

Acceleration Notes

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In this booklet we will look at acceleration and the equations and graphs that go with that topic. But, before we do, let's have a quick reminder about speed, velocity and quantities.

There are two types of quantities in GCSE physics, scalar and vector quantities.

Scalar quantities: are measures that only have a size.

Vector quantities: are measures that have a size and a direction included in them.

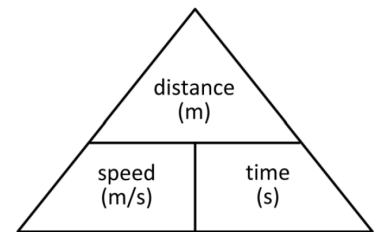
Speed: is a scalar quantity, as it has a size. The speed of an object is found by dividing the distance covered by the time taken to cover it. Both speed and velocity are calculated using almost the exact same equation.

The speed of an object is calculated using the equation:

Speed = distance in metres ÷ time in seconds

$$S = d \div t \quad \text{also written as} \quad S = \frac{d}{t}$$

The unit of speed is metres per second written as **m/s**.



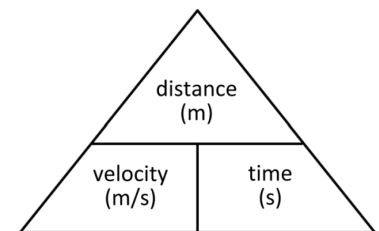
Velocity is a vector quantity, as it has both a size and direction. **Velocity:** is the speed of an object in a given direction.

The velocity of an object is calculated using the equation:

Velocity = distance in metres ÷ time in seconds

$$V = d \div t \quad \text{also written as} \quad V = \frac{d}{t}$$

The unit of velocity is metres per second written as **m/s**.



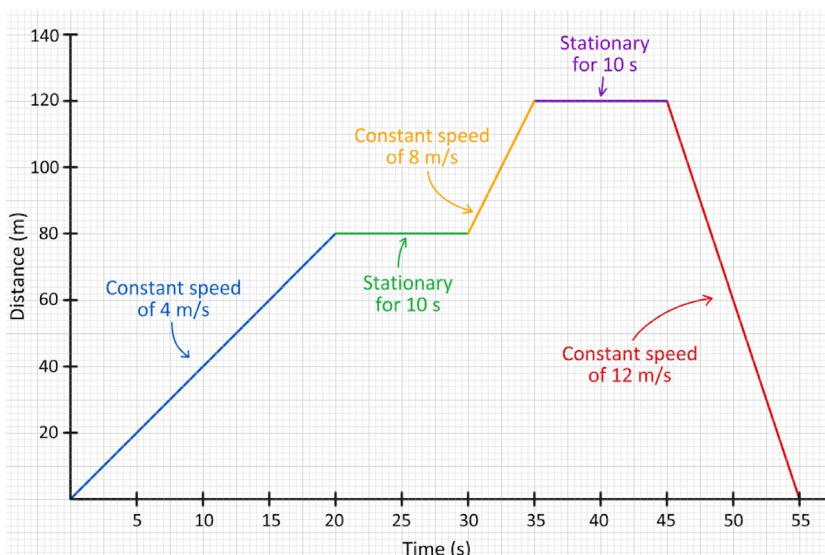
Distance Time Graphs

The graph below shows a typical distance time graph. Distance will always be on the y axis and time always on the x axis. Questions involving distance time graphs do not come up regularly in the GCSE. They are considered too easy.

What do we need to know? We need to know what the different lines on a distance time graph mean and how to calculate speed from a distance time graph.

Straight lines: each straight line shows a different constant speed. The gradient of each line is equal to the speed.

Horizontal lines: each horizontal line shows that the object is stationary, so it is not moving.



How do we find the speed on a distance time graph?

Simply divide the distance by the time taken for a section. For example, if we wanted to know the speed of the object 20 seconds after starting we would divide the distance (80 m) by 20 seconds.

$$S = \frac{d}{t} \quad S = \frac{80}{20} \quad S = 4 \text{ m/s}$$

Acceleration: the rate of change of velocity. So, acceleration is a measure of how velocity changes in a certain time. There are a number of ways to calculate acceleration.

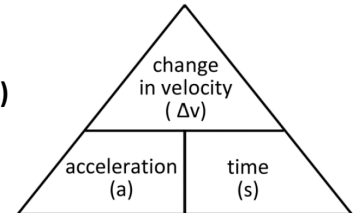
Note: acceleration in physics describes the changes to velocity in a given time. This covers objects that are both speeding up and slowing down. So even if the object is slowing down we still say it is accelerating as it is technically changing velocity in a given time. If the object is slowing down we write the figure as a negative value. It's crucial to use a negative sign for any object that is slowing down.

Let's look at the two most common methods of calculating acceleration 😊

The acceleration of an object is calculated using the equation:

$$\text{Acceleration (m/s}^2\text{)} = \text{change in velocity (m/s)} \div \text{time (s)}$$

$$a = \Delta V \div t \quad \text{also written as} \quad a = \frac{\Delta V}{t}$$



The unit of acceleration is **m/s²**. This is one of the most commonly mistaken units in GCSE physics. Please make sure that you know this unit very well. ΔV = change in velocity (m/s).

Let's have a look at a few examples using this equation.

Example 1: A car accelerates from 0 m/s to 60 m/s in 6 s. What is its acceleration?

$$a = \frac{60}{6} \quad a = 10 \text{ m/s}^2$$

Example 2: A person slows down from 30 m/s to 5 m/s their rate of acceleration is -5 m/s^2 . What was the time taken?

$$t = \frac{\Delta V}{a} \quad t = \frac{-25}{-5} \quad t = 5 \text{ s}$$

The acceleration of an object is found using the equation:

$$\text{Final velocity squared} - \text{initial velocity squared} = 2 \times \text{acceleration (m/s}^2\text{)} \times \text{distance (m)}$$

$$V^2 - U^2 = 2 \times a \times s \quad \text{also written as} \quad V^2 - U^2 = 2as$$

Let's have a look at a few examples using this equation.

Example 3: A person running reaches a speed of 3.5 m/s from an initial speed of 1.25 m/s. The runner covered 10 m during this time. Calculate the acceleration of the runner.

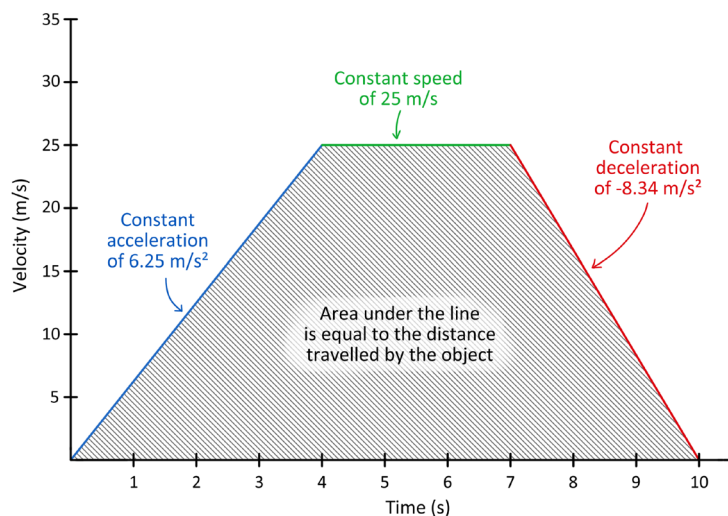
$$\begin{aligned} V^2 - U^2 &= 2as \\ 3.5^2 - 1.25^2 &= 2 \times a \times 10 \\ 10.6875 &= 20a \\ a &= 0.534 \text{ m/s}^2 \end{aligned}$$

Example 4: A car is moving at a speed of 1 m/s and has accelerated at a rate of 3 m/s^2 . The car covered a distance of 80 m. Calculate the final speed of the car.

$$\begin{aligned} V^2 - U^2 &= 2as \\ V^2 - 1^2 &= 2 \times 3 \times 80 \\ V^2 - 1 &= 480 \\ V^2 &= 480 + 1 \\ V^2 &= \sqrt{481} \\ V &= 21.9 \text{ m/s} \end{aligned}$$

Velocity Time Graphs

What are velocity time graphs? They are a type of graph that compares how velocity changes over a period of time. This type of graph can be used to understand both the velocity of an object, the direction it is moving, its acceleration and the displacement of the object. Displacement is the object's change in position. It is a vector quantity.



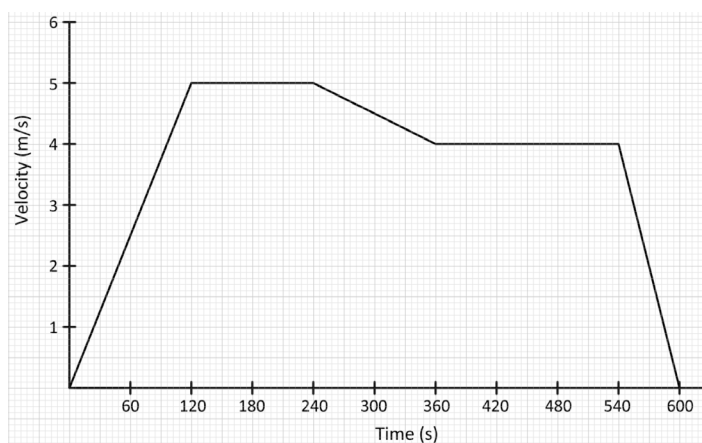
What should we look out for in a velocity time graph?

1. The gradient of each straight line is equal to its acceleration at that point.
2. Horizontal straight lines mean the object is at a constant speed.
3. The area under the line is equal to the distance travelled by the object.

How do we calculate the area under the line?

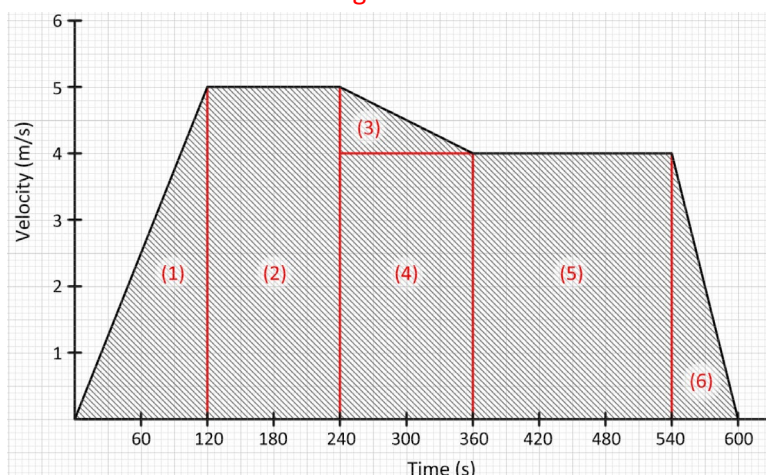
There are two ways that we can calculate the area and it will depend on the question which way we use. Either we break the space into different shapes and then add them together or treat it as a trapezium and do it in one go.

Example 5: The velocity time graph below is for a person running.



- a. What is the speed of the runner at 120 seconds? 5 m/s
- b. For how long was the runner at a constant velocity? 360 s
- c. What was the total distance covered by the runner in the 600 seconds?

For this we would break the whole shape into smaller shapes. Find the area of each and add them all together. This has been done in the diagram below.



$$\text{Shape 1} = (120 \times 5) \div 2 = 300 \text{ m}$$

$$\text{Shape 2} = 120 \times 5 = 600 \text{ m}$$

$$\text{Shape 3} = (120 \times 1) \div 2 = 60 \text{ m}$$

$$\text{Shape 4} = 120 \times 4 = 480 \text{ m}$$

$$\text{Shape 5} = 180 \times 4 = 720 \text{ m}$$

$$\text{Shape 6} = (60 \times 4) \div 2 = 120 \text{ m}$$

$$\text{Total distance} = 2280 \text{ m}$$

Terminal Velocity

Terminal velocity: describes when an object falls at a constant velocity in a fluid, as the forces acting on it are equal.

Exam note: exam questions on terminal velocity usually involve a person who is sky diving or sinking underwater. Either way the concept is the same 😊 We could write a huge amount here about terminal velocity but let's not 😊 Let's look at how to answer a question involving terminal velocity.

Remember! At all stages when we are answering a question about terminal velocity, we should talk about the forces that are acting on or affecting the object. Assuming the object is moving...

When the forces are not balanced, there will be a resultant force, the object will be accelerating.

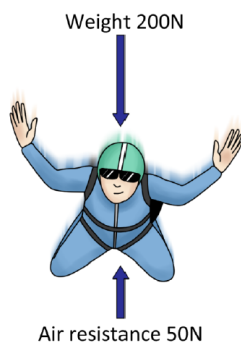
When the forces are balanced, there is no resultant force, the object will be moving at a constant speed.

What forces are we talking about? In general, weight is the force pushing the object downwards and air resistance is the force pushing the object back. We can use the term drag here instead of air resistance if we prefer.

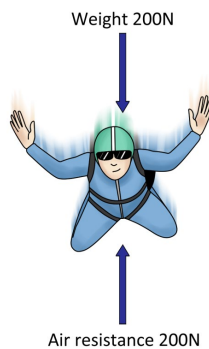
The Parachutist... when are they at terminal velocity?

The diagrams below show a typical parachutist at different stages of their fall.

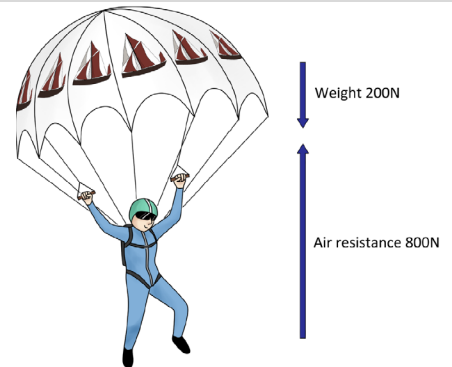
Just jumped out of the plane...



Been falling a while...



Just opened their parachute...

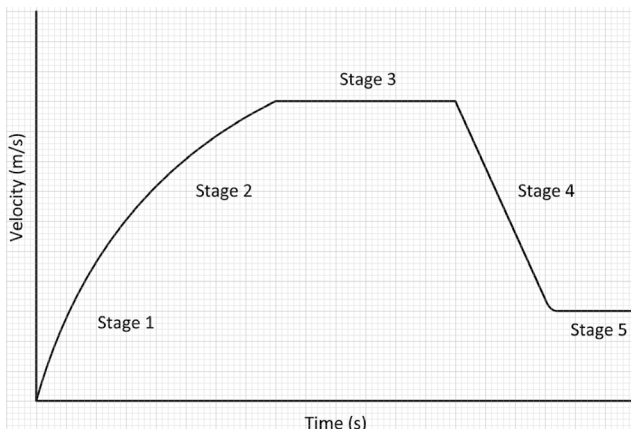


Only one of these is at terminal velocity. But which one? Did you think the middle one? **Correct** 😊

The **“Been falling a while”** diagram shows that the forces acting on the skydiver are equal 😊 so there is no resultant force. Therefore the skydiver does not accelerate and continues to move at their terminal velocity.

Terminal Velocity – Velocity time graphs

Yes – velocity time graphs are back 😊 they can indeed come up in questions involving terminal velocity. Again it's all about talking about the forces that we meet at each stage. The velocity time graph below shows the fall of a parachutist.



Stage 1: The parachutist has just jumped.

The force of weight is greater than the force of air resistance. There is a resultant force so the parachutist accelerates.

Stage 2: The parachutist is falling.

The force of weight is still greater than the force of air resistance. There is a resultant force so the parachutist accelerates.

Stage 3: The parachutist is at terminal velocity.

The force of weight is equal to the force of air resistance. There is no resultant force.

Stage 4: The parachutist has opened the parachute. The force of weight is less than the force of air resistance. As there is now a much larger surface area for air resistance to affect. There is a resultant force, the parachutist decelerates.

Stage 5: The parachutist is at a new much slower terminal velocity.

The force of weight is once again equal to the force of air resistance. There is no resultant force.

Stopping Distances

Stopping distance: the total distance that a car travels from the driver noticing the hazard to the car coming to a complete stop. The stopping distance of a car is equal to the thinking distance and the braking distance added together.

We mentioned cars in the definition above but that would apply to anything we are moving from a ship to a e-scooter.

Thinking distance – what do I need to know?

What is thinking distance? Thinking distance is the distance that the car will travel in the time that it takes the person to see the hazard and move their muscles to begin stopping. Typical reaction times range from 0.2s to 0.9s.

Let's say we are driving at 70 mph which is 31.30 m/s and it takes us 0.5 seconds to react how far will we travel before we push the brake?

$$\text{Distance} = \text{speed} \times \text{time}$$

$$\text{Distance} = 31.30 \text{ m/s} \times 0.5 \text{ s}$$

$$\text{Distance} = \mathbf{15.65 \text{ m}}$$

That's the same as the length of a standard shipping container or a large bus.

What factors can slow down a drivers reaction time? Reaction times could be slower if the driver has taken drugs or alcohol, is tired, or is distracted.

Braking distance – what do I need to know?

What is braking distance? Braking distance is the distance that the car will travel while the brakes are being applied to stop the car. Let's have a look at an example of calculating braking distance.

Example: a car with a mass of 1000 kg is travelling at 30 m/s. The driver applies the brakes, which produce a maximum braking force of 6000 N. Calculate the braking distance of the car.

Step 1: Calculate the kinetic energy the car has before it brakes.

$$\text{Kinetic Energy} = \frac{1}{2} m \times v^2$$

$$E_k = 0.5 \times 1000 \times 30^2$$

$$E_k = 500 \times 900$$

$$E_k = 450,000 \text{ J}$$

Step 2: then use the work done equation to find the distance.

$$\text{Work done} = \text{Force} \times \text{distance}$$

$$\text{Distance} = 450,000 \div 6000$$

$$\text{Distance} = 75 \text{ m}$$

What factors can affect the braking distance of a car? There's quite a few, let's look at each.

1. **Mass of the car** – if the car is heavier than normal then it can take the car longer to stop.
2. **Weather conditions** – is the road wet? Is there snow and ice on the road? All of these factors increase the braking distance as they reduce the friction between the road and the tyres.
3. **Condition of the tyres** – the tyres need to be in good condition to work correctly. If the tires are worn or balding then this will greatly reduce the friction between the road and the tyres.
4. **Condition of the brakes** – the brakes need to be in good condition and in working order to function. If they are not, if they're worn or need to be replaced this can really impact your braking distance.

Stopping suddenly... that's the bad part

Moving at high speed isn't in itself that dangerous. Most of us fly to different parts of the world at over 500 mph without even thinking twice about it. But coming to a sudden stop can be fatal.

What are the hazards of a large deceleration?

1. **Overheating:** the huge amount of friction causes the brakes to severely overheat, which can cause them to fail.
2. **Skidding:** the tyres can lose their grip on the road, resulting in losing control of the car or skidding.