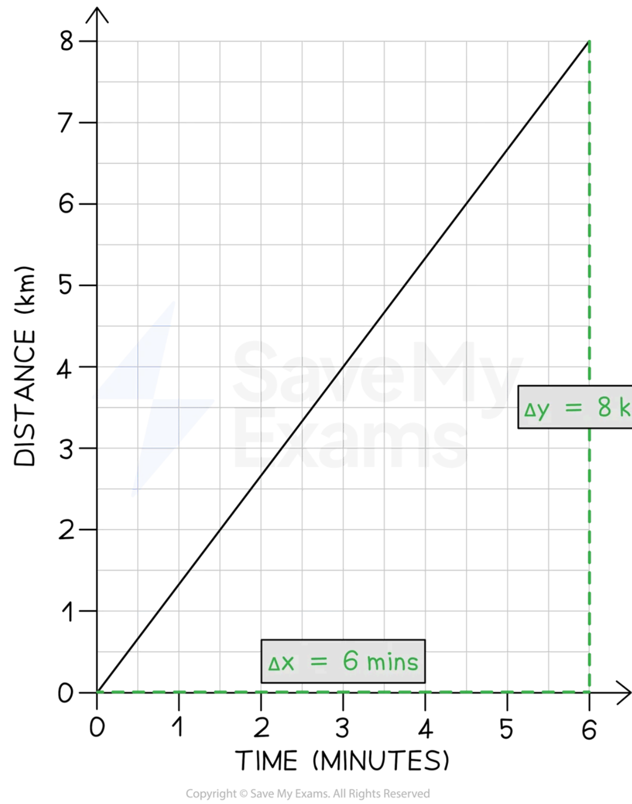
Calculate the speed of the train.

Answer:

Step 1: Draw a large gradient triangle on the graph

- The image below shows a large **gradient triangle** drawn with dashed lines
- Δy and Δx are labelled, using the **units** as stated on each axes

Your notes



Step 2: Convert units for distance and time into standard units

- The distance travelled = 8 km = **8000 m**
- The time taken = 6 mins = **360 s**

Step 3: State that speed is equal to the gradient of a distance-time graph

- The **gradient** of a **distance-time** graph is equal to the **speed** of a moving object:

$$\text{speed} = \text{gradient} = \frac{\Delta y}{\Delta x}$$

Step 4: Substitute values to calculate the speed

$$\text{speed} = \frac{8000}{360}$$

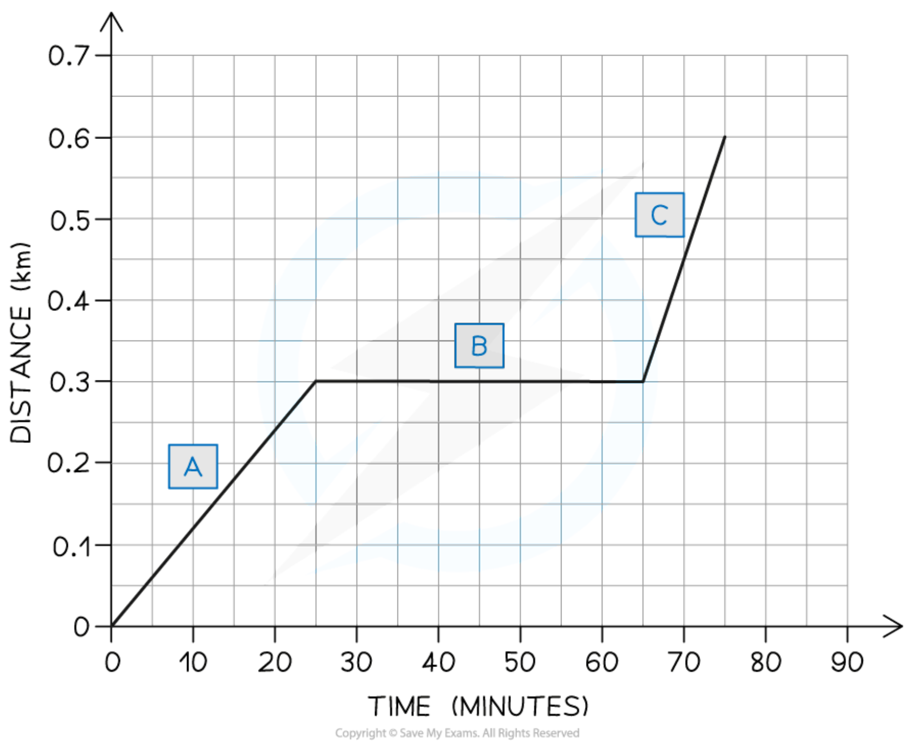
$$\text{speed} = 22.2 \text{ m/s}$$

Your notes

Worked 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 realises 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 labelled on the graph, A, B and C. Which section represents Ose running home?

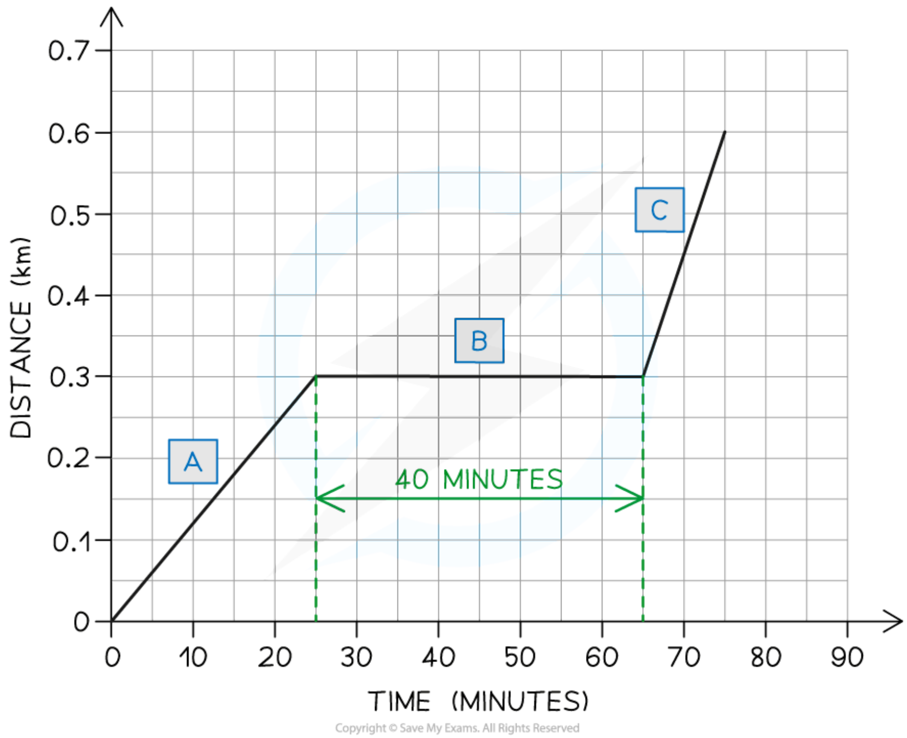
(c) What is the total distance travelled by Ose?

Answer:

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

Your notes



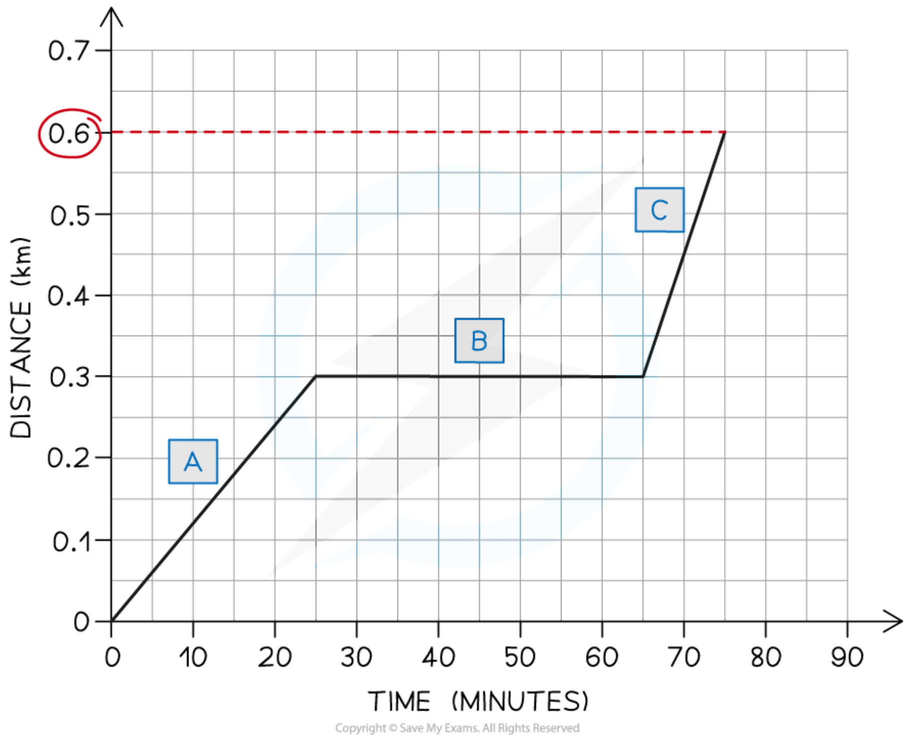
Part (b)

- **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 **faster** 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:

Your notes



Examiner Tip

Use the **entire line**, where possible, to calculate the gradient. Examiners tend to award credit if they see a **large gradient triangle** used - so remember to draw these directly on the graph itself!

Remember to check the **units** of variables measured on each axis. These may not always be in standard units - in our example, the unit of distance was **km** and the unit of time was **minutes**. Double-check which units to use in your answer.

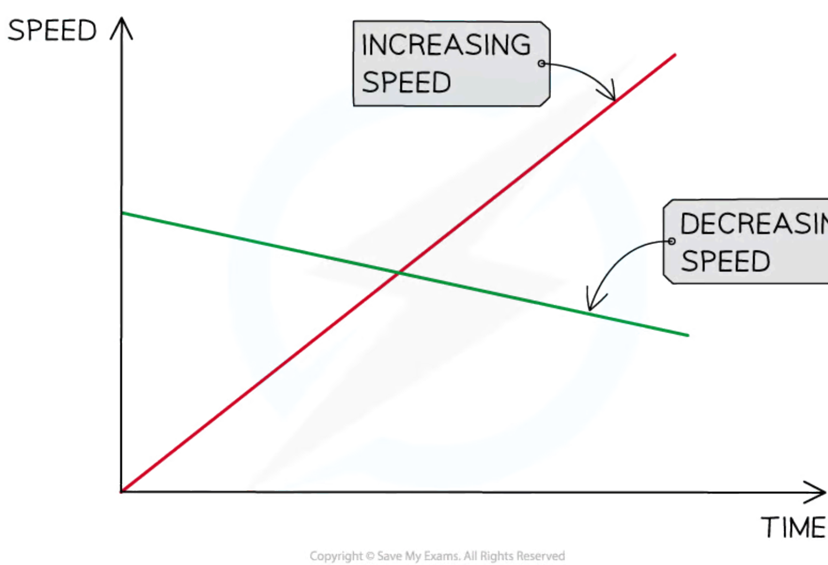
Your notes

Velocity-Time Graphs

Velocity-Time Graphs

- A **speed**-time graph shows how the **speed** of an object varies with **time**
- A **velocity**-time graph shows how the **speed** of an object moving in a certain **direction** varies with **time**

Acceleration & Deceleration on a Speed-Time Graph



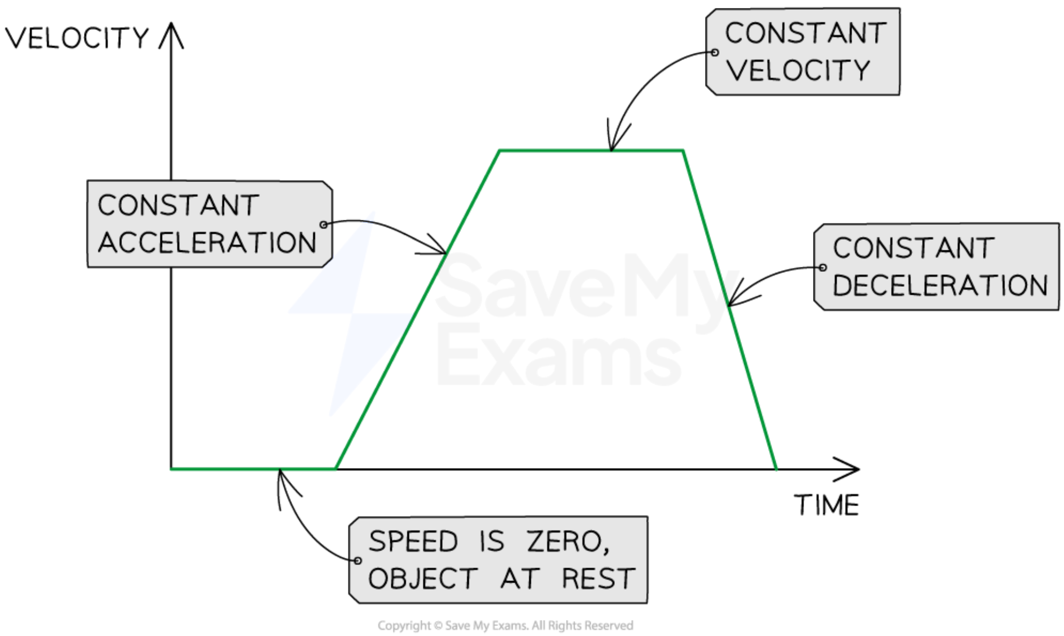
The red line shows the speed of an object increasing over time, whilst the green line shows the speed of an object decreasing over time

Acceleration on a Velocity-Time Graph

- The **slope** of the line represents the **magnitude** of acceleration
  - A **steep** slope means **large acceleration** (or deceleration)
    - The object's velocity changes very **quickly**
  - A **gentle** slope means **small acceleration** (or deceleration)
    - The object's velocity changes very **gradually**
  - A **flat line** means the acceleration is **zero**
    - The object is moving with a **constant velocity**
    - A constant velocity means a **constant speed** in a **straight line**

Interpreting Gradients on a Velocity-Time Graphs

Your notes

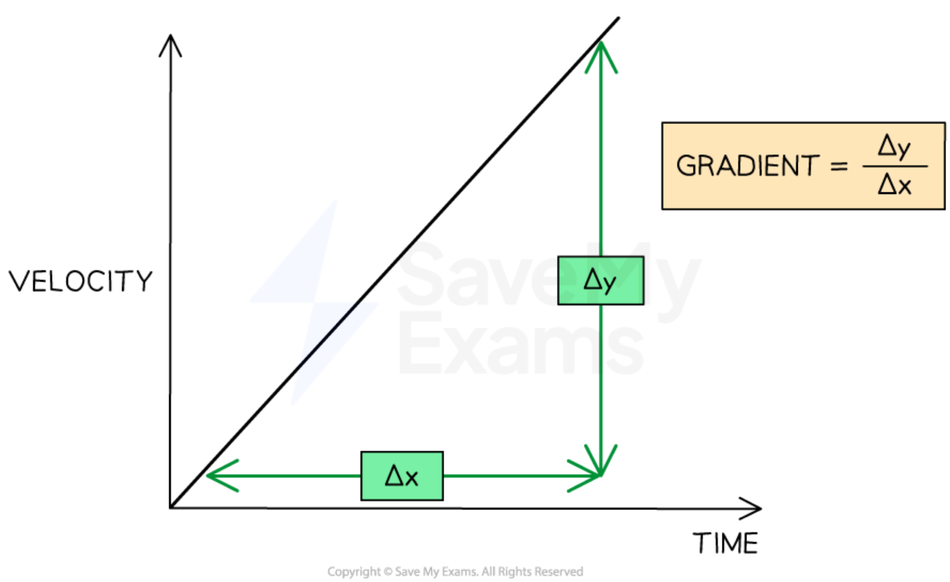


This image shows how to interpret the slope of a velocity-time graph

- The **acceleration** of an object can be calculated from the **gradient** of a velocity-time graph

$$\text{acceleration} = \text{gradient} = \frac{\Delta x}{\Delta y}$$

Calculating Gradient of a Velocity-Time Graph

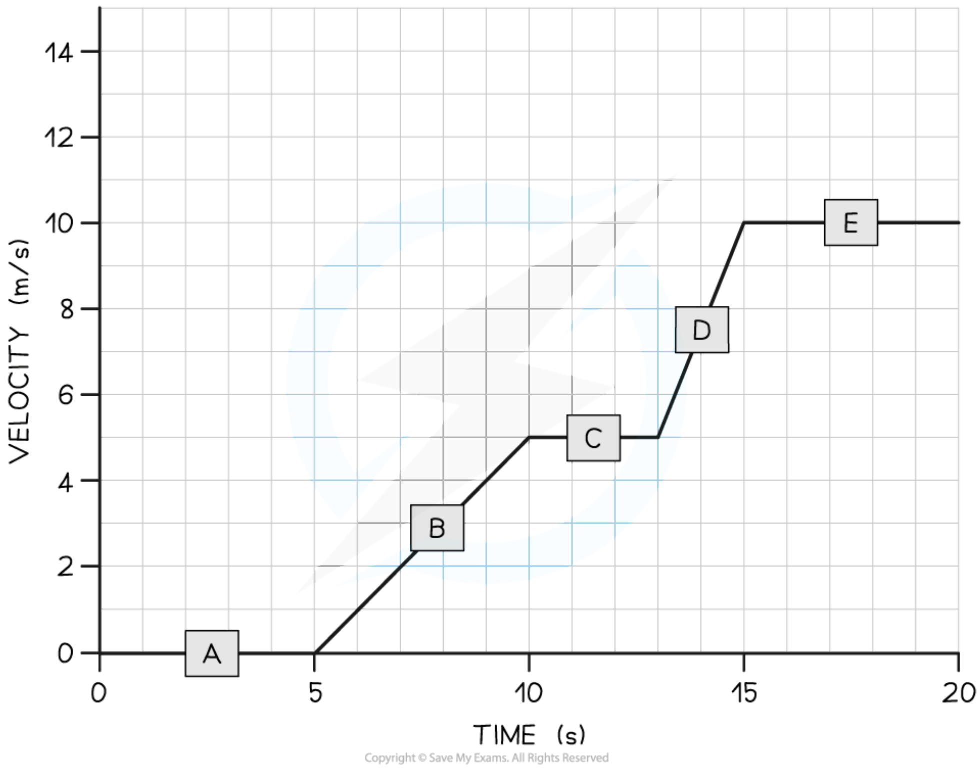


The gradient of a velocity-time graph can be found by dividing the change in velocity by the change in time

Worked example

A cyclist is training for a cycling tournament.

The velocity-time graph below shows the cyclist's motion as they cycle along a flat, straight road.



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

(b) Calculate the cyclist's acceleration between 5 and 10 seconds.

Answer:

Part (a)

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

- The slope of a velocity-time graph indicates the magnitude of acceleration
  Therefore, the only sections of the graph where the cyclist is accelerating are sections B and D
- Sections A, C, and E are flat; in other words, the cyclist is moving at a constant velocity (therefore, 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

Your notes

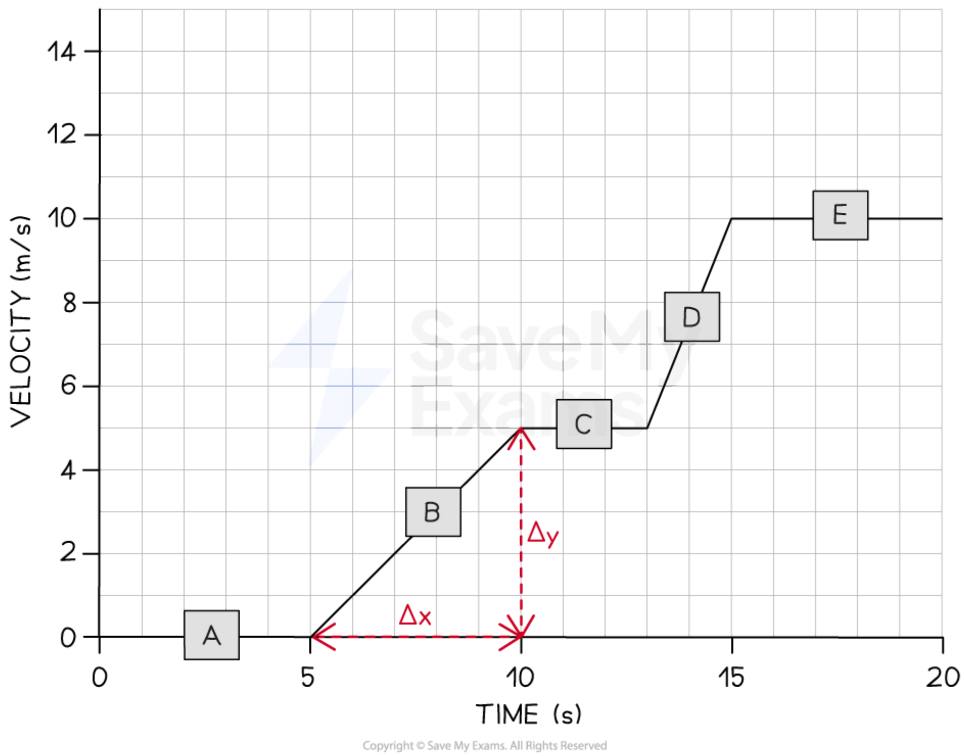
Part (b)

Step 1: Recall that the gradient of a velocity-time graph gives the acceleration

- Calculating the gradient of a slope on a velocity-time graph gives the acceleration for that time period

Step 2: Draw a large gradient triangle at the appropriate section of the graph

- A gradient triangle is drawn for the time period between 5 and 10 seconds



Step 3: Calculate the size of the gradient and state this as the acceleration

- The acceleration is given by the gradient, which can be calculated using:

$$a = \frac{\Delta y}{\Delta x}$$

$$a = \frac{5}{5}$$

$$a = 1 \text{ m/s}^2$$

- Therefore, the cyclist accelerated at 1 m/s^2 between 5 and 10 seconds

Examiner Tip

Use the **entire slope**, where possible, to calculate the gradient. Examiners tend to award credit if they see a **large gradient triangle** used.

Remember to actually draw the lines directly on the graph itself, particularly when the question asks you to **use the graph** to calculate the acceleration.

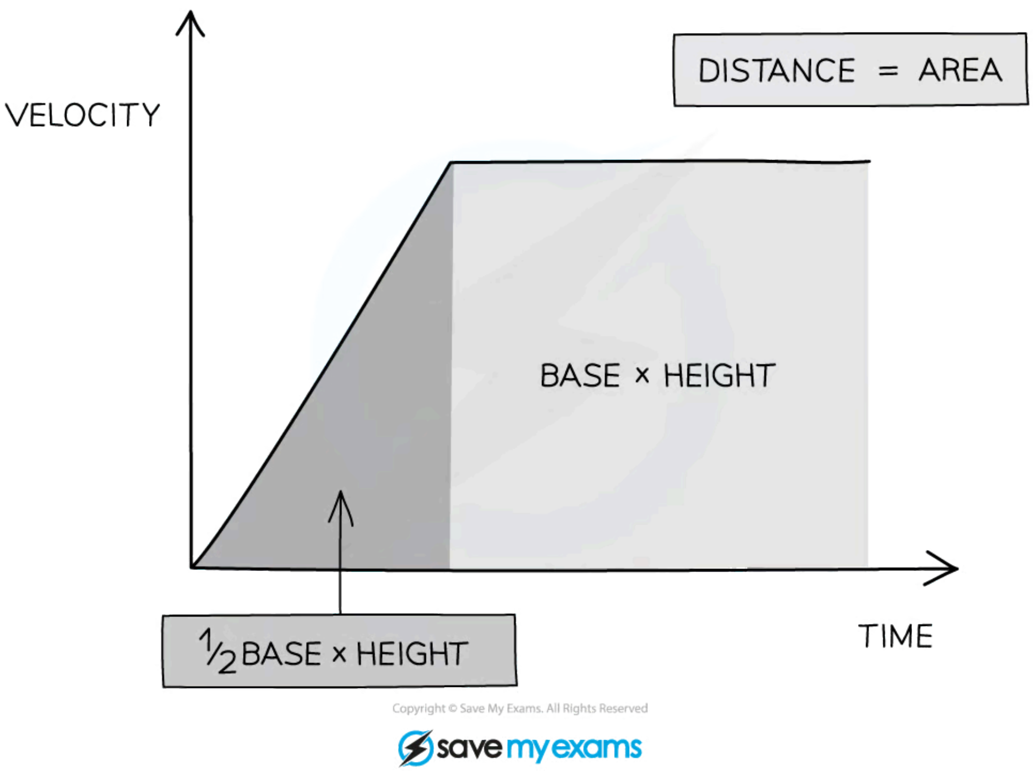
Your notes

Area Under a Velocity-Time Graph

Higher Tier

- The **distance travelled** by an object can be found by determining the **area beneath a velocity-time graph**

Calculating the Area Under a Velocity-Time Graph



The distance travelled can be found from 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:

$$\text{area} = \frac{1}{2} \times \text{base} \times \text{height}$$

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

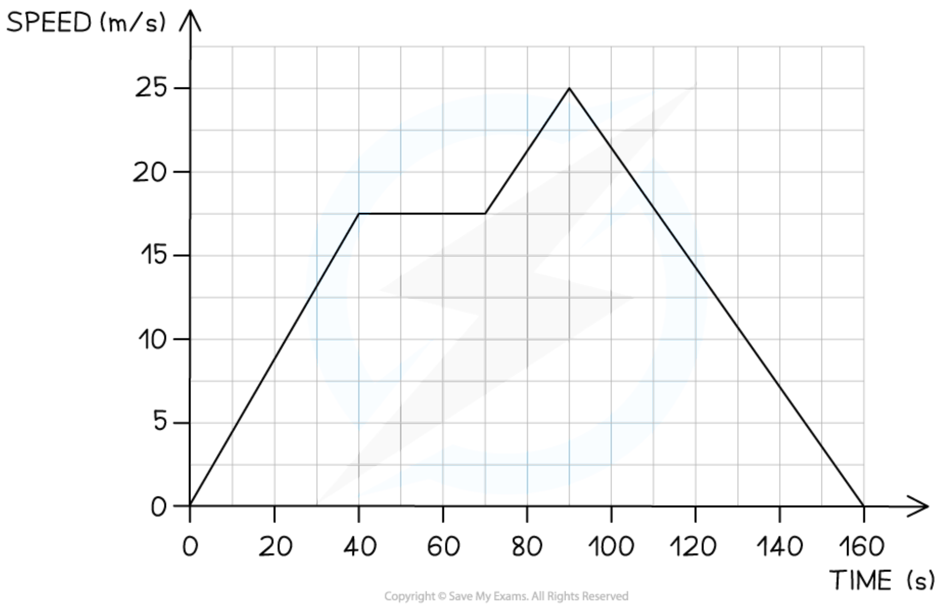
$$\text{area} = \text{base} \times \text{height}$$

Your notes

Your notes

Worked example

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



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

Answer:

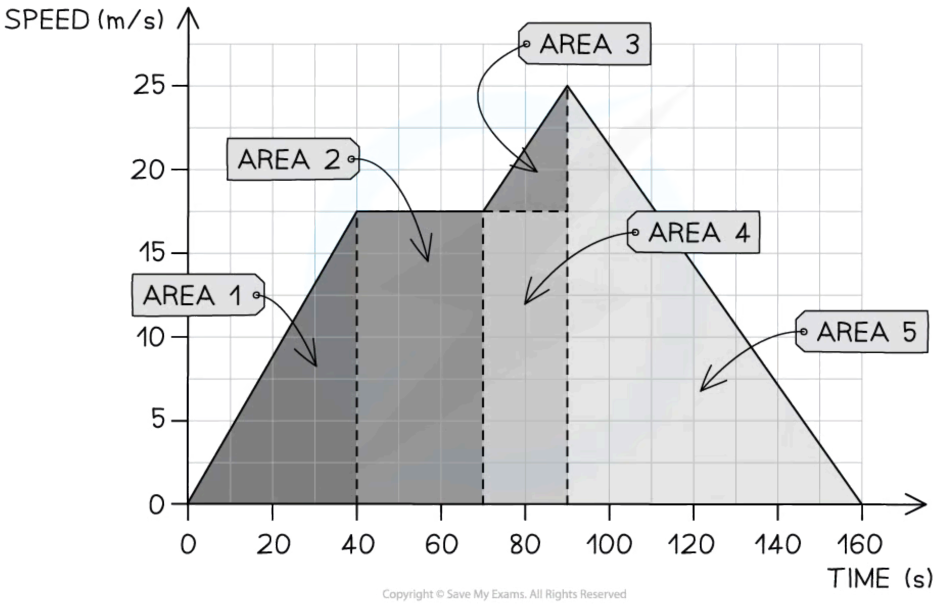
Step 1: Recall that the area under a velocity-time graph represents the distance travelled

- 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:

Your notes



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:

$$\text{total distance} = 350 + 525 + 75 + 350 + 875$$

$$\text{total distance} = 2175 \text{ m}$$

Your notes

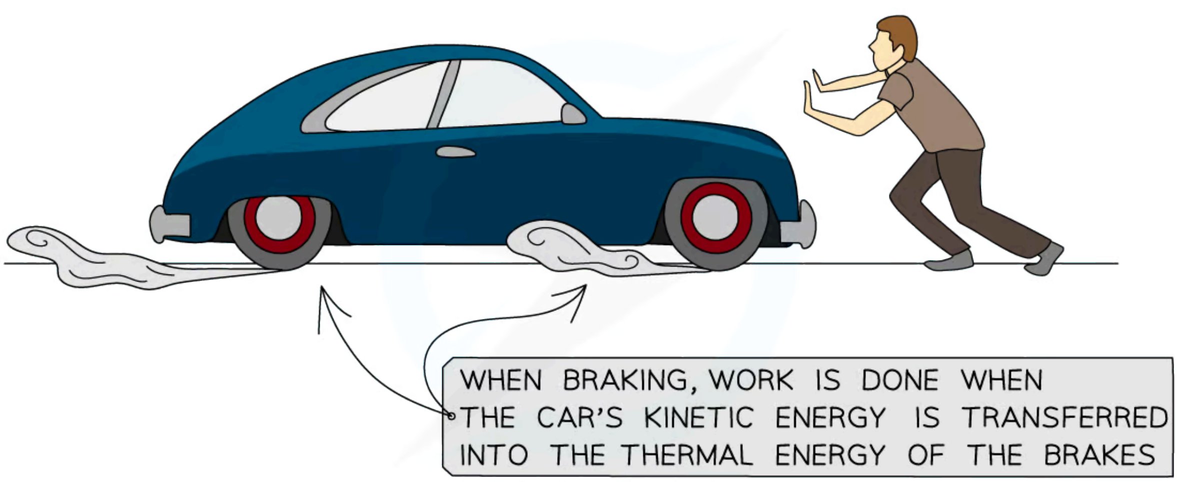
Thinking, Braking & Stopping Distances

Thinking, Braking & Stopping Distances

Principles of Forces and Motion

- When a driver applies the brakes, there is a **frictional force** between the **brakes** and the **wheels** of the car, also known as the **braking force**
- This frictional force does **work** on the brakes - i.e. it **transfers energy** from the car to the brakes
- Therefore, the **kinetic energy** of the car **decreases** and the **thermal energy** of the brakes **increases** - i.e. the brakes **heat up**
- This means the car **decelerates** (slows down)

Work Done when the Braking Force is Applied



Work done by breaking transfers energy from the kinetic store into the thermal energy store

- The **greater** the speed of a vehicle, the **greater** the braking force required to bring the vehicle to a **halt** for a given distance
  - This is due to the link between resultant force and acceleration as stated in **Newton's second law of motion**
  - Since the **braking force** would need to be **larger**, the **deceleration** of the vehicle will be **large** as well
- **Large decelerations** could lead to the brakes **overheating** and / or **loss of control** of the vehicle

Stopping Distance

- The **stopping distance** of a car is defined as:

  The total distance travelled during the time it takes for a car to stop in response to some emergency

- It can be written as an equation involving two distances:

Your notes

Stopping distance = Thinking distance + Braking distance

Thinking Distance

- **Thinking distance** is defined as

The distance travelled in the time it takes the driver to react (reaction time) in metres (m)

- The **main factors** affecting thinking distance are:
  - The **speed** of the car
  - The **reaction time** of the driver
- The **reaction time** is defined as:

A measure of how much time passes between seeing something and reacting to it

- The average reaction time of a human is 0.25 s
- Reaction time is increased by:
  - **Tiredness**
  - **Distractions** (e.g. using a mobile phone)
  - **Intoxication** (i.e. consumption of **alcohol** or **drugs**)

Breaking Distance

- **Braking distance** is defined as

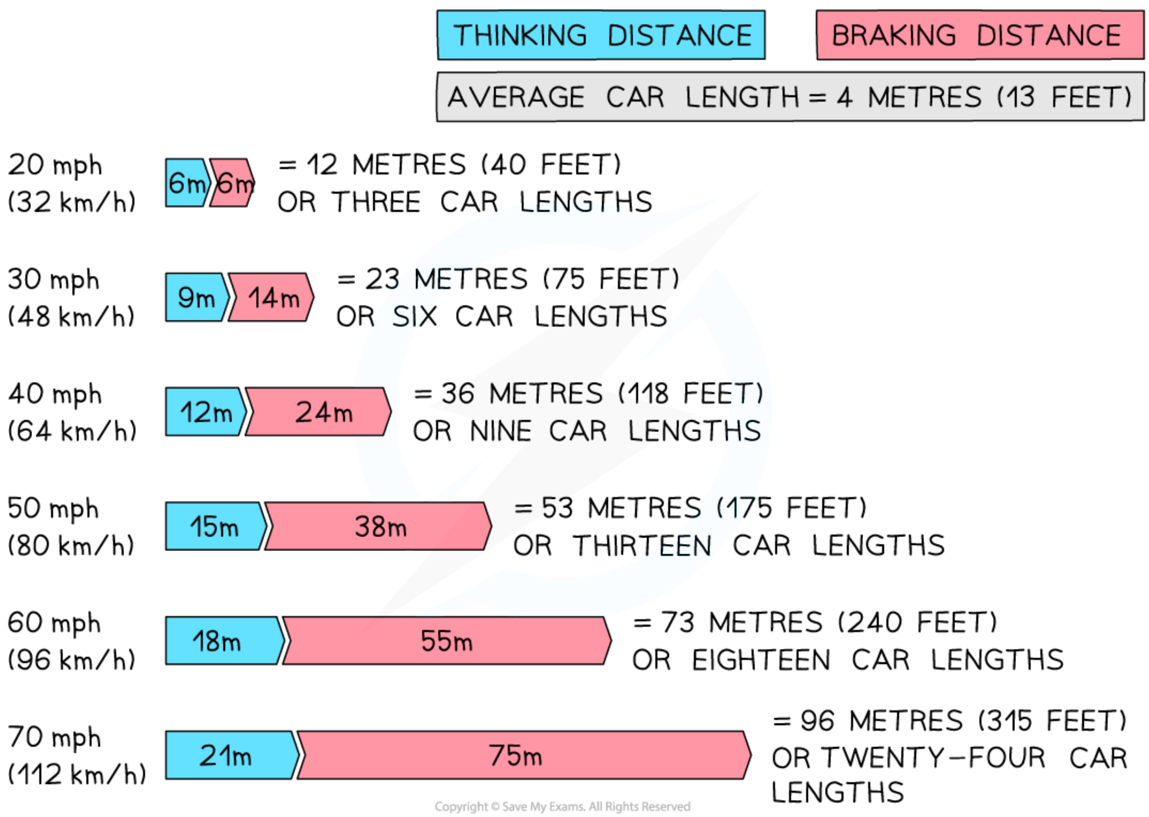
the distance travelled under the braking force in metres (m)

- For a given braking force, the **greater the speed** of the vehicle, the **greater the stopping distance**

Calculating Stopping Distance

- For a given braking force, the **speed** of a vehicle determines the size of the **stopping distance**
- The **greater the speed** of the vehicle, the **larger the stopping distance**

The Effect of Speed on Stopping Distance



A vehicle's stopping distance increases with speed. At a speed of 20 mph the stopping distance is 12 m, whereas at 60 mph the stopping distance is 73 m (reproduced from the UK Highway Code)

A Table Showing Speed and Stopping Distance

Speed (mph)	Speed (m/s)	Stopping Distances (m)
20	9	12
30	14	23
40	18	36
50	22	53
60	27	73

Your notes

Worked example

At a speed of 20 m/s, a particular vehicle had a stopping distance of 40 metres. The car travelled 14 metres whilst the driver was reacting to the incident in front of him.

What was the braking distance?

A 54 m

B 34 m

C 26 m

D 6 m

Answer: C

Step 1: Identify the different variables

- Stopping distance = 40 m
- Thinking distance = 14 m

Step 2: Rearrange the formula for stopping distance

Stopping distance = Thinking distance + Braking distance

Braking distance = Stopping distance – Thinking distance

Step 3: Calculate and identify the correct braking distance

Braking distance = 40 – 14

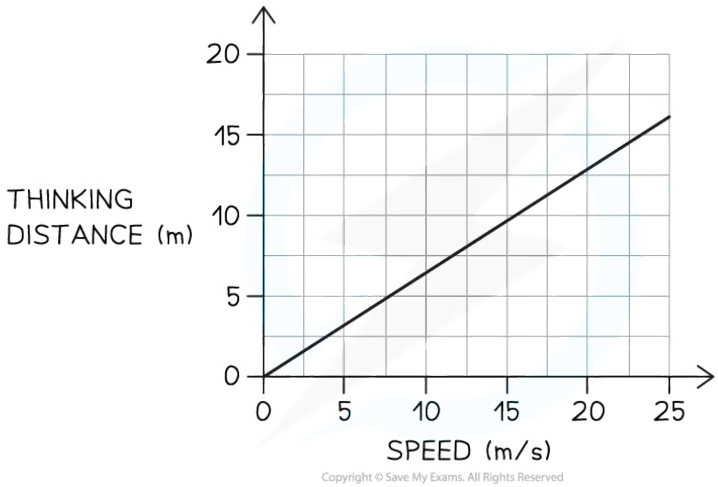
Breaking distance = 26 metres

Therefore, the answer is **C**

Your notes

Worked example

The graph below shows how the thinking distance of a driver depends on the speed of the car.



(a) Use the graph to describe the relationship between thinking distance and speed.

(b) Some people drive when they are tired, despite warnings against doing so.
Draw a new line on the graph to show how thinking distance varies with speed for a tired driver.

Answer:

Part (a)

Step 1: Check if the line is straight and if it goes through the origin

- The graph shows a **straight line** through the **origin**
- Therefore, the thinking distance is **directly proportional** to the speed of the car

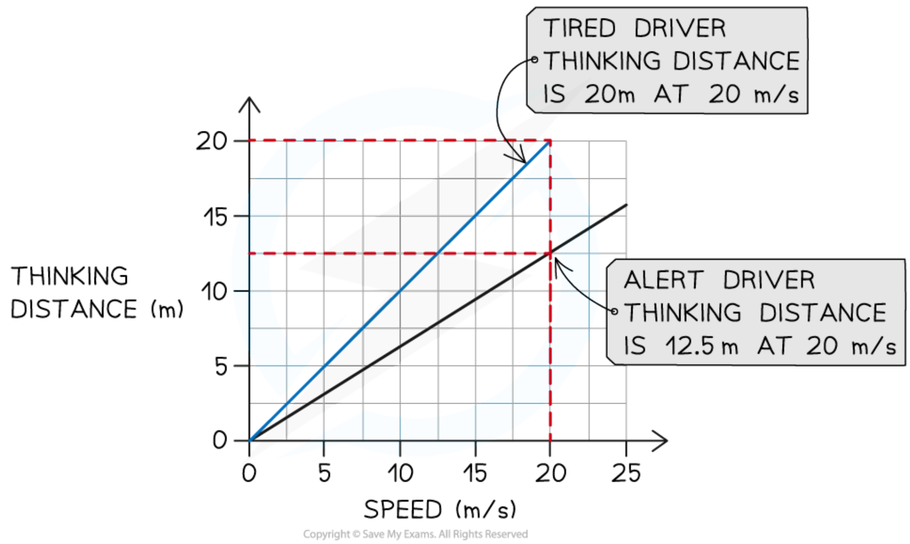
Part (b)

Step 1: Recall the factors which affect the thinking distance

- **Three** additional factors affect the **thinking distance**, because they affect **human reaction time**:
  - **Tiredness**
  - **Distractions**
  - **Intoxication**
- Hence, a tired driver's reaction time is **greater** (i.e. it takes longer for them to react)

Step 2: Draw a line that shows greater thinking distance for the same speed

- At the **same speed**, a tired driver's thinking distance will be **greater** than a driver who is alert
- This means a line should be drawn with a steeper gradient, as shown below:


TIRED DRIVER THINKING DISTANCE IS 20m AT 20 m/s
ALERT DRIVER THINKING DISTANCE IS 12.5 m AT 20 m/s
THINKING DISTANCE (m)
SPEED (m/s)
0
5
10
15
20
25
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Your notes

Worked example

Higher Tier

A car is travelling at 15 m/s when the driver applies the brakes. The car decelerates uniformly and stops. The mass of the car and the driver is 1500 kg, and together they have a total kinetic energy of 168 750 J.

(a) Determine the work done by the braking force to stop the car and the driver.

(b) The braking force used to stop the car and the driver was 6000 N.
Calculate the braking distance of the car.

Answer:

Part (a)

Step 1: Recall the process of applying brakes to a vehicle

- The **work done** is the **energy transferred** from the **car and driver** to the **brakes**
- This energy transfer is from **kinetic energy** to **thermal energy**
- In this case, the car is brought to a complete stop, so **168 750 J** of energy is **transferred** from **kinetic energy** to **heating** up the brakes (assuming all energy is transferred to heat only!)

Part (b)

Step 1: State the equation for work done

Work done = Force × distance travelled

$$W = Fs$$

- In this case, the **force doing the work** (transferring energy) is the **braking force**

Step 2: Rearrange the equation and solve for distance travelled

$$s = \frac{W}{F}$$

Step 3: Substitute the values for work and force

$$s = \frac{168\ 750}{6000}$$

$$s = 28.1 \text{ m}$$

- Hence the **braking distance** (the distance travelled by the car under the braking force) is **28.1 m**

Examiner Tip

If you are asked to explain why the temperature of the brakes increases when a vehicle stops, remember, work is done by the **frictional force** between the **brakes** and the **wheel**. It's a common mistake to write about the friction between the wheels and the road. This does happen, but in this case, the wheels heat up the road! The brake temperature **increases** because there is a **transfer of energy** from the car's **kinetic energy** to the **thermal energy** of the brakes.

Your notes

Your notes

Traffic Control Measures

Traffic Control Measures

- There are two ways to make travelling in a car safer:
  - Having cars move at a **slower speed**, so the stopping distance is shorter
  - Making traffic collisions **safer** if they do happen

Reducing Traffic Speed

- There are many methods employed on UK roads to reduce the speed cars can travel:
  - Speed limits
  - Speed humps
  - Speed cameras

Speed limits

- **Speed limits** tell drivers the **maximum speed** they are **legally allowed** to drive on a section of a street
- In most urban (town) areas across the UK, the speed limit is 30 mph (miles per hour)
- In residential areas across the UK, the speed limit is sometimes reduced to 20 mph
  - This is because there is a higher risk of **hazards** on the road
    - Children playing
    - People walking
    - Other cars parking or manoeuvring
    - People opening car doors
    - Pets crossing the road
    - People taking longer to cross the road
- In Wales, most 30 mph roads have been changed to 20 mph roads
- This decision was made to:
  - Reduce the number of **collisions** and resulting **injuries**
  - **Encourage** more people to walk, cycle or use public transport
  - Improve the **health** of Welsh citizens
  - Make the streets **safer**
  - Reduce air **pollution**

- A speed limit is indicated by the number of miles per hour inside a red circle on a post next to the road

An Example Speed Limit Sign

Your notes

A 30 mph speed limit sign

- **Speed humps** are used to force drivers to slow down
- They are often used:
  - On roads prone to accidents
  - Outside schools and hospitals
  - In residential areas
- Driving over speed humps can cause **damage** to cars and be **uncomfortable** for passengers

An Example of a Speed Hump

A speed hump in the road is designed to slow cars down

- **Speed cameras**
  - Can be both mobile or permanent
- **Mobile** cameras are set up by the Police along any stretch of road
  - They record the instantaneous speed of cars using a laser gun
  - They are set up in areas notorious for speeding and dangerous driving

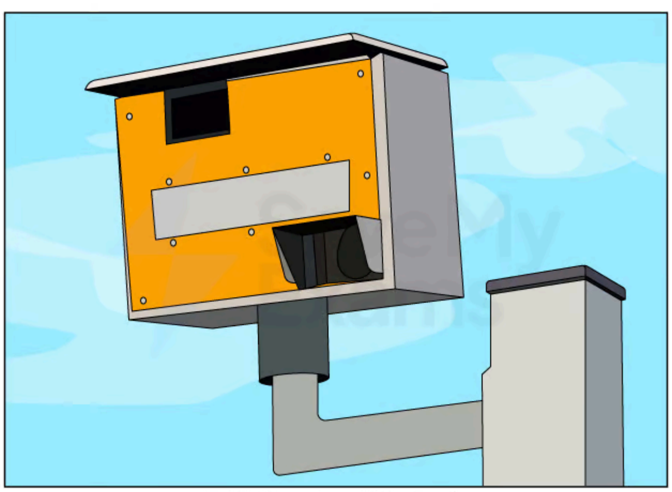
An Example of a Mobile Speed Camera

Your notes

Police officers set up mobile speed cameras to temporarily check the speed of passing motorists

- **Permanent** speed cameras are erected on posts and record the speed of cars 24 hours a day
  - They measure the average speed of cars over a set distance
  - Are marked by white lines on the road
- Permanent speed cameras are constructed along stretches of road where there may have been accidents or where mobile speed cameras have caught many offenders

An Example of a Permanent Speed Camera



A permanent speed camera is constructed on a pole on the side of the road and is always recording the speed of passing cars

Your notes

- If speed cameras catch motorists travelling above the speed limit then they can receive one or a combination of the following:
  - A fine
  - A warning
  - Further training via an online training course
  - Points on their driver's license

Safety Features in Cars

- There are many strict requirements in place for the safety features installed in modern cars
- These include:
  - **Crumple zones**
  - **Airbags**
  - **Seat belts**
- Car **manufacturers** are held accountable for how well these features perform
  - New and old models of cars undergo regular testing to ensure they are up to standard
- **Police officers** are responsible for enforcing the law that all passengers travelling in a car are wearing a **seatbelt**
  - A seatbelt restricts the distance a passenger will move during an impact
  - It can stop a passenger from falling through the front windscreen for example