ST. MARY'S *Catholic High School*

Year-9- Vectors and Scalars
Velocity and Acceleration

Scalar Quantity
Quantities that have only magnitude (size) but no direction are scalar quantities.
Examples: mass, distance, time, energy and speed.

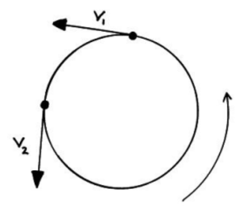
Vector Quantity
Quantities that have both magnitude (size) and direction are vector quantities.
Examples: force, velocity, displacement, momentum and acceleration.

Distance
Distance is the total length of the path travelled.

B The bend in the road means that the distance the cyclists cover is greater than their final displacement.

Displacement is the distance travelled in a particular direction. It is equal to the shortest distance between the final and initial positions of the body.

The displacement at the end of a journey is usually less than the distance travelled because of the turns or bends in the journey. Displacement is a vector but distance is not.



Q1. Runners in the 400m race complete one circuit of the athletics track. What is their displacement at the end of the track?

Q2: A car is driving around a roundabout at 20 km/h. Explain whether or not

(a) Its speed is changing (b) Its velocity is changing

Distance/ Time Graph

Speed is the distance travelled by an object per time. It is measured in metres per second (m/s). Other common units are kilometer per hour (Km/h) and miles per hour (mph). It is a scalar quantity. Speed of an object tells how quickly an object travels a certain distance.

Velocity is the speed of an object in a particular direction. It is measured in metres per second (m/s). Velocity is a vector, speed is not.

Average Speed is the total distance traveled per total time taken.

$$Average\ Speed\ (m/s) = \frac{Distance\ (m)}{Time\ Taken\ (s)}$$

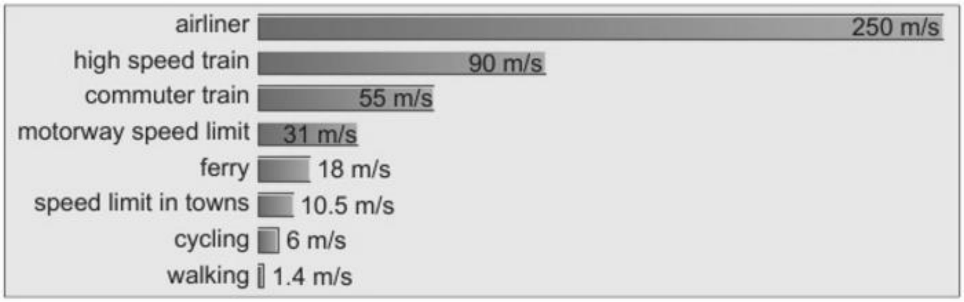
Q3. A car travels 3000 m in 2 minutes. Calculate its average speed in m/s

Instantaneous Speed is the speed at a particular instant of time in the journey.

Q4. How far a high speed train travels in 10 minutes? Use table below.

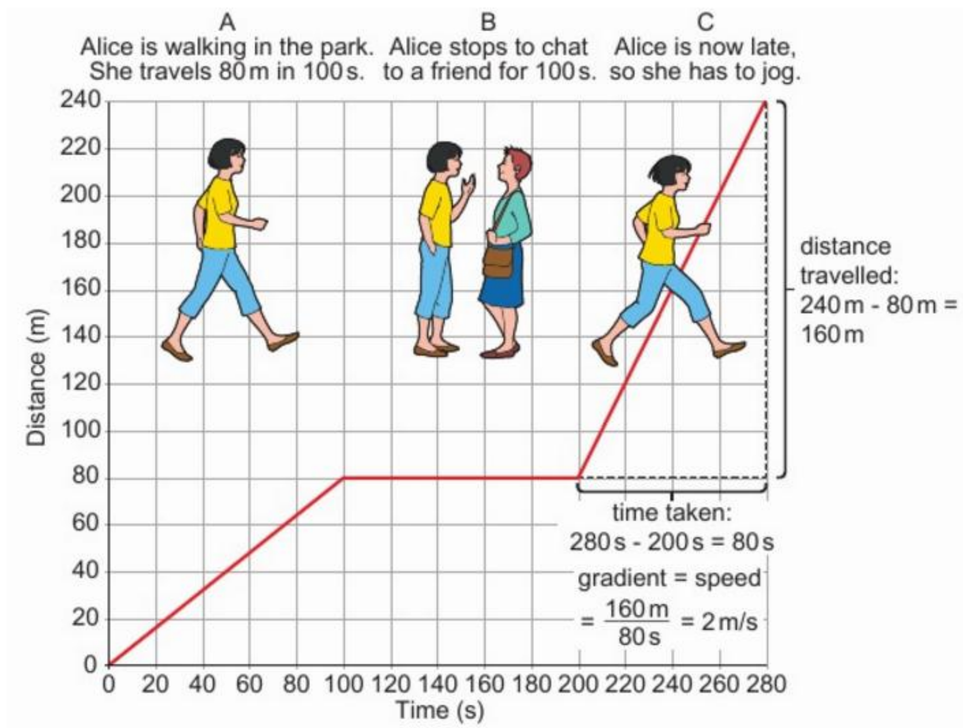
Q5. A car travels at 20 m/s for 10 seconds and then at 30 m/s for 15 seconds. Calculate its average speed.

Some Typical Speeds



<u>Distance – time graphs</u>

- Distance is taken along Y axis and time on X axis.
- A horizontal line represents a stationary object. Its distance from origin is not changing.
- A straight and sloping line shows object moving with constant speed. Its distance from origin increases or decreases in equal intervals in equal intervals of time.
- Gradient of a distance-time graph represents speed. Steeper the line, greater the speed. This is because the object travels greater distance in the same amount of time when speed is more.



Q6. Calculate Alice's speed for

a) Part A on the graph

b) If Alice has not stopped to chat but had walked at her initial speed for 280 seconds how far would she have traveled?

c) Find her average speed.

Q7. A peregrine falcon flies at 50 m/s for 7 seconds. How far does it fly?

Q8. a) Zahir starts a race fast, then gets a stitch and has to stop. When he starts running again he goes more slowly than before. Sketch a distance/time graph to show Zahir's race if he runs at a constant speed in each section of the race.

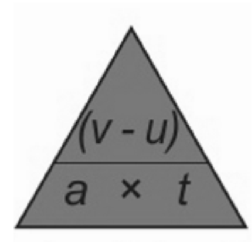
b) Zahir's speeds are 3m/s for 60 seconds, 2m/s for 90 seconds and his rest lasted for 30 seconds. Plot a distance/time graph on graph paper to show his race.

Acceleration

Acceleration

Change in velocity per unit time is known as acceleration. It is a vector quantity and measured in m/s^2.

$$Acceleration\ (m/s^2) = \frac{Change\ in\ velocity\ (m/s)}{Time\ taken\ (s)} \qquad a = \frac{v-u}{t}$$



where u is the initial velocity and v is the final velocity after a time t.

Q9. A fighter plane can accelerates form 0 to 80 m/s in 2 seconds. Find its acceleration.

Acceleration does not always mean getting faster. D**eceleration is the decrease in speed per time** and is called negative acceleration.
Acceleration is ralated to initial velocity, final velocity and distance traveled by the formula

$$v^2 - u^2 = 2aS$$

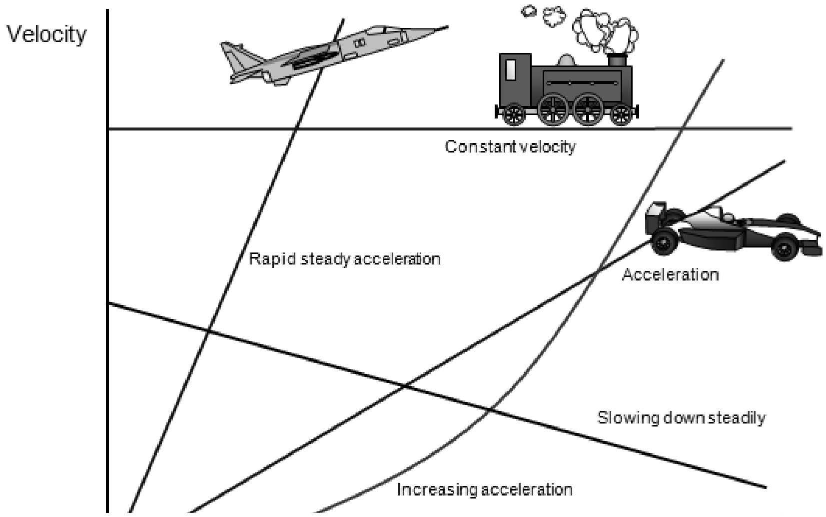
Q10. A car slows down from 25m/s to 5m/s in 5 seconds. Calculate its acceleration
Q11. A car traveling at 15m/s accelerates at 1.5 m/s^2 over a distance of 50m. Calculate its final velocity.
Q12. Explain how positive, negative or zero acceleration changes the velocity of a moving object.
Q13. A car traveling at 40m/s comes to a halt in 8 seconds. What is the cars acceleration and how far does it travel while stopping?
Q14. A train is traveling at 35m/s. It slows down with acceleration $-0.5 m/s^2$. How much time does it take to stop and how far does it travel while stopping.

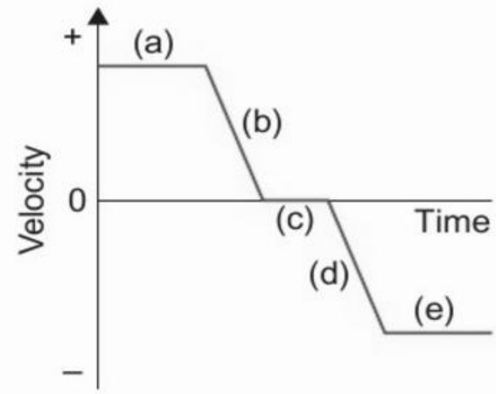
Acceleration due to gravity

Any freely falling body will accelerate towards earth at the same acceleration of 9.8 or 10 m/s^2 irrespective of its mass.

Velocity/Time Graph

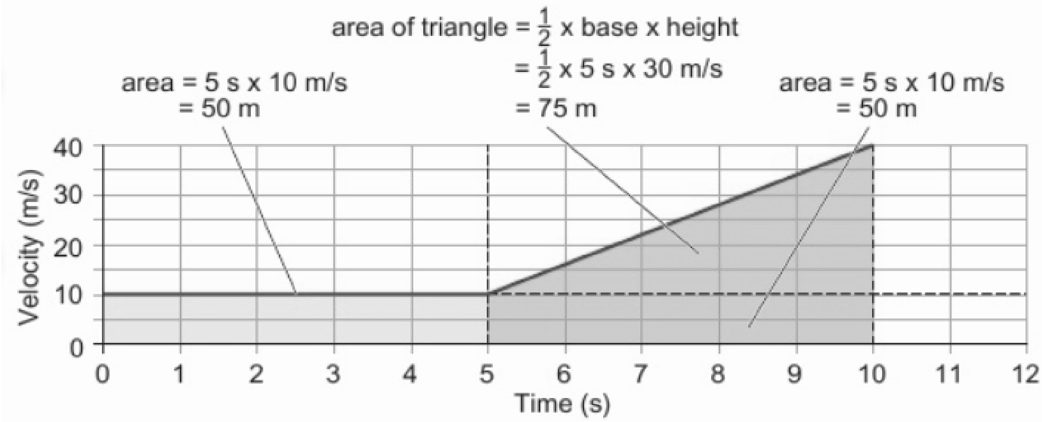
- Velocity is taken on Y axis and time on X axis.
- A horizontal line means the object is travelling at constant velocity.
- A sloping line shows that the object has constant acceleration. Its velocity increases in equal amounts in equal intervals of time.
- The gradient of velocity /time graph is acceleration.
- The steeper the line, grater the acceleration.
- If the line slopes down to the right, the object is decelerating (slowing down)
- A negative velocity (a line below horizontal axis) shows the object moving in the opposite direction
- The area under the velocity/time graph gives the distance travelled.





The graph shows a lift moving up at a constant speed (a), slowing to a stop (b) and waiting at a floor (c) then accelerating downwards (d) and then travelling downwards at a constant speed (e).

The area under a velocity/time graph is the distance the object has travelled (distance is calculated by multiplying a velocity and a time). In graph the distance travelled in the first 5 seconds is the area of a rectangle. The distance travelled in the next 5 seconds is found by splitting the shape into a triangle and a rectangle, and finding their areas separately.



Total distance travelled by the object is the sum of all the area

Total distance travelled = 50m + 75m + 50m = 175m

Q15. Table gives some data for an object moving. Draw a velocity/time graph. Label the graph.

a) Calculate the acceleration for

(i) 0-30 s (ii) 30-40 s (iii) 40-50 s

Time /s	Velocity m/s
0	0
10	5
20	10
30	15
40	15

50	0

(b) Calculate the total distance
(c) Calculate the average speed

FORCES

A **force** is anything that can cause a change to objects. Forces can change the shape of an object, accelerate or slow an object, and change the direction of a moving object.

Types of Forces

1. Gravitational force is an attractive force between objects with mass. It is greater if the mass of the object or the planet is more.

2. Friction is the resistive force acting between two surfaces in motion. It is greater at higher speeds.

3. Air resistance is the frictional force exerted by air on objects moving through air. Air resistance is greater if surface area of the object or its speed is more. Similar force in a liquid is called drag.

(Frictional forces such as air resistance, friction and drag act **against** the direction of motion, so tend to **slow** the object down)

4. Up thrust is an upward force exerted by a medium on an immersed object. It does not depend on speed, but is greater if the volume of the object or density of the fluid is more.

5. Tension is the stretching elastic force exerted on a string or rope.

6. Contact force (Normal reaction) is the supporting force from a surface on an object placed on it.

7. Electric forces acting between charged objects

8. Magnetic forces exerted by magnets

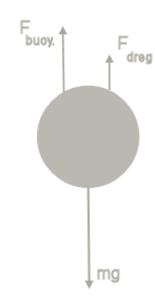
9. Lift force acts upwards on wings of aircrafts due to their peculiar shape.

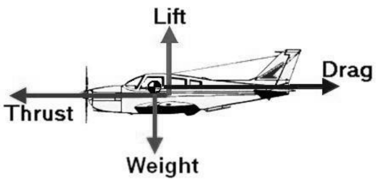
Gravitational, electric and magnetic forces do not need contact while others need contact between objects.

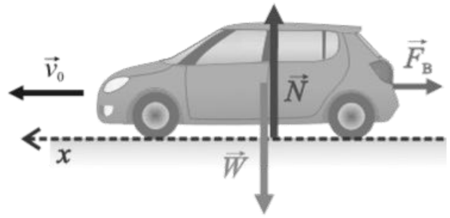
Force diagrams show the forces acting **on an object.** In a force diagram, each force is shown as an arrow which shows

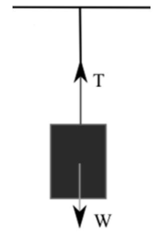
- the size of the force (the longer the arrow, the bigger the force)
- the direction in which the force acts.

The arrow is labeled with the name of the force and its size in Newton (N). Since forces are **vector** quantities, it is important to know the direction in which they act.



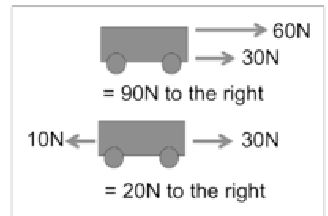




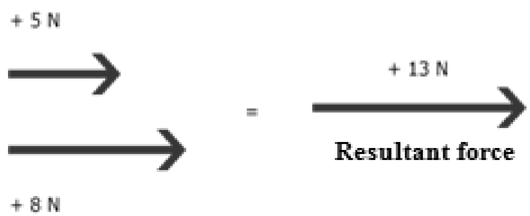


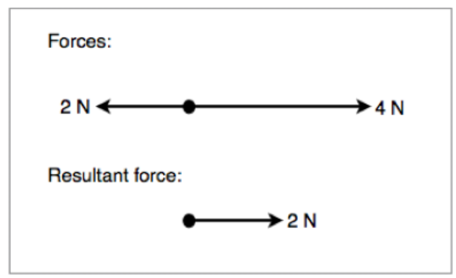
Resultant force

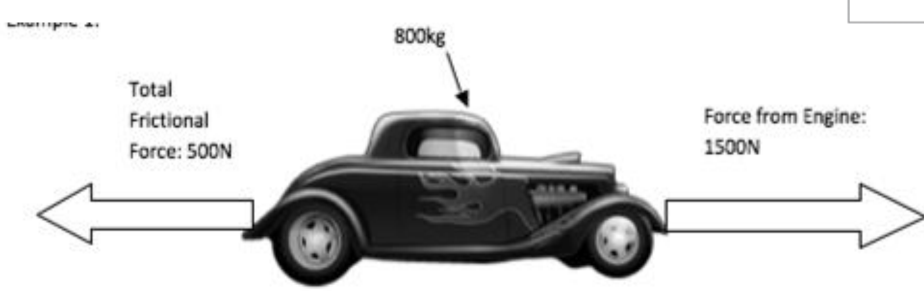
An object may have several different forces acting on it, which can have different strengths and directions. But they can be added together to give the **resultant force**. This is a single force that has the same effect on the object as all the individual forces acting together.



If the two forces are acting in the same direction, **add** them
If they are acting in the opposite direction **subtract** one from the other.







Resultant force =………..

Calculate the resultant force on the air craft in the

(a) vertical direction

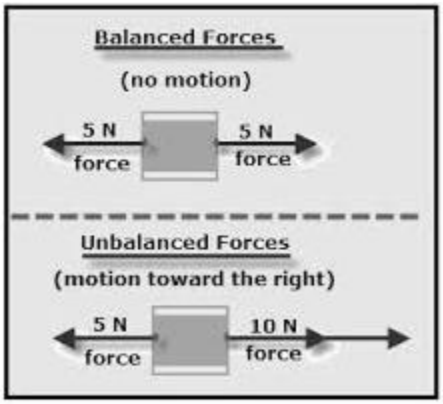
(b) horizontal direction

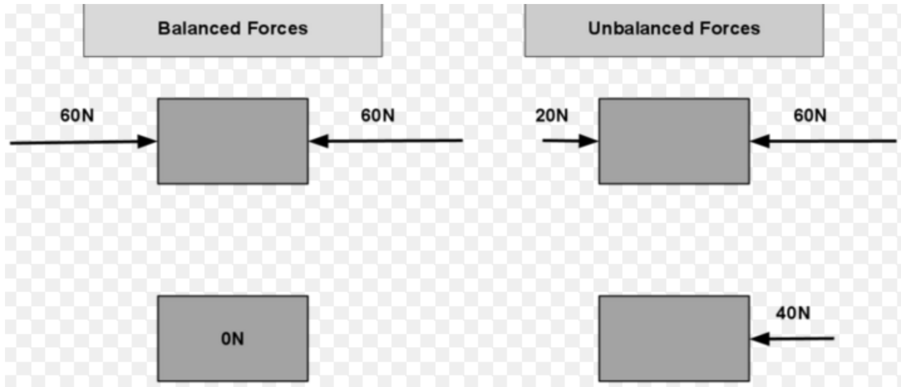
Balanced and Unbalanced forces

If the resultant force acting on an object is zero, the forces are **balanced** and if the resultant force is non-zero, the forces are **unbalanced.**

Comment whether the forces acting on the aero plane shown above are balanced or unbalanced in (a) vertical direction

(b) horizontal direction



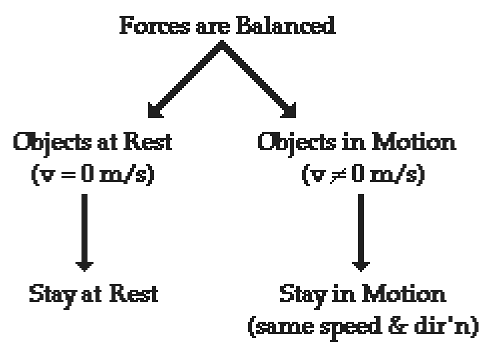


CP2b. Newton's first law

Newton's First Law of motion predicts the behaviour of objects for which all existing forces are **balanced**.

Newton's first law of motion states that a moving object continue to move at the same speed and direction unless an external force acts on it. This means that a stationary object remains at rest unless a external force acts on it.

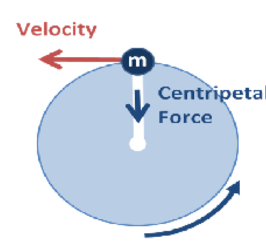
Balanced force (**resultant force zero**) will not change the velocity of the object. They move with the same velocity. Unbalanced force (**resultant force non zero**) will change the velocity of the object.



The Newton's first law of motion is sometimes referred to as the **law of inertia**.

The inertia of an object is a measure of how difficult it is to change its motion. Inertia increases as mass increases. It is more difficult to push a car than to push a shopping trolley.

Circular Motion



An object moving in a circle has changing velocity even though the speed remains the speed. There are many examples of objects travelling in a circular motion. Examples include fairground rides, a hammer-thrower spinning a hammer, the Earth orbiting the Sun etc.

These objects continuously change direction as they move in a circle. This needs a *resultant force* to act on the object. This force is the **centripetal force.** The centripetal force pulls an object toward the centre of the circle. Centripetal force does not exist in its own right, but is provided by the action of other forces.

For a stone whirled on a piece of string around in a circle, the centripetal force is provided by the **tension** within the string. For a vehicle turning a corner, the centripetal force is provided by **friction** between the tyres and the road. For objects in orbit, for example the Earth orbiting the Sun, the centripetal force is provided by **gravi<u>tational</u>** force.

A satellite is in a circular orbit around the earth moving with constant speed. Is it accelerating? Explain how and why its velocity is changing continuously.

CP2c. Mass and Weight

Mass is the quantity of matter there is in an object and changes only the object itself changes. Mass remains the same irrespective of the position. Mass is measured in kilograms (kg).

Weight is a measure of pull of gravity on an object and depends on the strength of gravity. Weight is a force, therefore is measured in Newton (N).

On Earth, the gravitational field strength has a value about 10 Newton per kilogram(N/kg). This means that each kilogram is pulled down with a force of 10 N.

The gravitational field is different on other planets and moons.

You would weigh less on the Moon because the gravitational field strength of the Moon is about one-sixth of that of the Earth. But note that *your mass would stay the same.*

The weight of an object can be calculated using the formula

weight = mass × gravitational field strength [W= m × g]

<u>Worked out examples</u>

1. What is the weight of 90kg astronaut on the surface of the earth? W = m × g = 90 × 10 =900 N

2. A space probe has a weight of 3000 N on the earth. What is its mass? m = $\frac{W}{g}$ = $\frac{3000}{10}$ = 300 kg

Newton's second law states that resultant force acting on an object is the product of its mass and acceleration.

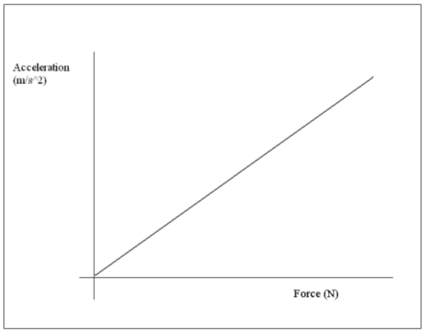
The acceleration in the direction of a resultant force depends on

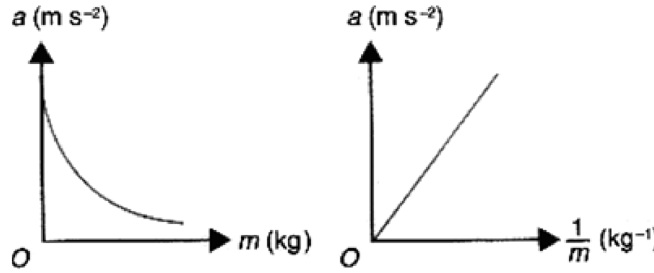
the **size** of the force(for the same mass, the bigger the force the bigger the acceleration). a α F
the **mass** of the object(for the same force the more massive the object, the smaller the acceleration). a α $\frac{1}{m}$

The acceleration of an object is inversely proportional to the mass of the object and directly proportion to the force acting on the object. Force (N) = Mass (m) × acceleration (m/s^2) **F = m × a**

*Note that when you use this relationship, F always stands for **unbalanced force**.*

1 Newton is the force needed to accelerate a mass of 1 kg by 1 m/s^2





The astronaut, David Scott carried out a famous experiment on the Moon. He dropped a hammer and a feather at the same time and found they landed **together**. As there is no **air** on the Moon there is no **air resistance**. The only force on both the hammer and feather was the Moon's **gravity** which made them both fall with the same **acceleration** as a = F/m. If force of gravity is more, mass is also more.

A motorcycle has a mass of 200 kg. What force is needed to give it an acceleration of 7 $m/s^{2.}$

F = m × a =200 × 7 = 1400 N

Inertial mass

The more massive an object is, the more force is needed to change its velocity (either to make it start moving or to change the velocity of a moving object).

We define **inertial mass** of an object as the force on it divided by the acceleration that force produces.

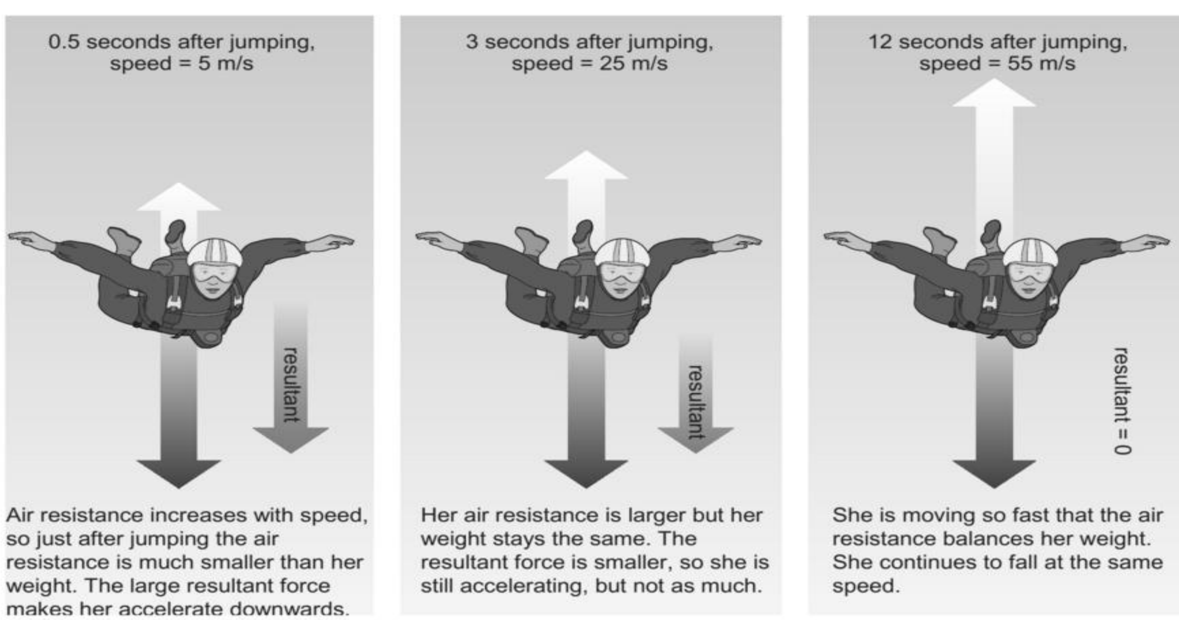
Question: A force of 160 N on a bicycle produces an acceleration of 2 $m/s^{2.}$. What is the total inertial mass of the bicycle and its rider?

Falling objects

Falling objects increase their speed as they fall, because their **weight** (the force of gravity) pulls them to Earth. They also experience an upward force called **air resistance** (drag), which slows them down.

Resultant force = Weight – Air resistance

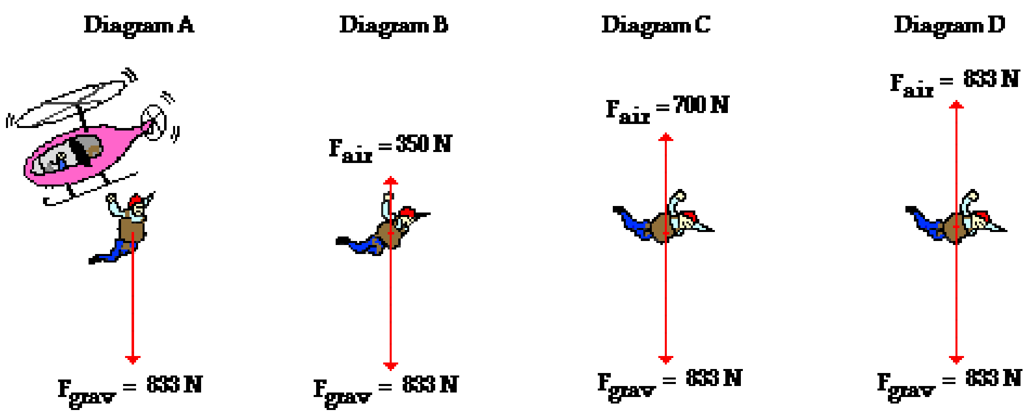
Consider a sky diver falling from a height. Initially air resistance is less as speed is less. So weight is much greater than air resistance. Resultant force and hence the acceleration is maximum in the beginning.



Speed increases at a rapid rate.

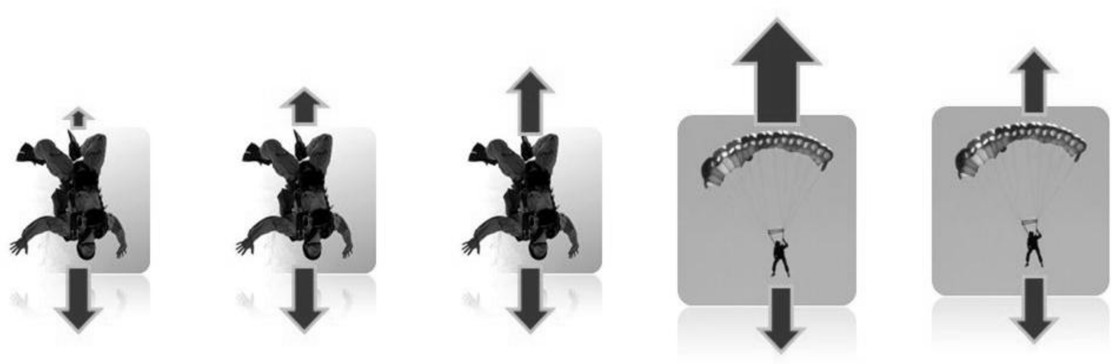
As speed increases, air resistance increases. Resultant force and hence acceleration decreases. Speed increases but at a smaller rate.

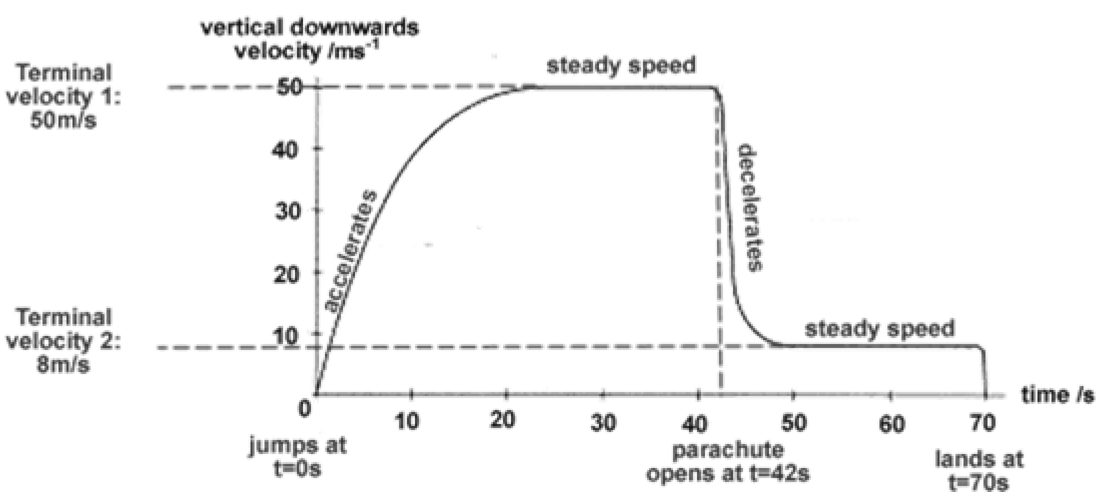
Finally weight and air resistance balance so that resultant force becomes zero and the diver attains **terminal speed**. Speed will remain constant.



If a parachute is opened, suddenly air resistance increases due to the increased surface area. Now it is greater than weight. So resultant force acts upward. The diver continues to fall but decelerates. His speed decreases because resultant force acts opposite to the direction of his motion.

As speed decreases, air resistance starts to decrease and again will balance the weight. A new terminal speed is attained which is considerably less than the first one. Thus he lands safely with a moderate speed.





Questions
1. The resultant force on a ball is zero. What will happen to the ball?
2 a. Same force is used to accelerate a small car and a lorry. What will be different about their motions? Explain your answer.
b. If you want to make the vehicles accelerate at the same rate, what can you say about the forces needed to do this? Explain your answer.

Newton's Third Law

***Newton's third law* states that for every action force there is an equal (in size) and opposite (in direction) reaction force.**

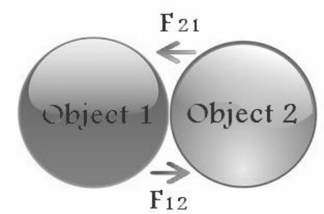
When two objects interact with each other, then the force exerted on the second object by the first object (F_{12}) is equal in magnitude and opposite in direction to the force exerted on the first object by the second object (F_{21}).

When objects interact, forces always occur in pairs. These are often called action–reaction forces.

Action and reaction never cancel each other since they act on two different objects.

The two forces are always:

- the same size and in opposite directions
- the same *type* of force



That is F_{12} (action) = $- F_{21}$ (reaction)

Examples: When you stand on the floor, your body exerts a downward contact force on the floor, while the floor exerts an equal and upward contact force on your body.

How we walk

When we walk, we exert a backward force on the ground and the ground exerts a forward force on us to make us move.

How Fish Swim
A fish pushes water backward by using its fins. The water pushes the fish forward with same force as the fish had exerted on the water.

Newton's Laws Applied to Collisions

When two bodies collide, according to Newton's third law, the forces on the two objects are equal in magnitude and opposite in direction. But the accelerations of the objects are not necessarily equal in magnitude. According to **Newton's second law of motion**, the acceleration of an object is greater if the mass is less. So the lighter object will have greater acceleration compared to the heavier one since force is same for both.

Example: When the club head of a moving golf club collides with a golf ball, the force experienced by the club head is equal to the force experienced by the golf ball.

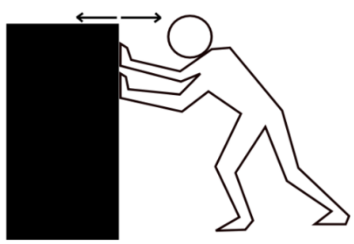
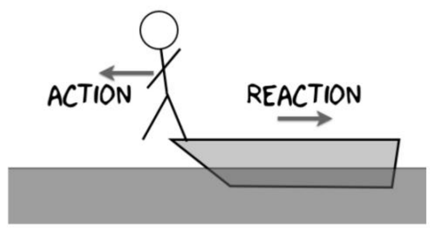
Both club head and ball experience equal forces, yet the ball experiences a greater acceleration due to its smaller mass.

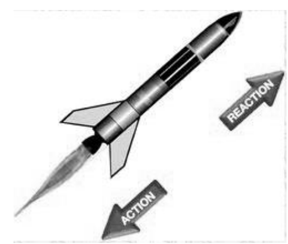
Newton's Laws applied to Explosions

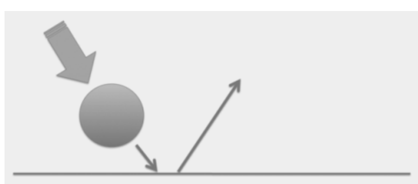
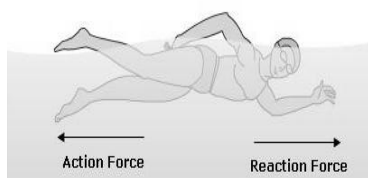
When a cannonball is fired from a cannon, the cannon exerts a force on the cannonball and the cannonball exerts an equal and opposite force on the cannon. However, the cannon being more massive, recoils with less speed, but the cannonball moves faster by Newton's **second law of motion** which states that acceleration is inversely proportional to the mass of the object.

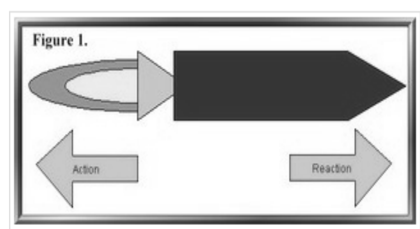
Questions

Describe the action -reaction forces in each example





Momentum

Momentum is a measure of the tendency of an object to keep moving and is determined as a product of its mass and velocity.

Momentum (p) = mass x velocity . The unit of momentum is kg m/s.

Momentum is a vecter quantity so if two objects are moving in opposite direction, we give the momentum of one object a positive sign and the other a negative sign.

Momentum and acceleration

Newton’s second law says that F=ma. We know a= (v-u)/t

These can be combined to give F = (mv – mu)/t

Therfore we can say, **Force** is the rate of change of momentum.

Question

A 1000 kg car accelerates from rest to 15 m/s in 15 seconds. What resultant force had caused this?

Conservation of momentum

When moving objects collide the total momentum of all the objects before collision is equal to total momentum after collision, as long as there are no external force acting . **This is known as law of conservation of momentum.**

Consider two bodies of mass m_1 and m_2 moving initially with velocities u_1 and u_2.

Let after collision their velocities become v_1 and v_2

$$\mathbf{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}$$

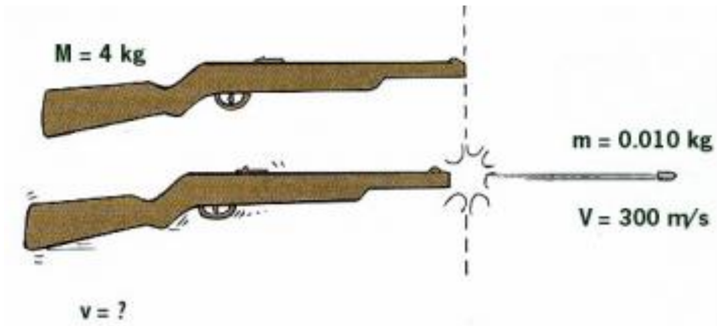
After collision if the objects stick together

$$\mathbf{m_1u_1 + m_2u_2 = (m_1 + m_2)\, v}$$

Questions

1, A 2 kg blob of putty moving at 4 m/s slams into a 6 kg blob of putty at rest. What is the speed of the two stuck-together blobs immediately after colliding?

2. Calculate the velocity of the rifles recoil after firing.

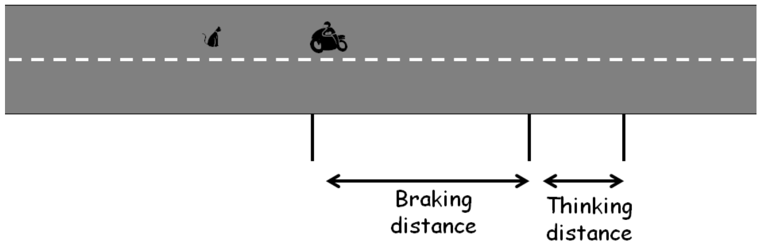


3. A 3000-kg truck moving rightward with a speed of 5 km/hr collides head-on with a 1000-kg car moving leftward with a speed of 10 km/hr. The two vehicles stick together and move with the same velocity after the collision. Determine the post-collision speed of the car and truck.

Stopping distance

When a driver sees a problem ahead, he will take some time to react before he applies brakes. This time is called reaction time. The vehicle will travel at constant speed during this time. The distance travelled by the vehicle during the reaction time of the driver is called the **thinking distance**. When the brakes are applied, the vehicle will decelerate travelling a further distance called **braking distance**.

Stopping distance = thinking distance + braking distance



Reaction time

A reaction time is the time between a person detecting a stimulus and he responding and applying the brakes.

Factors affecting reaction time

Reaction time increases if a person is tired, has been taking drugs or alcohol**,** ill or distracted.

Suggest why the reaction time measured in a driving stimulator might be longer than the time measured using a test on a computer.

In a computer test there is just a light/colour change (or a sound); in the simulator there are lots of things to look at/the driver might not be looking in the correct direction when the hazard appears / the driver has to decide if something they can see is a hazard.

Thinking distance

Factors affecting thinking distance- Reaction time and speed

The car is moving at constant speed during the driver's reaction time, so the longer the driver takes to respond to a stimulus, the further the car will have moved.

The faster the car is moving, the further it will go during the driver's reaction time.

Braking distance

Factors affecting braking distance

Braking distance increases with higher speed of the car, higher mass of the car, worn brakes, worn tyres, low friction road surface, e.g. mud, gravel, wet, ice

How visibility (fog) affect stopping distance

Fog **does not** affect the thinking or braking distances

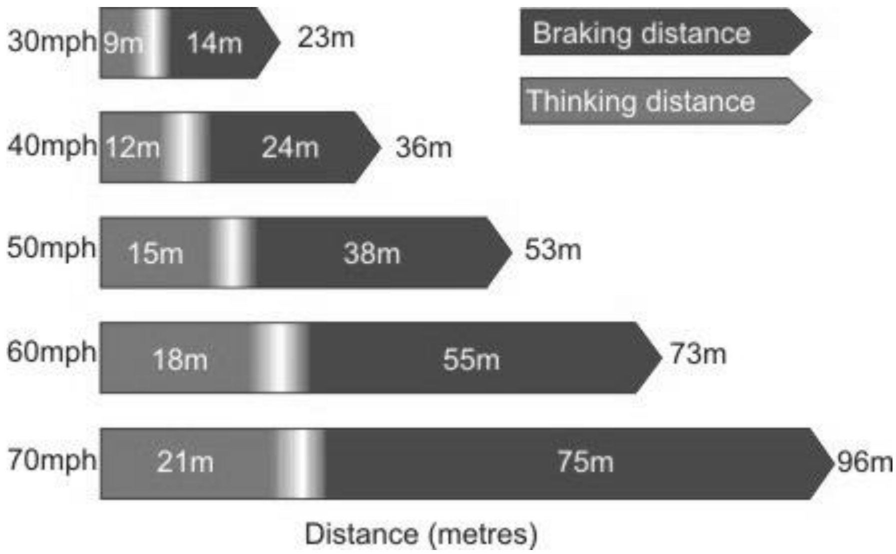
● Fog reduces the distance at which a hazard can be identified

● If the distance at which the hazard is identified is less than the stopping distance, the car will hit the object

● Drivers need to reduce their speed in foggy conditions until the stopping distance is less than the maximum distance they can see ahead

Highway code

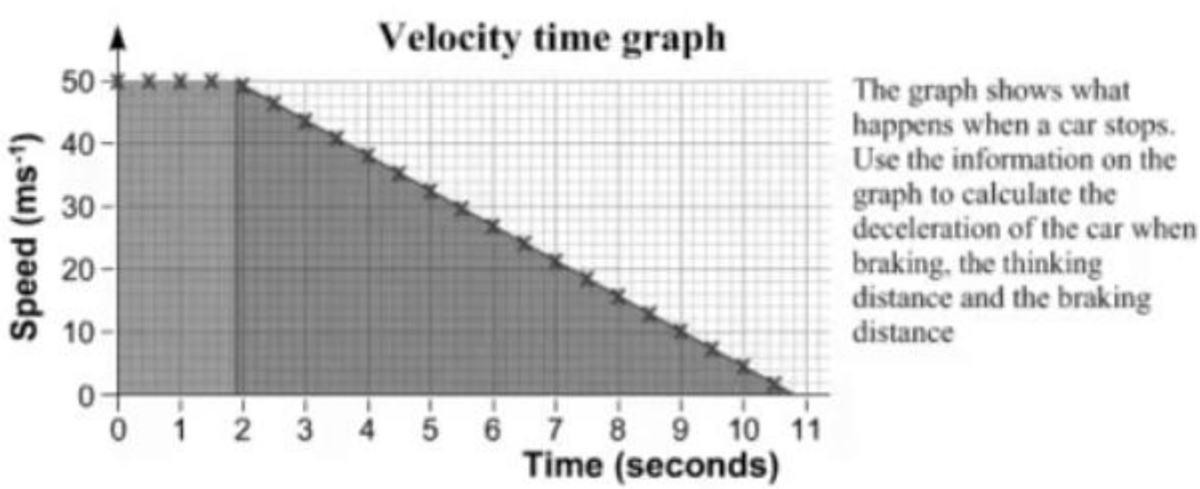
Typical stopping distances for cars are shown below.



The distances above are based on a reaction time of 0.67 seconds, which assumes the driver is alert, concentrating and not impaired. Driving when tired, distracted or impaired significantly increases reaction times, so the thinking distances above should be regarded as minimum.

The braking distance depends on how fast the vehicle was travelling before the brakes were applied, and is **proportional** to the square of the initial speed. That means even small increases in speed mean significantly longer braking distances.

Velocity time graph



Crash Hazards

In a car crash, the vehicles involved come to a stop very quickly. The car decelerates. The force needed for any kind of acceleration depends on the size of the acceleration and on the mass of the object.

Explain why the force on a vehicle in a crash is larger:

a) if the vehicle is moving faster before the crash

b) for a lorry than for a car travelling at the same speed.

Modern cars also have **safety features** that that help to reduce the forces on the occupants in **collisions**. These typically include:

- seat belts
- air bags
- crumple zones

All these features reduce injuries to the people in the car. As they **deform** they increase the amount of **time** the person takes to come to a stop. Since F= m(v-u)/t, this reduces the **acceleration and force** on the person, so reducing injury.

Seat belts

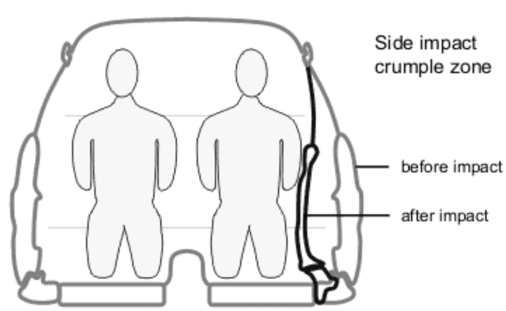
Seat belts are designed to stretch a bit in a collision. This increases the time taken for the body's momentum to reach zero, so reduces the forces on it.

Air bags

Air bags increase the time taken for the head's momentum to reach zero, so reduce the forces on it. They also act a soft cushion and prevent cuts.

Crumple zones

Crumple zones are areas of a vehicle that are designed to crush in a controlled way in a collision. They increase the time taken to change the momentum in a crash, which reduces the force involved.



The force in a road collision depends on the change of momentum as the car comes to a stop. We can use the formula below to calculate the force

$F = (mv—mu) /t$ where u is the intial velocity and v is final velocity