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PiXL Science

PiXL KnowIT!

GCSE Physics

Edexcel Motion and forces

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The PiXL Club Ltd, Company number 07321607

Overview
Edexcel Topic 2

Motion and forces

Part 1
- Scalar and vector quantities

Part 2
- Velocity/speed
- Distance/time relationship
- Acceleration
- Velocity/time relationship

Part 3
- Newton's First Law
- Newton's Second Law
- Weight

Part 4
- Circular motion (HT)
- Inertia (HT)
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- Reaction time
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- Factors affecting reaction times

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Motion and forces
Part 1

- Scalar and vector quantities

Scalars and Vectors

Materials in a classroom can be grouped into two groups – metals and non-metals.

Things we measure can be put into two groups as well – scalars and vectors.

Scalars: Things that we measure that have a magnitude (size) only are scalars.

Vectors: Things that we measure that have both magnitude and direction are vectors.

Sometimes direction is really important. In a crash the direction, as well as the speed, of the vehicles will determine how much damage is caused.

Examples of Scalars and Vectors

Some examples of scalars and vectors are shown in the table below.

Scalars	Vectors
Direction	Displacement
Speed	Velocity
Mass	Forces (including weight)
Temperature	Acceleration
Energy	Momentum

Definitions

Distance: How far an object has travelled. Distance is a scalar quantity.

Displacement: How far an object has travelled in a straight line from the starting point to the finishing point and the direction of that line. Displacement is a vector quantity.

Examples:

A runner runs around a track. The track is 400 m long.

After completing one complete circuit of the track the runner has travelled a distance of 400 m. After the one complete circuit the runner ends up at their starting point. This means that their displacement is 0 m.

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QuestionIT!

Motion and forces
Part 1

- Scalar and vector quantities

Part 1– QuestionIT

1. What is a scalar quantity?

2. Explain how a car can be moving at a constant speed but have changing velocity.

3. State whether the following quantities are scalars or vectors:

speed direction energy displacement mass weight

velocity acceleration momentum

AnswerIT!

Motion and forces
Part 1

- Scalar and vector quantities

1. What is a scalar quantity?
 Scalars quantities have magnitude ONLY i.e. no direction.

2. Explain how a car can be moving at a constant speed but have changing velocity.
As velocity is a vector if the direction of the car changes the velocity will change, at a constant speed.

3. State whether the following quantities are scalars or vectors:

Scalars	Vectors
direction	displacement
speed	velocity
mass	forces (including weight)
temperature	acceleration
energy	momentum

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Motion and forces
Part 2

- Velocity/speed
- Distance/time relationship
- Acceleration
- Velocity/time relationship

Definitions

Speed is the rate of change of distance. Speed can be found using the equation:

$$\text{(average)speed} = \frac{\text{distance travelled}}{\text{time}}$$

Speed is a scalar quantity which means that it has magnitude but no direction.

Velocity is the rate of change of distance. Velocity is found using the equation:

$$\text{velocity} = \frac{\text{displacement}}{\text{time taken}}$$

Velocity is a vector quantity which means that is has magnitude and direction.

Speed Calculations

Example 1:

A bike travels 800 m in 160 seconds.
Calculate the (average) speed of the bike.

Recall and use the equation:

(average) speed (metre per second, m/s) = distance (metre, m) ÷ time (s)

(average) speed = 800 / 160

Click to reveal answer

Speed Calculations

Example 2: A boy walks to the bus stop at an average speed of 1.5m/s, it takes him 22 s to get there.
Calculate the distance he has travelled.

Recall and use the equation:

distance travelled (metre, m) = average speed (metre per second, m/s) x time (s)

distance travelled = 1.5 x 22

Click to reveal answer

Velocity Calculations

Example 1:

A track runner runs around a 400 m athletics track 4 times in 3 m and 10 s.

Calculate:

a) The speed of the track runner

(average) speed = distance / time

(average) speed = 1600 / 190

Click to reveal answer

b) The average velocity of track runner.

As the displacement at the end of the run is 0 m (they end up where they started after four loops of the track) **so their average velocity is** Click to reveal answer

Average and Instantaneous Speed

Average speed is the speed of an object over the entire journey. The average speed is found by using the total distance travelled divided by the total time taken.

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

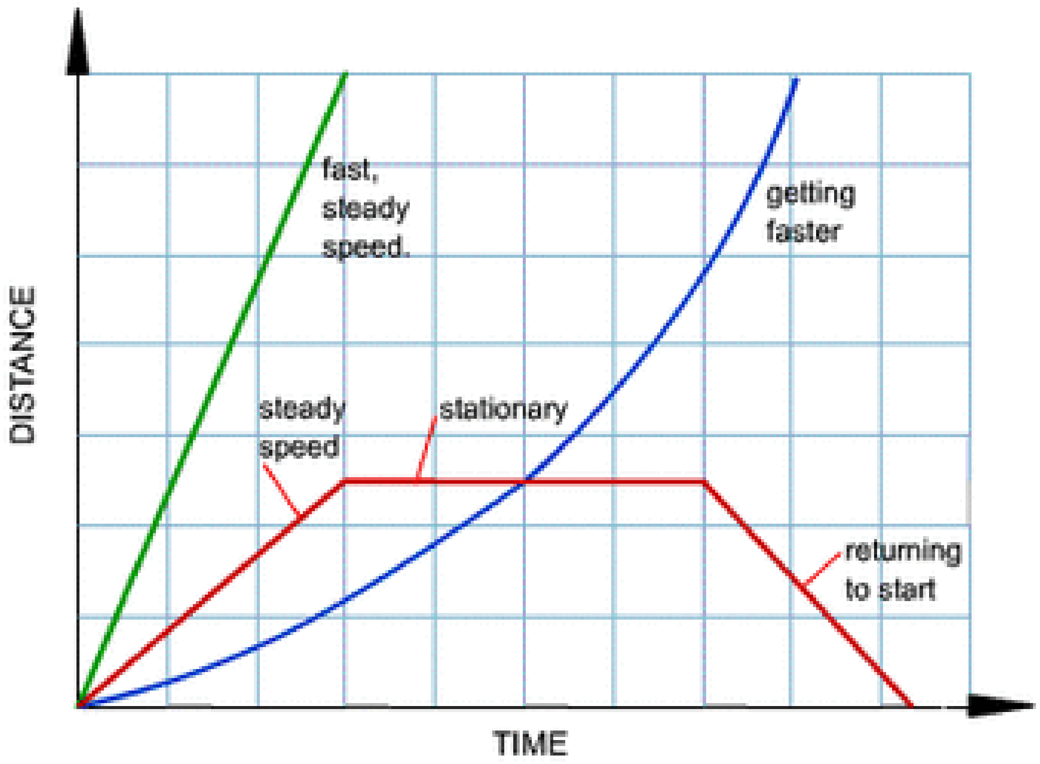
Instantaneous speed is the speed of an object at a given moment in time. The speedometer in a car gives the instantaneous speed of the car.

Distance/time graphs

Distance/time graphs can be used to represent the motion of an object.

The different gradients (steepness) of line on the graphs show different motions of the object.

The shapes of line that you need to know are shown opposite.



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Work Done:

- The American unit of work done is the foot-pound force. The S.I. unit for work done is the joule, J. Find out how to convert from the S.I. unit to the non-standard American unit.
- The space shuttle enters the Earth's atmosphere at 17,500 mph. On re-entry the temperature of the space shuttle will exceed 1500 °C. Find out why the temperature of the space shuttle gets so high on re-entry.

Calculating speed from a d

From the shapes of distance/time graphs it of different objects. The steeper the gradie graph the faster the object is travelling.

The gradient of the line on a distance/time graph is the speed of the object.

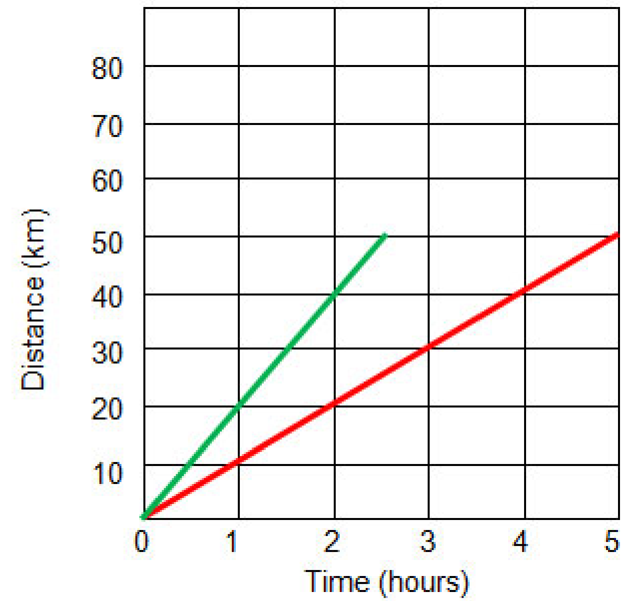
Example:

Work out the speed of the objects shown by the red and green line.

Solution:

Red = distance / time = 30 / 3 = Click to reveal answer

Green = distance / time = 40 /2 Click to reveal answer



Acceleration

When objects accelerate they can be changing speed or changing direction or changing both speed and direction.

Acceleration is the rate of change of velocity, and since velocity is a vector so is acceleration.

Example 1: A car accelerates from rest to 30 m/s in 17 seconds.
Calculate the acceleration of the car.
Recall and use the equation:

acceleration (m/s²) = change in velocity (m/s) ÷ time taken (s)

$$a = \frac{(v - u)}{t}$$

$$a = \frac{(30 - 0)}{17}$$

Click to reveal answer

u = initial velocity
v = final velocity

Negative Acceleration

As acceleration is a vector the direction is important.

When a moving object has a negative acceleration it can either be slowing down (often just called decelerating) or it could be increasing speed in the opposite direction.

If a car is moving along a straight motorway at 70 mph and then has a negative acceleration the car will slow down.

On the on the other hand if the positive direction is chosen to be upwards then a ball that is dropped will have a negative acceleration (as it is in the opposite direction) and will continue to speed up (accelerate) in the opposite direction.

Example 2: A car accelerates at 3m/s^2 causing its velocity to increase from 13m/s to 22 m/s.
Calculate the distance travelled by the car while it is accelerating.
Select and use the equation:

(final velocity)^2 – (initial velocity)^2 = 2 x acceleration x distance
(m/s) (m/s) (m/s^2) (m)

$$v^2 - u^2 = 2 \times a \times x$$

$$22^2 - 13^2 = 2 \times 3 \times x$$

$$484 - 169 = 6 \times x$$

$$x = \frac{315}{6}$$

Click to reveal answer

An acceleration of 3 m/s^2 means that an object is getting 3 m/s faster every second.

Example 3: A stone is dropped off a 30 m high cliff.
The stone falls under gravity (g = 9.8 m/s^2).
Work out the speed of the stone as it hits the floor.

As the stone is dropped the initial speed is 0 m/s.

$$\mathbf{v^2 - u^2 = 2 \times a \times x}$$

$$v^2 - 0^2 = 2 \times 9.8 \times 30$$

$$v^2 = 2 \text{ x } 9.8 \text{ x } 30 + 0^2$$

$$v^2 = 588$$

$$v = \sqrt{588} =$$

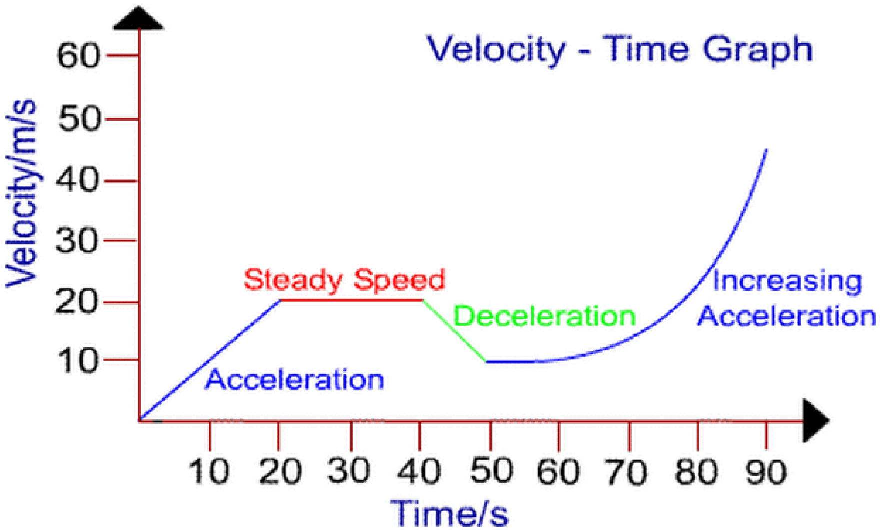
Click to reveal answer

Velocity/time Graphs

A velocity/time graph gives more information than a distance/time graph. As well as speed, distance travelled and time, a velocity-time graph will give the acceleration of the object.

Although the line shapes look the same as a distance/time graph, as the axes are different the line meanings are different.

Below are the line shapes for velocity-time graphs.



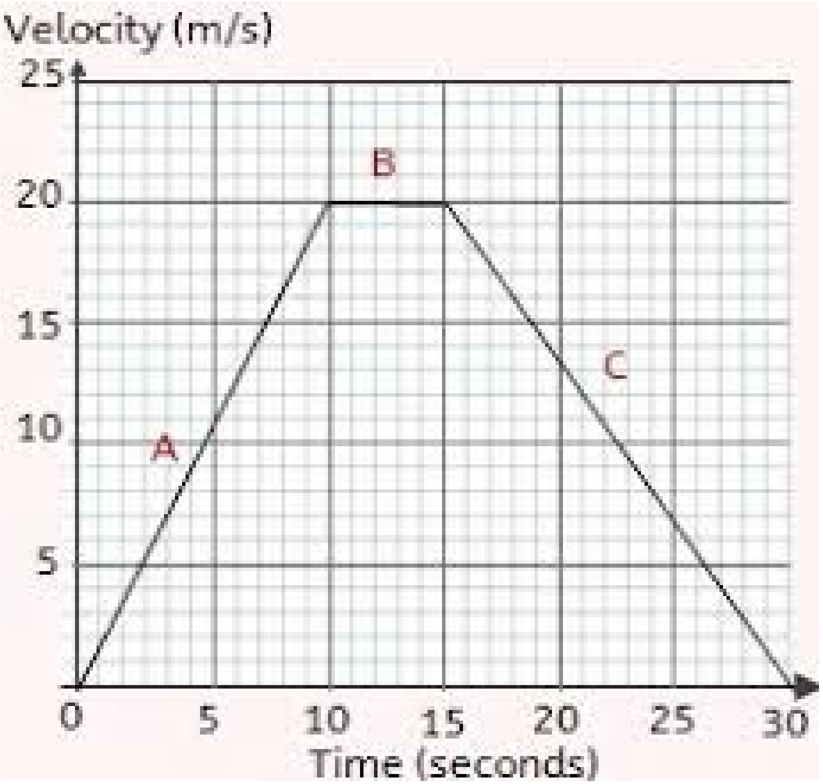
Velocity/time graph calculations

The following information can be gathered from a velocity/time graph:

The velocity: **From reading off the axes on the graph.**

The acceleration: **Found from the gradient of the line on the velocity-time graph.**

The distance travelled: **The area under the line on a velocity-time graph is the distance travelled.**



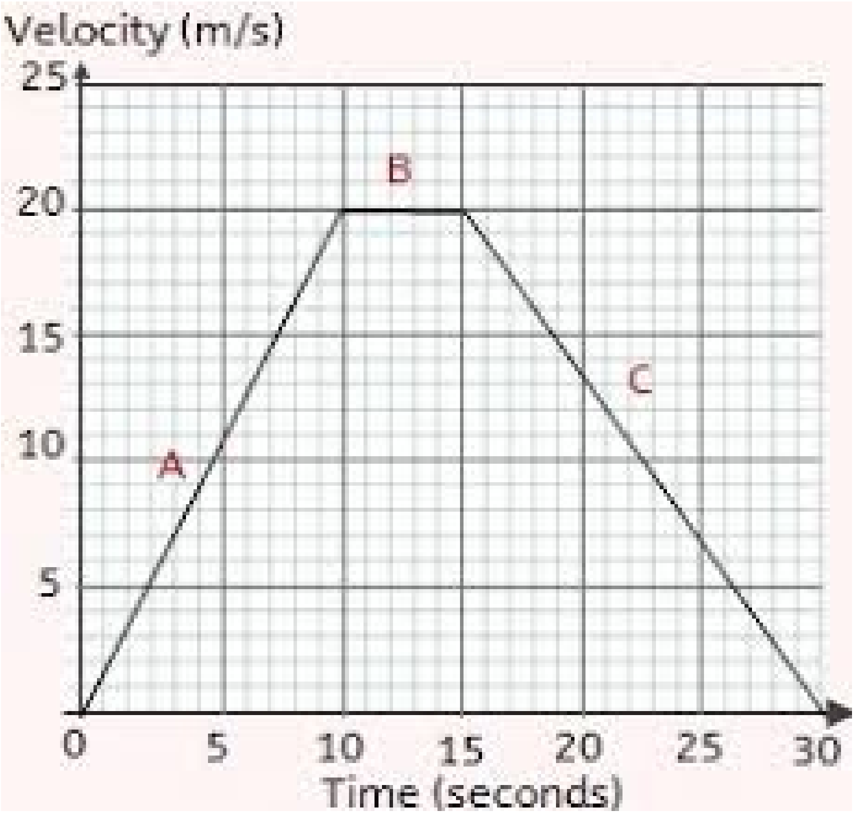
Interpreting velocity/time graphs

Example:
Describe fully the motion shown in the velocity/time graph.

Solution:

From 0 to 10 s: Constant rate of acceleration of 2 m/s^2.
From 10 to 15 s: Constant speed of 20 m/s.
From 15 to 30 s: Constant rate of deceleration of 1.33 m/s^2.

Distance-travelled is the area under the line = 100 m + 100 m + 150 m = 350 m

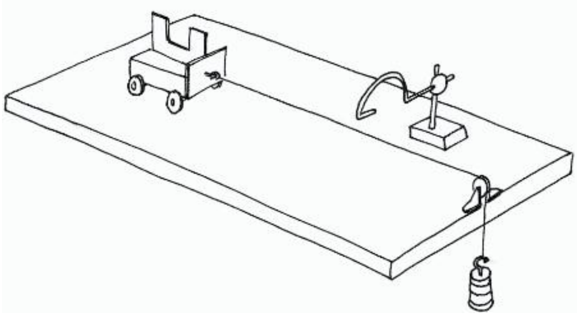


Investigating motion

You can investigate motion by using a trolley and a ramp.
There are different ways to investigate the acceleration of an object down a ramp.

You can time it with:

- **A stop watch**
- **Light gates**
- **Ticker timer**



Video 1

Video 2

These are the typical speeds of everyday situations that you should know.

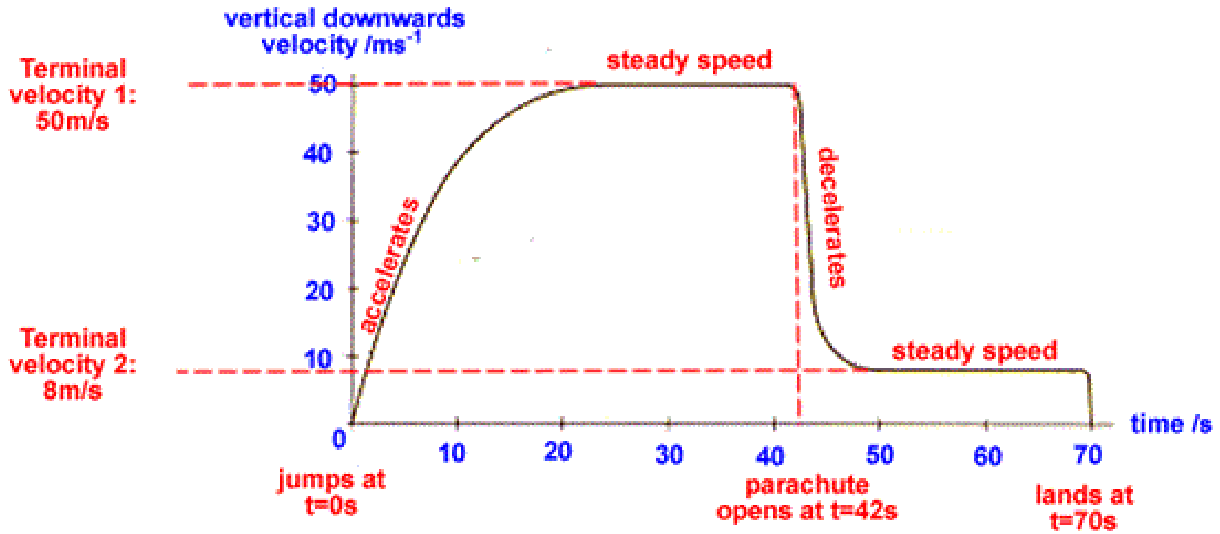
Situation	Typical Speed m/s
Wind	5 - 20
Walking	1.5
Running	3
Cycling	6
Cars (in towns)	13
Cars (motorways)	31

The speed of sound in air is 330 m/s (though this does changes with temperature and pressure).

Acceleration

When a skydiver jumps out of a plane they may reach terminal velocity.

At terminal velocity the pull of gravity (the skydiver's weight) is equal in size and opposite in direction to the air resistance on the skydiver. As there is no resultant force there is no acceleration and the skydiver will fall at a steady speed.



The acceleration, g, in free fall is: $10\ m/s^2$

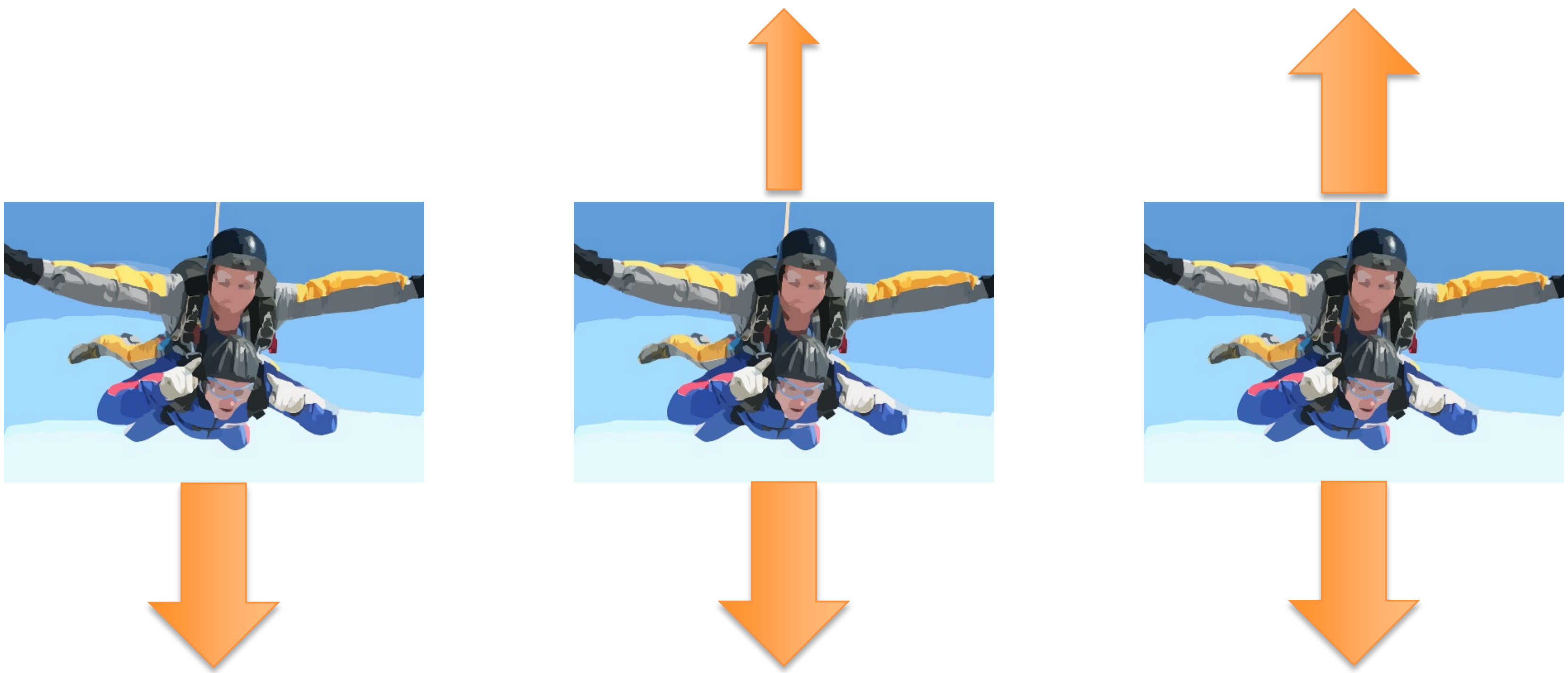
Example forces acting on a Skydiver

During the course of a skydive the weight of a skydiver will not change. As a result of this the skydiver will have a constant pull downwards caused by the gravitational attraction of the Earth.

Also acting on the skydiver is air resistance, or drag. As the skydiver moves through the air faster the skydiver will experience more drag.

Drag reduces the acceleration the skydiver experiences, from $10\ m/s^2$ when they have just jumped out of the plane to $0\ m/s^2$ when they reach terminal speed.

More Forces acting on a Skydiver



As the skydiver falls faster the amount of drag experienced increases, reducing the skydiver’s acceleration, until weight and drag are equal in size. At this point the skydiver will be falling with terminal velocity.

These are estimations of the magnitudes of everyday accelerations

Situation	Acceleration m/s^2
High speed train	0.35
Family saloon car	4.3
Space shuttle	29.4
Formula 1 car	49
Parachutist (during opening of parachute)	59
Cheetah	5.4
Gazelle	4.5

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QuestionIT!

Part 2

Forces and Motion

- Velocity/speed
- The Distance/time relationship
- Acceleration

1. **Recall the equations that link speed, distance and time, including units.**

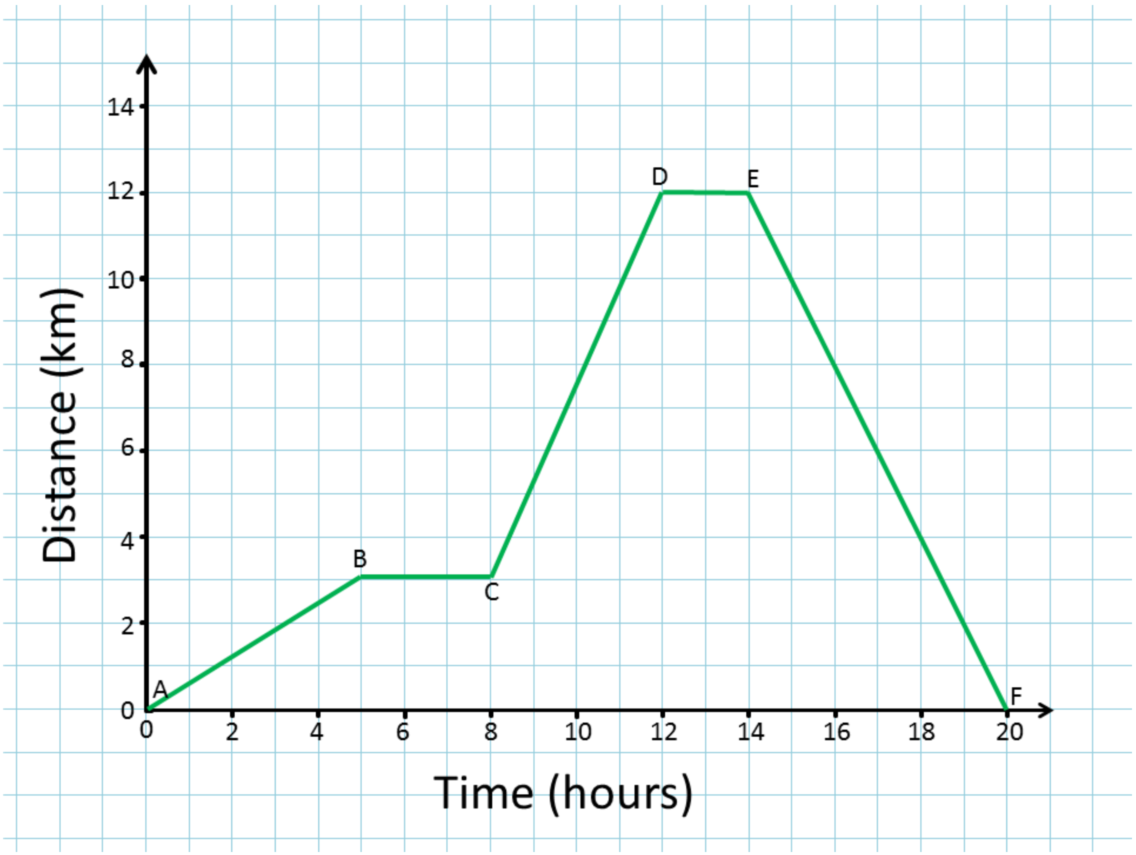
2. **Describe the difference between speed and velocity.**

3. A car moves round a circular track at 120 mph.
Give the average velocity of the car. Explain your answer.

4. A motorcycle travels a distance of 420 miles in 8.5 hours.
Give the average speed of the motorcycle.

5. Describe the difference between instantaneous speed and average speed.

6. Describe fully the motion shown in the distance-time graph shown below.



7. Describe how you would find the instantaneous speed of an object from a distance-time graph where the line is a curve. (Higher Tier Only).

8. State the equation that links acceleration, change in velocity and time taken, including units.

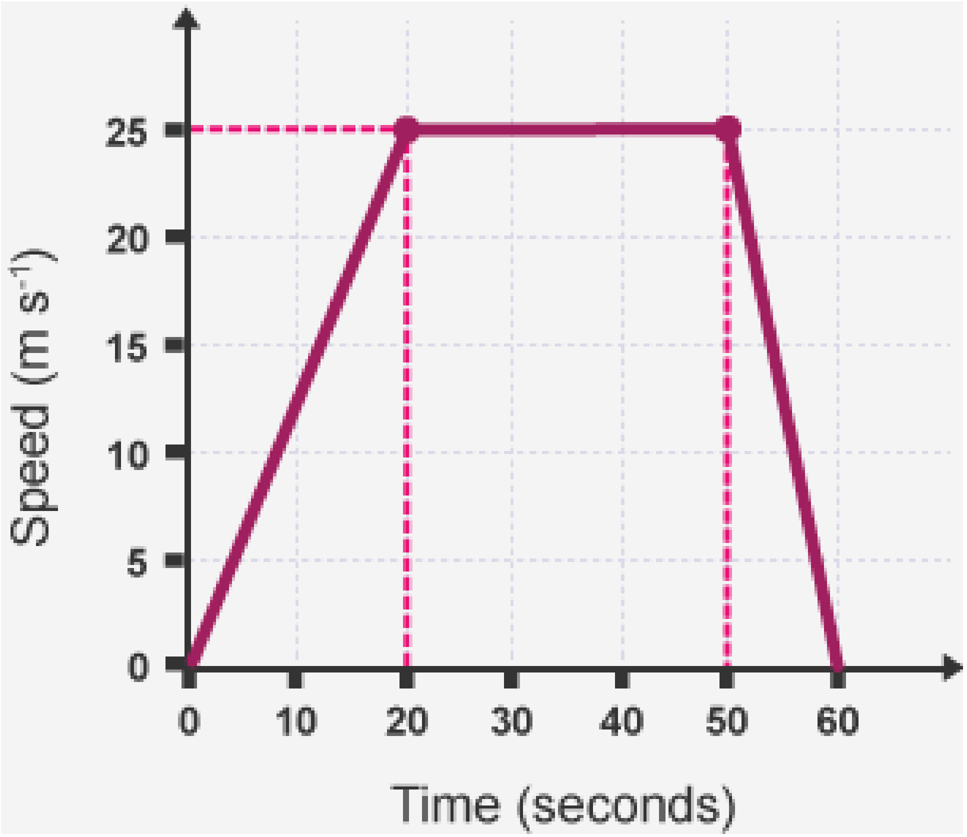
9. Describe what is meant by a negative acceleration.

10. Give the units of acceleration.

11. A stone is dropped off a cliff.
    The stone hits the floor at 30 m/s.
    Calculate the height of the cliff.
    Take g = 9.8 m/s^2

12. Describe how the distance travelled by an object can be found from a velocity-time graph.

13. Describe fully the motion shown in the velocity-time graph shown below.



14. State the typical speed of a person

Walking

Cycling

15. Explain how the motion of a skydiver changes from the moment they jump out of the plane until they land.

AnswerIT!

Part 2

Forces and Motion

- Velocity/speed
- The Distance/time relationship
- Acceleration

1. **Recall the equations that link speed, distance and time, including units.**

(average) speed (metre per second, m/s) = distance (metre, m) ÷ time (s)

distance travelled (metre, m) = average speed (metre per second, m/s) x time (s)

2. **Describe the difference between speed and velocity.**

Speed is a scalar quantity – it has magnitude but no direction.

Velocity is a vector – it has magnitude and direction.

3. A car moves round a circular track at 120 mph.

Give the average velocity of the car. Explain your answer.

Average velocity is 0 m/s
As on completion of every lap the car has a displacement of 0 m
and velocity is found using displacement / time
the average velocity must be 0 m/s

4. A motorcycle travels a distance of 420 miles in 8.5 hours.

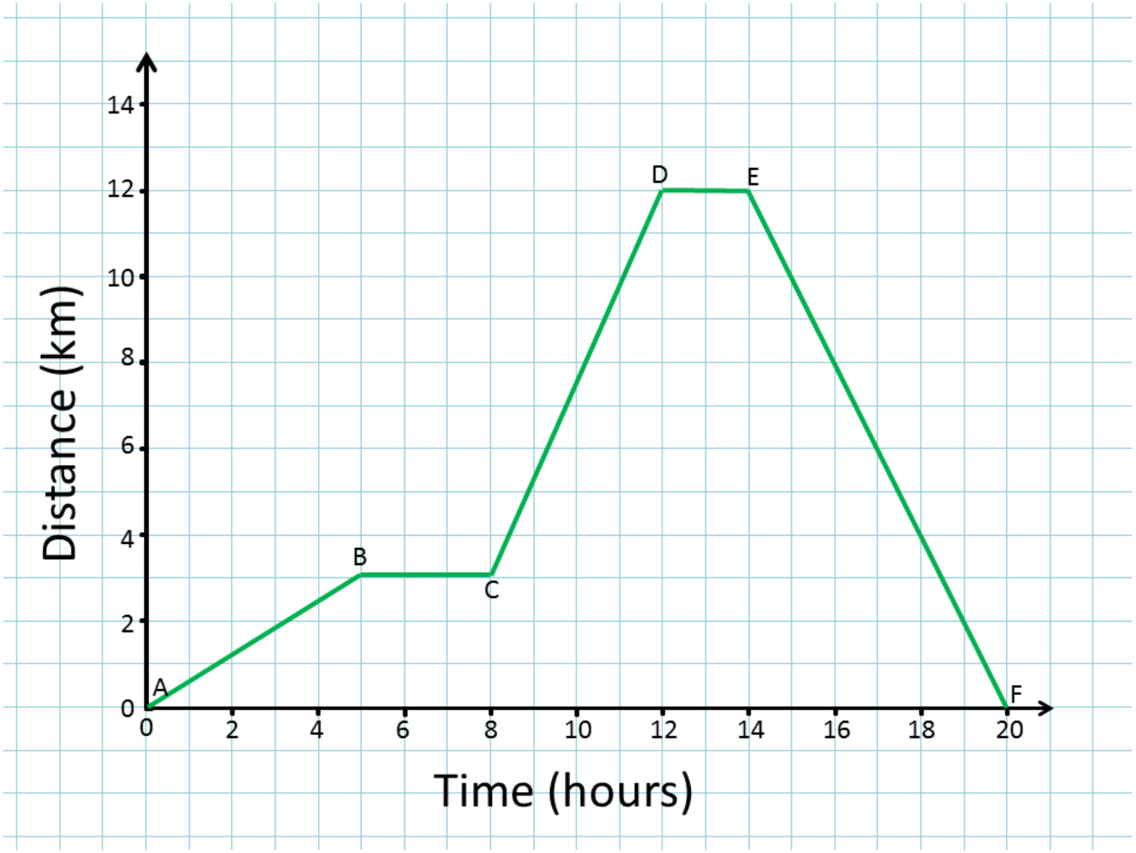
Give the average speed of the motorcycle.

(average) speed = distance / time
(average) speed = 420 / 8
(average) speed = 52.5 mph

5. Describe the difference between instantaneous speed and average speed.

Instantaneous speed is the speed at a given moment in time.
Average speed is the speed over the whole journey including periods
of acceleration and deceleration.

6. Describe fully the motion shown in the distance-time graph shown below.



A to B: Constant speed of 0.6 km/s

B to C: Stationary (for 4 s)

C to D: Constant speed of 2.25 km/s

D to E: Stationary (for 2 s)

E to F: Constant speed of 2 m/s going back to the origin

7. Describe how you would find the instantaneous speed of an object from a distance-time graph where the line is a curve. (Higher Tier Only).

Draw the tangent to the curve.

Find the gradient of the line you have drawn.

The gradient of the line is the instantaneous speed.

8. State the equation that links acceleration, change in velocity and time taken, including units.

acceleration (m/s^2) = change in velocity (m/s) ÷ time taken (s)

$$a = \frac{(v - u)}{t}$$

9. Describe what is meant by a negative acceleration.

A negative acceleration means that the object is slowing down or speeding up in the opposite direction (to that which has been assumed to be positive).

10. Give the units of acceleration.

m/s^2 or $m/s/s$ or ms^{-2}

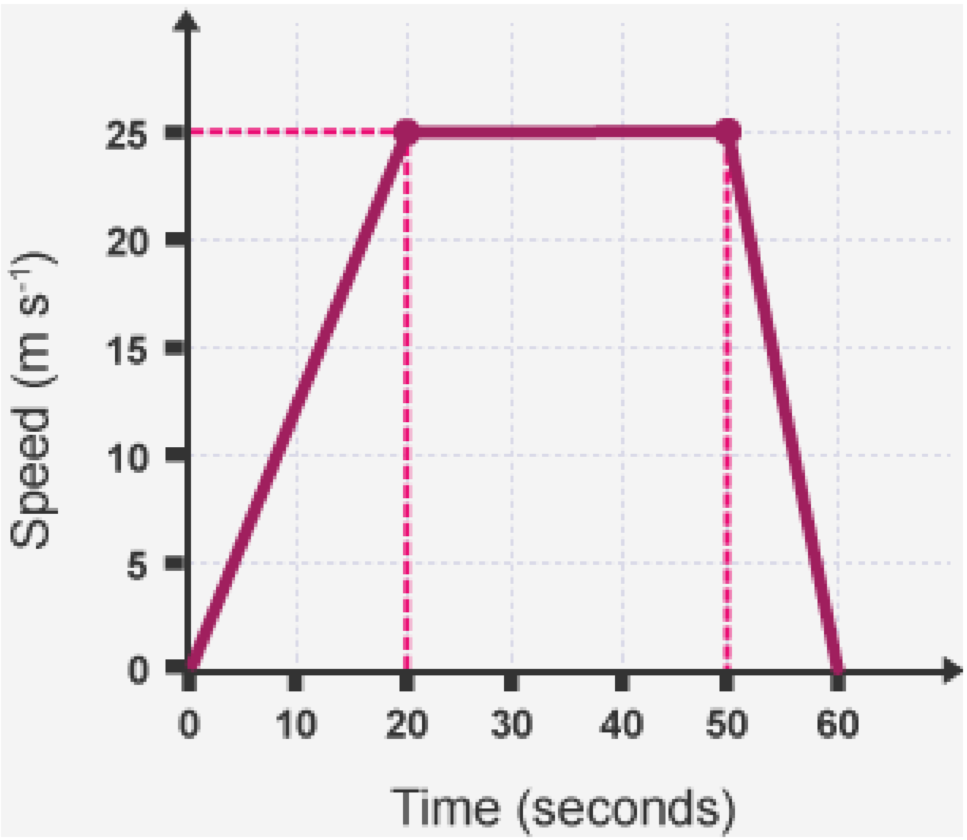
11. A stone is dropped off a cliff.
The stone hits the floor at 30 m/s.
Calculate the height of the cliff.
Take $g = 9.8 \text{ m/s}^2$

Since the stone is dropped $u = 0$ m/s

Using	$v^2 - u^2 = 2 a s$
Substituting gives	$30^2 - 0^2 = 2 \times 9.8 \times s$
Simplifying gives	$900 = 19.6 \times s$
Rearranging gives	$900 / 19.6 = s$
Therefore	$s = 45.9$ m

12. Describe how the distance travelled by an object can be found from a velocity-time graph.
The area under the line on a velocity-time graph represents the distance travelled by that object.

13. Describe fully the motion shown in the velocity-time graph shown below.



From 0 to 20 s: Constant rate of acceleration of 1.25 m/s^2

From 20 to 50 s: Constant speed of 25 m/s

From 50 to 60 s: Constant rate of deceleration of 2.5 m/s^2

Total distance travelled over the 60 seconds is:
250 m + 750 m + 125 m = 1125 m

14. State the typical speed of a person

Walking 1.5 m/s

Cycling 6 m/s

15. Explain how the motion of a skydiver changes from the moment they jump out of the plane until they land.

- Skydiver accelerates due to gravity (at a rate of 10 m/s^2)
- As the skydiver picks up speed the drag they experience increases
- But the gravitational attraction stays the same
- so the acceleration of the skydiver decreases in size.
- When drag and weight are equal in size but opposite in direction the skydiver will fall with terminal speed
- as there is no resultant force so no acceleration
- When the parachute is opened there is an increase in drag
- Decelerating the skydiver
- Until weight and drag are equal in size but opposite in direction
- Then the skydiver falls at a new (lower) terminal speed
- Which is lower as the the large surface area of the parachute increases the amount of drag at a given speed.
- Skydiver decelerates to 0 m/s when they hit the ground.

LearnIT!
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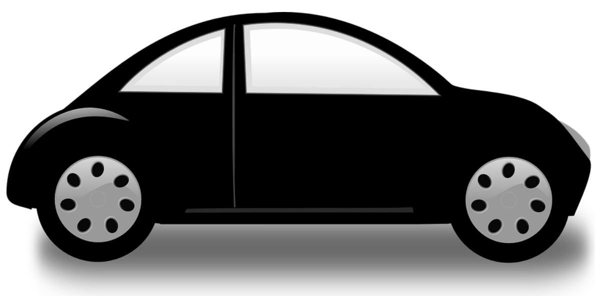
Forces, Accelerations and Newton's Laws of Motion

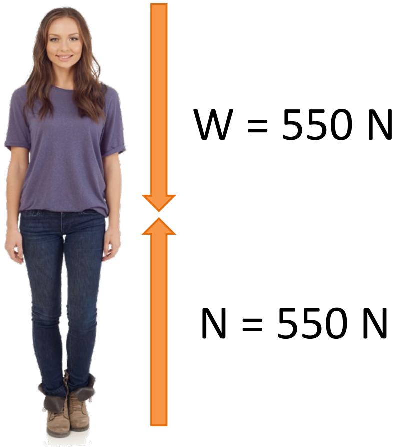
- Newton's First Law
- Newton's Second Law

Newton's First Law of Motion: balanced forces

If the resultant force acting on an object is zero and:

1. the object is stationary, the object remains stationary





If a car is not moving it will remain stationary until a force acts upon it

A person standing still has two forces acting on them their weight downwards and the normal contact force from the ground upwards. The forces balance so the person remains stationary.

Newton’s First Law of Motion: balanced forces

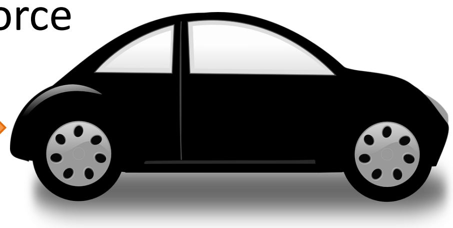
If the resultant force acting on an object is zero and:

2. the object is moving, the object continues to move at the same speed and in the same direction. So the object continues to move at the same velocity.

Weight = 800 N

Air resistance =800 N

Driving force = 750 N



Air resisitance = 750 N

If a car is moving along a road and the driving force, the air are balanced it will move at a constant speed.

At terminal velocity the skydivers weight and air resistance acting on them are balanced so they move at a constant speed.

The velocity of an object will only change if there is a resultant force acting upon it. If the forces are balanced (there is no resultant force) then the object will continue with a steady velocity (speed and direction).

Newton’s Second Law of motion: unbalanced forces

When the forces acting on an object do not balance, the resultant force will cause the object to accelerate in the direction of the resultant force.

Unbalanced forces will cause: acceleration, deceleration, change in direction

Recall and use Newton’s Second Law as:

force (N) = mass (kg) x acceleration (m/s^2)

$$F = m \times a$$

Driving force
= 1000 N

Air resisitance
= 750 N

The driver of the car presses the accelerator and the driving force increases this causes the car to accelerate

Using Newton's Second Law of motion equation

Example 1:

A motorcycle has a mass of 240 kg and accelerates at a rate of 4 m/s^2. Calculate the driving force of the motorcycle.

$$F = m\,a$$

$$F = 240 \times 4$$

Click to reveal answer

Using Newton's Second Law of motion equation

Example 2:

A car brakes sharply from a velocity of 30 m/s to rest in 4.2 s.
The braking force applied by the brakes was 4800 N.
Calculate the mass of the car.

Finding the acceleration of the car:

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

Click to reveal answer

Substituting gives

$$F = m\,a$$

$$4800 = m \times 7.1$$

Click to reveal answer

Weight and mass

- Weight is not the same as mass. Mass is a measure of how much ”stuff” or matter there is in an object. Weight is a force acting on that matter.
- Weight is the result of gravity.

On Earth gravitational field strength (g) = 10 N/kg

Recall and use the equation:

weight (N) = mass (kg) × gravitational field strength (N/kg)

$$W = m \times g$$

This means that a one kilogram mass would have a weight of 10 N. This can also be found using a calibrated spring balance (a newton meter).

The value of the gravitational field strength will depend on where you are. Your weight on top of a mountain will differ slightly from your weight at sea level. On the Moon your weight will be approximately one sixth of your weight on Earth.

Weight and mass are directly proportional

Calculating Weight

On Earth gravitational field strength (g) = 10 N/kg)

Example 1:

Luke has a mass of 75 kg.

Calculate Luke's weight on Earth.

$$W = m \times g$$

$$W = 75 \times 10$$

Click to reveal answer

Calculating Weight

On Earth gravitational field strength (g) = 10 N/kg)

Example 2:

On the Moon Thomas, of mass 60 kg, would have a weight of 100 N. Calculate the gravitational field strength on the Moon.

$$W = m \times g$$

$$100 = 60 \times g$$

$$g = \frac{100}{60}$$

Click to reveal answer

Calculating Weight

On Earth gravitational field strength (g) = 10 N/kg)

Example 3:

Elena weighs 630 N.

Calculate her mass on Earth.

$$W = m \times g$$

$$630 = m \times 10$$

$$m = \frac{630}{10}$$

Click to reveal answer

QuestionIT!

Forces, Accelerations and Newton's Laws of Motion

- Newton's First Law
- Newton's Second Law
- Newton's Third Law

1. What does Newton's first law state about objects that are stationary?

2. What does Newton's first law state about objects that are moving

3. Describe why a cannon ball, when fired from a cannon does not continue to move with constant velocity.

4. Recall the equation used for Newton’s second law.

5. A car has an acceleration of 1.7 m/s^2 and a mass of 700 kg.
   Calculate the driving force of the car.

6. A skydiver has a weight of 686 N and a mass of 70 kg.
   Calculate the acceleration of the skydiver the moment he jumps out of the plane.

7. A motorcycle has a driving force of 1400 N and an acceleration of 6 m/s^2.
   Calculate the mass of the motorcycle.

8. A boy has a mass of 40 kg.
   Calculate the boy's weight.
   Take g = 10 N/kg.

9. Name a piece of scientific equipment that you would use to find the weight of a block in a science laboratory.

10. On The Moon an astronaut has a weight of 130 N. The gravitational field strength on The Moon is 1.7 N/kg. The gravitational field strength on the Earth is 10 N/kg.

Calculate the weight of the astronaut on the Earth.

AnswerIT!

Forces, Accelerations and Newton’s Laws of Motion Part 3

- Newton’s First Law
- Newton’s Second Law

1. What does Newton's first law state about objects that are stationary?

- Objects will remain stationary if the resultant force acting on it is zero.

2. What does Newton's first law state about objects that are moving

- Objects will object continues to move at the same speed and in the same direction (constant velocity).

3. Describe why a cannon ball, when fired from a cannon does not continue to move with constant velocity.

- Gravity acts pulling the cannon ball downwards
- So, there is a resultant force
- Objects will only continue with uniform motion when no resultant force acts.

4. Recall the equation used for Newton's second law.

force (N) = mass (kg) x acceleration (m/s^2) *F = m* x *a*

5. A car has an acceleration of 1.7 m/s^2 and a mass of 700 kg.
   Calculate the driving force of the car.
   Using F = m a
   force = 700 x 1.7
   force = 1190 N

6. A skydiver has a weight of 686 N and a mass of 70 kg.
   Calculate the acceleration of the skydiver the moment he jumps out of the plane.
   acceleration = force / mass
   acceleration = 686 / 70
   acceleration = 9.8 m/s^2

7. A motorcycle has a driving force of 1400 N and an acceleration of 6 m/s^2.
   Calculate the mass of the motorcycle.
   mass = force / acceleration
   mass = 1400 / 6
   mass = 233 kg

8. A boy has a mass of 40 kg.
Calculate the boy's weight. Take g = 10 N/kg.

W = mg

W = 40 x 10

W = 400 N

9. Name a piece of scientific equipment that you would use to find the weight of a block in a science laboratory.

A newtonmeter

10. On The Moon an astronaut has a weight of 130 N. The gravitational field strength on The Moon is 1.7 N/kg. The gravitational field strength on the Earth is 10 N/kg.
Calculate the weight of the astronaut on the Earth.

W = mg

Mass of astronaut = 130 / 1.7

Mass of astronaut = 76.5 kg

W = mg

Weight of astronaut on Earth = 76.5 x 10

Weight of astronaut on Earth = 765 N

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Motion and forces Part 4

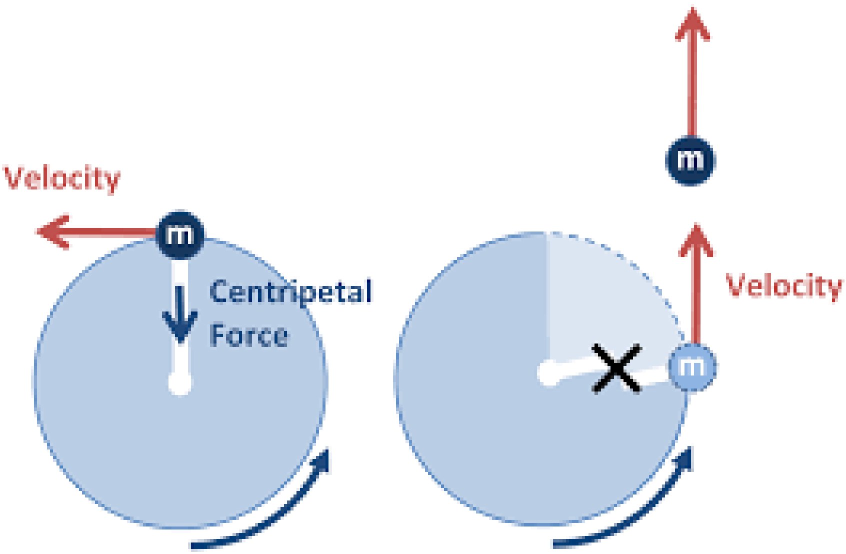
- Circular motion (HT)
- Inertia (HT)
- Newton’s Third Law
- Momentum (HT)

Circular motion (Higher tier)

- In a perfectly circular orbit, an object will travel at constant speed to maintain its orbital distance.
- However, gravity is constantly changing the direction of the object.
- As velocity depends on speed and direction, the velocity is constantly changing even though speed remains the same.

Examples are: fairground rides orbiting planets, moons and satellites.

As the objects travels in a circular motion it is prevented from moving off in a straight line by centripetal force. This is a resultant force it pulls objects toward the centre of the circle, continually changing the direction that an object is travelling in to keep it in circular motion.



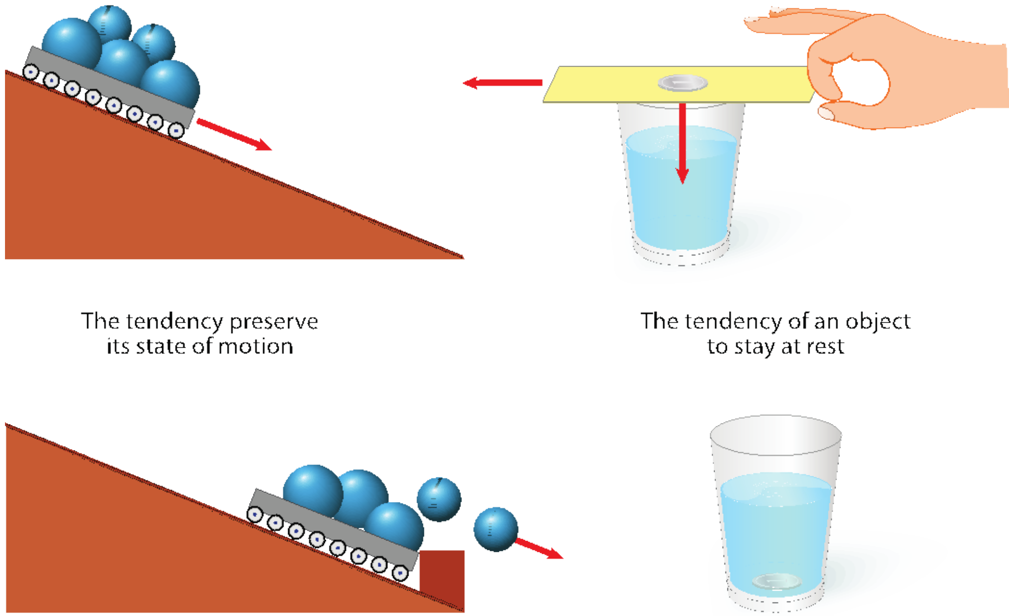
[Video - circular motion]

Inertia (Higher tier)

- **Inertia is a property of matter it is a measure of how difficult it is to change the velocity of an object (including from rest) it is defined as the ratio of force over acceleration.**
- **It is the resistance of the object to change its motion (speed and/or direction).**
- **Mass is a measure of the amount of inertia an object has. The more inertia (or mass) an object has the harder it is to get that object to change its motion.**

To find out which of two objects has the most inertia:

- **Apply an equal force to both of them when they are at rest.**
- **The one that has the greatest acceleration has the lowest inertia – it was easier to get it to change its motion.**

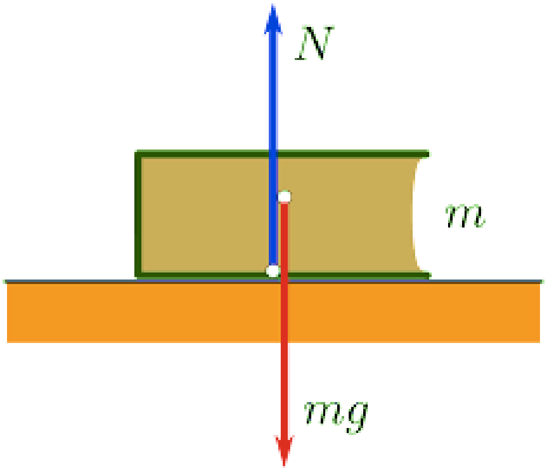


Newton's Third Law of motion

Whenever two objects interact, the forces they exert on each other are equal in size and opposite in direction.

Example:

A a book on a table will be pulled down by the Earth by its weight and the normal reaction force from the table pushes it up.



Momentum (Higher tier)

Momentum is a vector quantity.
Moving object have momentum. It is the tendency of an object to keep moving in the same direction. It is difficult to change the direction of movement of an object that has a lot of momentum.
The momentum of an object depends on it's mass and it's velocity.

Recall and use the equation:

$$\text{momentum (kg m/s)} = \text{mass (kg)} \times \text{velocity (m/s)}$$

$$p = m\,v$$

From this equation we can see that if an object is not moving (it has a velocity of 0 m/s) then it has no momentum.

Conservation of Momentum: Collisions

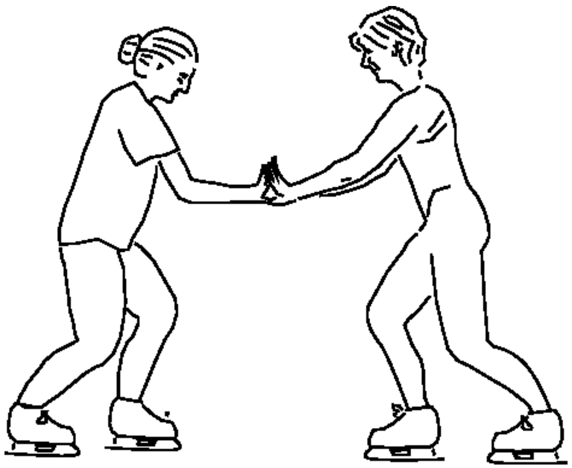
Momentum is a conserved quantity. The momentum of a system remains the same before and after an event.

e.g. In a car crash the momentum of the vehicles before the crash equals the momentum of the vehicles after the crash.

Conservation of Momentum: Explosive Events

In an explosion the momentum of the system is also conserved. This may seem strange as everything is stationary to begin with, but after the explosion parts are moving to the left and right and these cancel – since velocity is a vector and depends on direction.

An example of an explosive event is two ice skaters pushing themselves apart, where the momentum of each ice skater is equal in size and opposite in direction to the other. This then adds to be 0 kgm/s, which is what it was at the start.



Changes in Momentum (Higher tier)

Newton's second law changes in momentum:

The force acting on an object is usually found using the equation

$$F = m\,a$$

As the acceleration of an object is found using the equation:

acceleration (m/s^2) = change in velocity (m/s) ÷ time taken (s)

$$a = \frac{(v - u)}{t}$$

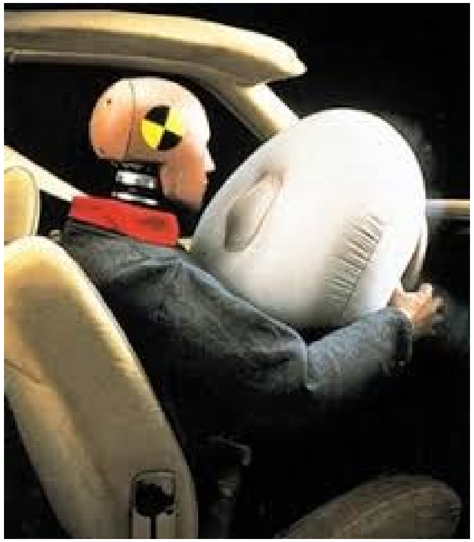
Combining the two equations gives:

$$F = \frac{(mv - mu)}{t}$$

The quantity $(mv - mu)$ is the change in momentum of an object. So, force is the rate of change of momentum.

Changes in momentum: Safety Features

Cars have air bags to reduce the injuries caused in a crash.



Air bags work by increasing the time of impact – it takes a person's head longer to come to a stop (compared to hitting the steering wheel).

As the time of impact increases the force acting on the person's head decreases since.

force (N) = change in momentum (kg m/s) ÷ time (s)

$$F = \frac{(mv - mu)}{t}$$

Changes in Momentum: Safety Features continued…

Seatbelts also increase the time it takes a person to stop.

By increasing the time it takes to stop the force acting is reduced as,

force (N) = change in momentum (kg m/s) ÷ time (s)

$$F = \frac{(mv - mu)}{t}$$

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QuestionIT!

Motion and forces
Part 4

- Circular motion (HT)
- Inertia (HT)
- Newton’s Third Law
- Momentum (HT)

1. State the units of momentum.

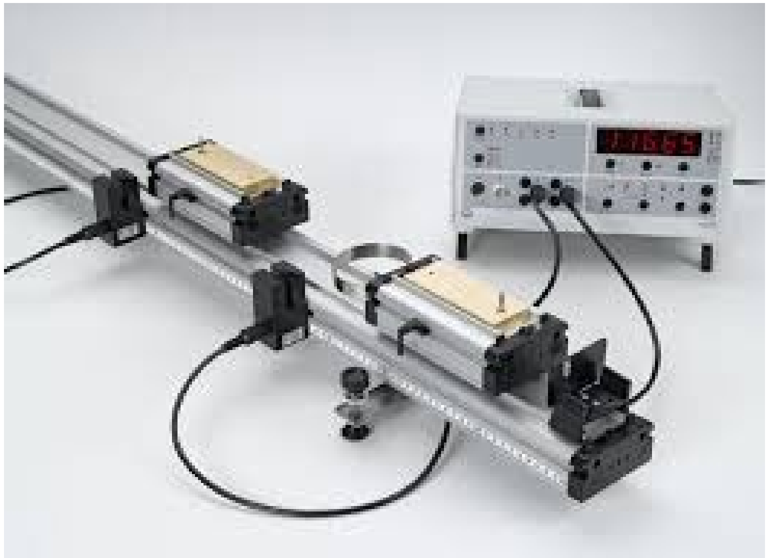
2. State the equation that links mass, momentum and velocity.

3. Momentum is a conserved quantity.
   Explain what is meant by a conserved quantity.

4. A football has a mass of 0.75 kg and is kicked with a speed of 12 m/s.
   Calculate the momentum of the kicked football.

5. Two ice skaters push themselves apart on the ice.
   Explain how the conservation of momentum applies in this case.

6. A trolley has a mass of 1.2 kg and a speed of 4.5 m/s. The trolley crashes into a stationary trolley of mass 0.8 kg. On impact the two trolley's stick together and move off with speed, v.



a. Calculate the momentum of the trolleys before impact.

b. Calculate the speed of the trolleys after impact.

7. A gymnast falls onto a crash mat. The crash mat reduces the risk of injury to the gymnast.

   Explain how the crash mat reduces injury.

8. A car of mass 850 kg hits a crash barrier at a speed of 30 m/s. The car stops in 0.4 s. Calculate the force on the car.

AnswerIT!

Motion and forces
Part 4

- Circular motion (HT)
- Inertia (HT)
- Newton’s Third Law
- Momentum (HT)

1. **State the units of momentum.**
   kg m/s

2. **State the equation that links mass, momentum and velocity.**
   momentum (kg m/s) = mass (kg) x velocity (m/s)

   $p = m\,v$

3. **Momentum is a conserved quantity.**
   Explain what is meant by a conserved quantity.
   The momentum before and after an event is equal in a closed system

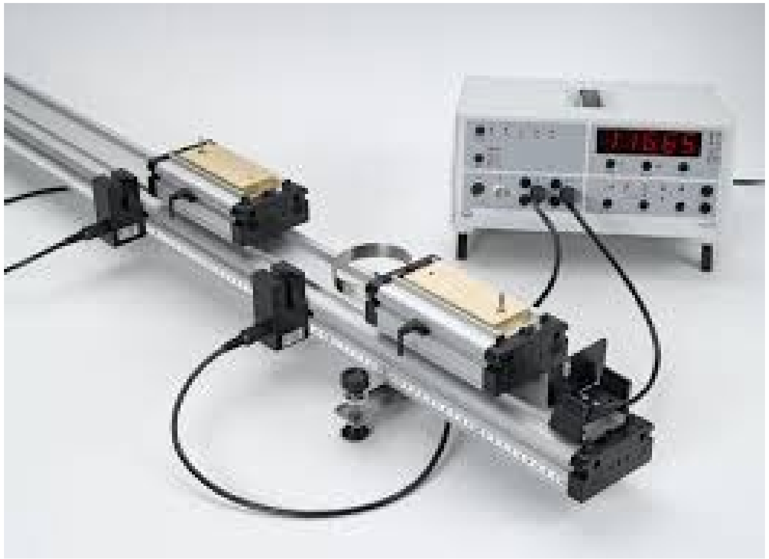
4. A football has a mass of 0.75 kg and is kicked with a speed of 12 m/s. Calculate the momentum of the kicked football.

using momentum = mass x velocity
momentum = 0.75 x 12
momentum = 9 kgm/s

5. Two ice skaters push themselves apart on the ice. Explain how the conservation of momentum applies in this case.

The momentum before pushing is 0 kgm/s as they are not moving
On pushing apart the momentum of each ice skater is the same size but in the opposite direction
When adding (vector addition) of the momentum of the two ice skaters sum is also 0 kgm/s
So momentum is conserved.

6. A trolley has a mass of 1.2 kg and a speed of 4.5 m/s. The trolley crashes into a stationary trolley of mass 0.8 kg. On impact the two trolley's stick together and move off with speed, v.



a. Calculate the momentum of the trolleys before impact.

Using momentum = mass x velocity
momentum = 1.2 x 4.5
momentum = 5.4 kgm/s

b. Calculate the speed of the trolleys after impact.

Using conservation of momentum; momentum before = momentum after
5.4 = $\text{mass}_{\text{after}}$ x $\text{velocity}_{\text{after}}$
$\text{velocity}_{\text{after}}$ = 5.4 / 2 = 2.7 m/s

7. A gymnast falls onto a crash mat. The crash mat reduces the risk of injury to the gymnast.

Explain how the crash mat reduces injury.

The crash mat increases the time taken to come to a stop

This decreases the acceleration

Since $F = \frac{(mv - mu)}{t}$

This reduces the force acting on the gymnast

8. A car of mass 850 kg hits a crash barrier at a speed of 30 m/s. The car stops in 0.4 s. Calculate the force on the car.

Using $F = \frac{(mv - mu)}{t}$

$F = 850 \times \frac{30}{0.4}$

F = 63 750 N

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Motion and forces
Part 5

- Reaction time
- Stopping and braking distance
- Factors affecting reaction times

Reaction Time

A typical person's reaction time varies from 0.2 to 0.9 seconds.

There are a number of factors that will affect your reaction time, and in turn thinking distance.

These factors include:

Factor	Affect on Reaction Time
Alcohol	Increases
Caffeine	Decreases
Tiredness	Increases
Distractions	Increases

Drugs can either increase or decrease reaction times as some drugs are stimulants and some are depressants.

Measuring Reaction Time

A person's reaction time is very short. Trying to measure this reaction time is going to be difficult but there are ways of measuring it.

1. **There are online tests that display a stimulus and measures the time taken to respond to the stimulus – often by clicking a mouse button.**

2. **Ruler drop. This is where a ruler is dropped through your hand. As soon as you see the ruler move you close your hand. The distance that the ruler moves through your hand corresponds to a given reaction time - these can be found online at:**

   http://www.topendsports.com/testing/tests/reaction-stick.htm

Definitions

Thinking Distance: Thinking distance is the distance that you travel while reacting to a stimulus until you get your foot onto the brake pedal. Thinking distance depends on reaction time, but these are not the same thing.

Braking Distance: Braking distance is the distance you travel from pressing the brake pedal until you come to a stop.

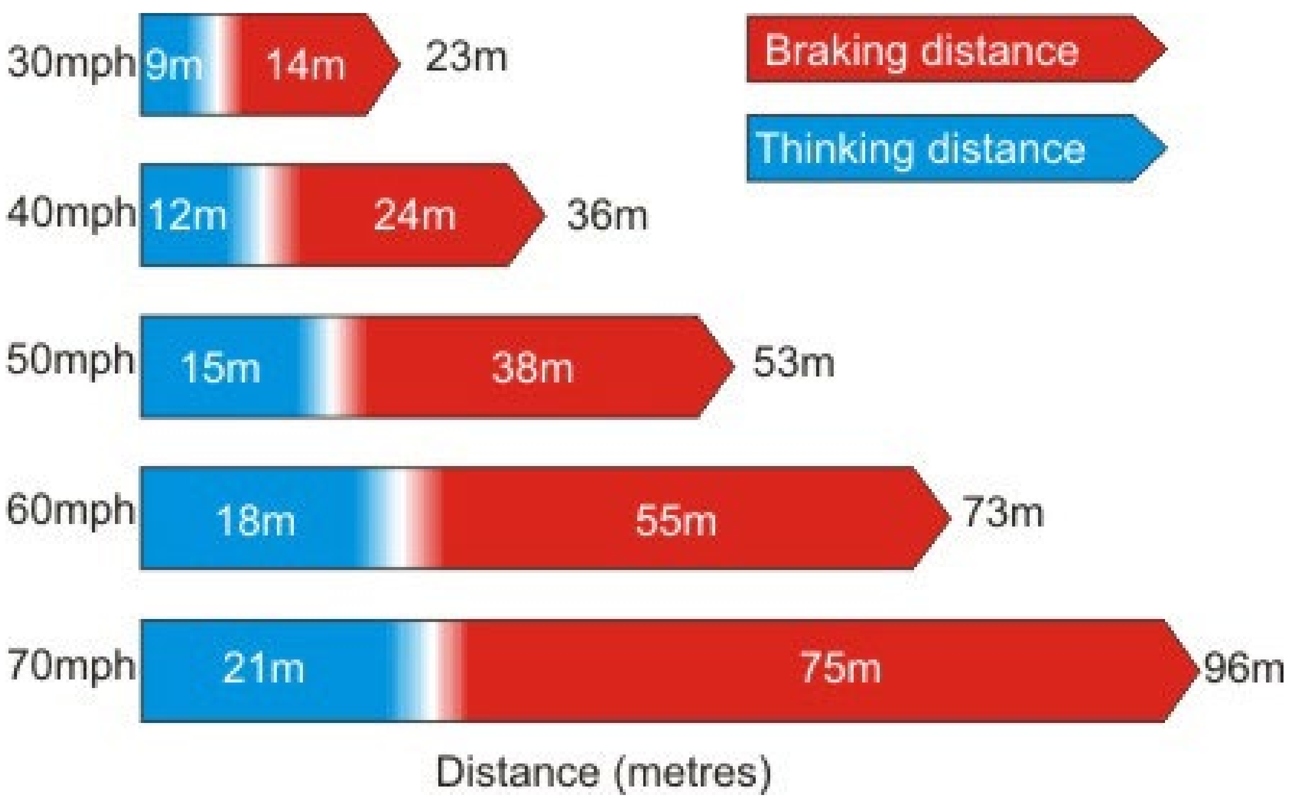
Stopping Distance: Stopping distance is the sum of thinking distance and braking distance, usually shown as:

stopping distance = thinking distance + braking distance

How speed affects stopping distance

Increasing the speed of a vehicle will increase its stopping distance.

The highway code shows the stopping distances for cars at various speeds…



As you can see, when speed increases so does the overall stopping distance.

Also, it is both parts of the overall stopping distance – thinking and braking distance – that increases.

Speed and Thinking Distance

From the highway code it is possible to see patterns in the data.

When you double your speed your thinking distance will also double. This is shown by the thinking distance being 9 m at 30 mph and 18 m at 60 mph. The reason this happens is because your reaction time does not change but you will now travel further while you react:

If you take 0.5 seconds to react then at a speed of 10 m/s you would travel 5 m while reacting to a stimulus. If the speed doubled to 20 m/s then you would now travel 10 m while reacting to the stimulus – the thinking distance has doubled when the speed has doubled.

Speed and Braking Distance

Doubling your speed will more than double your braking distance. In fact doubling the speed of a vehicle will cause the braking distance to quadruple.

At 30 mph the braking distance is 14 m and at 60 mph the braking distance is 55 m (according to the highway code) which is approximately four times greater: The difference of 1 m is accounted for by rounding.

When the speed of a vehicle doubles the kinetic energy of the vehicle is four times greater. This happens because kinetic energy is found using the equation:

$$\text{kinetic energy} = \tfrac{1}{2} \times \text{mass} \times (\text{velocity})^2$$

As there is four times the kinetic energy it takes four times longer to stop at a given braking force.

Factors affecting braking distance

There are a number of factors that affect the braking distance of a vehicle. Some of these are shown in the table below:

Factor affecting braking distance	How this factor affects braking distance
Speed	Increasing speed increases braking distance
Weight of Vehicle	Increasing weight of vehicle increases braking distance
Icy Roads	Braking distance increases due to reduced friction between tyre and road
Wet Roads	Braking distance increases due to reduced friction between tyre and road
Poor Brake Condition	Braking distance increases
Bald (worn) Tyres	Braking distance increases when wet.

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Braking Force

When a force is applied to the brakes of a vehicle, work done by the frictional forces between the brake pads and the brake disc reduces the kinetic energy of the vehicle and the temperature of the brakes increases.

The greater the speed of a vehicle the greater the braking force needed to stop the vehicle in a certain distance.

The greater the braking force the greater the deceleration of the vehicle. Large decelerations may lead to brakes overheating and/or loss of control.

QuestionIT!

Motion and forces
Part 5

- Reaction time
- Stopping and braking distance
- Factors affecting reaction times

1. Define thinking distance.

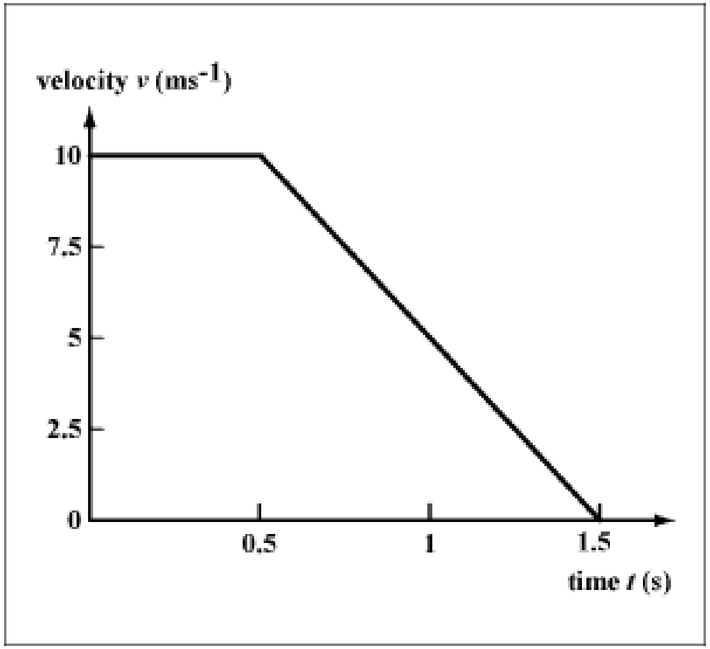
2. Complete the equation:

Stopping distance = ………………………………. + ………………………………….

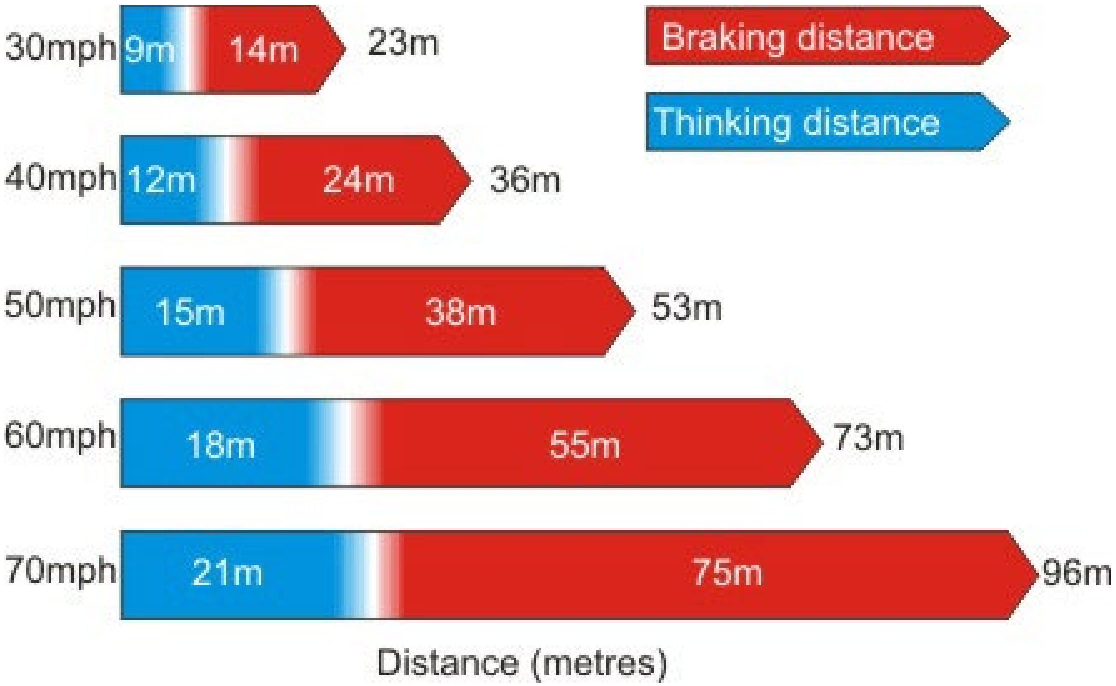
3. Describe how the speed of a vehicle affects the thinking distance.

4. A driver sees a car braking sharply in front of him. The driver takes 0.5 s to react to the stimulus and then brakes. Figure 1 shows the velocity-time graph for the motion of the vehicle from seeing the stimulus to stopping. Calculate the stopping distance of the vehicle.

Figure 1



5. The highway code shows the stopping distances for vehicles up to 70 mph. In 2011 the government proposed a new 80 mph speed limit for UK motorways.
Use the information in the diagram, and your own knowledge, to determine the overall stopping distance of a vehicle at 80 mph.



6. Describe how you could measure the reaction time of a person.

7. Explain the dangers caused by large decelerations of a vehicle.

8. Put the following factors under the correct headings to show whether the factor affects thinking distance, braking distance or both thinking and braking distance.

speed **mass** **icy roads** **tiredness**

poor brakes **mobile phone use** **alcohol** **bald tyres**

Thinking Distance	Braking Distance	Both

AnswerIT!

Motion and forces
Part 5

- Reaction time
- Stopping and braking distance
- Factors affecting reaction times

1. **Define thinking distance.**
   The distance travelled while the driver reacts to a stimulus until the driver gets their foot onto the brake pedal (but before the brake pedal is pressed).

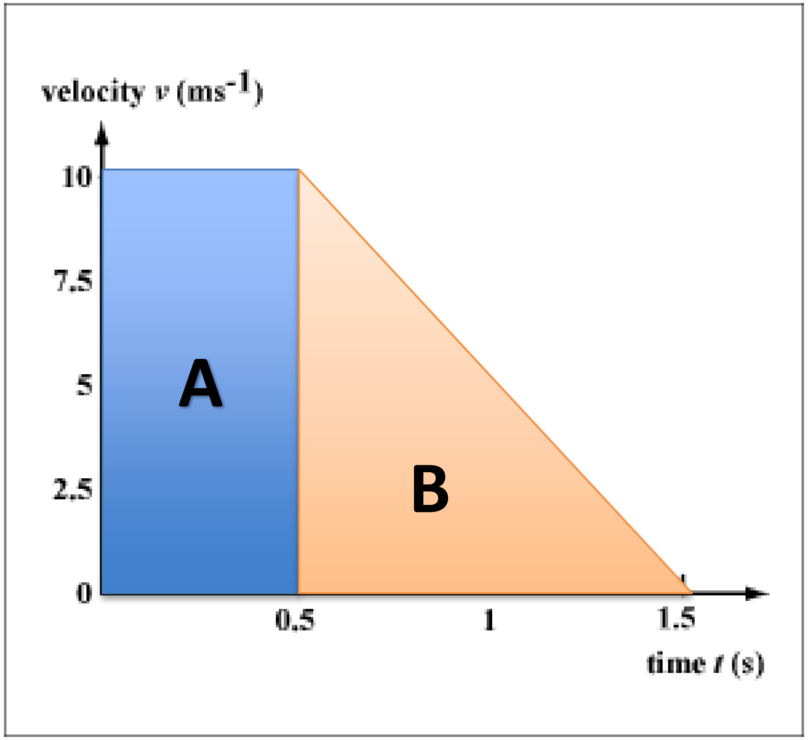
2. **Complete the equation:**

   stopping distance = thinking distance + braking distance

3. **Describe how the speed of a vehicle affects the thinking distance.**
   Increasing speed increases thinking distance
   Doubling your speed doubles the thinking distance.

4. A driver sees a car braking sharply in front of him. The driver takes 0.5 s to react to the stimulus and then brakes. Figure 1 shows the velocity-time graph for the motion of the vehicle from seeing the stimulus to stopping. Calculate the stopping distance of the vehicle.

Figure 1



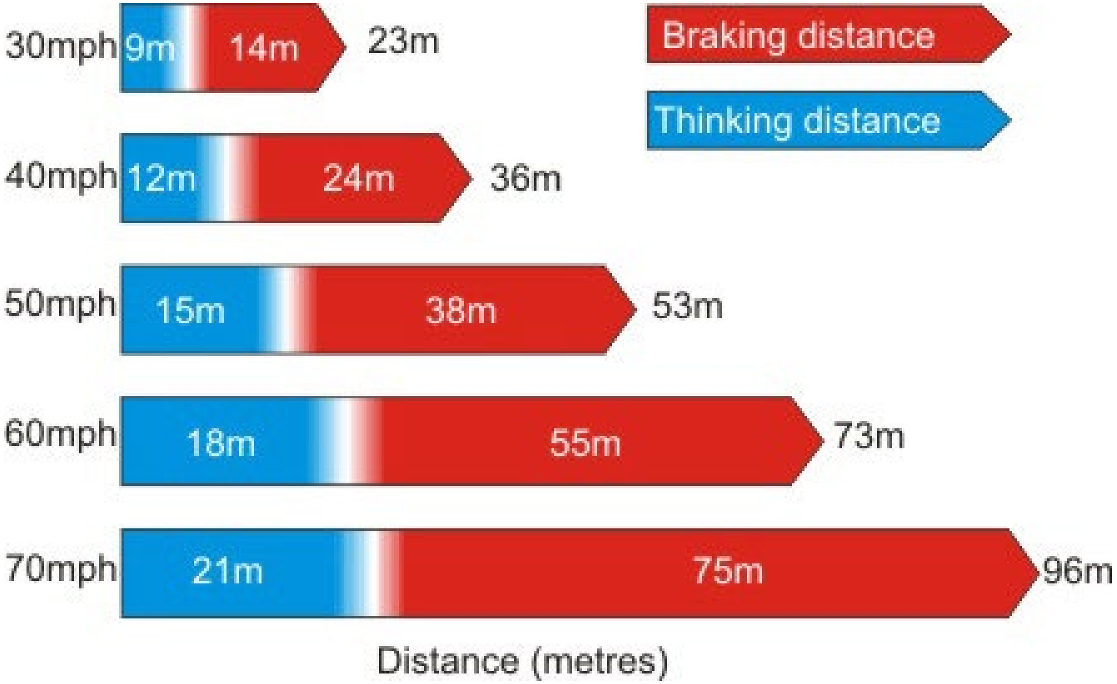
stopping distance = area under line

stopping distance = Area A + Area B

stopping distance = 5 + 5

stopping distance = 10 m

5. **The highway code shows the stopping distances for vehicles up to 70 mph. In 2011 the government proposed a new 80 mph speed limit for UK motorways. Use the information in the diagram, and your own knowledge, to determine the overall stopping distance of a vehicle at 80 mph.**



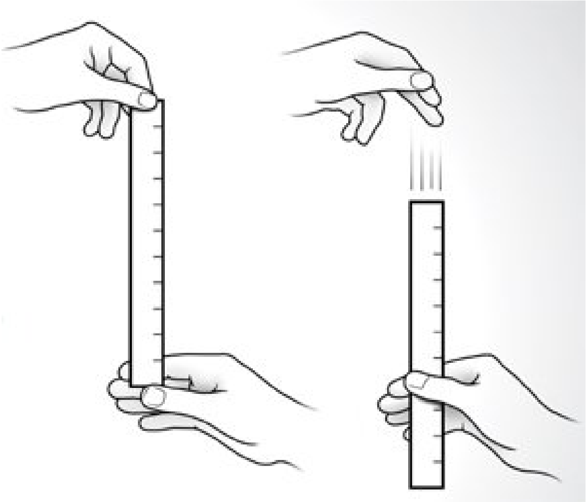
When speed doubles thinking distance doubles and braking distance quadruples. So,

At 80 mph:

Thinking distance = 24 m
Braking distance = 96 m
Stopping distance = 120 m

6. **Describe how you could measure the reaction time of a person.**

- Get the person to stand with their hand open
- Place a ruler at the top a the person's hand
- Drop the ruler through their hand
- When the person sees the ruler move they need to close their hand
- The distance the ruler travels corresponds to the thinking distance



6. **Explain the dangers caused by large decelerations of a vehicle.**

- Large decelerations can cause the brakes to overheat and become less effective
- Large decelerations can also cause a loss of control
- Large decelerations can also exert large forces of people within a vehicle.

8. **Put the following factors under the correct headings to show whether the factor affects think distance, braking distance or both thinking and braking distance.**

Speed **Mass** **Icy roads** **Tiredness**

Poor brakes **Mobile Phone use** **Alcohol** **Bald tyres**

Thinking Distance	Braking Distance	Both
Tiredness	Mass	Speed
Mobile Phone use	Icy roads	
Alcohol	Poor brakes	
	Bald tyres	