Edexcel GCSE Physics

Your notes

Stopping Distances

Contents

Stopping Distances

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Thinking & Braking Distances

- 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:

  Stopping distance = Thinking distance + Braking distance

- Where:
  - Thinking distance = the distance travelled in the time it takes the driver to **react** (reaction time) in metres (m)
  - Braking distance = the distance travelled under the **braking force** in metres (m)
  - Stopping distance = the **sum** of the **thinking distance** and **braking distance**, in metres (m)
- For a given braking force, the **greater the speed** of the vehicle, the **greater the stopping distance**

Worked Example

At a speed of 20m/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

- The stopping distance is 40 metres
- The car travelled 14 metres while the driver was reacting
  - This is the thinking distance

Step 2: Rearrange the formula for stopping distance

Stopping distance = Thinking distance + Braking distance

Braking distance = Stopping distance – Thinking distance

Step 3: Calculate the correct braking distance

- Braking distance = 40 – 14 = 26 metres

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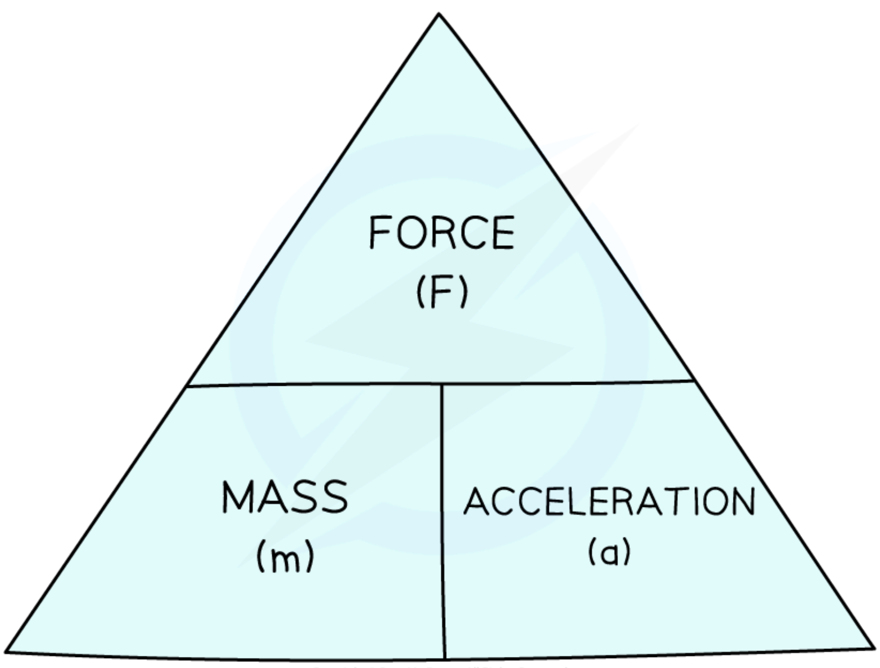
Dangers on the Road

- A large deceleration can be dangerous for a number of different reasons
- For any object to decelerate, a force is required and for **heavy** objects, **large** decelerations will require **large forces**
- This is true according to **Newton's Second Law**:

$$F = ma$$

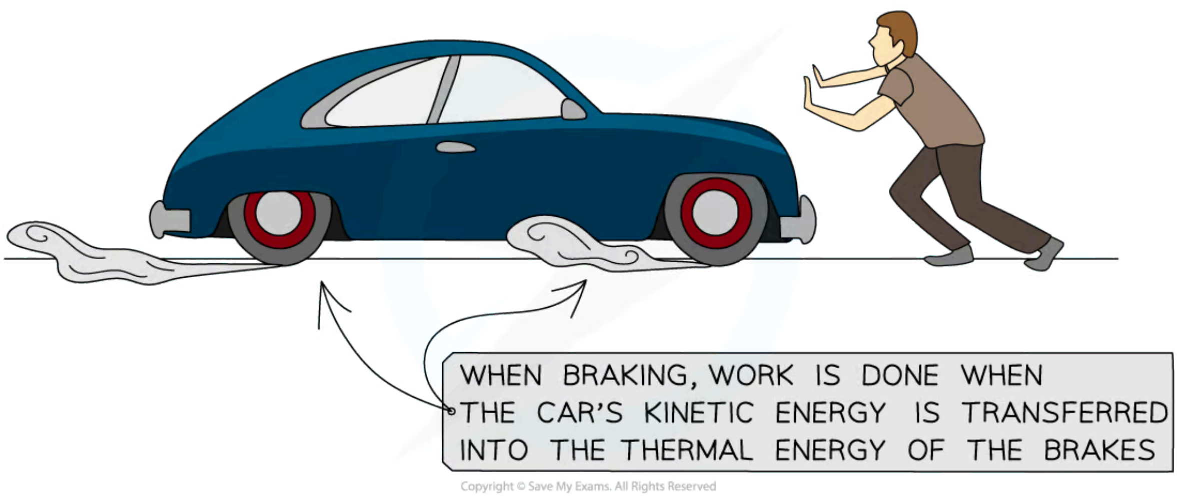
- Where:
  - F = force in newtons (N)
  - m = mass in kilograms (kg)
  - a = acceleration in metres per second squares (m/s^2)
- This equation can be rearranged with the help of a formula triangle:



Force, mass, acceleration formula triangle

Overheating of Brakes

- Vehicles use brakes to decelerate
- These reduce the speed of the vehicle by creating a **friction** force between the brake and the wheel
- The **kinetic** energy of the vehicle is converted to **thermal** energy of the brakes
- If brakes get too hot then they can **fail**, meaning that they will not work effectively the next time they are used



Work done by breaking transfers kinetic into thermal energy

Loss of Control and Injury

- When a vehicle undergoes a deceleration then the driver and passengers **also** experience a deceleration
- This can cause **injuries** such as whiplash is a neck injury caused when a persons head moves suddenly, relative to their body
- It is also more difficult to control a vehicle that is decelerating
- Losing control can cause a collision

Worked Example

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A passenger travels in a car at a moderate speed. The vehicle is involved in a collision, which brings the car (and the passenger) to a halt in 0.1 seconds. Estimate:

a) The acceleration of the car (and the passenger).

b) The force on the passenger.

Answer:

Part (a)

Step 1: Estimate the required quantities and list the known quantities

A moderate speed for a car is about 50 mph or 20 m/s

- Initial velocity ~ 20 m/s
- Final velocity = 0 m/s
- Time, t = 0.1 s

Step 2: Calculate the change in velocity of the car (and the passenger)

change in velocity = Δv = final velocity – initial velocity

$$\Delta v = 0 - 20$$

$$\Delta v = -20 \text{ m/s}$$

Step 3: Calculate the acceleration of the car (and the passenger) using the equation:

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

Step 4: Calculate the deceleration

$$a = -20 \div 0.1$$

$$a \sim \mathbf{-200\ m/s^2}$$

Part (b)

Step 1: Estimate the required quantities and list the known quantities

An adult person has a mass of about 70 kg

- Mass of the passenger, m ~ 70 kg
- Acceleration, a = –200 m/s^2

Step 2: State Newton's second law

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- This question involves quantities of force, mass and acceleration, so the equation for Newton's second law is:

$$F = ma$$

Step 3: Calculate an estimate for the decelerating force

$$F = 70 \times -200$$

$$F \sim \mathbf{-14\,000\ N}$$

Examiner Tips and Tricks

Remember that resultant **force** is a **vector** quantity. Examiners may ask you to comment on **why** its value is negative - this happens when the resultant force acts in the **opposite direction** to the object's motion. In the worked example above, the resultant force **opposes** the passenger's motion, slowing them down (decelerating them) to a halt, this is why it has a minus symbol.

Measuring Reaction Time

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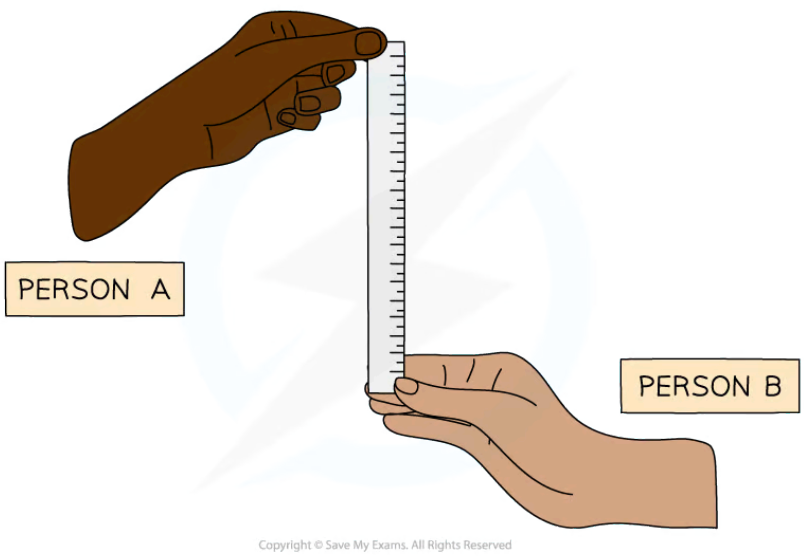
Measuring Reaction Time

- The **reaction time** is defined as:

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

- The human reaction time for someone who is **alert** - i.e. someone waiting to react to something happening, like an athlete waiting for the start of a race - is usually in the range of **0.2 – 0.9 seconds**
- A simple method for measuring human reaction time is illustrated below:



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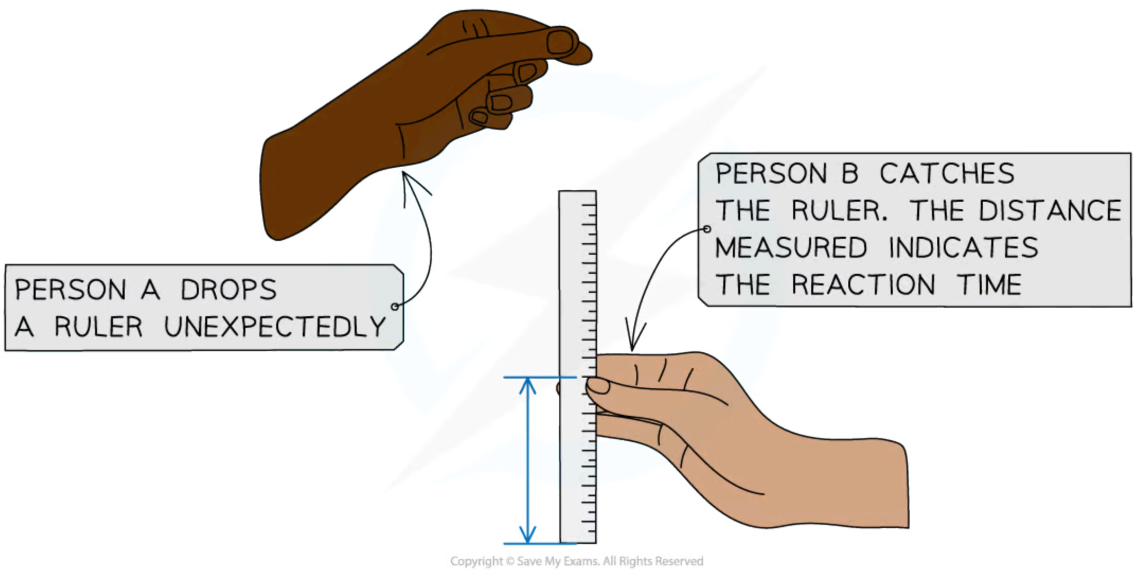

Dropping a ruler provides a simple and fun way of measuring someone's reaction time

- **Person A** holds a **30 cm ruler** vertically, such that the bottom end of the ruler hovers over the top of the hand of **Person B**
- Person A should **release the ruler unexpectedly**
- As soon as Person B sees the ruler move, they should close their hand, catching it
- The ruler is marked at the point at which it was caught by Person B - i.e. in line with the top of their hand
- This gives a measurement of the **distance** the ruler fell
  - The **greater** the distance, the **longer** the reaction time

Examiner Tips and Tricks

The method described here is a **standard** method for measuring reaction time, however there are numerous other methods possible, so don't be surprised if you are given a situation that you are not familiar with. Notice that **this method does not directly measure a time**. The distance that the ruler has fallen can be used to calculate a time accurately, but that is not required here.

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Factors Affecting Stopping Distance

Factors Affecting Braking Distance

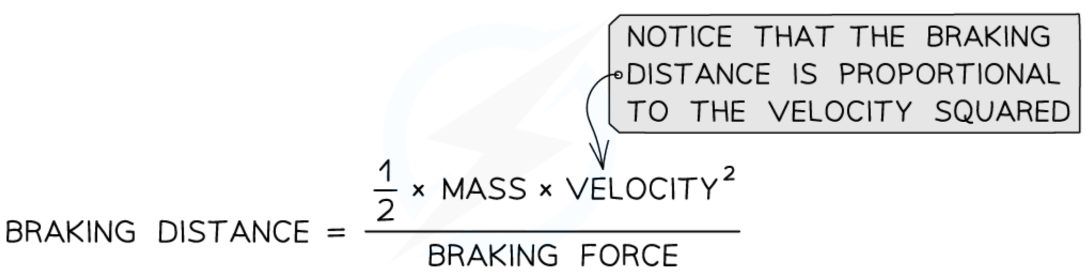
- The **braking distance** is defined as:

  The distance travelled by a car under the braking force – i.e. whilst it is slowing down

- The **main factor** affecting the braking distance of a car is its **speed**
  - The greater the speed, the greater the braking distance will be
- There are **additional factors** which affect the braking distance, such as:
  - **Vehicle condition** - e.g. worn tyres or poor brakes
  - **Road condition** - wet or icy roads make it harder to decelerate
  - **Vehicle mass** - a heavy vehicle, such as a lorry, takes longer to stop
- The smoother the road conditions, for example when they are wet and icy, the **less friction** there is between the tyres and the road surface so there would be a greater braking distance
- The braking distance is the ratio of the **kinetic energy** of the car and the **braking force**
  - This is because the work done in bringing a car to rest is the transfer of all its kinetic energy into other forms (thermal, sound)
- The kinetic energy is equal to

$$KE = ½mv^2$$

- This means the braking distance is **proportional to** the velocity **squared**
  - If the velocity doubles, the braking distance increases by $(2)^2$, 4 times!



Factors Affecting Thinking Distance

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- The **thinking distance** is defined as:

  The distance travelled by a car from when a driver realises they need to brake to when they apply the brakes

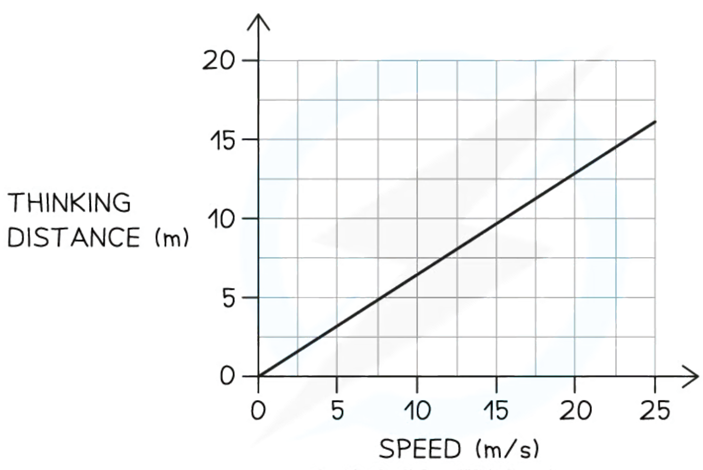
- The reaction distance is equal to:

  Reaction Distance = Speed of the car × Driver's reaction time

- The **main factor** that affects the **thinking distance** is the car's **speed**, however additional factors can affect the thinking distance
- It is increased by:
  - **Tiredness**
  - **Distractions** (e.g. using a mobile phone)
  - **Intoxication** (i.e. consumption of **alcohol** or **drugs**)
- Since these factors can affect the driver's reaction time, they directly affect the **thinking distance**

Worked Example

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



(a) Describe the connection between thinking distance and speed.

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(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**
- The graph shows that when speed is doubled, thinking distance is also doubled
- Therefore, the thinking distance is **directly proportional** to the speed of the car

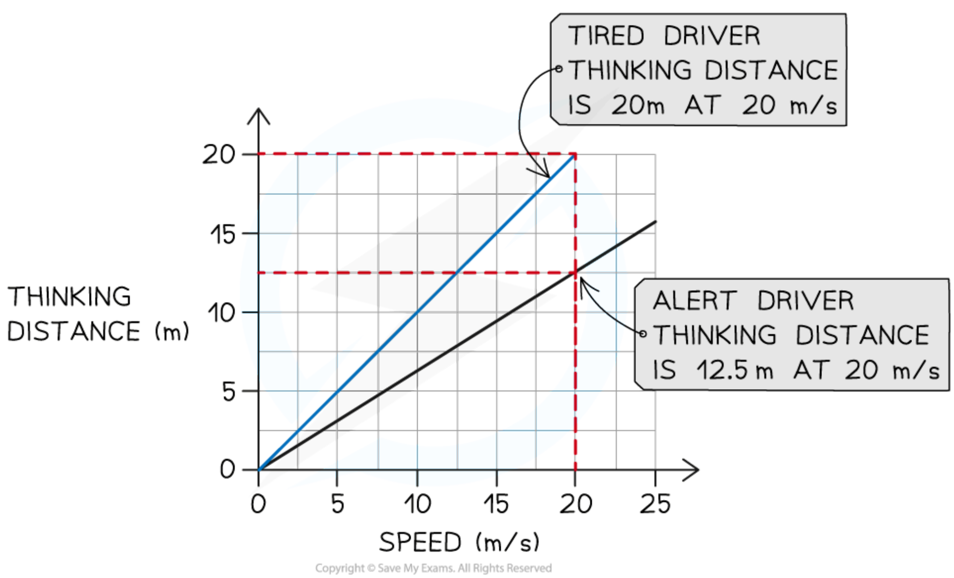
Part (b)

Step 1: Recall the factors which affect the thinking distance

- Three additional factors that affect the thinking distance (as they affect human reaction time) are:
  - **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 an alert driver
- This means a line should be drawn with a steeper gradient, as shown below:



Calculating Stopping Distances

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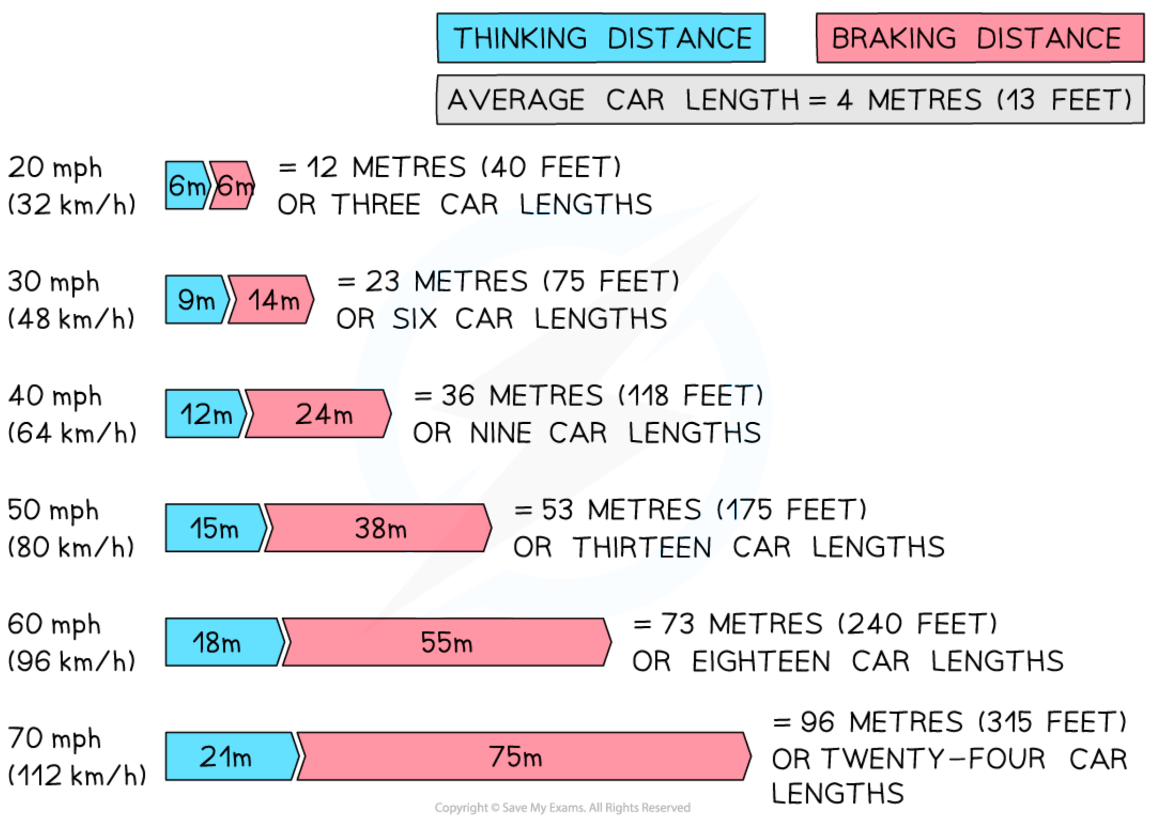
Estimating Stopping Distances

- 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 image below shows how the stopping distance of a typical family car increases with increasing speed:



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 under the

Speed (mph)	Speed (m/s)	Stopping Distance (m)
20	9	12
30	14	23
40	18	36
50	22	53
60	27	73
70	31	96

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Worked Example

A car is travelling with a velocity of 100 miles per hour. Use the information provided in the diagram above to estimate the thinking, braking and stopping distance for the car.

Answer:

Step 1: Identify the variables

- The diagram contains information for a car at a velocity of 50 mph as follows:
- Thinking distance = 15 m
- Braking distance = 38 m
- Stopping distance = 53 m
- The new speed is 100 mph which is **double** the velocity in the diagram

Step 2: State the relationship between thinking and braking distance, and velocity

- Thinking distance is **proportional** to the velocity
- Braking distance is proportional to the **velocity squared**

Step 3: Calculate the new thinking and braking distances

- Thinking distance at 100 mph = 15 × 2 = 30 m
- Braking distance at 100 mph = 38 × 4 = 152 m

Step 4: Calculate the new stopping distance

- Stopping distance = Thinking distance + Braking distance
- Stopping distance = 30 + 152 = 182 m

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Calculating Braking Distance

- When a vehicle stops work is done by a **force**
- The **kinetic energy** of the car is transferred to **thermal energy** in the brakes which does work
- This can also be represented by the braking force and braking distance by the following equation:

$$\overbrace{\text{BRAKING FORCE} \times \text{BRAKING DISTANCE}}^{\boxed{\text{WORK DONE BY THE BRAKES}}} = \underbrace{\frac{1}{2} \times \text{MASS} \times \text{VELOCITY}^2}_{\boxed{\text{KINETIC ENERGY OF THE CAR}}}$$

- This equation shows that the work done is the **transfer** of **kinetic energy**
- We can use this equation to estimate the **decelerating forces** required for a typical vehicle moving at everyday speeds
- This equation can be rearranged to show how the braking distance depends on velocity:

NOTICE THAT THE BRAKING DISTANCE IS PROPORTIONAL TO THE VELOCITY SQUARED

$$\text{BRAKING DISTANCE} = \frac{\frac{1}{2} \times \text{MASS} \times \text{VELOCITY}^2}{\text{BRAKING FORCE}}$$

Equation for braking distance from mass, velocity and braking force

- The **braking distance** is **proportional** to the vehicle's **velocity squared**

- For example, if the velocity of the vehicle **doubles** then the braking distance will increase by a **factor of 4**

Your notes

Worked Example

At 18 m/s (40 mph) the braking distance of a typical car of mass 1500 kg is about 24 m. Use this information to estimate the braking force for a typical car.

Answer:

Step 1: List the known quantities

- Mass, m = 1500 kg
- Braking distance, s = 24 m
- Speed, v = 18 m/s

Step 2: State the relevant equation

$$\text{Braking force} \times \text{braking distance} = \frac{1}{2}mv^2$$

Step 3: Rearrange for the braking force

$$\text{Braking force} = \frac{\frac{1}{2}mv^2}{\text{braking distance}}$$

Step 4: Substitute the values into the equation

$$\text{Braking force} = \frac{\frac{1}{2} \times 1500 \times (18)^2}{24} = 10\ 125 \text{ N}$$

Examiner Tips and Tricks

The equation for braking distance doesn't actually apply at **very high speeds** because the brakes get **hot** and become **less effective**. This **reduces** the **braking force**, causing the **braking distance** to **increase** even further. This is why it is important to prevent brakes from **overheating**.