Year 11 Physics Notes - 2020

https://syllabus.nesa.nsw.edu.au/physics-stage6/
https://syllabus.nesa.nsw.edu.au/assets/physics_stage_6/physics-stage-6-syllabus-2017.pdf
https://drive.google.com/file/d/1OQ2LPi3EhgywYYH4WaZ3difTBWbJDaBf/view?usp=sharing
https://syllabus.nesa.nsw.edu.au/assets/global/files/physics-formulae-sheet-data-sheet-periodic-table-hsc-exams-2019.pdf

Module 1: Kinematics

Distance and Displacement

Distance is a **measure of the total length of the path** taken during the change in position of an object.

- **Distance** is a ***scalar quantity***. Scalar quantities are those that specify size/magnitude, but not direction. E.g. Distance is 11m

Displacement is a **measure of the change in the position** of an object - a straight line between where it started compared to where it finished

- **Displacement** is a ***vector quantity***. Vector quantities are those that specify a direction as well as magnitude.
  - E.g. Displacement is 5m north (from original position, even if the total distance travelled is 11m)

Example of Distance vs Displacement: A runner going around a 400m circular race track. Even if the runner runs a distance of 400m around the racetrack, since they end up at the start/finish line, their total displacement is 0m.

Speed and Velocity

Speed is the rate at which distance is covered per unit of time - it is a **scalar quantity**

There are two types:

Instantaneous speed

- Speed of an object at a *particular moment*

Average speed

- The average speed of an object tells us generally about the speed *over a given time*
  - For example, a car that makes a 120 kilometre journey from one side of the city to the other in two hours will have an average speed of 60km/h.
  - This doesn't mean that the car is constantly travelling at exactly 60 km/h for the whole trip

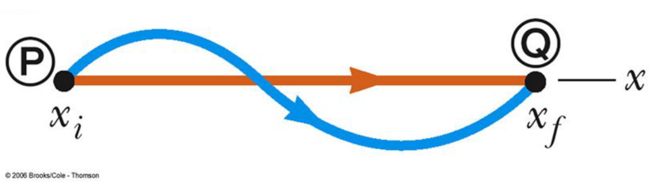
Distance = Speed x Time

Velocity is a measure of the rate of change in position/displacement in a given direction - it is a **vector quantity**

- It is the measure of speed in a given direction - E.g. wind speed
- Velocity has magnitude as well as direction
- If a ball is thrown up in the air and falls back straight down, it has a displacement of zero, so the velocity of the ball is zero

Displacement = Velocity x Time

Speed vs Velocity example:



- Cars on both paths have the same average velocity since they had the same displacement in the same time interval
- The car on the blue path will have a greater average speed since the distance it traveled is larger

Acceleration

Acceleration is the rate of change of velocity in a given direction - it is a **vector quantity**

- Like velocity, **acceleration has a direction**.
- If the **acceleration is at an angle** to the direction of motion, **the object will turn**.
  - Because acceleration is a vector quantity (which includes direction), if an object turns and keeps the same speed, it is still accelerating because it has changed its direction.
- Constant Acceleration is when an object's speed is increasing by a constant amount each second (e.g 10 m/s)
- Acceleration is measured in units of m/s^2 (metres per second per second, or metres per second squared)

Acceleration (m/s^2) = Change in Velocity (m/s) ÷Time (s)

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

Where v = final velocity, and u = initial velocity

When displacement is given instead of time, acceleration can be calculated with the formula:

$a = (v^2 - u^2)/2s$

Motion Graphing

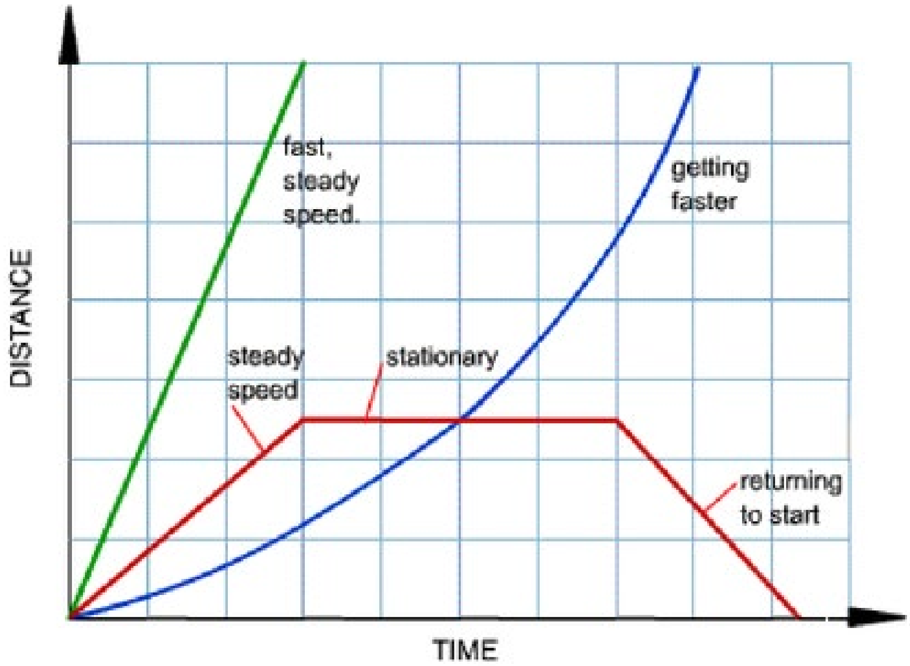
Motion Graphs are only useful for linear motion (forward/backwards). They graph either displacement, velocity or acceleration against time.

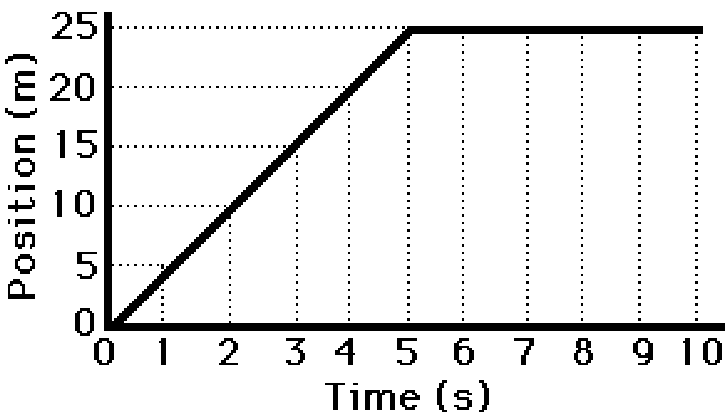
Displacement-Time Graphs

- Graph position of an object against time
  - Position on y-axis, Time on x-axis

How to Read:

- Horizontal line = Stationary
- Slope/Gradient = Velocity
  - Positive Gradient = Forward, Negative Gradient = Backward
  - Straight Line = Constant Velocity, Curved Line = Acceleration/Deceleration
- Instantaneous Velocity = Gradient of Tangent to curve
- Average Velocity = Gradient of Line between Two Points
- Total Distance = Sum of all Forward/Backward paths
- Total Displacement = Y-value of final point

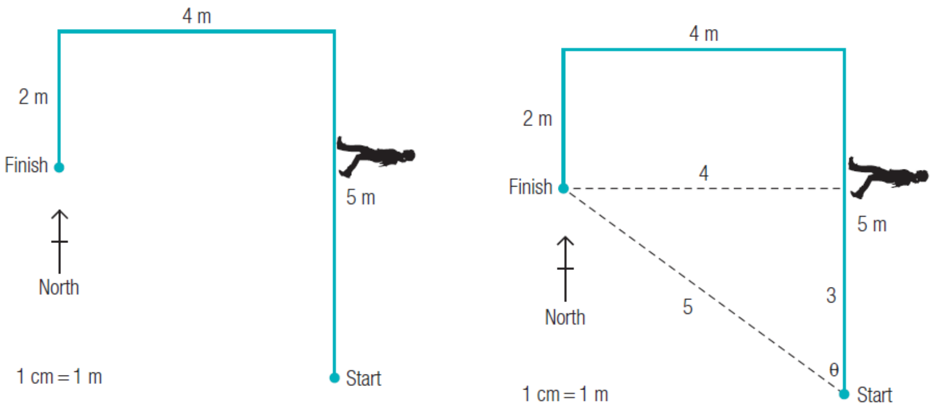




E.g. Describe the motion of the object above:
The object is moving at a continuous speed of 5m/s for 5 seconds, after which the object becomes stationary, keeping its final displacement at 25 metres north.

Displacement Diagrams

- Visually represent the displacement and path of an object in 2 dimensions
- The graph must have a compass, arrows, start, finish, units and a scale

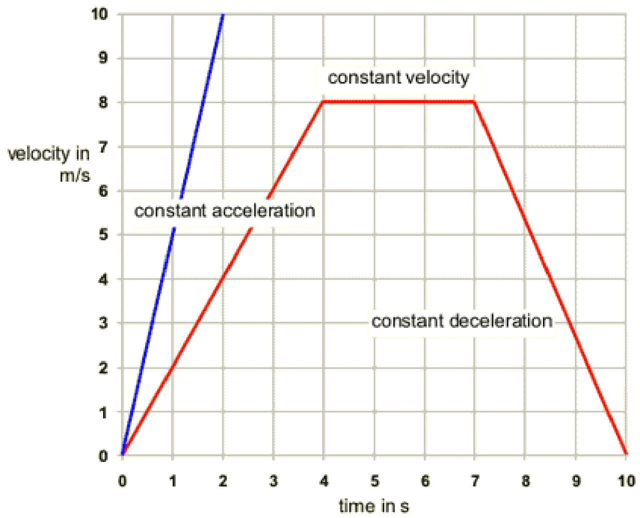


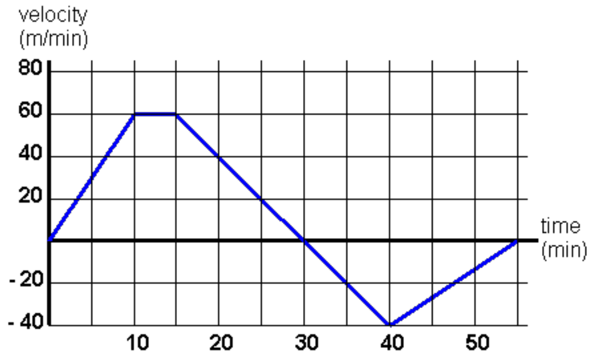
Velocity-Time Graphs

- Graph of velocity of an object against time
  - Velocity on y-axis, Time on x-axis

How to Read:

- Y-intercept = Initial Velocity, X-intercept = Object Stopped
- Below X-axis = Traveling Backwards
- Gradient = Acceleration
  - Positive Gradient = Acceleration, Negative Gradient = Deceleration
    - Until it hits the x-axis, after that, it begins accelerating in the opposite direction
  - Straight Line = Constant Acceleration, Curved Line = Non-constant Acceleration
  - Zero slope = Constant Velocity and Zero Acceleration
- Instantaneous Acceleration = Gradient of Tangent to curve
- Average Acceleration = Gradient of Line between Two Points
- Area under Curve = Displacement
  - Total Displacement = Area above x-axis - Area under x-axis
  - Total Distance = Area above x-axis + Area under x-axis





Acceleration-Time Graphs

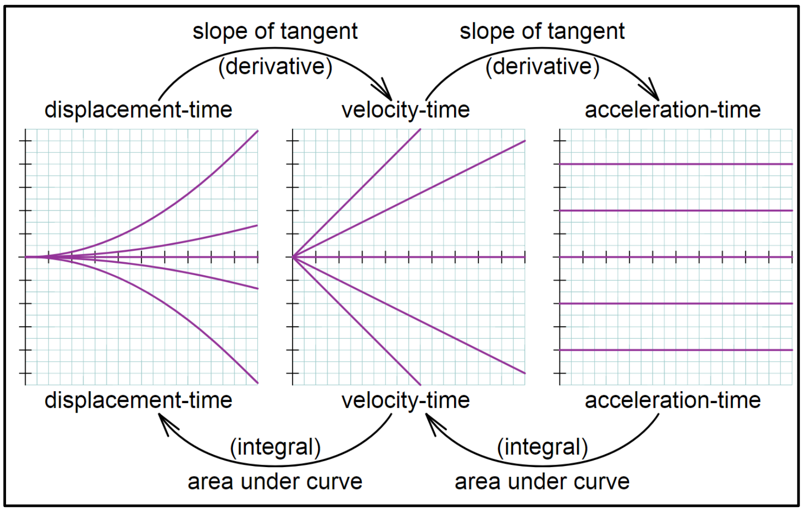
- Graph of acceleration of an object against time
  - Acceleration on y-axis, Time on x-axis

How to read:

- Same rules as other graphs
- HOWEVER, the gradient doesn't reveal anything
- Area under Curve = Change in Velocity

Graph	Slope	Area under the graph
position vs. time	velocity	-----
velocity vs. time	acceleration	displacement
acceleration vs. time	-----	change in velocity

** You don't need calculus for physics. **



Motion Formulae

- **$v = s/t$**
- **$a = (v-u)/t$**

CONSTANT VELOCITY

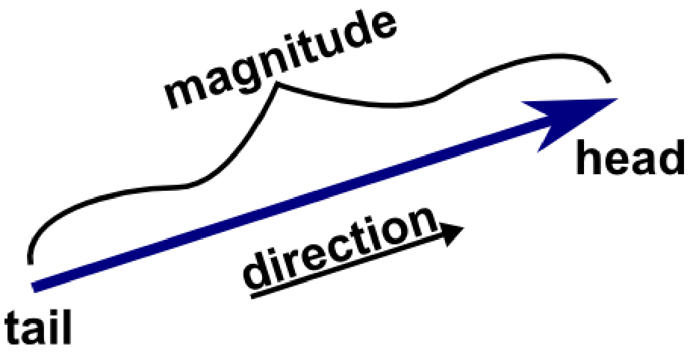
- **$s = vt$**

CONSTANT ACCELERATION

- **$v = u + at$**
- **$s = ut + \frac{1}{2}at^2$**
- **average velocity = $[v + u]/2$**
- **$v^2 = u^2 + 2as$**

Symbol	Meaning
v	Velocity
s	Displacement
t	Time
u	Initial Velocity
a	Acceleration

Vectors

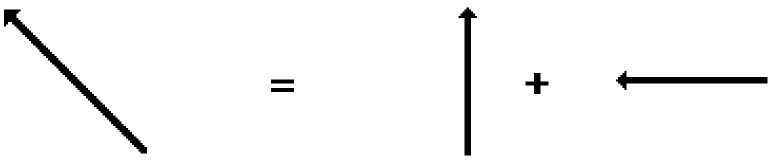


Vectors are lines with arrows which have a direction and magnitude - representing 2D motion (vector quantities in general)

The **direction** of a vector can be given both as words or as an **angle/bearing**

Vector Components

- If a vector isn't up/down or side-to-side, it is said to be made up of two **vector components - an x-component and y-component**
  - E.g. A vector that is directed to the North-West can be thought of as having two components - a leftward x-component and upward y-component



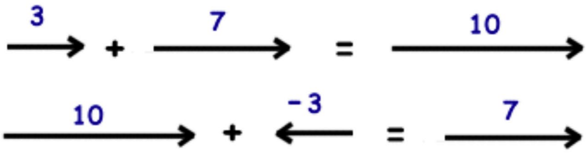
Northwest vectors have a northward and westward part.

Vector Analysis

An object can have multiple vectors (e.g. to represent multiple forces acting on it). By considering all these vectors, the motion of the object can be predicted.
Multiple vectors of an object can be added, subtracted or multiplied to get a resultant (final) vector, with rules being applied to each:

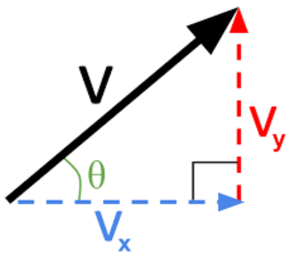
Vector Addition and Subtraction

Adding Parallel Vectors
- Add the magnitudes of vectors in the same direction
- Subtract the magnitudes of vectors in opposite directions



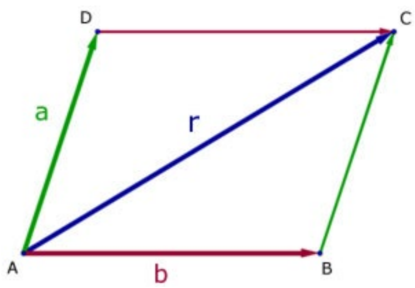
Adding Perpendicular Vectors

- Use Pythagorean theorem to determine magnitude of the resultant vector
- Use tan to determine direction (angle)
  - E.g. if a person walks 4 units to the right (Vx) and 3 units up (Vy), their resultant displacement vector will be $\sqrt{(3^2+4^2)}$ = 5 units and 37 degrees (V).



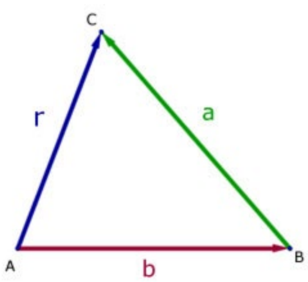
Adding Vectors that share the same origin

- If two vectors share the same starting point, then you can use the **parallelogram rule**
  - Construct a parallelogram using the two vectors
  - The resultant vector is the diagonal of the parallelogram coming out of the common vertex



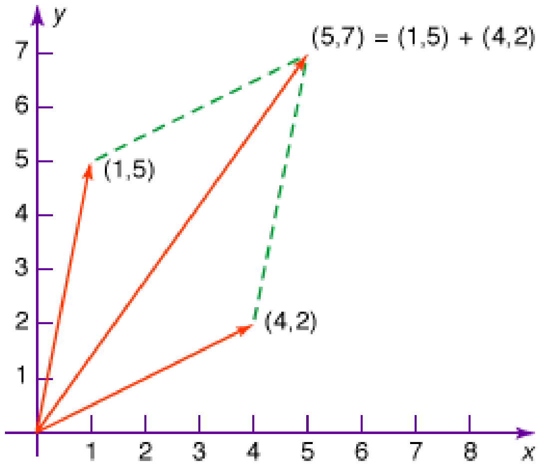
Adding Vectors arranged head-to-tail

- If two vectors are arranged head to tail, use the **triangle rule**
  - The resultant vector is the vector drawn from the tail of the first to the head of the second



Adding Vectors when the components are known

- The resultant vector’s y-component is the sum of the two other vector’s y-components, and the resultant vector’s x-component is the sum of the two other vector’s x-components
  - E.g. if one Vector is (x, y) and another Vector is (a, b), then the resultant vector is (x+a, y+b)



Vector Subtraction follows the same rules as vector addition, but the vector that will be subtracted is drawn in the opposite direction

Commutative Law - states that it does not matter in which order two vectors are added

Associative Law - states that if three or more vectors are to be added, it does not matter which two are added first

Vector Multiplication

Vectors can be multiplied by scalar quantities.

- When a vector is multiplied by a positive scalar quantity, it’s direction does not change, only magnitude.
  - E.g. if a vector pointing to the right was multiplied by 3, it would get three times longer, but still point to the right
- When a vector is multiplied by a negative scalar quantity, it’s direction flips 180 degrees, and it’s magnitude changes
  - E.g. if a vector pointing to the right was multiplied by -3, it would get three times longer, and point to the left
- Dividing a vector by a scalar follows the same rules
  - E.g. Dividing a vector by 3 is the same as multiplying it by 1/3

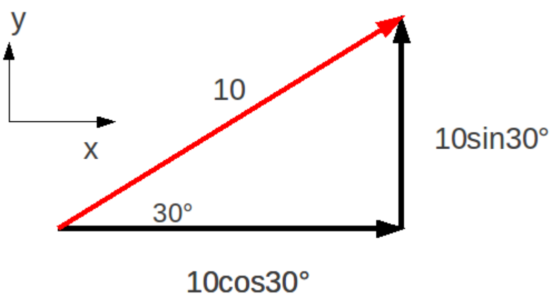
Distributive Law - If a vector’s components are known, then when multiplying by a scalar, both the x-component and y-component are multiplied by that number

- E.g. if the vector (x,y) was multiplied by 3, the resultant vector would be (3x,3y)

Vector Resolution

A vector **can be split into its x- and y-components** using trigonometry - this is called vector resolution.

If R is the vector that we need to resolve, and θ is the direction given as angle, then it's **x-component = Rcosθ**, and it's **y-component = Rsinθ.**



E.g. If R is 10, and θ is 30°, then the x-component = 10cos(30), and y component = 10sin(30)

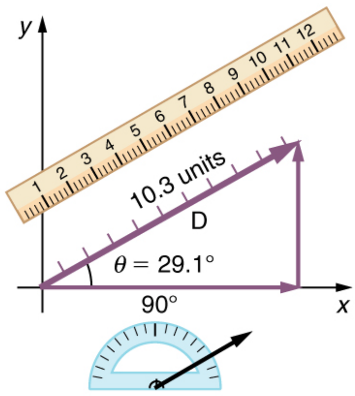
<u>IMPORTANT NOTE:</u> This only applies when the angle is from the horizontal - if the angle comes out from the bottom, then x = Rsinθ, and y = Rcosθ

Graphical vs Analytical Methods

The two ways of finding the resultant vector are through the graphical method (drawing a scaled diagram) or the more precise analytical method (using trigonometry).

<u>Graphical Method</u>

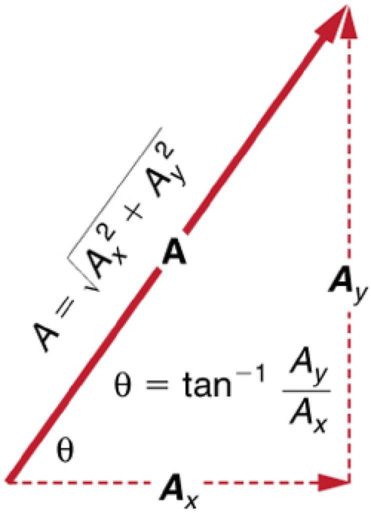
1. Using a ruler and protractor, draw the vectors on a cartesian plane, to scale.
2. Arrange them head-to-tail or starting at the origin
3. In accordance with the triangle rule or parallelogram rule, use a ruler and protractor to draw a triangle/parallelogram on the vectors
4. Draw the resultant vector, and then measure the magnitude and angle



<u>Analytical Method</u>

Remember, if the x- and y- components are known for two vectors, adding them simply means adding the two x- and two y- components together to get the x and y component of the resultant vector.

Vector Resolution enables the splitting of a vector into its components, so by splitting the vectors that need to be added, it makes it easier to add them mathematically.



1. Split the two vectors that need to be added into their x- and y- components using vector resolution.
2. Add the x- and y-components of the two vectors together to get the x- and y-component of the resultant vector
3. Use pythagoras/the cartesian distance formula to get the magnitude of the resultant vector.
4. Use $\tan^{-1}()$ to get the angle (direction) of the resultant vector.

Basically, if adding Vector A + Vector B, the resultant vector has coordinates:

$$\mathbf{R(x, y) = (A\cos\theta + B\cos\theta, A\sin\theta + B\sin\theta)}$$

https://www.texasgateway.org/resource/33-vector-addition-and-subtraction-analytical-methods ← There's an example question at the bottom of this page

Relative Velocity

Relative Velocity refers to the fact that **velocity depends on the observer's frame of reference.**

For example, a water bottle in a bus may look like it's stationary to the person next to it, but relative to a person outside, the bottle is moving at 50 km/h along with the bus.

Evaluating the Relative Velocity of an object involves vector addition. The basic formula is given by:

$$V_{AB} = V_{AE} - V_{BE}$$

→ This formula means that the **velocity of A relative to B is equal to the velocity of A relative to the Earth (E) minus the velocity of B relative to the Earth (E)**.

Note, $V_{BA} = -V_{AB}$

Example Relative Velocity Questions

If A = train, B = car, and E = Earth

The train is travelling at 60 km/h, and the car is on a road next to it travelling in the same direction at 50 km/h. What is the velocity of the train relative to the car?

- The train (A) is travelling at 60 km/h relative to the Earth (E) - this is V_{AE}
- The car (B) is travelling at 50 km/h relative to the Earth (E) - this is V_{BE}
- The velocity of the train relative to the car is V_{AB}, whis is the vector subtraction of $V_{AE} - V_{BE}$ = 10 km/h

If A = ball, B = person on train, and E = Earth:

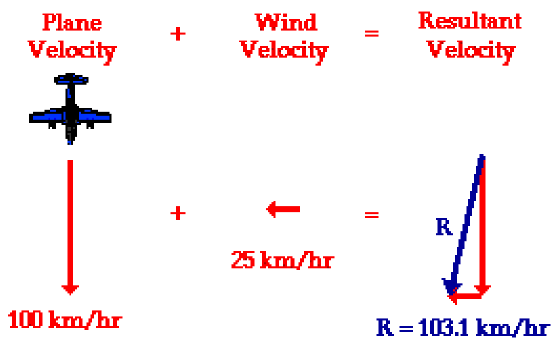
The ball is thrown forward at 1 km/h by the passenger. The passenger is on a train travelling at 60 km/h. What is the velocity of the ball relative to Earth?

- The ball (A) is travelling only at 1 km/h relative to the passenger (B) - this is V_{AB}.
- The passenger (B) is travelling at 60 km/h relative to the Earth (C) - this is V_{BE}.
- The velocity of the ball relative to Earth is V_{AE}, which is equal to the vector sum of $V_{AB} + V_{BE}$ = 61 km/h.

If A = plane B = air (wind) and E = Earth:

The plane is travelling south at 100 km/h, and encounters a crosswind of 25 km/h west. What is the velocity of the plane relative to the Earth?

- The plane (A) is travelling at 100km/h south relative to the air (B) - this is V_{AB}
- The air (B) is travelling 25 km/h west relative to Earth (E) - this is V_{BE}
- The velocity of the plane relative to Earth is V_{AE}, which is equal to the vector sum of $V_{AB} + V_{BE}$, using pythagoras:



The *riverboat physics problem* contains a trick question which is likely to come up in exams. Scroll to the bottom of this page for a thorough explanation:

http://www.physicsclassroom.com/class/vectors/Lesson-1/Relative-Velocity-and-Riverboat-Problems

Module 2: Dynamics

Forces

A force is a push or pull acting on an object, as a result of its interaction with another object, causing it to accelerate, decelerate, change direction or change shape.

- Forces are vector quantities with symbol (F), and are measured in Newtons (N). Multiple forces can act on a single object.

Unbalanced forces (i.e. one side having a greater force) is what causes objects to change their motion.

- E.g. the upward force of your legs can temporarily overcome the downward force of gravity, allowing you to jump

Net Force refers to the overall/final force acting on an object once all forces are considered.

- E.g. An object that has a 300N forward force and 200N backward force has a net force of 300N-200N = 100N forwards
- If the forces on an object all balance out, it is said to have **zero net force**, and does not accelerate

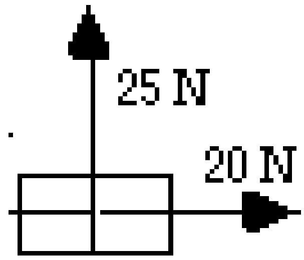
There are two types of forces - contact and non-contact forces.

- **Contact forces** are those that physically touch an object, such as *Friction* or *Air Resistance*.
- **Non-contact Forces** do not physically touch an object, such as *Electromagnetic* or *Gravitational Forces.*

Force Diagrams

The net force of an object can be calculated through vector addition/subtraction of all its forces. Also, given the net force of an object, vector resolution can be used to find the individual forces acting on it.

For example, given the following vector diagram:



- Using pythagoras, $\sqrt{(25^2+20^2)} = 32$,
- Using trig, $\tan^{-1}(25/20) = 51°$.
- So the net force has a magnitude of 32N and a direction of 51°

Conversely, if you were given a vector of 32N and direction of 51°:

- Using Vector Resolution, the x-component is 32cos51 = 20N, and the y-component is 32sin51 = 25N, which are the individual forces of the object as shown in the diagram

Newton's Three Laws of Motion

The Law of Inertia

An object at rest will remain at rest unless acted on by an unbalanced force. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an unbalanced force.

- **Inertia** is the tendency of an object to resist changes in its state of motion. The more mass an object has, the more inertia it has and the harder it is to change its motion.

- E.g. An asteroid in space continues forward in a straight line until another asteroid bumps it in another direction

The Law of Acceleration

The acceleration of an object is directly related to the magnitude and direction of the force acting on an object, and inversely related to the mass of the object.

- Basically, the more mass an object has, the greater the force needed to accelerate it, and the more force is applied, the more the object accelerates. This law can be summarised by the formula:

Force(N) = Mass(kg) x Acceleration(m/s^2) → *F=ma*

- E.g. Pushing a large, heavy cabinet is much slower than pushing around a coffee table

The Law of Reaction

For every action there is an equal and opposite reaction.

- Basically, every force applied has an equal and opposite force pushing back. But the effect of the force on each object involved is dependent on the mass, size, material etc of the objects.

- E.g. If you push someone forward on an ice-skating rink you'll slide backwards as well.

Types of Noncontact Forces

Magnetic, Electric and Gravitational are the three fields that exert a noncontact force on objects, in order of highest to lowest strength.

Mass and Weight

Mass is a scalar quantity that is used to describe the **absolute quantity of matter in an object**

- Mass is measured in Kilograms (kg)

Weight is a vector quantity that is a measure of the **force of gravity on a mass**

- Weight is measured in Newtons (N), and needs a direction as well
- Weight is directly proportional to the strength of the gravitational field, summarised in the formula:

Weight(N) = Mass(kg) x Gravitational acceleration(m/s^2)

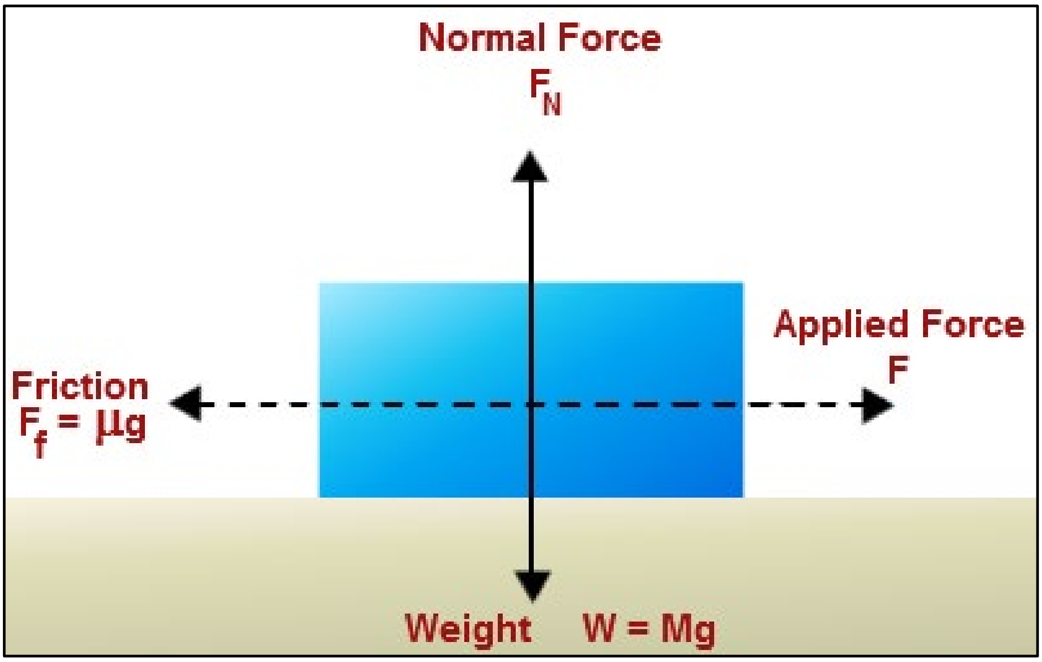
$$W = mg$$

(Gravitational acceleration on Earth = 9.8 m/s^2)

For Example, If someone has a mass of 100kg on Earth, then their mass will still stay the same on the moon because mass is constant. However, a reading on a scale on the moon would change because the gravity (and therefore weight) is much lower:

- Weight on Earth = 100 kg x 9.8 m/s^2 = 980 N
- Weight on Moon = 100kg x 1.6 m/s^2 = 160 N

Types of Contact Forces



Normal and Applied Force

Normal force is the support force exerted upon an object that is in contact with another stable object.

- The normal force is perpendicular to the surface it is in contact with

For Example, a when a book rests on a table, the table exerts an upward normal force on the book that is equal and opposite to the book's downward weight force - to support the book and stop it from falling through the table.

Applied Force is a force applied to an object by a person or other object.

For Example, when a person pushes a table, the force they produce is an applied force.

Friction

Friction is the force that opposes the motion of an object, acting between an object and a contacting surface.

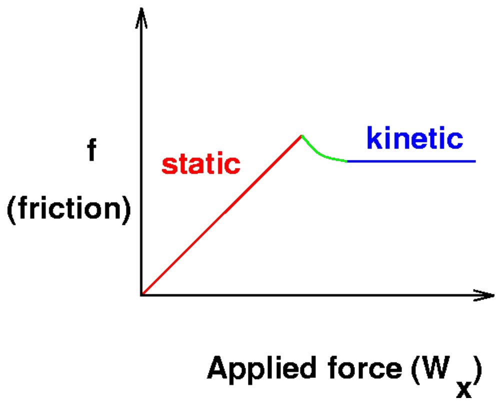
- Friction is parallel to the surface it is in contact with
- Due to friction, an equal size pushing force needs to be supplied to maintain zero net force i.e. constant velocity.
  - E.g. if you stop applying accelerating force to a car, friction will eventually make it slow down and stop

- Friction can only be neglected in certain situations, such as in space or across a smooth frictionless surface.

Static Friction is the friction between a stationary object and a surface. When the object is moving, then **Dynamic/Kinetic Friction** exists.

- Static Friction is equal to the applied force until it reaches a peak, after which the object starts moving and Dynamic friction is present. Dynamic friction is constant no matter how much force is applied

A graph of friction as the applied force increases is shown below:



Air resistance is a specific type of friction force between a moving object and air particles and is only significantly noticeable at high speed and in objects with large surface areas.

Friction can be defined mathematically as:

Friction(N) = Coefficient of Friction x Normal Force(N)

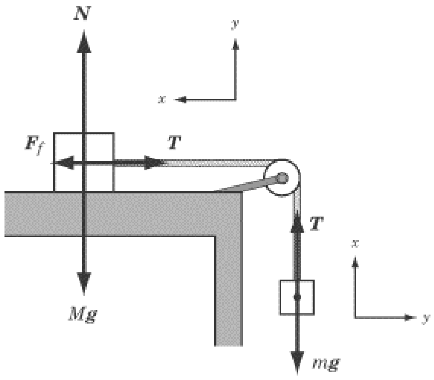
$$F_f = \mu F_N$$

The Coefficient of Friction (μ) is a number between 0 and 1 determining the amount of friction between two surfaces. It's value depends on the material, surface texture, motion etc of the two objects, so is not constant.

Tension

Tension is the pulling force exerted by a rope, string, or chain. Tension can only pull, so ensure you draw the vector in the correct direction in force diagrams.

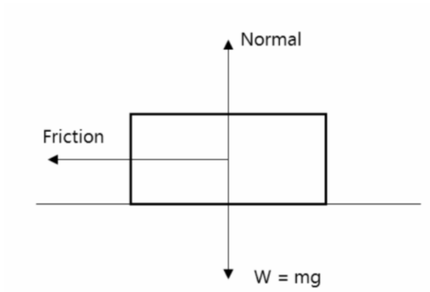
Pulleys are devices used to change the direction of a tension force in a rope - such as in the diagram below - again, think about which direction the tension is acting in.



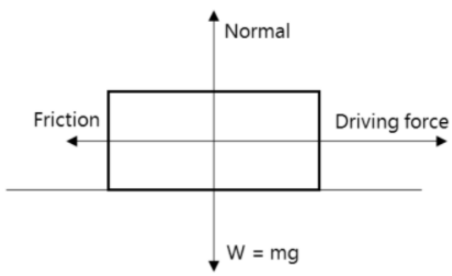
<u>Vehicle-based Examples of Newton's Laws</u>

The downward weight force of gravity on the car is counteracted by the equal and opposite upward normal force, allowing it to move, and preventing it from being crushed by gravity - Newton's' 3rd Law.

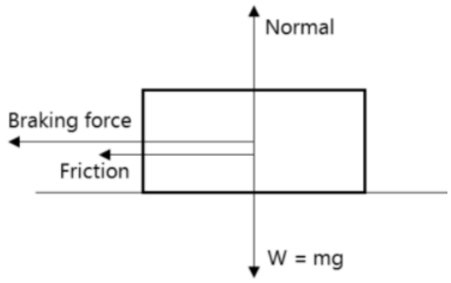
- No pressure on the accelerator → Friction acts as an unbalanced force (1st Law) and gradually slows the car down



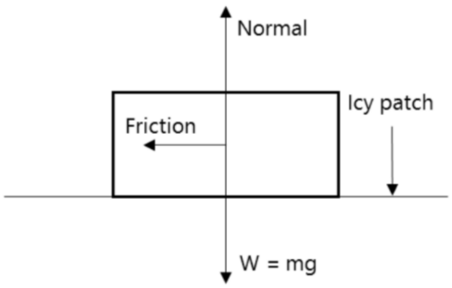
- Pressure on accelerator → Overcomes Friction (1st Law), is strong enough to move the car forward (2nd Law)



- Pressure on brakes → Decelerating force works alongside friction (1st Law) and slows the car down much faster (2nd Law)

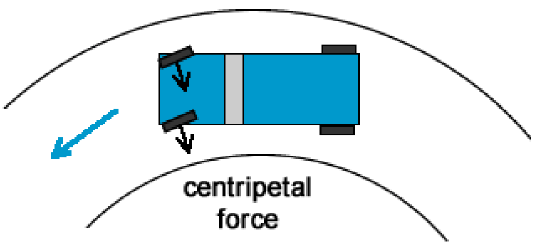


● Driving over an icy patch → Friction force is reduced, accelerating becomes much easier and decelerating becomes harder (1st Law), possibly causing skidding.



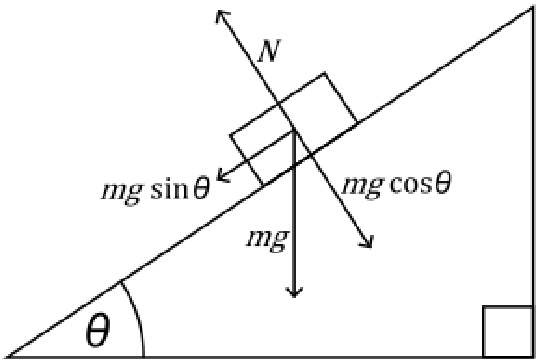
● Driving around a bend → The combination of applied (driving) force and friction force of the wheels against the road is what causes the centripetal force that leads the car around the bend.

Objects on an Incline



On a plane inclined θ degrees, the Normal force (N) is tilted because it has to be perpendicular to the surface, and the Weight force (mg) is directly down.

To find the net force, the **Weight vector can be split into two perpendicular components (mg*sinθ and mg*cosθ) using vector resolution**. Then, use basic vector addition to find the net force, just like on a normal object.



Work

Work is done whenever an **object is moved any distance by a force**.

- Work is a **scalar quantity** with symbol (W), and measured in Joules (J)

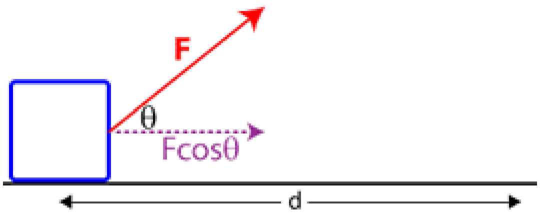
If an object *does not move*, then work is *not done*. If an object is moved by a force, then it gains kinetic energy.

Work is proportional to the magnitude of the force and the distance over which it moves, summarised in the formula:

Work (J) = Force (N) x Distance (m)

W=Fd

Note: The force that you use in the equation must be in the *same direction as the distance* travelled. For example, in the following,



The net force is F, but the object moves a distance in a different direction. So in the equation, you would use Fcosθ (the x-component of F) instead of F.

When the net force and distance travelled are in different directions, W = Fs*cosθ

Work-Energy Principle

Work requires energy to be done. Therefore, following the law of energy conservation, the work done on an object is equal to the change in its energy. For example, if we equate work to the change in kinetic energy:

Work = Change in Kinetic Energy

$$W = \Delta KE = \frac{1}{2}mv_a^2 - \frac{1}{2}mv_b^2$$

This principle also applies for other forms of energy, such as change in gravitational energy where $W = mgh_a - mgh_b$

This principle is very useful for many physics problems.

Power

Power is the **rate of doing work**, or the amount of energy transferred per unit of time.

- Power is a **scalar quantity**, with symbol (P), and measured in Watts (W) or joules-per-second (J/s)

Power, unlike work, is also dependent on time. For example, A person walking a box upstairs or running a box upstairs does an equal amount of work, but running needs more power as it takes less time. This is summarised in the formula for average power:

Power (W) = Work (J) ÷ Time (s)

$$P_{av} = W/t$$

Alternatively, for instantaneous power

$$P_{instant} = Fv$$

Energy

Energy is defined as the **"ability to do work"** or cause change - i.e, if 100 Joules of work is done, 100 Joules of energy is needed.

- It is a scalar quantity, measured in Joules (J)

There are many forms of energy, and each form can be transferred between objects, or converted (or **transformed**) into another form. The two main forms of energy involved with motion are:

<u>Kinetic Energy</u>

- Energy that an object has because it is in motion
- KE is directly proportional to the mass and velocity of an object
    - Objects with larger mass or higher velocity will have more KE

Kinetic Energy (J) = ½ x Mass (kg) x Velocity^2 (m/s)

$$KE = ½mv^2$$

<u>Gravitational Potential Energy</u>

- Energy that an object stores by being lifted to a height
- GPE is directly proportional to the altitude and mass of an object
    - Objects that are higher up or have more mass will have more GPE

Gravitational Potential Energy (J) =
Mass (kg) x Gravitational acceleration (m/s^2) x Height (m)

$$GPE = mgh$$

(Gravitational Acceleration on Earth = 9.8 m/s^2)

Sound and Heat/light energy are also involved, especially in collisions where some of the ke/epe/gpe is turned into sound and heat

- Friction also wastes energy by converting it to heat and sound

Conservation of Energy

The Law of Conservation of Energy states that **energy cannot be created or destroyed**. Therefore, the **total energy** within an isolated system (i.e the Universe) **does not change**.

E.g. If you lift a 100g object 1m high, you give it 1 joule of gravitational potential energy (GPE). When the object is dropped and falls 1m, the GPE is converted to Kinetic Energy (KE), and it accelerates. After falling 1m, it has turned 1 joule of GPE into 1 joule of KE (ignoring friction etc). The total energy is the same.

Collisions

A **Collision** is an mechanical interaction between two or more objects that results in an exchange of energy.

- Collisions can be physical or indirect (i.e. with colliding electromagnetic fields pushing magnets away)
- Collisions do not have to be powerful - a car crash is a collision, but an ant touching a leaf is also a collision

There are two types of collisions:

Elastic Collisions

A perfectly elastic collision is one where **kinetic energy is fully conserved**.
These collisions are impossible in real life, as some kinetic energy is usually converted to heat, sound etc - however, some collisions are almost perfectly elastic so this is ignored.

- For example, if there is a rubber ball that is bounced on the ground and comes back up at the same speed, then it is an elastic collision as it keeps its kinetic energy

Inelastic Collisions

An inelastic collision is one where **kinetic energy is partially converted to other forms**, such as heat/sound.
While kinetic energy may not be conserved here, momentum is always conserved.
A fully inelastic collision is impossible irl.

- For example, if a car crashes into a wall, it stops completely, and its kinetic energy is converted to heat and sound - an inelastic collision. Inelastic collisions are generally more damaging than elastic collisions.

Momentum

Momentum is "mass in motion" - it refers to the direction and quantity of motion that an object has.

- It is a **vector quantity**, with symbol **p**, measured in kilogram metres per second (kg m/s)

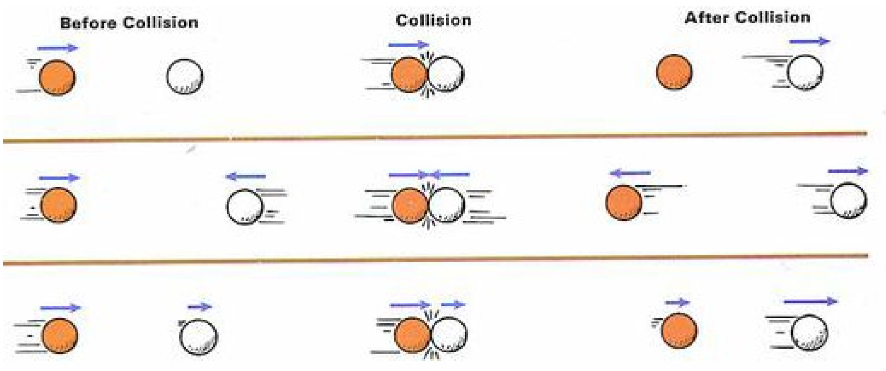
Momentum (kg m/s) = Mass (kg) x Velocity (m/s)

$$p = mv$$

Momentum is directly linked to inertia. The larger and/or faster an object is moving, the more difficult it is to stop. Therefore, since momentum is proportional to mass and velocity, **objects with greater momentum have greater inertia.**

Conservation of Momentum

The Law of Conservation of Momentum states that in an isolated system, the **total momentum** of two objects **before a collision is the same as after the collision**.



The effect of each collision will be different depending on the properties and motion of the two objects - i.e. the objects may bounce back, continue forward as one unit, or one may stop while the other gains speed.

However, in each case, total momentum is conserved, even though each object will have a different individual momentum.

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

When two objects join together after a collision:

$$m_1u_1 + m_2u_2 = (m_1 + m_2)v$$

Impulse

Impulse is defined as a **change in momentum** of an object.

- It is a **vector quantity**, with symbol (J), measured in kilogram-metres-per-second (kg m/s)

Impulse (kg m/s) = Change in Momentum = Force (N) x Time (s)

$J = mv - mu = \Delta p = Ft$

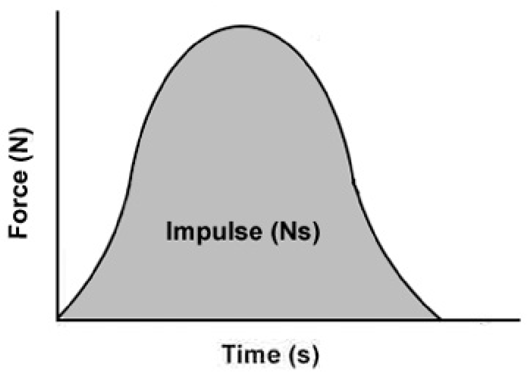
Also, The net force acting on an object is equal to the rate of change of momentum:

Force (N) = Change in Momentum (kg m/s) ÷Time (s)

$F = \Delta p/t$

In a collision, two objects are exerting forces upon one another. The magnitude of the force and the time that it is exerted also affects the motion and damage incurred by the two objects. I.e. giving someone a quick, light push vs a long, hard shove.
To completely stop an object (i.e. change it's momentum to 0), there either needs to be a large force for a short period of time, or a smaller force for a longer period of time.

Force-Time Graphs



Impulse is the area under the force-time curve

Example Impulse Question

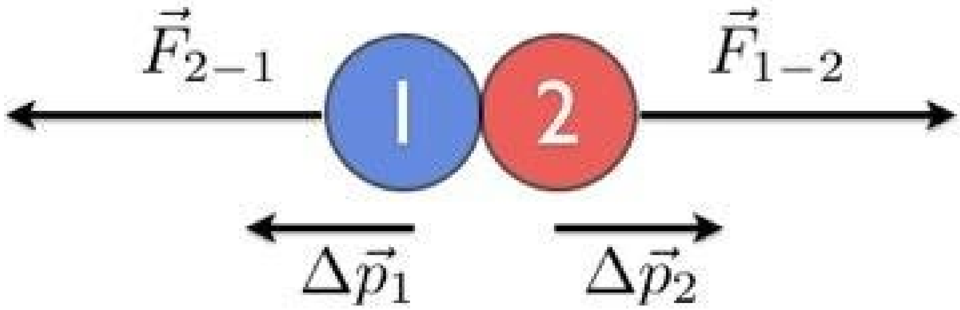
An astronaut must push a 4000 kg capsule in space as fast as possible. Trying his hardest, he can hold a 50kg weight above himself for 3 seconds. How fast can he make the capsule move?

- First, calculate the impulse he can apply.
  - J = Ft, so J = m*a*t
  - In this case, the mass is 50 kg, acceleration is 9.8 m/s^2 (due to gravity), and time is 3 seconds. Therefore, Impulse = 50*9.8*3 = 1471.5 kg m/s
- Remember, Impulse is also equal to the change in momentum
  - $J = \Delta p = mv - mu$

- The mass of the spaceship is 4000kg. If we divide the change in momentum by the mass, we get v-u, which is the velocity that the astronaut can move the capsule.
- Impulse/Mass = 1471.5/4000 = 0.37 m/s

The astronaut can move the capsule at 0.37 m/s.

Newton's Cradle - Demonstration of Conservation of Momentum



When the ball is raised, it gains gravitational potential energy, which is converted to kinetic energy when it hits the other ball in an inelastic collision - sound energy is released.

The reason only one ball moves at a time demonstrates the conservation of momentum, were the change in momentums of all the balls are the same.

When two balls are collided, they also move up at the same time period - which demonstrates Newton's third law: (Ft = -Ft, therefore F = -F), and thus the force exerted by each ball has an equal and opposite reactionary force.

Module 3: Waves and Thermodynamics

A **wave** is a disturbance that transfers energy through matter or space. Waves consist of a vibration (oscillation) in a physical medium or field

Types of Waves

Mechanical Waves

Mechanical Waves propagate through physical matter by the motion of the particles in the matter itself - for example, sound travels by air particles bumping into their neighbors. However, after the wave has passed, the particles return to their original positions - there is no net displacement.

- Mechanical waves are subject to friction, air resistance and other physical retarding forces, so slow down over time due to loss of energy
- Other examples include: Water waves, Slinky waves, Waves in a rope

Temperature, Density and Elasticity

Mechanical Waves are affected by temperature, density and elasticity

- **Temperature** refers to the kinetic energy of the particles in the medium - higher temperatures mean the particles vibrate faster, so waves can travel faster
- **Density** refers to the mass in a certain volume of the medium - waves travel slower through denser substances (given that all other properties are the same) - i.e. a wave will still travel faster in a solid than a gas etc
- **Elasticity** refers to the tendency of a material to maintain its shape and not deform when a force is applied to it. Rigid materials are actually more elastic than flexible materials - the force between their particles is stronger, so they come back to their resting positions faster. Thus, waves travel faster through more elastic materials.
  - Gases are much less elastic than solids, so waves travel fastest through solids, and slowest through gases

Waves travel fastest in hot, less dense, rigid solids.

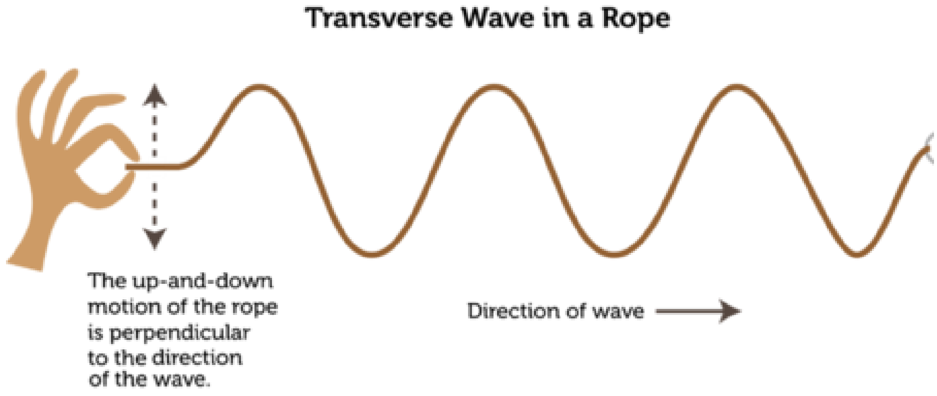
Electromagnetic Waves

Electromagnetic waves do not require a medium. Instead, they consist of periodic vibrations of electrical and magnetic fields, and can therefore travel through a vacuum - for example, visible light.

- They are not subject to the same energy losses due to physical forces as Mechanical Waves, so have a much greater travel distance.
- Other examples include: Gamma rays, Infrared, Radio Waves, Micro Waves

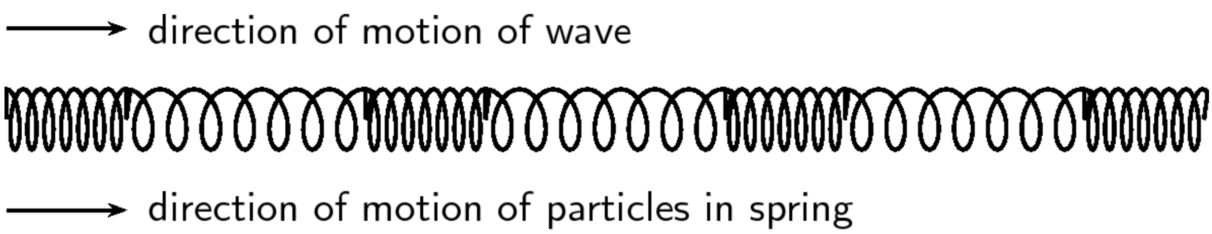
Transverse vs Longitudinal

A **transverse wave** is a wave in which particles of the medium move in a direction perpendicular to the direction that the wave moves.



Another example is water waves, where the water particles move up and down, but the wave travels forward.

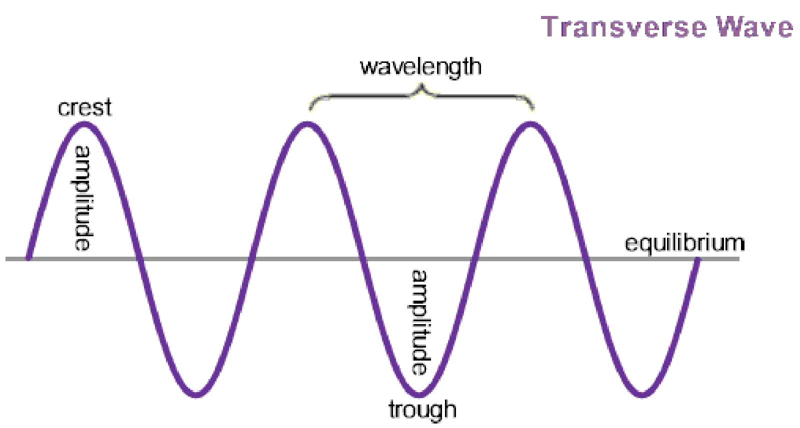
A **longitudinal wave** is a wave in which particles of the medium move in a direction parallel to the direction that the wave moves.



I.e. When you push a slinky, the displacement of the spring hoops is in the same direction that the wave is travelling

When represented as a graph of displacement against time, compressions are crests, while rarefactions are troughs

<u>The Wave Model</u>



Crest/Trough - The highest or lowest points of the wave respectively

Amplitude - The distance from the centre line (or still point), measured in Metres.

- It is the maximum amount a particle can move from its still position.

Wavelength - The distance between two crests or troughs, measured in Metres, with the symbol (λ). In a longitudinal wave, it is the distance between two compressions or rarefactions.

- It is technically defined as the distance between a point on one wave and an identical point on an adjacent wave.

Period - The time it takes to complete one cycle (one wavelength), measured in seconds (s), with symbol (T)

Frequency - How many waves (wavelengths) pass a point in a second, measured in Hertz (Hz), with symbol (f)

$$f = 1/T$$

(Frequency (Hz) = 1 / Period (s))

Velocity - The product of the wavelength and frequency, measured in m/s

$$V = \lambda f$$

(Velocity (m/s) = Wavelength (m) x Frequency (Hz))

Wavenumber - the number of wavelengths per unit distance

$$k = 2\pi/\lambda$$

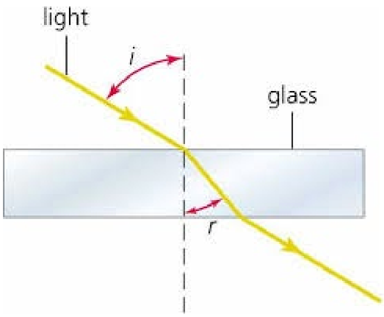
(Wavenumber = 2 pi radians / Wavelength (m))

Movement of Waves

Waves can reflect, refract, disperse or diffract depending on the medium or field that they make contact with.

Reflection - the wave bouncing off a material

Refraction - the wave passing through a material and changing direction



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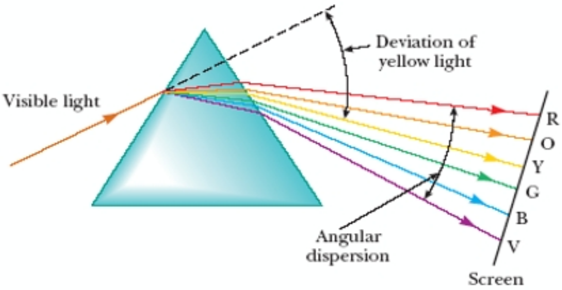
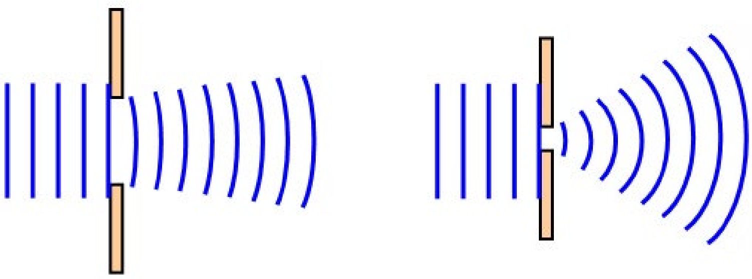
Dispersion - occurs when different wavelengths of light are refracted different amounts, separating the light into its constituent colors



Diffraction - the wave propagating outwards when encountering a slit/gap



Inverse Square Law

Waves lose intensity as they get further from the source because the energy in them disperses in multiple directions, so has an increasingly large surface area to cover over time.

E.g. sound gets quieter the further away you are, light gets dimmer the further away you are (light intensity is measured in lux)

The inverse square law only applies to waves that travel in all directions from the source - a ripple in a pond only travels in two dimensions, so the law doesn't apply.

The inverse square law illustrates this phenomenon in the formula (∝ = inversely proportional to):

$$I \propto 1/r^2$$

(Intensity ∝ 1 / Distance from source Squared)

$$I_1 r_1^2 = I_2 r_2^2$$

Wave Superposition and Interference

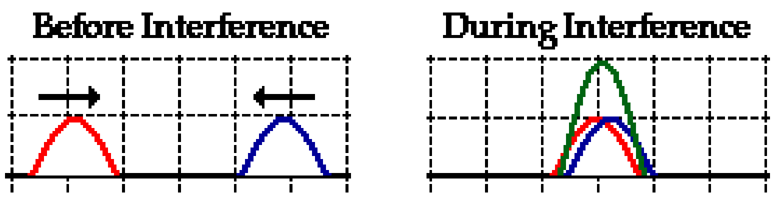
http://www.physicsclassroom.com/class/waves/Lesson-3/Interference-of-Waves

The Principle of Superposition:
When two waves interfere, the resulting displacement of the medium at any location is the algebraic sum of the displacements of the individual waves at that same location.

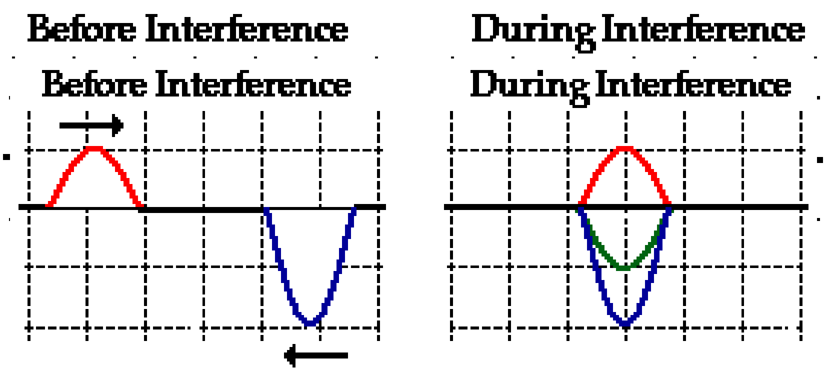
When two waves in the same medium meet, their resulting shape (amplitude) is equal to the addition of the heights of the two waves.

Interference can be **constructive** or **destructive**.

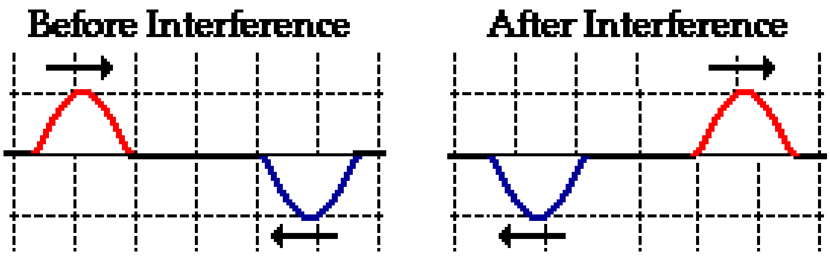
When two waves which are displaced in the same direction meet, they create a higher wave.



When two waves which are displaced in opposite directions meet, they cancel out if they have equal amplitudes, or make a smaller wave if they have different amplitudes.



However, waves continue to move in their original motion after interfering with each other - it isn’t like a usual collision.



Resonance: an object free to vibrate tends to do so at a specific rate called the object's natural, or resonant, frequency.
Such an object will vibrate strongly when it is subjected to vibrations at a frequency equal to or very close to its natural frequency.

<u>Standing vs Progressive Waves</u>

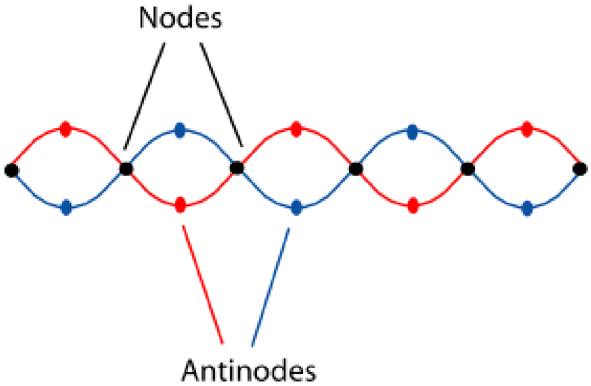
Progressive Waves - waves propagate through the medium

Standing Waves - particles in the wave oscillate but the wave itself stays stationary.

It is created when the vibrational frequency of the source causes reflected waves from one end of the medium to interfere with incident waves from the source. This interference occurs in such a manner that specific points along the medium appear to be standing still.

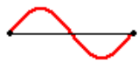
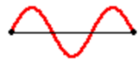
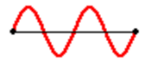
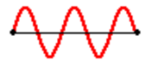
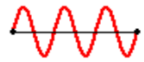
For example, a wave on a slinky attached to a wall, if at a particular wavelength, will become a standing wave.

- The points on the standing wave that do not displace at all (remain at equilibrium position) are called nodes. The points which reach maximum displacement are called antinodes



Harmonics

Standing waves form at specific wavelengths - known as **harmonics**. If vibrations occur at any other frequency, then the wave after reflection becomes irregular and not a standing wave.
The first harmonic is called the fundamental frequency/wavelength.

Harmonic	# of Nodes	# of Antinodes	Pattern
1st	2	1	
2nd	3	2	
3rd	4	3	
4th	5	4	
5th	6	5	
6th	7	6	
nth	n + 1	n	--

Harmonics (excluding the first) are also often called overtones - which are tones of higher frequency than the fundamental frequency. Thus, the 2nd harmonic is the 1st overtone, 3rd harmonic is the 2nd overtone, etc.

The **frequency** of each harmonic is it's harmonic number x fundamental frequency. For example, if a string has a fundamental frequency of 40Hz, then the frequency of the third harmonic = 3 x 40 = 120 Hz.

$$f_n = nf_1$$

Frequency of nth harmonic = n x Fundamental Frequency

For wavelengths, the relationship is:

$$L = n \times (\lambda_n / 2)$$

Length of String = n x (Wavelength of nth harmonic / 2)

The velocity of a wave in a string is determined by the length of the string, the tension and the mass per unit length:

$$v = \sqrt{(T/ml^{-1})}$$

Velocity(ms^{-1}) = $\sqrt{}$(Tension (N)/ Mass per unit Length 9(gm^{-1}))

Sound Waves

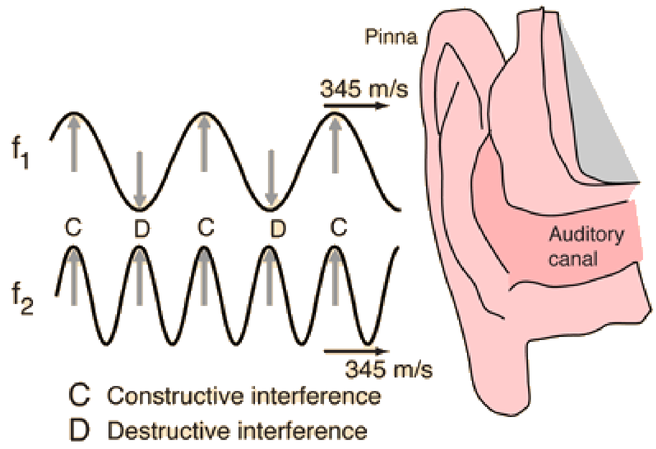
A Sound wave is a mechanical wave travelling as vibrations in the air.

- Amplitude is directly proportional to volume
- Frequency is directly proportional to pitch

Sound travels as a longitudinal wave, with compressions and rarefactions. It also travels in all directions from the source.

Beats

When two sound waves of different frequencies approach your ear, the alternating constructive and destructive interference sound simultaneously soft and loud - these are known as beats.

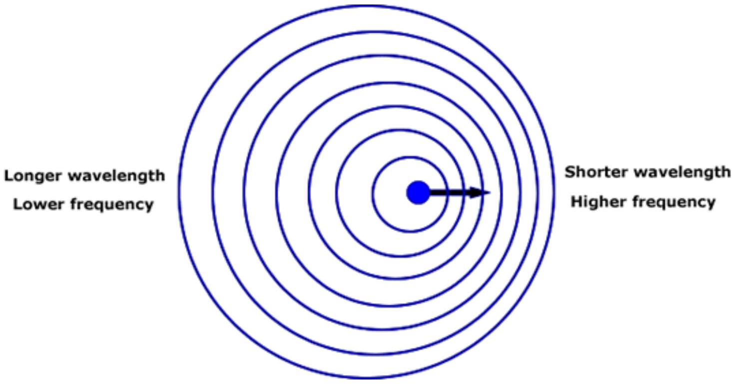


The number of beats per second is equal to the difference in frequencies:

$$f_{beat} = |f_2 - f_1|$$

Doppler Effect

The Doppler Effect is defined as the change in frequency or wavelength of a wave for an observer who is moving relative to the wave source. This is easily noticeable in sound waves, where the pitch of a sound changes as the sound source moves towards/away from an observer - for example, a siren that deepens in pitch as it moves away.



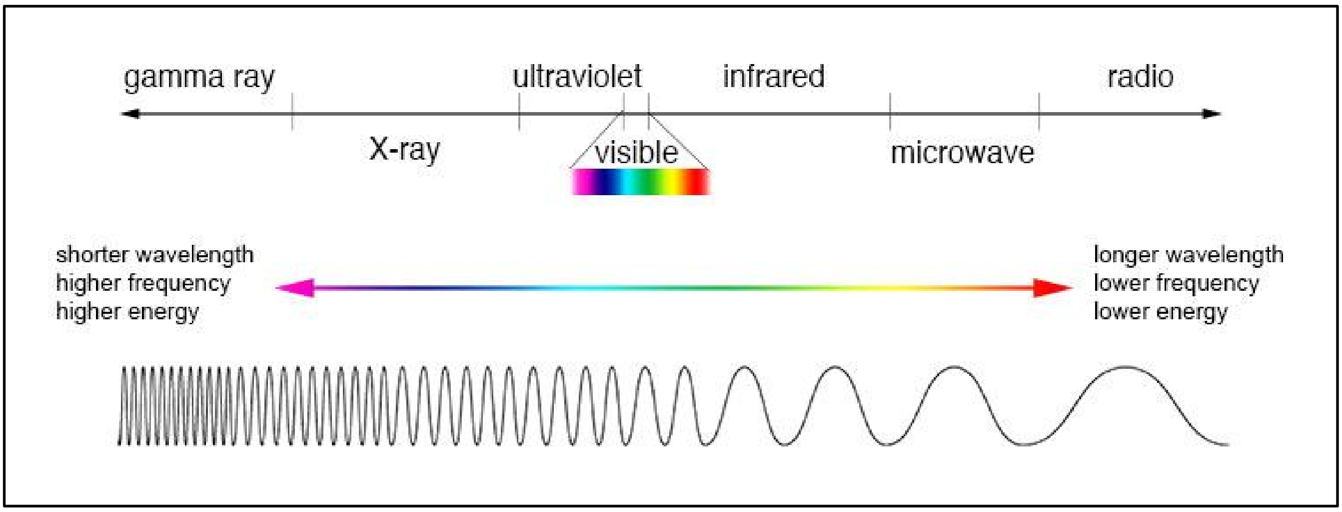
The equation relating the velocity of an object and the frequency shift due to the doppler effect is:

$$f_d = f_0\left(\frac{v \pm v_o}{v \pm v_s}\right)$$

- $\mathbf{f_d}$ is the observed frequency
- $\mathbf{f_0}$ is emitted frequency
- **v** is the velocity of waves in the medium
- $\mathbf{v_o}$ is the is the velocity of the observer relative to the medium; positive if the receiver is moving towards the source (and negative in the other direction)
- $\mathbf{v_s}$ is the velocity of the source relative to the medium; positive if the source is moving away from the receiver (and negative in the other direction)

Light

Light encompasses all electromagnetic waves, but usually refers to those in the visible spectrum.

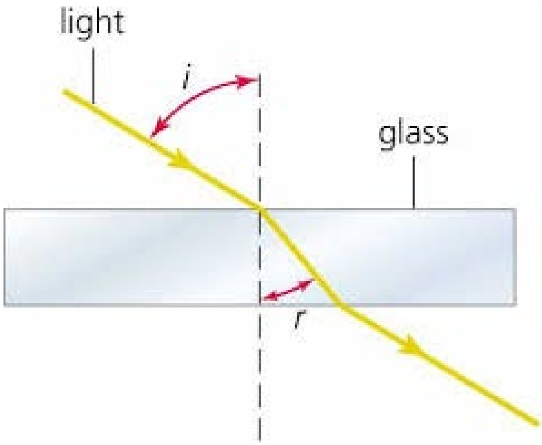


- Light itself has wave-particle duality, it exists as a particle (photon) and a wave - but this module only looks at the wave properties
- Light does not need a medium to travel, and travels as a transverse wave
- Light travels at the speed-of-light in a vacuum (299 792 458 m/s or 300,000 km/s), which is the fastest speed anything can travel at - represented by the symbol c. This speed is slower in air, light or glass.
- Light can reflect, refract, disperse and diffract

Visible Light is a small part of the electromagnetic spectrum, and appears (from lower to higher frequency) as:

Refraction

Occurs when light passes through a different material than the one that was previously travelling in. **The different density of the new material causes the light to change velocity, so it bends.**



- When a ray of light travels from a less dense medium into a denser medium, such as from air into water, it slows down and consequently bends closer to the normal.
- When a ray of light travels from a denser medium into a less dense medium, such as from glass into air, it speeds up and bends away from the normal.

- When light moves from one medium to another:
    - Frequency of the light remains unchanged.
    - Wavelength of light changes.
    - Velocity of light changes.
    - Therefore, v µ l

Bending of the Wave
If a wave bends towards the normal (angle of refraction<angle of incidence), the wavelength decreases.

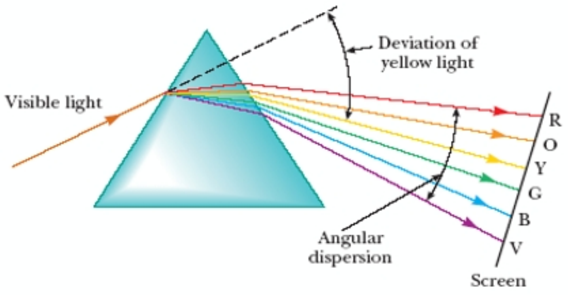
- The speed must also decrease (as *f* is a constant).

If a wave bends away from normal (angle of refraction>angle of incidence), the wavelength increases.

- The speed must also increase (as *f* is a constant).

Dispersion

Occurs when different wavelengths of light are refracted different amounts, separating the light into its constituent colors - this can be seen irl as rainbows



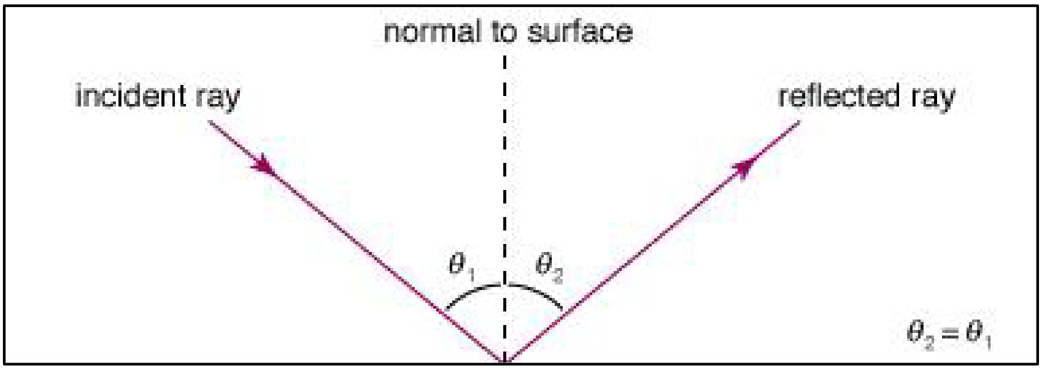
Violet travels the slowest through the prism so it is on the bottom (most bent) and red travels the fastest through the prism so is on the top (least bent).

The Ray Model of Light

The Ray Model of Light is a representation of photons as straight lines - “rays”. It helps us visualise the behaviour of light in different circumstances.

Law of Reflection

Angle of incidence (i) = Angle of reflection (r)



Types of Lenses, Real and Virtual Images, Focal Points

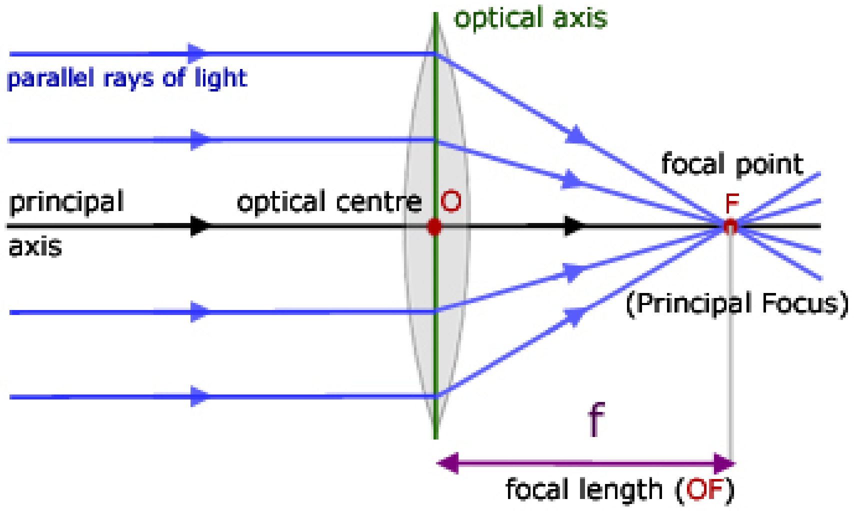
THIS BASICALLY SUMS IT UP:

https://drive.google.com/a/baulkhamhillshighschool.com.au/file/d/0B1tYkUX1W0dIcEJENmJPZzdlbWs/view?usp=sharing

Convex - Thicker at the centre than at the edge. Is a **converging** lense, meaning that it bends the light inwards.

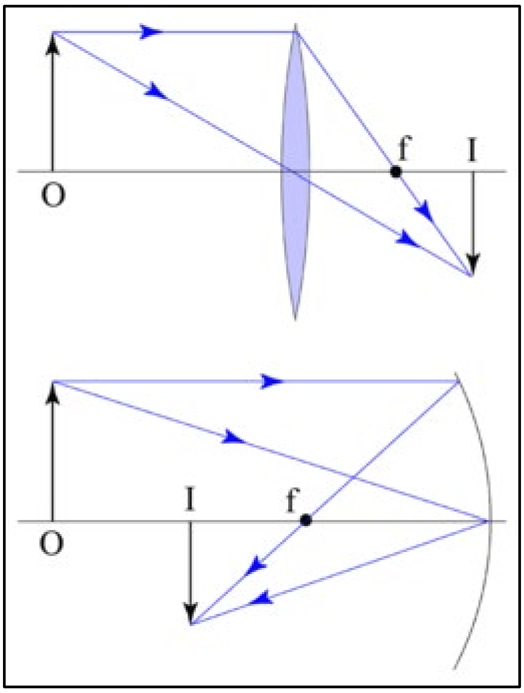
Concave - Thinner at the centre than at the edge. Is a **diverging** lense, meaning that it bends the light outwards.

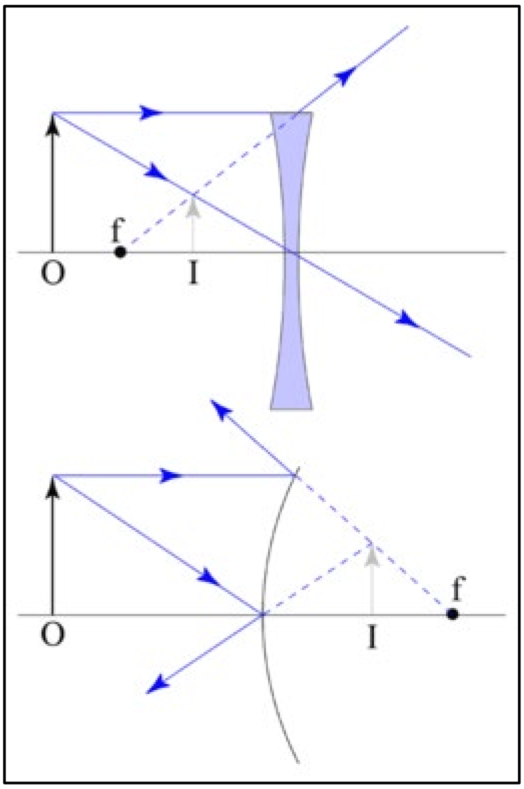
The centre of the lens is called the optical centre **'O'** and the principal focus (focal point of the light rays) is called the **'F'**. The distance of F from C is the focal length *f* of the lengths.



Real images are those where light actually converges (if the lines actually intersect, then it's real), whereas **Virtual images** are locations from where light appears to have converged (since the brain traces light in straight lines).

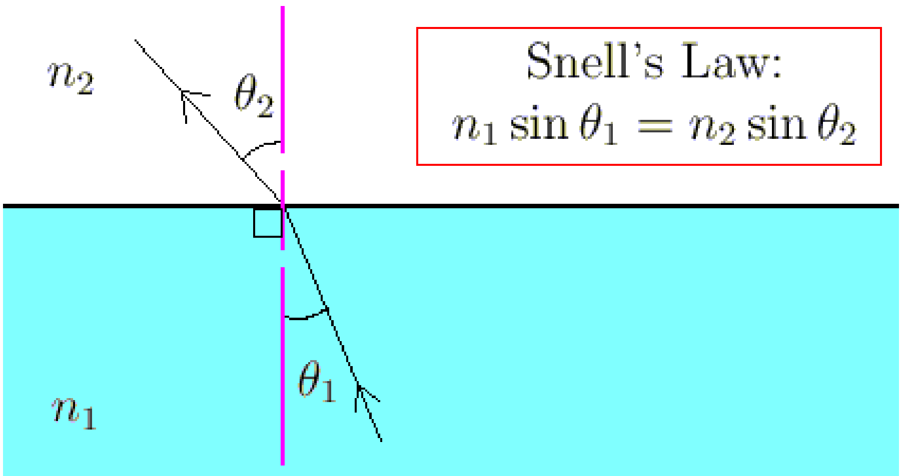
Real on the left, virtual on the right:





Snell's Law

Snell's Law is a formula used to describe the relationship between the angles of incidence and refraction of light passing through a boundary between two different isotropic media, such as water, glass, or air.



n_x = index of refraction of the medium x (no units)

For example, water has an index of refraction of 1.33. This means that if light is passing from air (refractive index 1) to water with an angle of incidence of 40 degrees,

$$n_{air} * \sin 40 = n_{water} * \sin y$$
$$\sin 40 = 1.33 * \sin y$$
$$y =$$

Other Important Light Formulae

Relationship between refractive index of a material and the velocity of light through that material:

n_x = index of refraction of the medium x
c = speed of light in a vacuum
v_x = speed of light in a medium x

$$n_x = c / v_x$$
$$\text{Therefore, } n_1 v_1 = n_2 v_2$$

Relationship between critical angle and refractive index:

I_c = critical angle of medium x

$$\sin (I_c) = 1 / n_x$$

When the other medium is air, if it isn't just use Snell's law and make it sin 90^0

Light Intensity at two points (r_1 and r_2 metres) away from a light source:

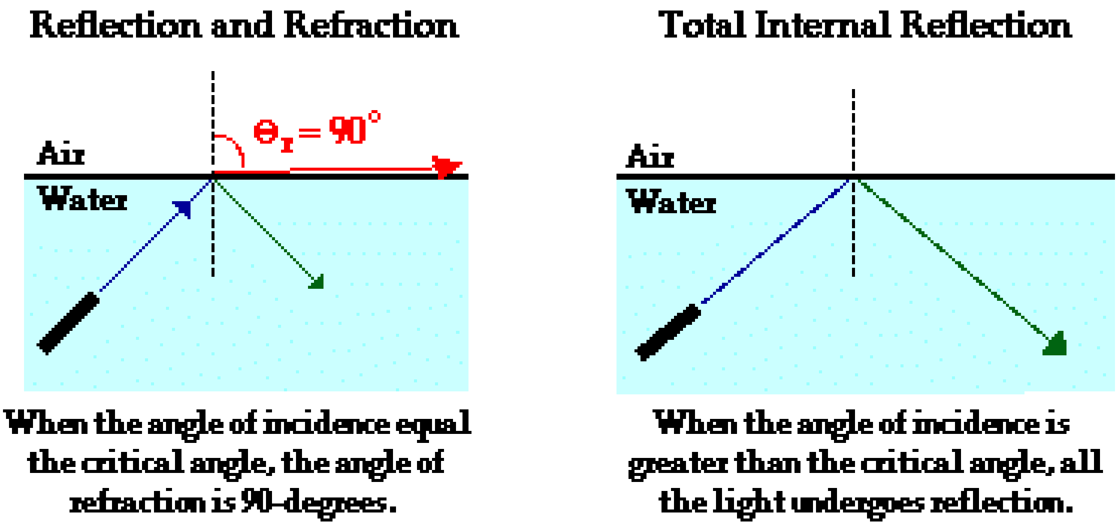
I = Light Intensity (Lux)

$$I_1 r_1^2 = I_2 r_2^2$$

Critical Angle and Total Internal Reflection

In accordance with Snell's Law, as the Angle of Incidence increases, the Angle of Refraction also increases, until the angle of refraction becomes 90^0. This is known as the **critical angle**.

After this point, all the light that enters reflects back out, in what is known as **total internal reflection.**

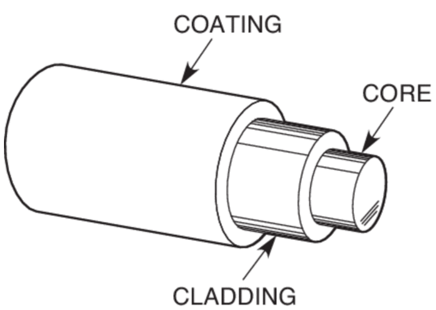


Diamonds have a very low critical angle of 24^0, so they sparkle, while glass has a critical angle of > 40^0.

Refraction requires a density barrier (the two materials must have different densities), or this concept doesn't apply.

Fibre-Optics

Fibre Optic cables use total internal reflection to rapidly transmit large amounts of data (in the form of light) across large distances very fast. They consist of three parts:



- The core has a higher refractive index than the cladding - both of which are made of transparent material (the core is usually glass)
- The difference in density between the core and cladding allow total internal reflection to work

- The opaque coating does not allow light to escape

Thermodynamics

Temperature, Thermal Energy and Particle Motion

Temperature is a measure of the thermal energy (average *Kinetic Energy* possessed by all the particles) in a substance.

- This is different to Internal Energy (U), which is KE + Potential Energy of an object

When an object heats up, it's particles are gaining kinetic energy, and begin to move faster, and vice versa for cooling down.

Heat is the ***flow of thermal energy*** from a higher temperature entity to a lower temperature entity - i.e. a mug of chocolate milk heats up the air around it, but a glass of ice will slowly melt as the warmer air heats it up. Objects containing more thermal energy will always heat objects containing less thermal energy.

NOTE: Objects all have some thermal energy, but they have no heat unless there is a transfer of energy occurring.

Laws of Thermodynamics

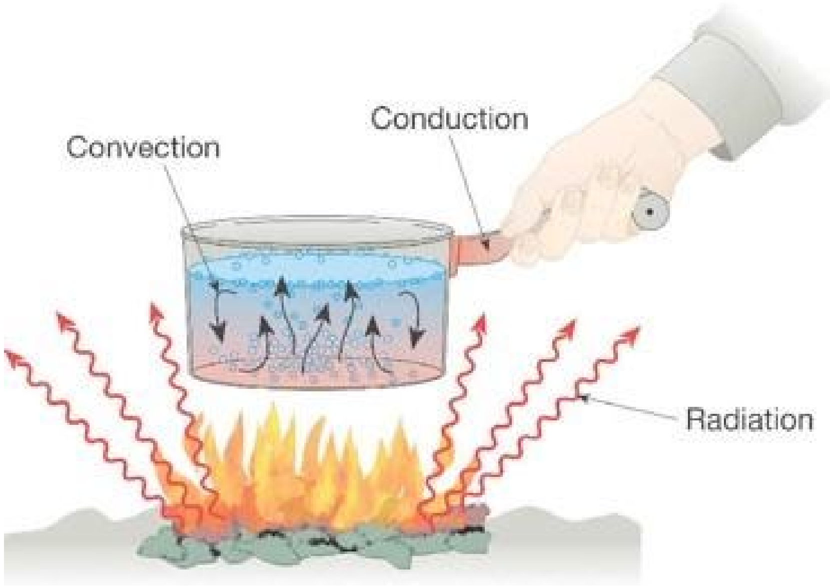
0^{th} Law: If two thermodynamic systems are each in thermal equilibrium with a third, then they are in thermal equilibrium with each other.

- E.g. If a thermometer is placed in a cup of water, it will heat up until it is in thermal equilibrium with the water at 50^0C (just an example number). If it is placed in a second cup and still reads 50^0C, then the two cups are in thermal equilibrium with each other.

1^{st} Law: Energy can neither be created nor destroyed. It can only change forms. In any process, the total energy of the universe remains the same. For a thermodynamic cycle the net heat supplied to the system equals the net work done by the system.

- The internal energy of the system (U) can be changed by heating and cooling. +/- ΔQ = **WORK** being done on a system ($\Delta U = Q - W$) [not required by syllabus]

Types of Heat Transfer



Conduction

Conduction is the transfer of heat energy by the collision of neighbouring particles, or the transfer of free electrons. It occurs in solids and liquids by the kinetic energy of one particle being passed to its immediate neighbour.

- There is no net displacement of particles (except electrons)
- Solids are better conductors than liquids, which are better conductors than gases because the particles are closer together, so can collide more as they vibrate

Convection

Convection operates when a fluid (a liquid or gas) is heated resulting in a change in density. Usually the fluid will expand on heating and so become less dense. The difference in density with the surrounding fluid leads causes the fluid to flow up, carrying thermal energy with it.

- This involves particles being displaced

Heated base of liquid → Liquid becomes less dense → Rises → Cools → Becomes more dense → Sinks down in a circular motion

Radiation

Radiation operates by an object emitting electromagnetic radiation which transfers thermal energy.

- Cooler objects (e.g. people) radiate in the near infrared and so can be detected with IR cameras.
- Hot objects (e.g. light bulbs) radiate strongly in the visible spectrum
- Very hot objects (e.g. electrical sparks and arcs) radiate strongly in the near ultraviolet.

In addition as the temperature of an object increases the amount of energy it emits at any given wavelength increases (but all objects above 0K emit some radiation).
Radiation is the only form of heat transfer that doesn’t require a medium, so it is the only way an object loses thermal energy in a vacuum

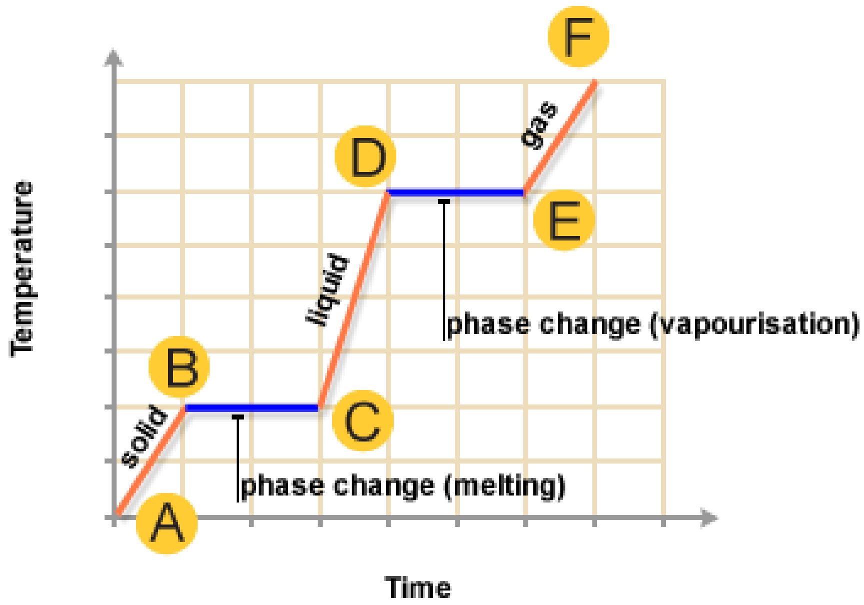
Black-Body Radiation

A Black-Body is a hypothetical substance that absorbs all radiation (reflecting none). Thus, the energy that it does radiate **depends only on its temperature,** not on external radiation being reflected.

Latent Heat and Change of State

Substances change state from Solid → Liquid → Gas, and vice versa. Sometimes they skip a state and can sublime from Solid → Gas, or deposit from Gas → Solid. However, all changes in state require a change in heat.

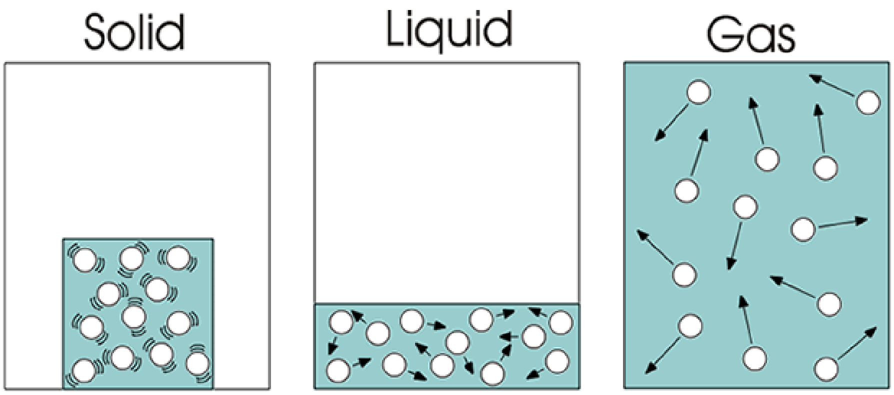
- fusion (melting): the substance changes from a solid to a liquid
- freezing: the substance changes from a liquid to a solid
- vaporisation: the substance changes from a liquid into a vapour
- condensation: the substance changes from a vapour to a liquid



For example, as you boil water in a pot, it's temperature rises until it reaches 100^{0}C.

However, when a substance is changing its state, the temperature of the substance remains constant: Boiling water at 100 °C on changing state becomes steam at 100 °C. This is because **any additional heat goes into breaking the forces** between the molecules. Once all the forces are broken, then the temperature will start to rise again.

- In the case of solid → liquid, the intermolecular forces are just stretched, so does not take as much energy as liquid → gas (where the forces are broken)



The thermal energy that is taken in or given out by a substance when it changes state is called **latent heat.** The two types of latent heat are the latent heat of fusion and the latent heat of vaporisation.

$$Q = mL$$

Heat Transfer (J) = Mass of Substance (kg) x Latent Heat (Jkg^{-1})

Specific Heat Formula

When thermal energy is added to a substance, the temperature will change by a certain amount. The relationship between thermal energy and temperature is different for every material, and the specific heat capacity (c) is a value that describes how they relate.

I.e. When thermal energy is added to gold, its particles gain kinetic energy (increase temperature) much easier than if the same amount of thermal energy was added to rubber

This is shown in the formula:

$$\Delta Q = mc\Delta T$$

ΔQ = heat energy (Joules, J)
m = mass of a substance (kg)
c = specific heat capacity (units J/kg·K)
ΔT = change in temperature (Kelvins, K)

heat energy = (mass of substance)(specific heat)(change in temperature)

E.g. The specific heat of gold is 129 J/kg·K. What is the quantity of heat energy required to raise the temperature of 100 g of gold by 50.0 K?

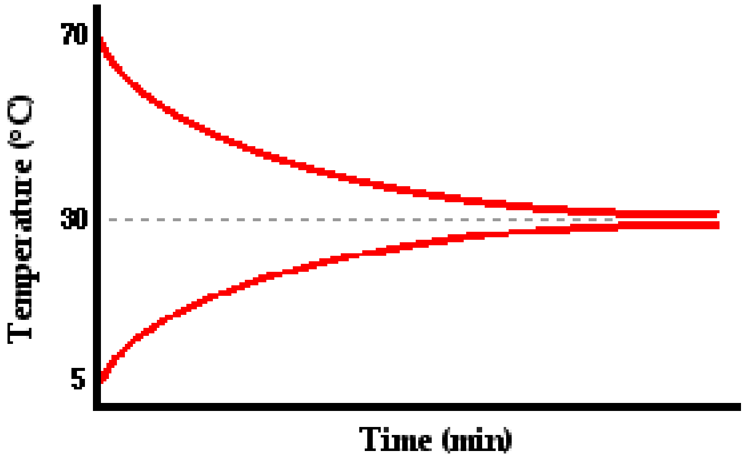
$Q = mc\Delta T$
Q =(0.100 kg)(129 J/kg·K)(50.0 K)
Q = 645 J

Examples of specific heat capacities:
- Water - 4185.5 J/kg·K
- Methylated Spirits - 2400 J/kg.K

Thermal Equilibrium

Two systems are in thermal equilibrium when they are connected by a path permeable to heat, but neither changes temperature or transfers thermal energy between them.

E.g. If you take a 20^0C piece of metal and place it touching a -20^0C piece of metal (ignoring ambient heat), then the hotter piece will transfer thermal energy to the colder piece until they both reach 0^0C. At this point, they are at thermal equilibrium, because neither will transfer heat anymore.



Example Thermal Equilibrium Question:

If 250g of 18^0C water is added to a 400g Aluminium saucepan at 130^0C, determine the temperature at which the two objects are in thermal equilibrium. All other conditions are constant, and no energy is lost to the surroundings.

Answer:

The higher temperature object (saucepan) loses heat, and if other conditions stay constant, then the thermal energy lost by one object is equal to the energy gained by the other:

$$\Delta Q_{water} = -\Delta Q_{saucepan}$$
$$mc\Delta T_{water} = -(mc\Delta T_{saucepan})$$

If the equilibrium temperature is T_{common}:

$$\Delta T_{water} = T_{common} - 18$$
$$\Delta T_{saucepan} = T_{common} - 130$$

Substituting into the equations and solving:

$$0.25 \times 4186 \times (T_{common} - 18) = -(0.4 \times 900 \times (T_{common} - 130))$$

Therefore, Thermal Equilibrium is reached at 46.7^0C

Rate of Thermal Conduction Formula

Different materials conduct heat at different rates - i.e. metals are good conductors, while wood, plastic etc are good insulators (they conduct very slowly).

$$Q/t = kA\Delta T/d$$

Q/t = amount of heat (J, Joules) transferred in a time (s, seconds).

- This is known as a Watt (Joules/second).

k = thermal conductivity constant.

- The thermal conductivity constant k is larger for materials that transfer heat well (like metal and stone), and k is small for materials that transfer heat poorly (like air and wood)

A = cross-sectional area of material transferring heat (m^2)

- since conduction is based on collisions, surface area matters

ΔT = change in temperature (Kelvins, K)

d = thickness of material (m)

- the thicker the material, the more collisions are needed to transfer heat through it, so it'll take longer to conduct heat

Module 4: Electricity and Magnetism

Electric Charge

Protons, neutrons and electrons all have a charge - positive, neutral and negative. Electricity refers to the movement of these charges.

Like charges repel, and unlike charges attract.

The SI unit of charge is **Coulomb (C)** - 1 Coulomb is defined as the total charge on 6.25×10^{18} electrons or protons.

- Microcoulombs (μC) are often used, which is 1 millionth of a coulomb
- The symbol for charge is **q**

Physical bodies can have their own **electrostatic charge** based on if they have an **excess or deficiency in electrons.** If they have excess electrons (more electrons than protons) then they are negatively charged, and vice versa.

- *We don't say excess or deficient protons, since electrons are generally the only charged particles that move around.*

Charge can also be measured in Electron Volts (eV), where 1 eV is 1.602×10^{-19} C.

Conductors and Insulators

A **conductor** is a material which contains charge carriers: charged particles (such as ions or electrons) that are free to move through the material. This makes it easily for electricity to flow through them, as it is passed on by the charged particles.

- Examples of conductors include salt solutions and metals

An **insulator** is a material that contains no charge carriers, and so does not let electricity easily flow through.

- Examples of insulators include dry air, glass, plastics, rubber and ceramics

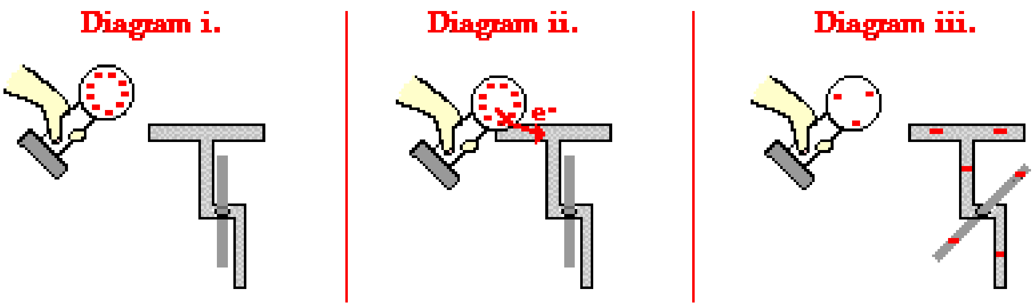
HOWEVER, Insulators tend to hold charge much better than conductors - this is because conductors let electrons flow onto or off of themselves, spreading the charge around it's surface and into the surroundings.
Insulators hold charge as they do not let it flow out into the surroundings.

Processes of Charging

Charging by Friction - if two bodies made of different materials are rubbed together, some electrons will be transferred from one body to another. Then, one piece will have a deficiency, and the other an excess of electrons.

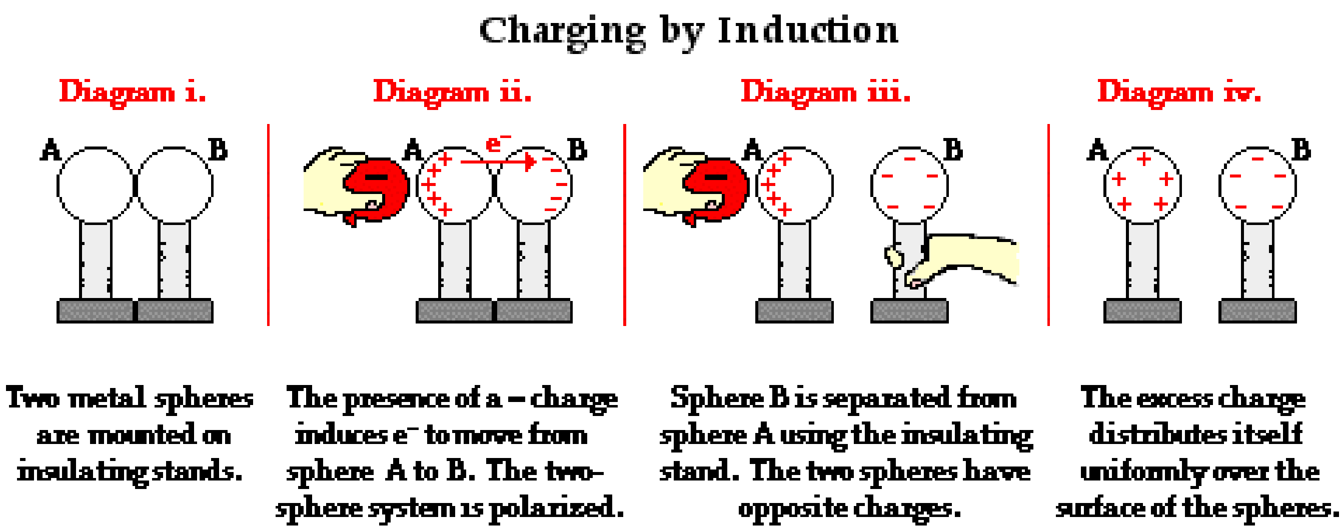
- Examples include glass and silk, or perspex and wool, or a balloon being rubbed on your head and then picking up hairs

Charging by Contact - if a charged conductor touches an uncharged conductor, the charge will be shared between the two conductors.



Induced Charges - when a positively charged body comes close to an uncharged, insulated conductor, it pulls the electrons in that conductor towards that side. This causes one side of the conductor to have an excess, and one side a deficiency of electrons. The charges on either side of the conductor are known as induced charges.

However, induced charges are not permanent - to make an object permanently charged with induction, the object either has to be grounded, or the two sides of the object must be separated.



Conservation of Charge

When two previously neutral bodies are charged by friction, the amount of positive charge produced on one body is equal to the amount of negative charge produced on the other.

When two charged conductors are brought into contact, the charges redistribute, but the total amount of charge remains the same.

Thus, with repeated similar observations, it can be concluded that **the total amount of electric charge never changes - electric charge is conserved.**

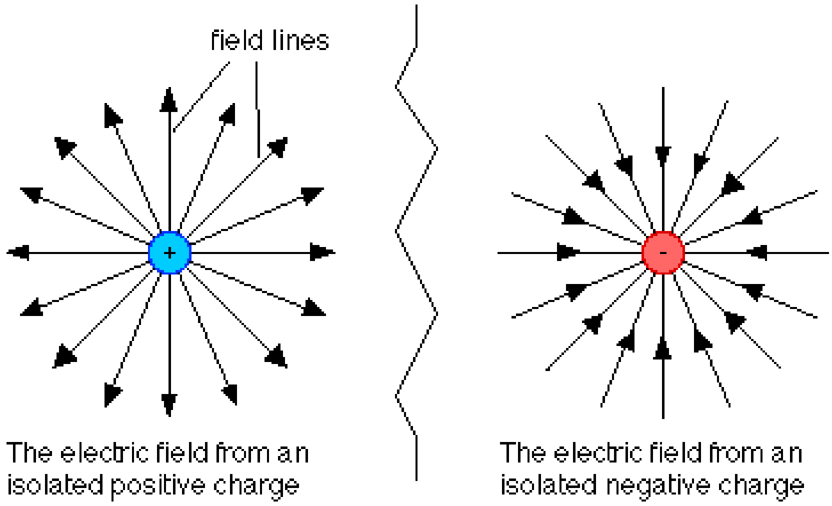
Electric Fields

An **electric field** is a region surrounding an electric charge in which a second charge will experience a force.

I.e. When two positively charged bodies (A and B) are next to each other, the electric field of A exerts a certain force on B, pushing it away, and the electric field of B exerts a force on A, pushing it away too.

Electric Field Direction

The direction of an electric field at a point i**s defined as the direction of the force that acts on a positive charge placed at that point** - i.e. the electric field direction of a positive body is outwards from the body, while the electric field direction of a negative body is inwards from the body.



A negative charge in an electric field experiences a force in the opposite direction to the field.

Electric Field Strength

The magnitude of the electric field strength at a point is determined by placing a charge at the point and measuring the force exerted on the charge.

NOTE: In questions, remember to always consider whether the charge is positive or negative, since it will indicate the direction of the electric field.

This is represented in the formula:

$$E = F/q$$

Electric Field Strength (NC^{-1}) = Force (Newtons) ÷ Charge (Coulombs)

The unit for Electric Field Strength is **newtons per coulomb (NC^{-1})** or **Volts per metre (V/m),** and it is a vector quantity.

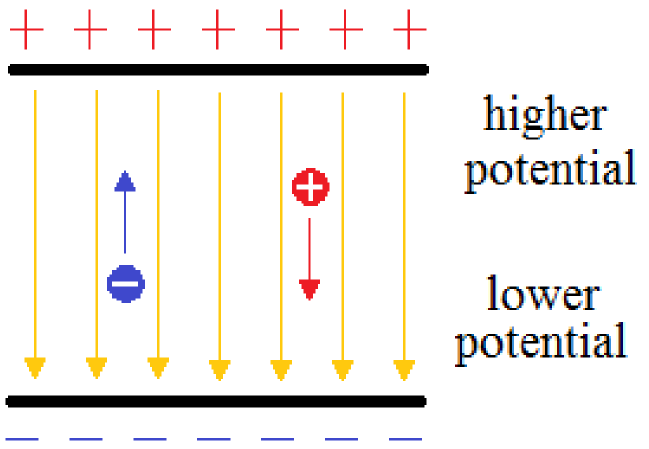
Electric Potential Energy

Electric Potential Energy is the potential energy of a charge in an electric field, measured in joules.

When a **positive charge** moves in the direction of an electric field, it will naturally increase in speed and gain kinetic energy, but will lose Electric Potential Energy.
If it moves in the opposite direction to an electric field, energy must be provided to do this, and it will gain Electric Potential Energy.

When a **negative charge** moves in the opposite direction of an electric field, it naturally gains speed and loses Electric PE
Moving it in the same direction as the field requires energy, so it gains Electric PE.

Basically, moving any charge in the opposite direction that it naturally wants to go makes it gain Electric Potential Energy.
If a charge moves in its natural direction, then Work is done by the field.
If a charge moves in the opposite direction, Work is done on the field.



Voltage

Voltage is the **potential difference** between two points in an electric field.
It is defined as the number of joules of electrical potential energy given up to each unit of charge passing through a device, such as a battery/resistor, measured in Volts (V).
This is represented in the formula:

$$V = \Delta U/q = W/q$$

Voltage (V) = Change in Electric PE (J) / Charge (coulomb)

Here, W is also Work: Work = Force x Distance, and the change in Electric PE is due to a force being applied to the charge over a certain distance.

By subbing in Work as Fd, where **d is the displacement of the particle**, and rearranging/equating, Electric Field Strength can therefore also be defined as:

$$E = -V/d$$

(Electric Field Strength (NC^{-1} or Vm^{-1}) = -Voltage (V) / Displacement(m))

Work done on or by the Field

$$W = qEd$$

Work (J) = Charge (C) x Electric Field Strength (NC^{-1}) x Displacement(m))

- When a charge moves in the direction it naturally wants to go, **work is done by the field** to move that charge.

- When a charge moves in the opposite direction that it naturally wants to go, **work is done on the field** to make it move backwards.

Coulomb's Law

The three factors affecting the force exerted onto a particle in an electric field are the quantity of charge on one particle, quantity of charge on the other particle, and the distance between the particles.

Coulomb's law quantitatively relates these three factors. As a formula, it is:

$$F = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_2}{r^2}\right) = k\frac{q_1 q_2}{r^2}$$

- F = Force (Newtons)
- q_1 = Charge on Particle 1 (Coulombs)
- q_2 = Charge on Particle 2 (Coulombs)
- r = Distance between Particles (m)

k is Coulomb's Constant, which is dependent on the medium that the charges are immersed in. When the electric permeability constant is $\varepsilon_0 = 8.85 \times 10^{-12}$, then $k = 8.99 \times 10^9$

Also, Subbing E = F/q into Coulombs Law:

$$E = kq/r^2$$

$$V = kq/r$$

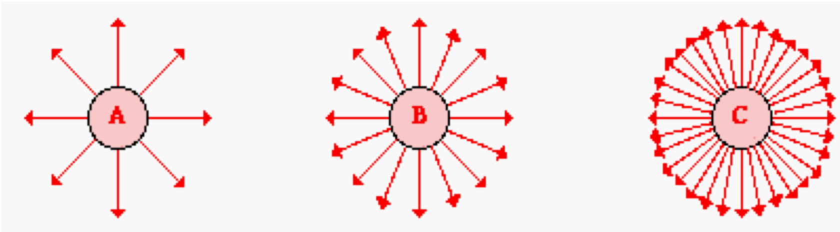
Electric Field and Equipotential Lines

http://hyperphysics.phy-astr.gsu.edu/hbase/electric/equipot.html

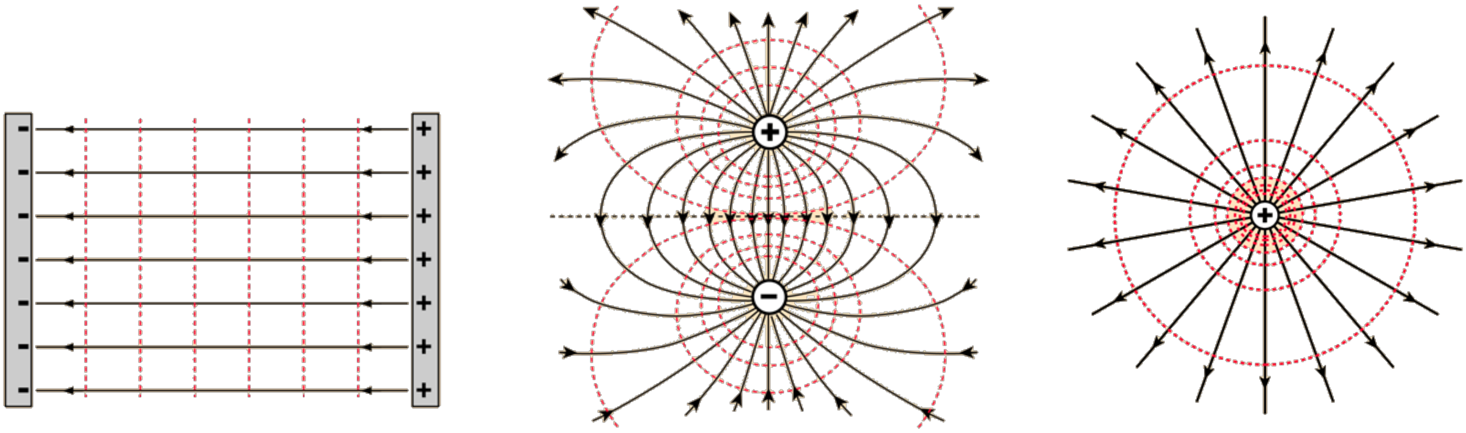
Electric Field lines are just lines that represent the electric field of a charged particle/object.

- Arrows show the direction of the electric field
- The density of lines shows the strength of the field at a particular location (more dense = stronger field)
- The total number of lines gives information on the quantity of charge that the particle/object possesses
- Electric Field Lines never cross

E.g. B clearly has a greater quantity of charge than A, since it has a greater density of lines, but less charge than C

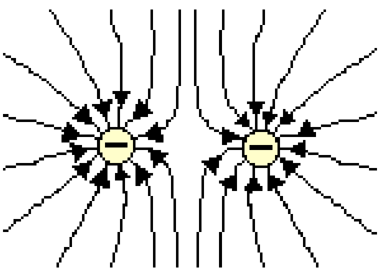


They can be used to model the electric fields of various situations, such as parallel charged plates, point charges, dipoles and pairs of charges:

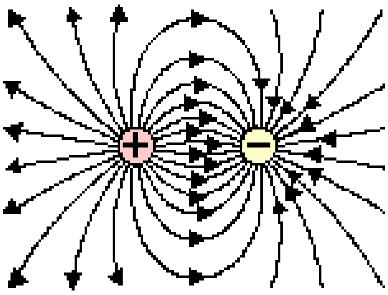


In the diagrams above, there are also red dotted lines. These are equipotential lines, which outline areas of equal electric potential/voltage - like contour lines on a map contain areas of equal altitude.

Other Charge Configurations



Two Negatively Charged Objects



A Positively and a Negatively Charged Object

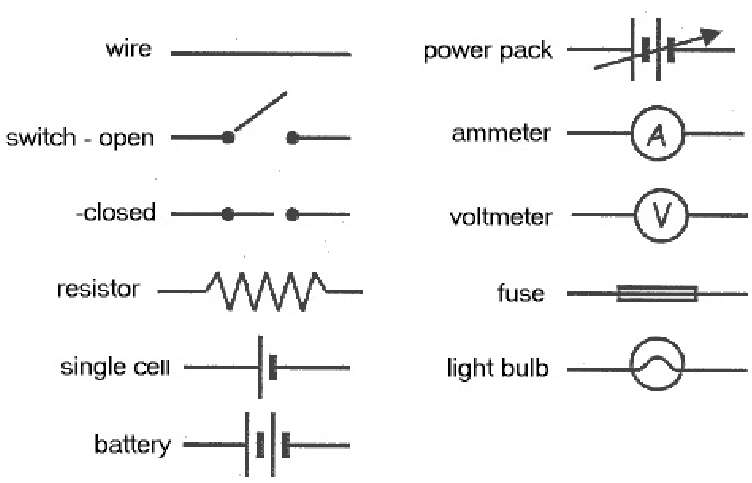
Parallel Charged Plates produce a **uniform electric field** between the plates, going from + to -. An electron or other charged particle placed in this field will undergo acceleration until it hits a plate, and this can be calculated using E = F/q and the suvat equations.

Electrical Circuits

An **electric circuit** is a path in which electrons from a voltage or current source flow. It can be either open (which does not allow current flow) or closed (i.e. a loop).

Batteries/Power Sources have a positive and negative terminal. Even though a *resistor* is one type of component, all components possess some resistance.

Components of a Circuit



Current, Voltage and Resistance

Current is a measure of the **amount of electrical charge transferred per unit time**. It represents the **flow of charge** through a conductive material due to the influence of an electric field. It is a scalar quantity, measured in Amperes (A), with symbol **I**.

$$I = q/t$$

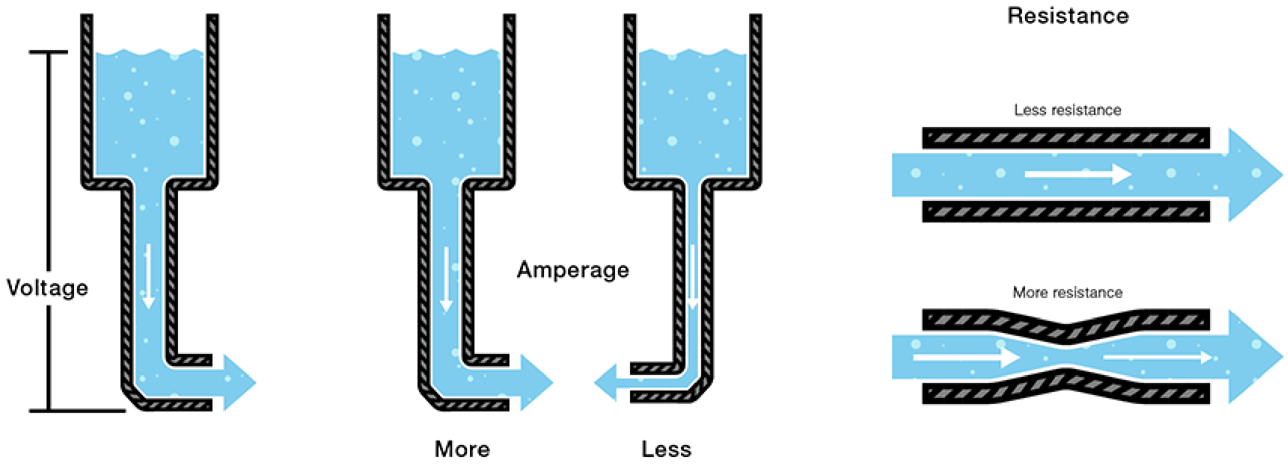
Current (A) = Charge (Coulombs) / Time (s)

Voltage (as defined earlier) is the **potential electrical difference** between two points. It is a scalar quantity, measured in Volts (V), with symbol **V**.

- The voltage across a power supply (+ to - terminal) is a voltage rise, since the power supply provides EPE. The voltage across a resistor (circuit component) is a voltage drop, since the resistor converts EPE into other forms of energy.

Resistance is the opposition that a substance offers to the flow of charge. Conductors have little resistance, and insulators have more resistance. It is measured in Ohms (Ω), with symbol **R**.

- Resistance is directly proportional to length, inversely proportional to the area of cross section of wire, and depends on the material and temperature of the material



Analogy of electricity as water flowing through pipes

Ohm's Law

This law states that electric current is proportional to voltage and inversely proportional to resistance. As a formula, it is:

$$V = IR$$

$$\text{Voltage (V)} = \text{Current (A)} \times \text{Resistance } (\Omega)$$

In a graph of Voltage vs Current, where voltage is on the y-axis, R is the gradient of the line.

An Ohmic conductor is one that completely obeys Ohm's law - i.e. Resistance stays constant. Real conductors are often non-ohmic, as the resistance changes with changes in temperature, or cross-sectional area can't cope with current flow etc.

E.g. From the same power point, 20 Christmas lights are brighter, 50 Christmas lights are dimmer. This is because the Voltage remains the same, but current decreases because every light has resistance, meaning that every extra light added causes the lights to dim due to reduced current.

Electrical Power

Power was previously defined as the rate of transfer of energy.
Thus, Electric Power is the rate at which electrical energy is transformed by a circuit component into other forms (heat, light etc). It is measured in Watts (W), with symbol P.

For any given component in a DC circuit, Power is the product of Voltage and Current:

$$P = VI$$

Power (Watts) = Voltage (V) x Current (A)

Since power is the rate of energy transfer, by multiplying power with time. We get the electrical energy:

$$E = Pt$$

Electrical Energy (J) = Power (W) x Time (s)

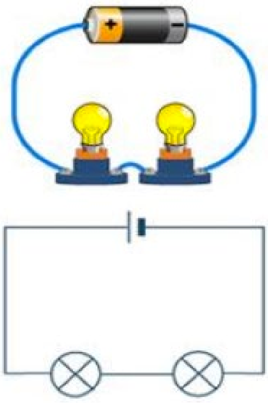
By subbing in Ohms Law, there are multiple variations of this:

$$E = Pt = VIt = I^2Rt$$

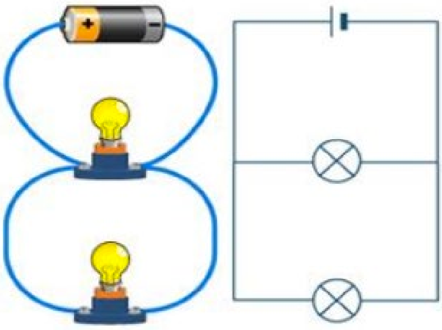
Parallel and Series Circuits

Series vs Parallel Circuits

A series circuit is a closed circuit where the current follows a single path, as opposed to a parallel circuit where it is divided into two or more paths, joining back at the end.



Series Circuit


Parallel Circuit

Ammeters (measuring current) must be connected in series, while **Voltmeters** (measuring voltage) must be connected in parallel.

NOTE:

By convention, current in a circuit flows from the positive terminal of the battery to the negative terminal - this is used for circuit diagrams/calculations.

However, electrons actually flow from negative to positive.

Current Direction

The positive sign for current corresponds to the direction a positive charge would move. In metal wires, current is carried by negatively charged electrons, so the positive current arrow points in the opposite direction the electrons move.

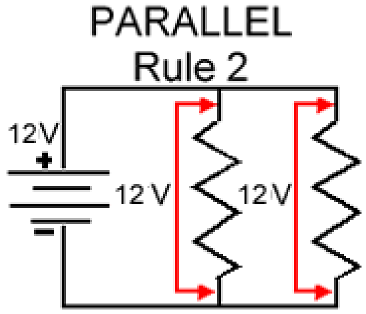
I.e. going from positive → negative terminal is **positive current.**

Kirchoff's Laws of Parallel and Series Circuits

Basic Rules of Parallel Circuits

1. A parallel circuit has two or more paths for current to flow through.
2. Voltage is the same across each component of the parallel circuit, and is the same as the voltage from the battery

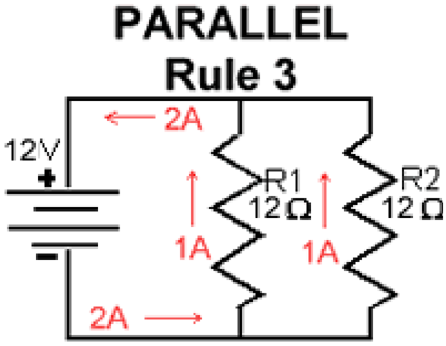
$$V_{battery} = V1 = V2 = V3 = ...$$



3. The sum of the currents through each path is equal to the total current that flows from the source

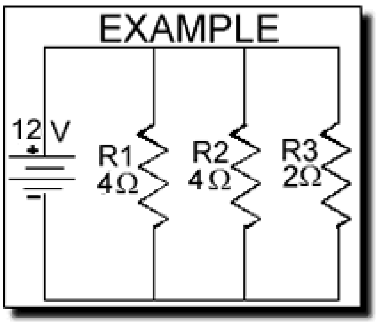
$$A_T = A_1 + A_2 + A_3 \ldots$$

- This doesn't mean each path has the same current, the current flowing through each path is dependent on the resistance of that path.
- How much current flowing through each path can be found when you know the resistance of each path, as well



4. You can find total resistance in a Parallel circuit with the following formula:

$$1/Rt = 1/R1 + 1/R2 + 1/R3 + \ldots$$



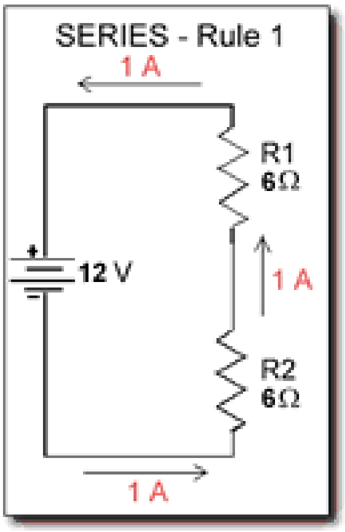
$\frac{1}{4} + \frac{1}{4} + \frac{1}{2} = 1/Rt = 1$ Therefore, Rt = 1

5. If one of the parallel paths is broken, current will continue to flow in all the other paths.

Basic Rules of Series Circuits

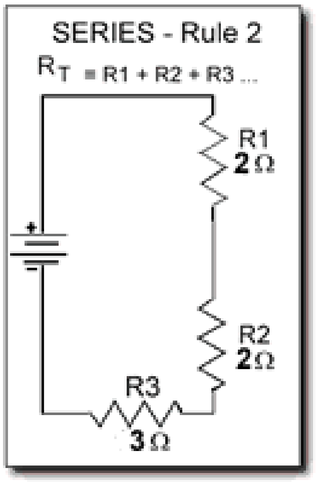
1. The same current flows through each part of a series circuit.

$$A_T = A_1 = A_2 = A_3 = \ldots$$



2. The total resistance of a series circuit is equal to the sum of individual resistances.

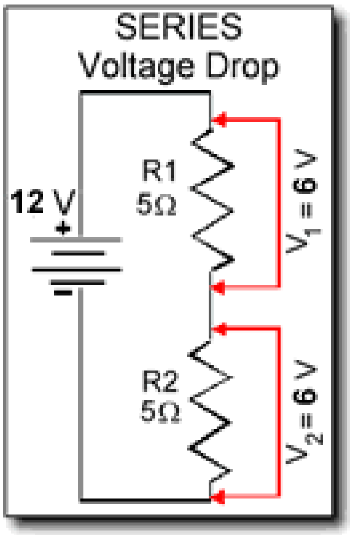
$$Rt = R1 + R2 + R3 + Rn\ldots$$



3. Voltage applied to a series circuit is equal to the sum of the individual voltage drops.

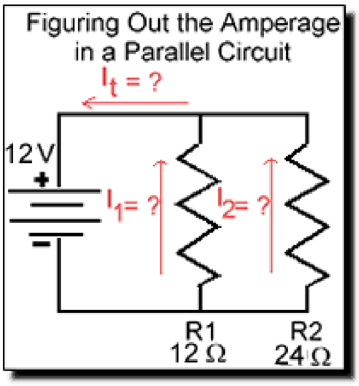
- A voltage drop is the amount the voltage lowers when crossing a component from the **negative side to the positive side** in a series circuit
- Every successive component causes a further voltage drop
- the voltage drops have to add up to the voltage coming from the battery

$$V_{total} = V_1 + V_2 + V_3 \ldots$$



4. If the series circuit is broken at any point, no current will flow.

Example: Calculating the Individual Current Flow of Each Path in a



Parallel Circuit

In the example we see a 12 and 24 ohm resistor in parallel with a 12 volt source.

- First we figure out the total resistance of the circuit:
  - 1/Rt = 1/12 + 1/24
  - Rt = 8 Ohms

- Now that you know this you can figure out the total amperage (It) using Ohm's Law:
  - Current total (It) = 12V / 8 Ohms = 1.5 Amps

- Therefore the total amperage between the two resistive paths must equal 1.5 Amps (Rule 3). Now we can figure out exactly what each path is pulling using Ohm's Law once more. Remember that the voltage is the same across every component in a parallel circuit. So we know the voltage and the resistance:
  - Current of Path 1 = I1 = 12V / 12 Ohm = 1 A

- Current of Path 2 = I2 = 12V / 24 Ohm = .5 A

Heating Effects of Electrical Circuits

When electrons travel through a material, they bump into the atoms of the material occasionally, and transfer some of their kinetic energy to them. Since thermal energy is just the kinetic energy of particles in a substance, this heats the material up.

- This follows the **law of conservation of energy**, since Electrical Potential Energy is transformed into Kinetic Energy.

This is why even the best conductors have some resistance - it is impossible for electrons to go through the conductor without bumping into any atoms. The higher the resistance of a material, the more the electrons bump into the atoms, and the more it heats up.

The relationship between Heat, Power and Resistance can be found by subbing in Ohm's Law into H = Pt:

$$P = VI = V^2/R$$
$$H = Pt$$
$$H = V^2t/R$$

For example:

- electric heaters contain highly resistive nichrome wire (thin because that increases resistance), and electricity is passed through it, producing heat
- Light bulbs contain a tungsten filament surrounded by gas which glows when heated.
- Electrical fuses melt when overheated to break the circuit for safety.

Magnetism

A magnet is any object that produces a magnetic field - i.e. it applies a force over a distance on other magnets, electrical currents, beams of charge, circuits, or magnetic materials.

The attracting/repelling properties of magnets are concentrated on two ends of the magnet - the **north/south poles**. These poles always come in pairs, and each pair is known as a *magnetic dipole.*

- Like poles repel, Unlike poles attract

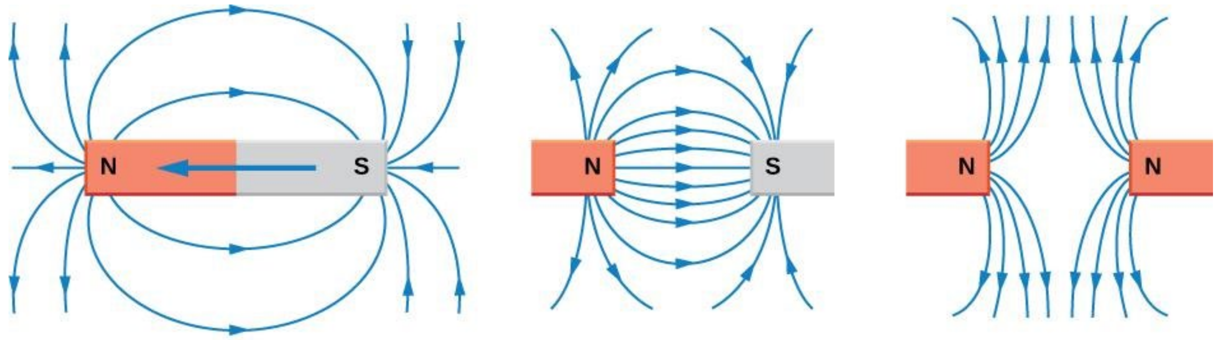
Magnetic Fields

Magnetic Fields apply forces to other poles, much like electric fields apply forces to other charges. Magnetic fields have symbol **B,** and are measured in **Tesla (T).**

The **direction of a magnetic field** is given by the force applied to a north pole in the magnetic field (i.e. the magnetic field direction of a north pole is outwards, while the direction of a south pole is inwards)

- To test this, If a compass is placed in a magnetic field, the north needle of the compass will point in the direction of the magnetic field

Magnetic Field Lines represent magnetic fields. Similar to electric field lines:
- They start at the north pole and end at the south
- Direction of the field is indicated by arrows
- Strength of the field is given by line density (the closer they are, the stronger the field)
- Magnetic Field lines can never cross
- Magnetic Field lines are always in closed loops (every north pole has a south pole)



Magnetic field lines of a bar magnet

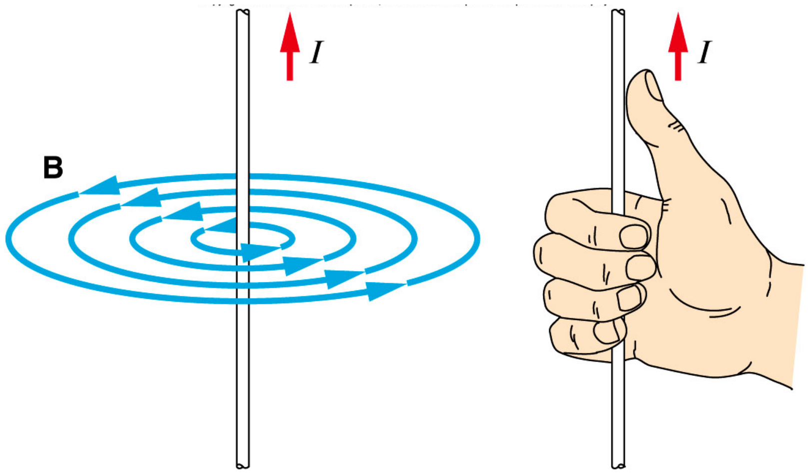
Magnetic field lines between unlike poles

Magnetic field lines between like poles

Magnetic Fields produced by Electric Currents

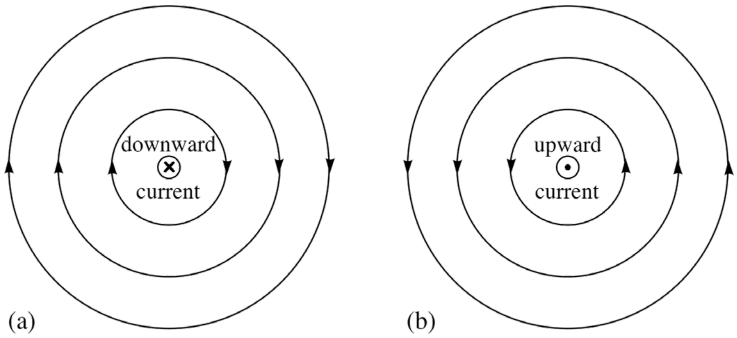
When a current is run through a wire, a magnetic field is also produced. This is observable by placing a compass next to a wire.

When current runs through a straight wire, the magnetic field is present as concentric circles around the wire:



The direction of the magnetic field is given by the **right-hand grip rule** - if you curl your right hand around the wire with your thumb in the direction of the current, the the magnetic field goes in the direction of your curl (as shown in the diagram above)

In diagrams, this can be represented as a **cross-section** of the wire, with the current going into (**crosses**) or out of the page (**circles**):



The magnitude of the magnetic field depends on the amount of current, and the distance from the wire.

The constant μ_0 is called the permeability of free space, and has a value $\mu_0 = 4\pi \times 10^{-7}$

$$B = \mu_0 I / 2\pi r$$

B = magnetic field strength (Tesla, T)

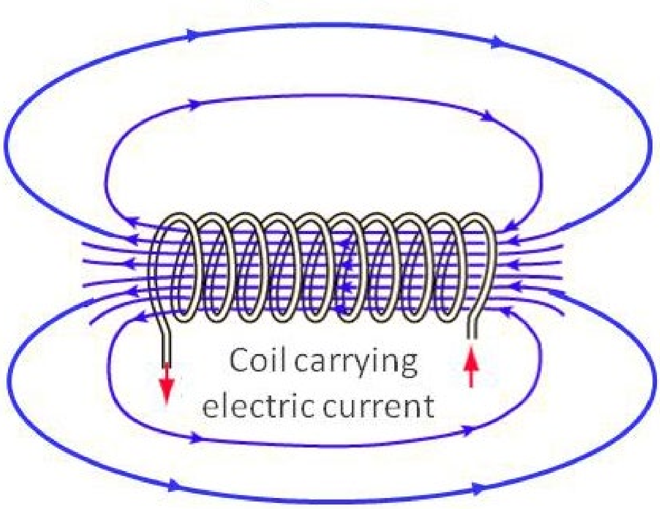
μ_0 = permeability of free space ($4\pi \times 10^{-7}$)

I = current (Amperes, A)

r = distance (m)

Magnetic Fields and Solenoids

A **solenoid** is a wire coiled into tightly packed loops. A current running through a solenoid produces a magnetic field that loops over and inside the solenoid.



- The field on the inside is much stronger and more uniform than the field on the outside of the solenoid.
- The direction of the **field comes outwards from the north pole end of the solenoid**, and loops into the south pole end.
- Use the **right hand rule** for the direction of the magnetic field in the solenoid - your fingers should curl in the direction of current flow around the coil, and your thumb is the direction of the north pole

The magnetic field is dependent on the number of turns and the length of the solenoid. This can be expressed in the formula:

$$B = \mu_0 IN/L$$

μ_0 = permeability of free space ($4\pi \times 10^{-7}$)
B = magnetic field strength inside the solenoid (Tesla, T)
I = current (A)
N = number of turns of the wire
L = Length of the solenoid (m)

Ferromagnetism and Magnetising

Only iron, cobalt, nickel, gadolinium, and their alloys exhibit *strong* magnetic effects. These materials are called **ferromagnetic.**

- Ferromagnetic materials respond strongly to magnets, and can be **magnetized** themselves.

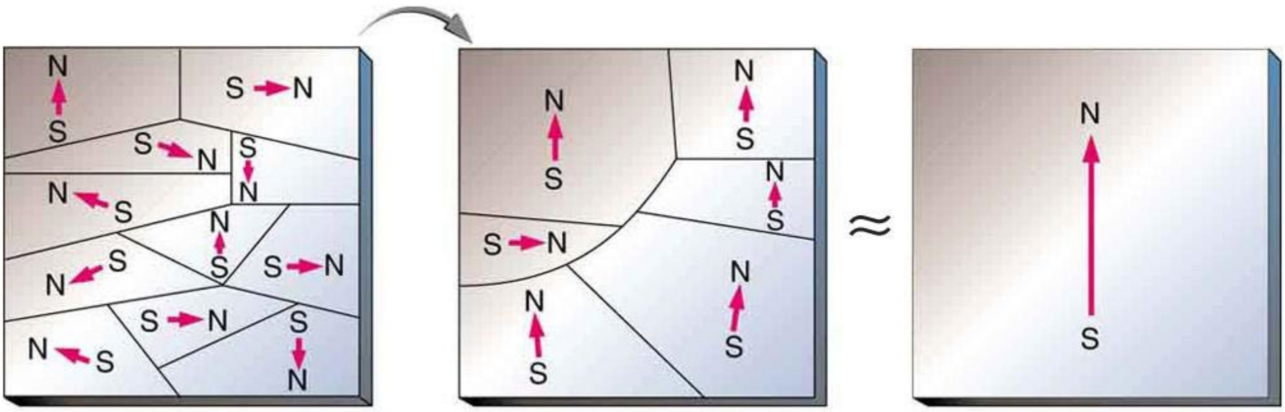
When a magnet is brought near a previously unmagnetized ferromagnetic material, it causes local magnetization of the material, attracting it to the pole - however, this is only temporary.

Soft iron cannot be used to make permanent magnets, while *Hard iron* can (referring to carbon content - hard iron has more carbon impurities in it)

There are many ways to **make a permanent magnet** with *hard iron*:

- Stroke it with an existing magnet
- Induce permanent magnetism by running an electric current around it
- Hit it on one end with a hammer
- Place it between two magnets, heat it, then cool it

When a ferromagnetic material gets magnetised, the **domains** (mini north/south poles) in the material all become **aligned in one direction**. To keep it a permanent magnet, these domains must be stuck in that position after the temporary magnetisation:



Magnets can be demagnetised by a force or excess thermal energy knocking the domains out of alignment.

Electromagnets

A solenoid with a soft-iron core is called an **electromagnet.**

- When a current flows through the solenoid, this quickly (but temporarily) magnetises the soft-iron core, producing a magnet that is much stronger than just the solenoid.
- When the current stops, the magnetism goes away.

Electromagnets can be used for sorting metal recycling, or in circuit breakers, electronic devices etc.