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GCSE Physics

Edexcel Motion and forces

Motion and forces

Part 1

- **Scalar and vector quantities**

Part 2

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

Part 4

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

Part 5

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

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Motion and forces Part 1

- Scalar and vector quantities

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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.

QuestionIT!

Motion and forces
Part 1

- **Scalar and vector quantities**

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 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

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.

average speed = total distance travelled
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.
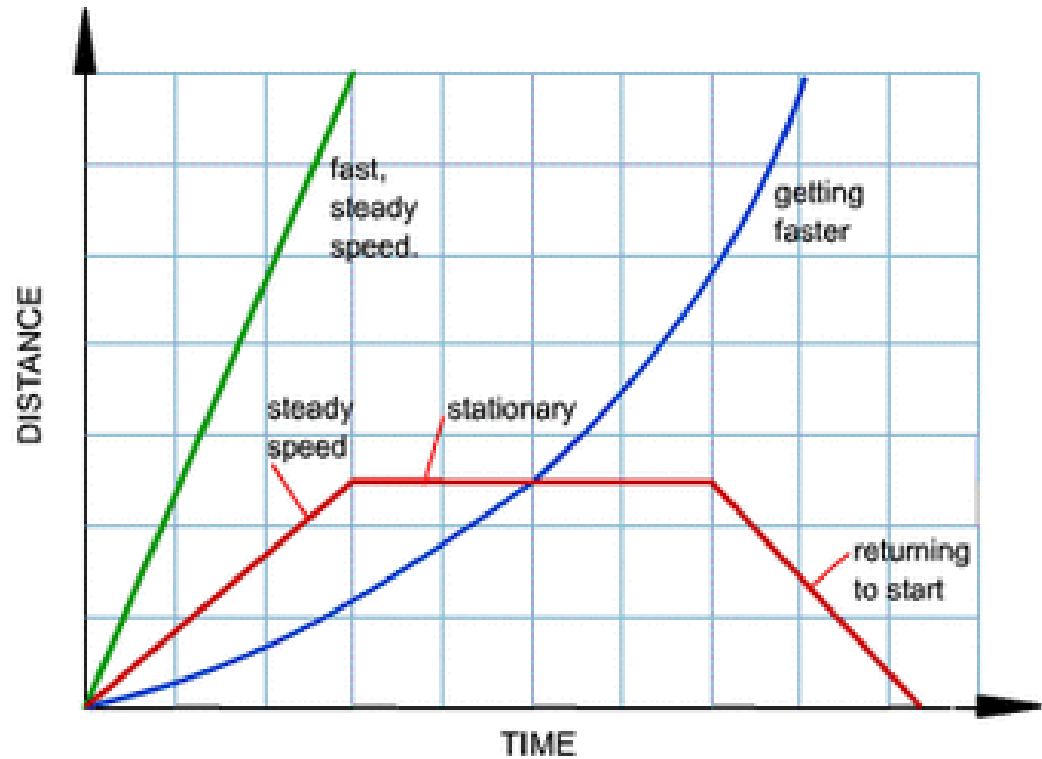
Calculating speed from a d...

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:

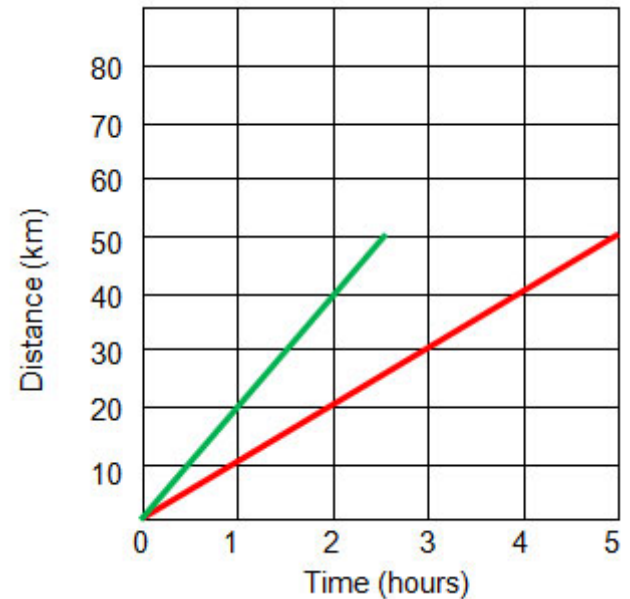**Work out the speed of the objects shown by the red and green line.**

Solution:

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

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

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**) <u>or</u> 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.
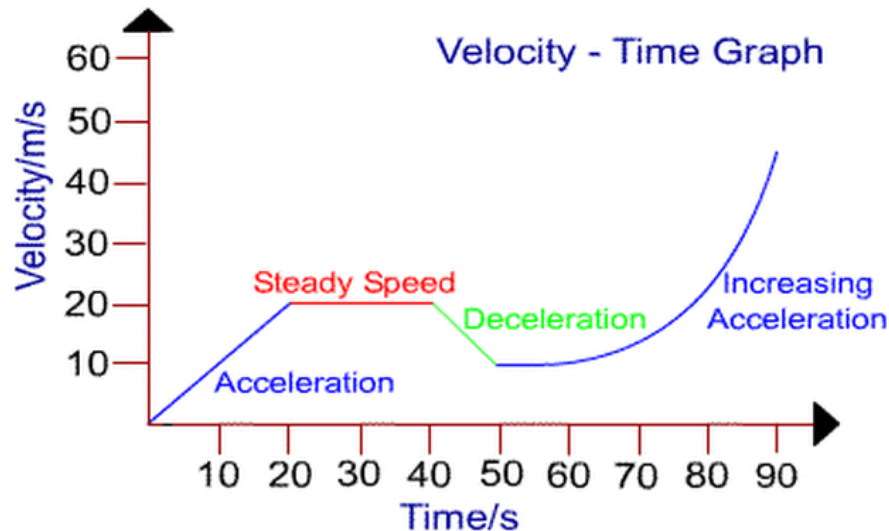
Velocity/time graph calculations

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.
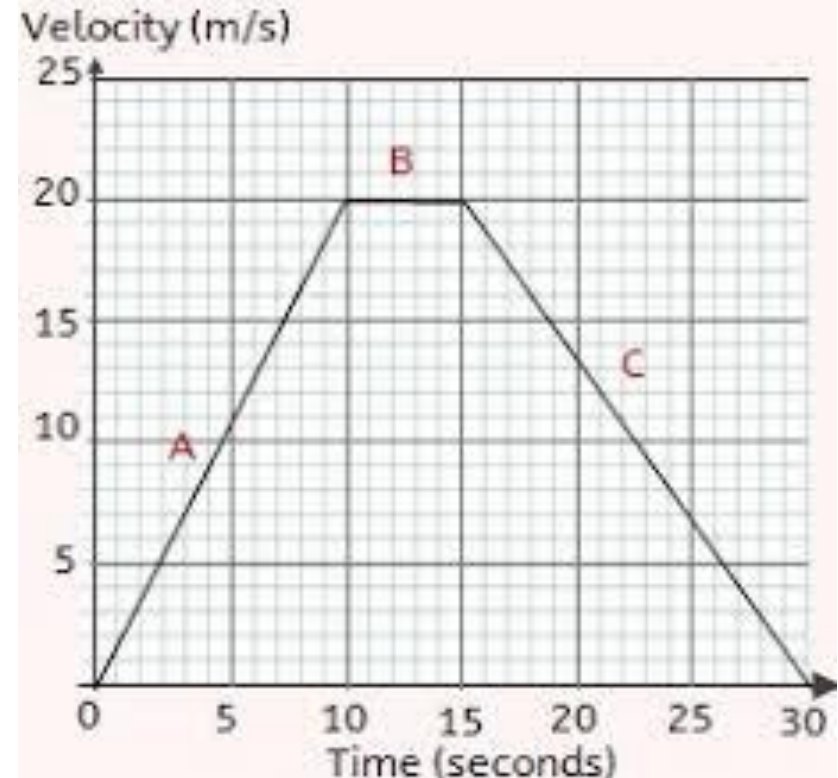
Interpreting velocity/time graphs

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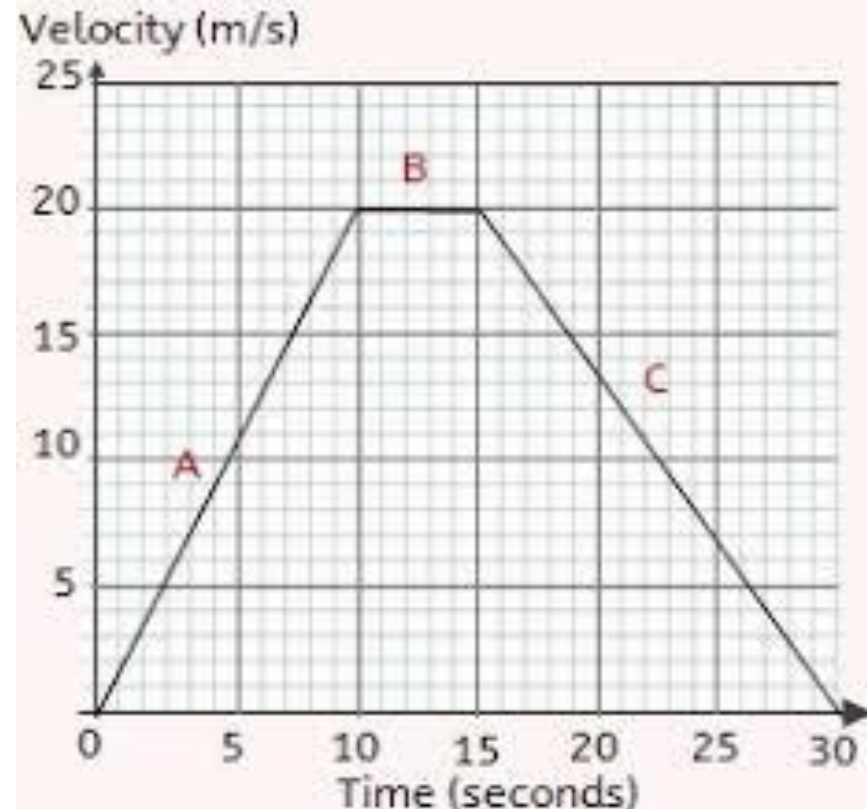**Describe fully the motion shown in the velocity/time graph.**

Solution:

From 0 to 10 s: **Constant rate of acceleration of 2 m/s².**
From 10 to 15 s: **Constant speed of 20 m/s.**
From 15 to 30 s: **Constant rate of deceleration of 1.33 m/s².**

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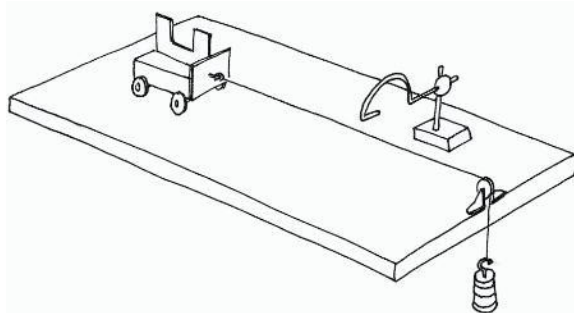
Investigating motion

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).

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.

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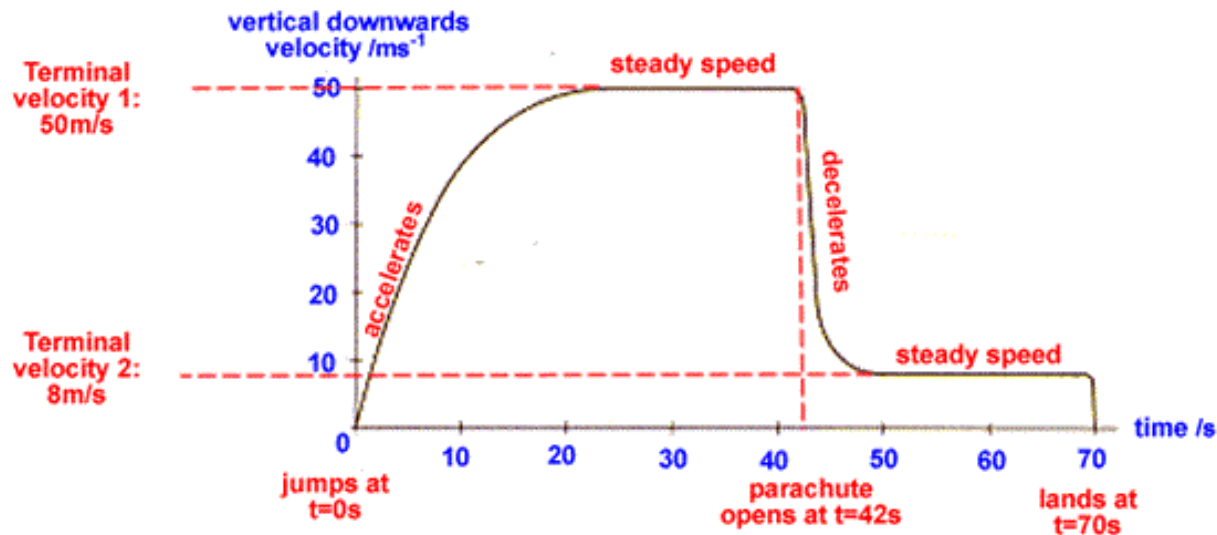
The acceleration, g, in free fall is: 10 m/s^2

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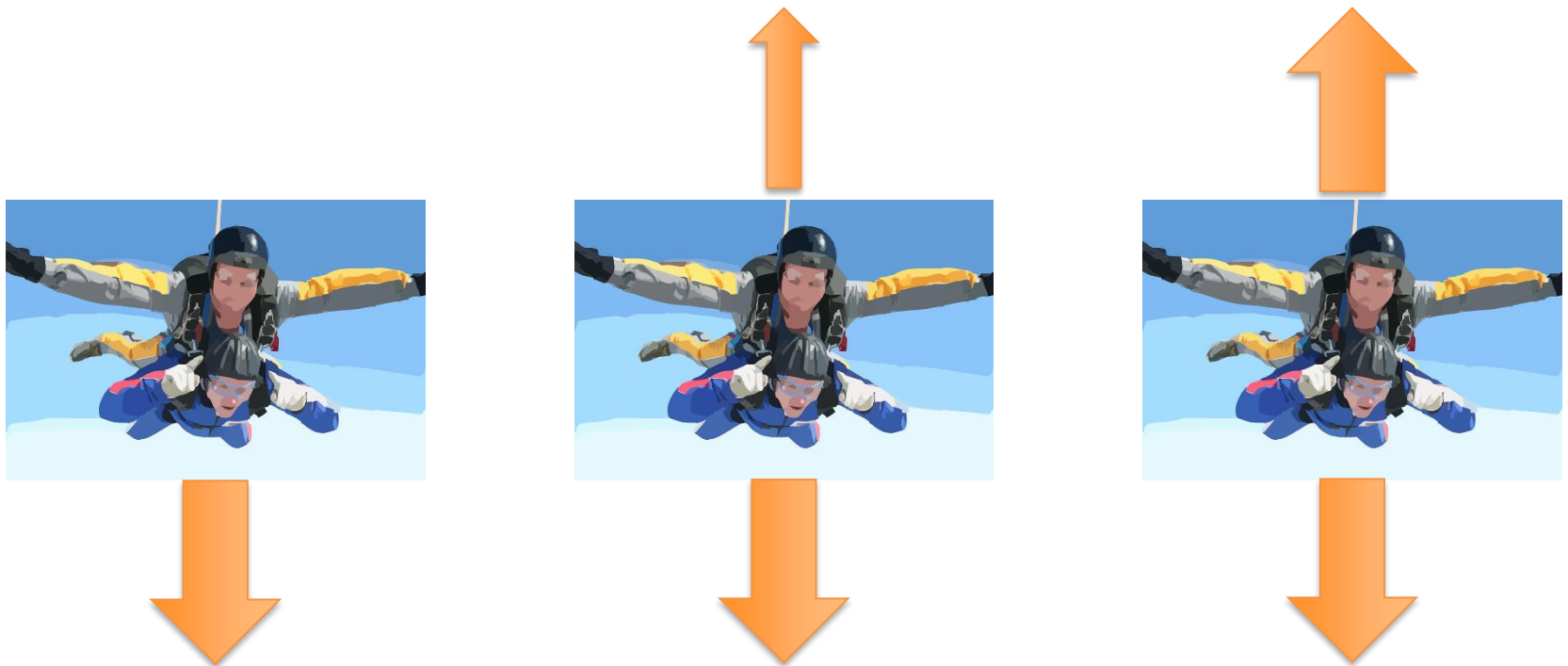
As the skydiver falls faster the amount of drag experienced increases, reducing the skydiver's acceleration, until weight and drag are equal in size. At this point the skydiver will be falling with terminal velocity.

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

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.
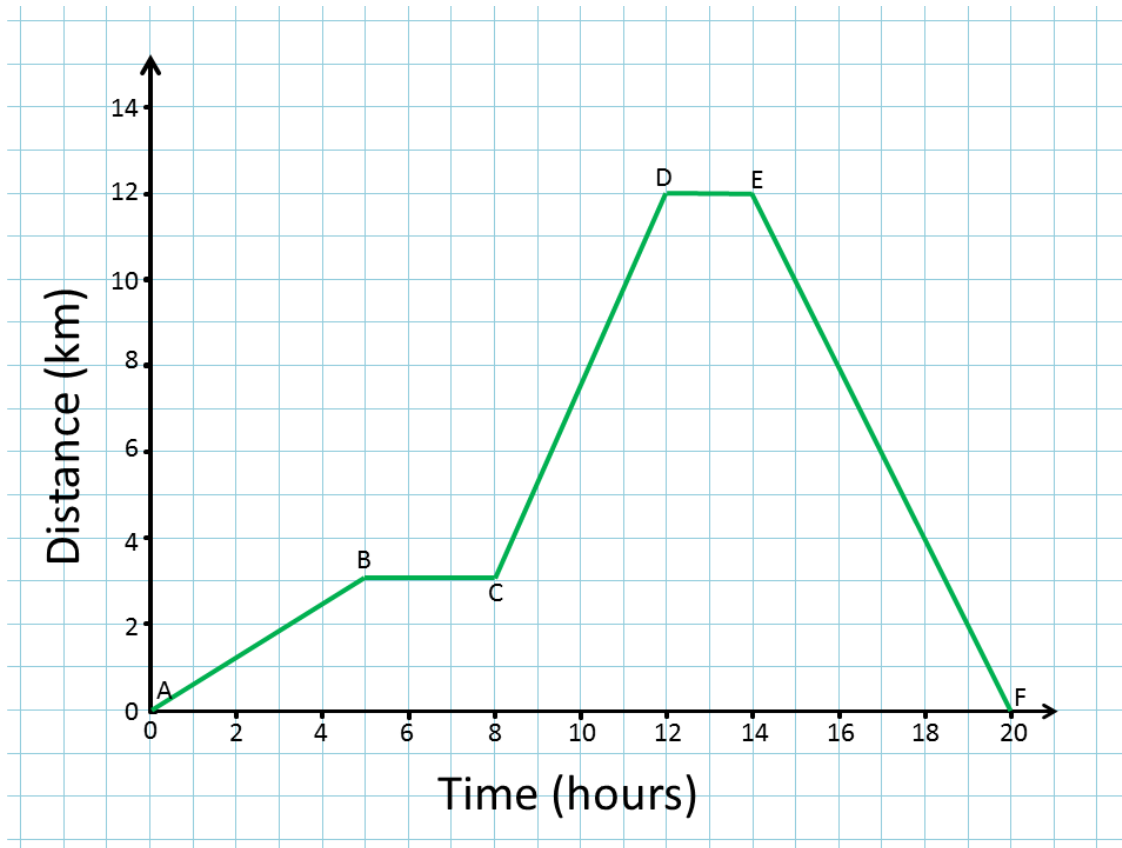
7. Describe how you would find the instantaneous speed of an object from a distance-time graph where the line is a curve. (Higher Tier Only).
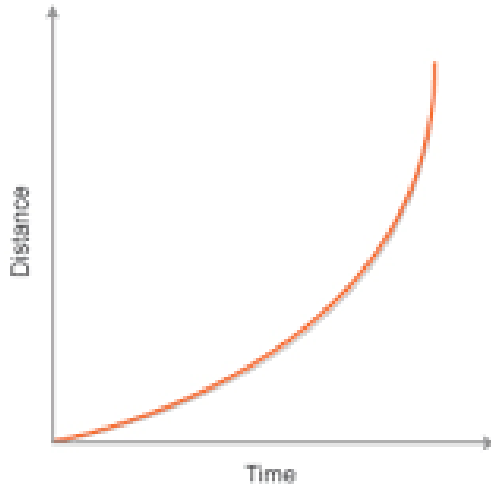
8. State the equation that links acceleration, change in velocity and time taken, including units.

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/s²

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.
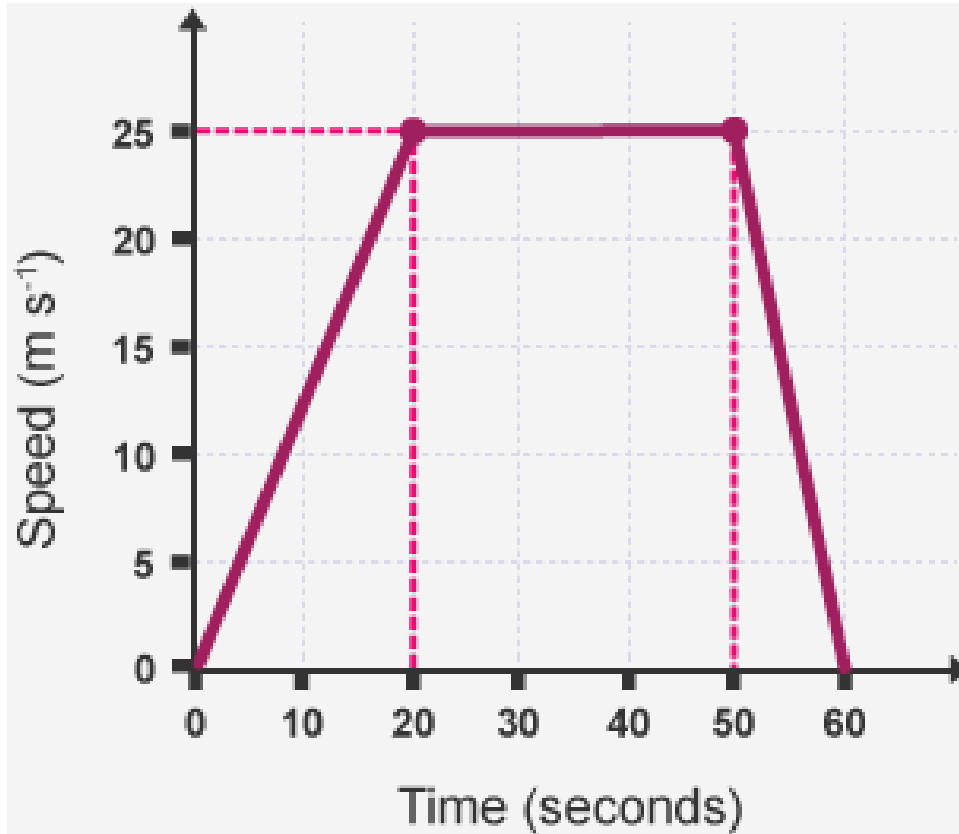
14. State the typical speed of a person
    Walking
    Cycling

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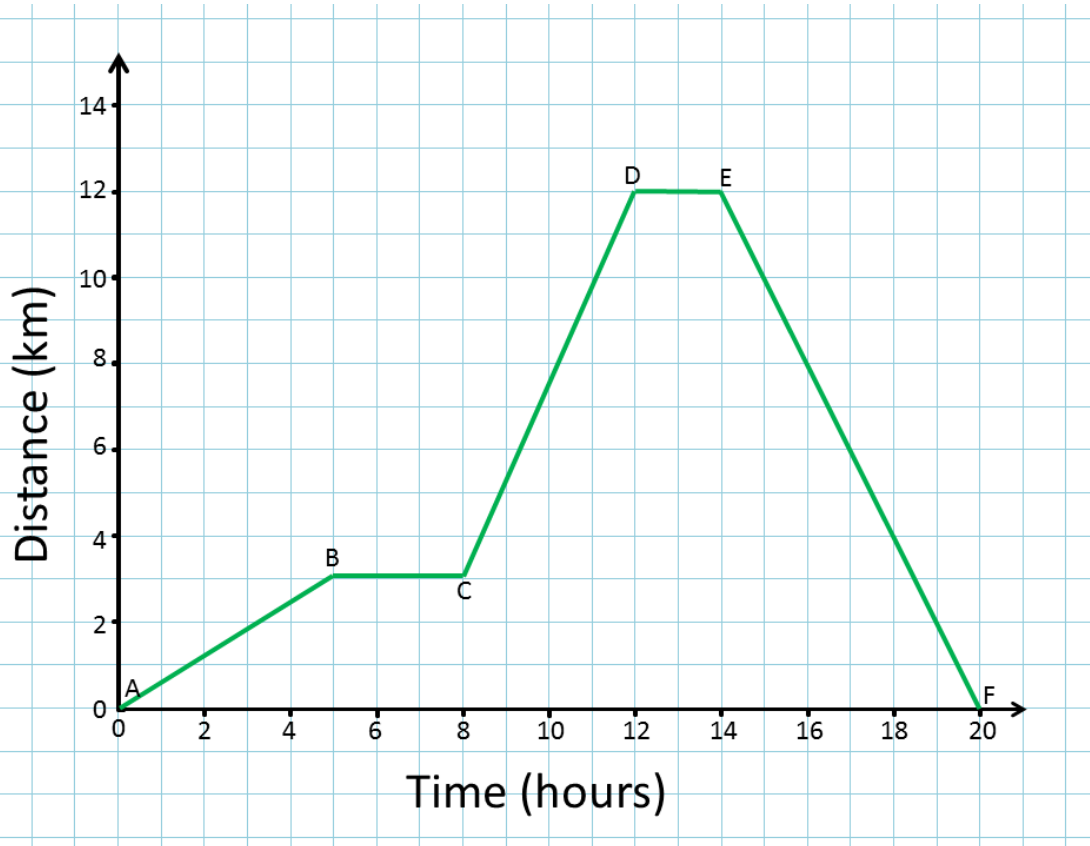   (average) speed = 420 / 8
   (average) speed = 52.5 mph

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.

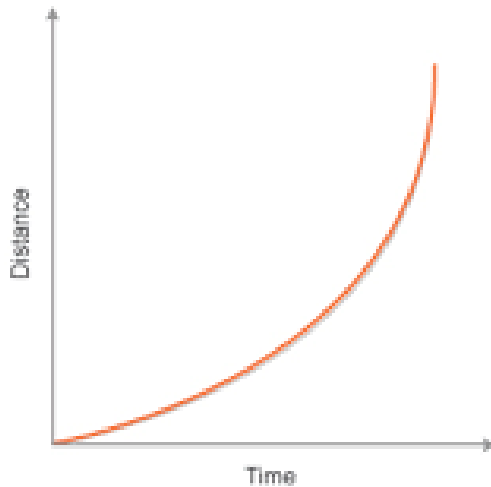A to B: Constant speed of 0.6 km/s

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/s²) = 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/s²   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 m/s²

   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.
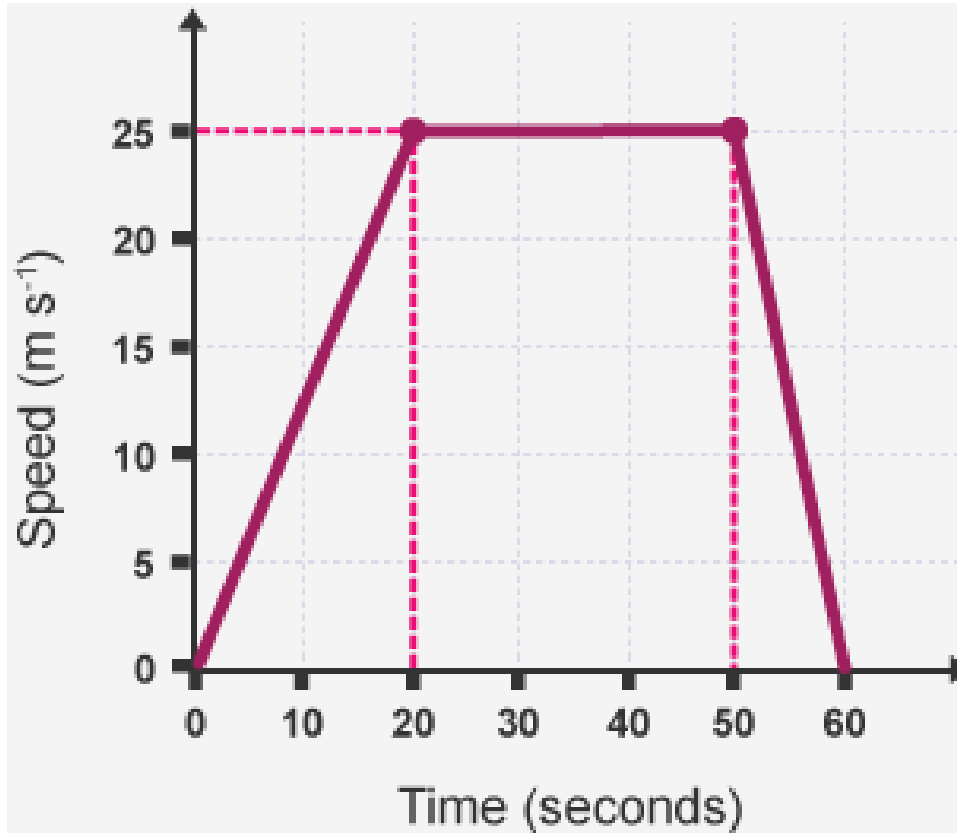
From 0 to 20 s: Constant rate of acceleration of 1.25 m/s²

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

From 50 to 60 s: Constant rate of deceleration of 2.5 m/s²

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/s²)**
- **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.**

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Motion and forces
Part 4

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

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- 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.

Velocity

Centripetal Force
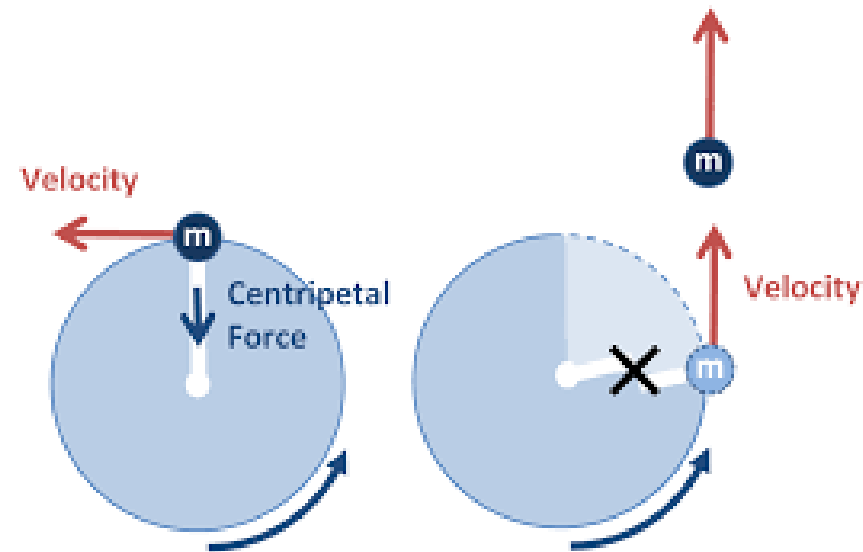
Velocity

Video - circular motion

- **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.

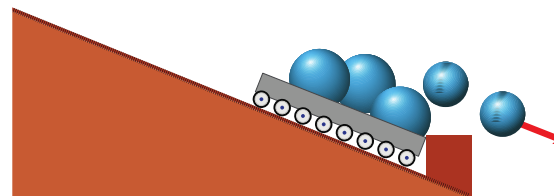**To find out which of two objects has the most inertia:**

- **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.**
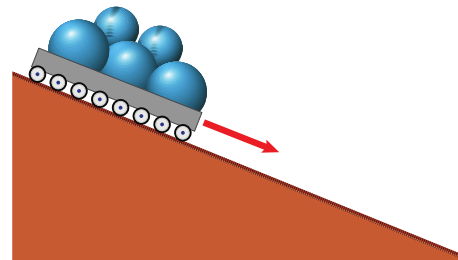
The tendency preserve its state of motion
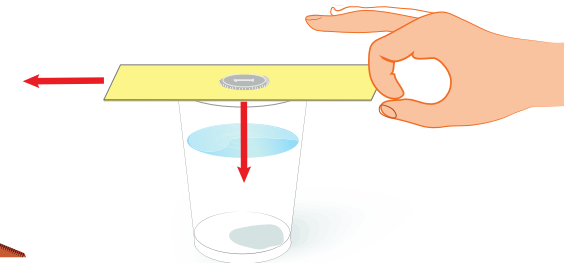
The tendency of an object to stay at rest

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.

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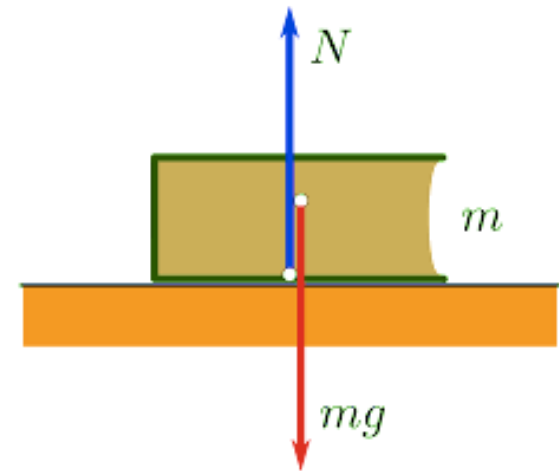
Momentum is a **vector** quantity.
Moving object have momentum. It is the **tendency of an object to **keep moving in the same direction**. It is difficult to change the direction of movement of an object that has a lot of momentum. **The momentum of an object depends on it's mass and it's velocity.**

Recall and use the equation:

momentum (kg m/s) = mass (kg) x 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.
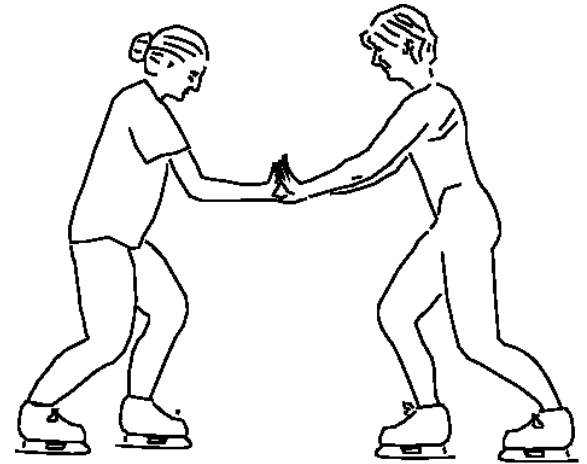
Newton's second law changes in momentum:

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

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

Combining the two equations gives:
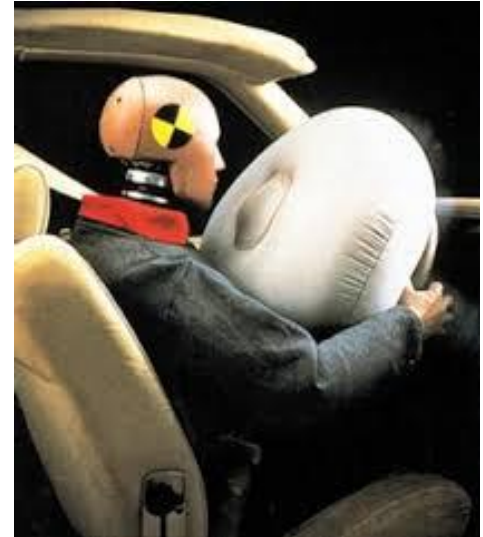
$$F = \frac{(mv - mu)}{t}$$

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)

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

QuestionIT!

Motion and forces
Part 4

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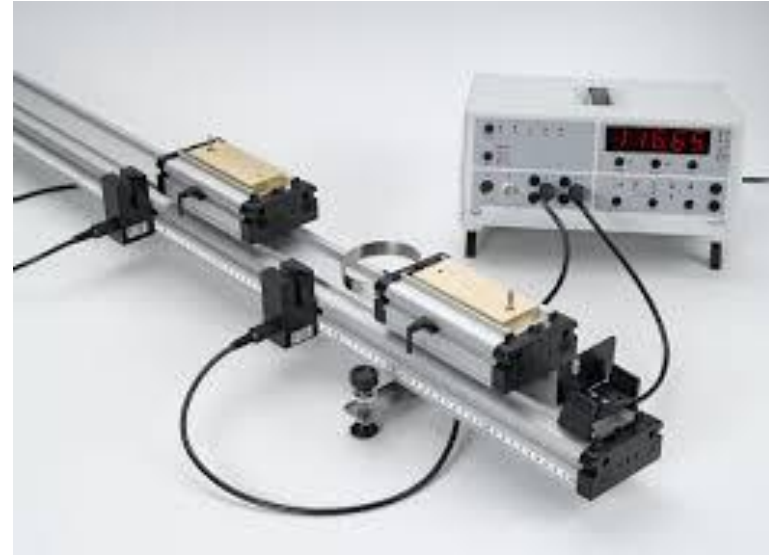- **Inertia (HT)**
- **Newton's Third Law**
- **Momentum (HT)**

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 = mass$_{after}$ x velocity$_{after}$
   velocity$_{after}$ = 5.4 / 2 = 2.7 m/s
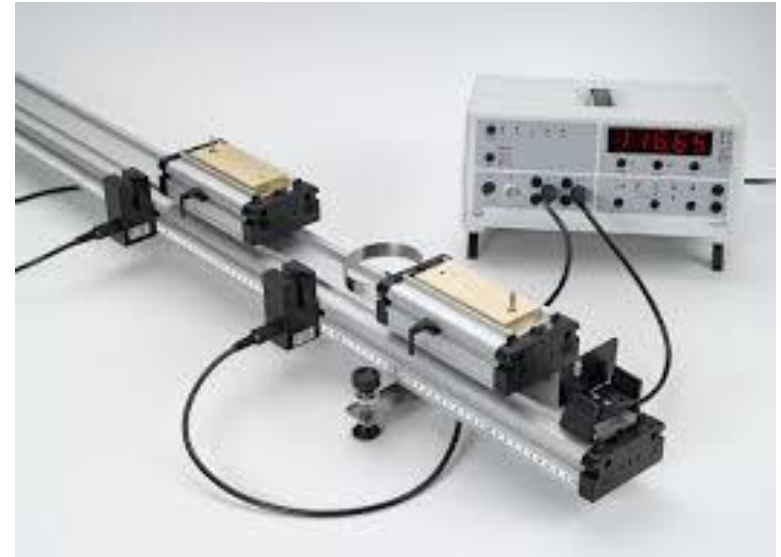
7. **A gymnast falls onto a crash mat. The crash mat reduces the risk of injury to the gymnast.**

   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 x $\frac{30}{0.4}$
   F = 63 750 N