IB Higher Level Physics Study Guide

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Topic 2: Mechanics

Mechanics is the branch of physics which investigates motion and the forces which induce motion.

2.1:Kinematics

2.1.1: Definitions	
Displacement (Vector)	**Distance** between two points in a straight line
Velocity (Vector)	Rate of change of **displacement**
Speed (Scalar)	**Distance** travelled per unit time
Acceleration (Vector)	Rate of change of **velocity**

The above properties can be said to have both average and instantaneous values. The instantaneous value of the property is the magnitude which it possesses at one point in time. The average value is however the mean magnitude over the entire motion (total change divided by total time)

2.1.3: UVATS

The set of equations that can be used to calculate various properties of the motion of an object undergoing **constant** acceleration are often referred to as the UVATS equations.

U	Initial Velocity
V	Final Velocity
A	Acceleration (**CONSTANT**)
T	Time taken
S	Distance travelled

UVATS Equations:

$v = u + at$	$v^2 = u^2 + 2as$	$s = \left(\frac{u+v}{2}\right)t$
$s = vt - \frac{1}{2}at^2$	$s = ut + \frac{1}{2}at^2$	

Any object close to earth will experience a force acting on it due to the mass of the earth. This force is equal to an acceleration of $9.81ms^{-2}$

2.1.6: Air Resistance

All objects traveling through an environment which is not a vacuum will experience air resistance. This resistance which it will experience is in the opposite direction of its acceleration and when these two forces are balanced the object will reach terminal velocity. This can be seen in the below graphs.

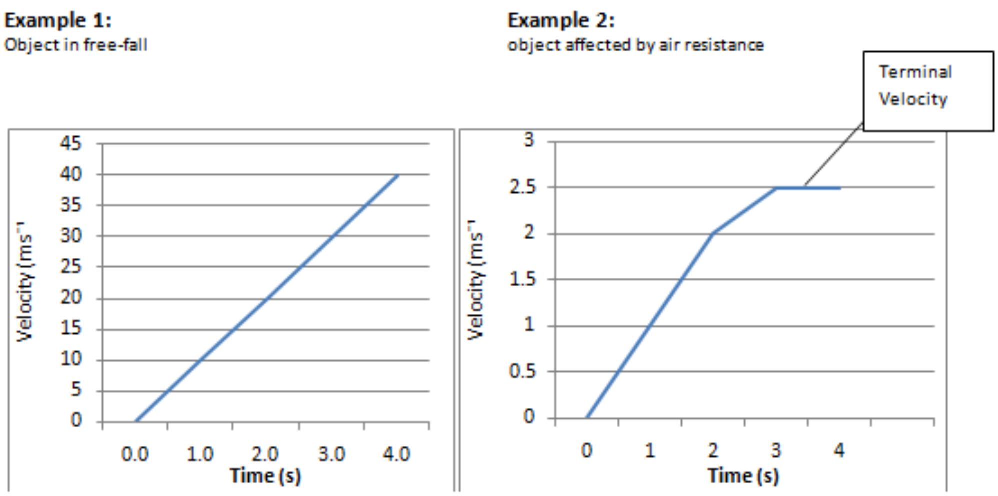
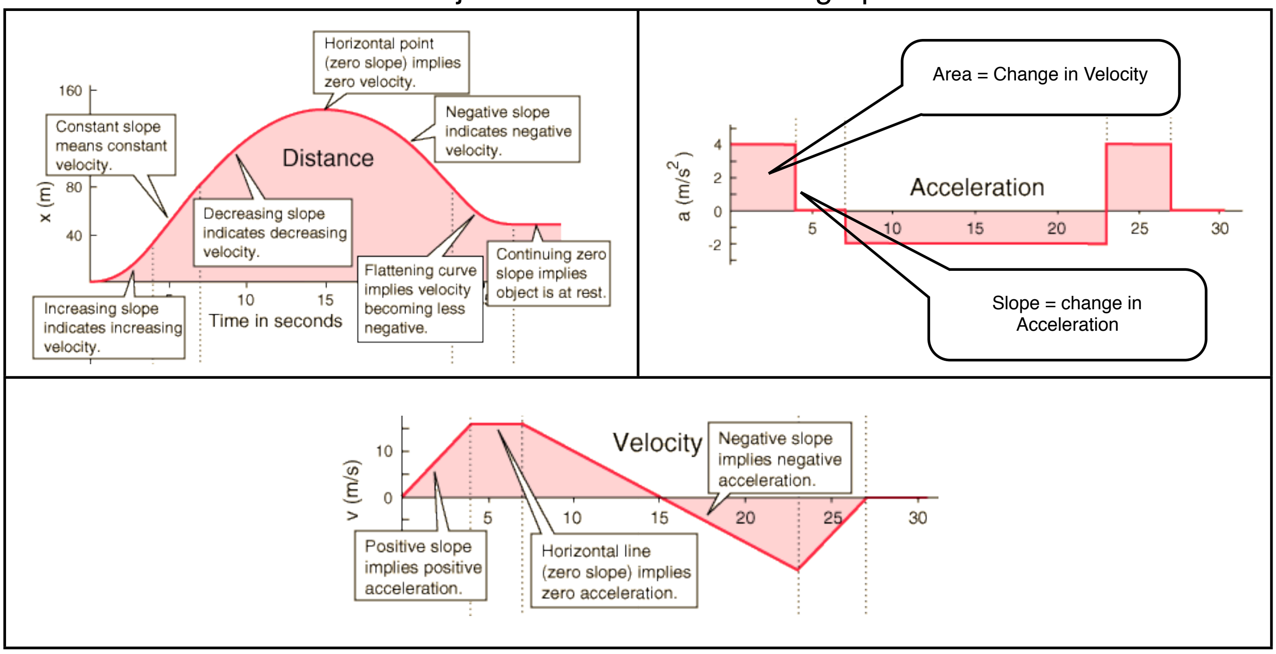


Figure 2.1.1 – air resistance in a velocity time graph

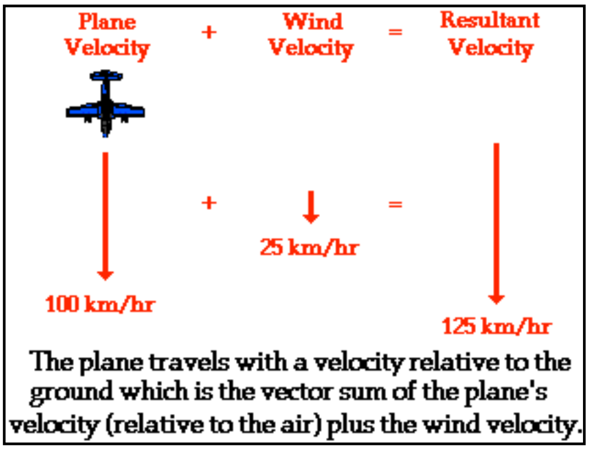
2.1.7: Analyzing graphs

Through looking at displacement, velocity and acceleration time graphs several inferences about the motion of an object can be made. These graphs can be seen below.



2.1.9: Relative Velocity

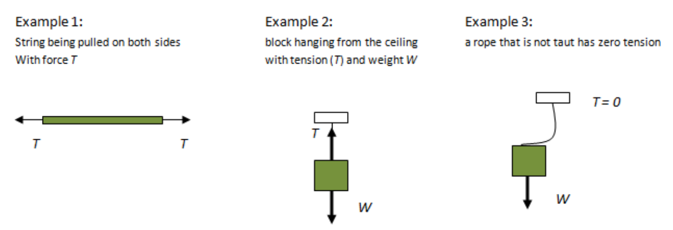
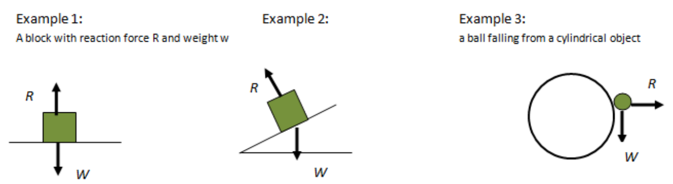
Relative velocity occurs when an object is moving through a medium which is also moving in relation to the observer. Two common examples are a plane flying through wind as seen below or a ship sailing through current.



2.2:Forces & Dynamics

The weight of an object is defined as the gravitational force that it experiences. It can be calculated by using the equation *w=mg*. Where *w* is the weight of the object (measured in Newtons, N), *m* is the mass of the object (measured in kilograms, Kg) and *g* is the gravitational field strength of the planet which the object is on (measured in N).

2.2.2: Free-body Diagrams

Tension	Tension is the force that arises when a body is being stretched	 Figure 2.2.1 - Tension forces
Normal Reaction Force	If a body touches another body, there is a reaction force (R) between the two bodies. This force is perpendicular to the body exerting the force	 Figure 2.2.2 - Normal reaction forces

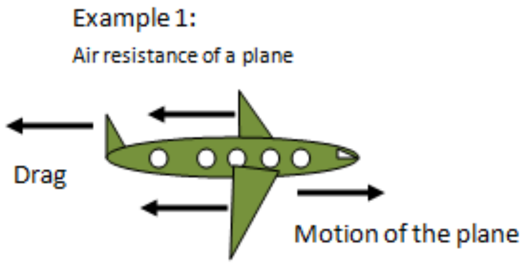
<table>
<tr><td>Drag Force</td><td>Drag forces are forces that oppose the motion of a body through a fluid (gas or liquid). They are directed opposite to the velocity of the body and generally depend on the speed of that body. Higher speed equals higher drag force.</td><td>

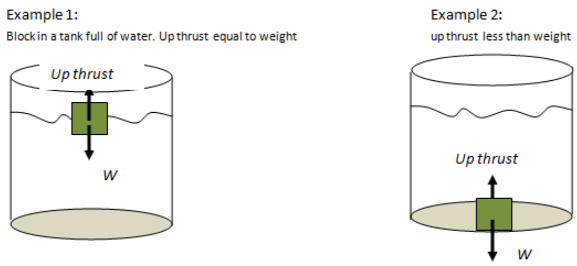
Figure 2.2.3 -Air resistance of a plane</td></tr>
<tr><td>Up Thrust</td><td>An object placed in a fluid medium will experience up thrust. If the up thrust force on a body is equal to the weight, the body will float in the fluid.</td><td>

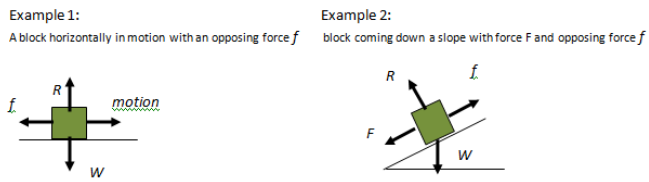
Figure 2.2.4 - Up thrust equal to weight and up thrust less than weight</td></tr>
<tr><td>Friction</td><td>Frictional forces (*f*) are forces that oppose the motion of a body</td><td>

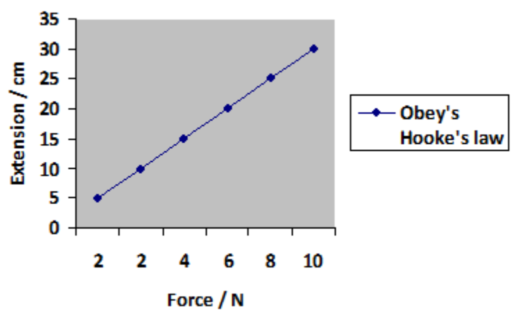
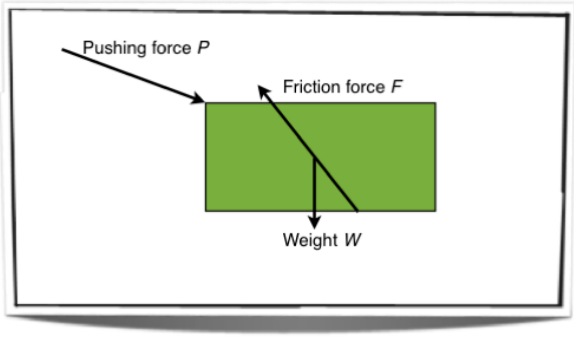
Figure 2.2.5 - Frictional forces acting on a body</td></tr>
<tr><td>Hooke's Law</td><td>Hooke's law states that up to the elastic limit, the **extension**, **x** of a spring is proportional to the **tension** force, **F**. The constant of proportionality **k** is called the **spring constant**. SI units of spring constant are $N\ m^{-1}$.</td><td>

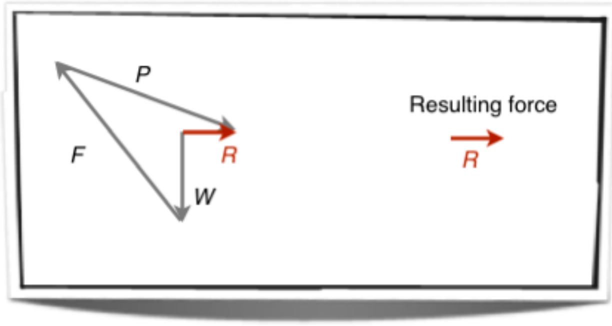
Figure 2.2.6 - Hooke's law represented graphically</td></tr>
</table>

2.2.3: Resultant Forces

The resultant force is the overall force acting on an object when all the individual forces acting on that object have been added together.

In order to determine the resultant force acting upon an object, we need to add the individual forces. Consider the figure below:





2.2.4: Newton's first law of motion

Newton's first law of motion states that "an object at rest will remain at rest unless acted upon by an external force" this is also true for an object in motion. An example of this is a block on a table. As long as no external force is applied to the block it will remain at rest.

2.2.6: Translational Equilibrium

Translational equilibrium occurs when all forces in one frame of reference are balanced, thus there is no acceleration but rather constant velocity.

2.2.8: Newton's second law of motion

Newton's second law of motion states that the force exerted by an object is equal to the product of its mass and acceleration. F=ma, this can also be expressed as the change in momentum divided by the change in time.

2.2.10: Momentum & Impulse

Momentum is defined as the product of the mass and the velocity of an object (p=mv). Momentum is measured in Newton seconds (Ns). Impulse is defined as the change in momentum that a body experiences. The area underneath a force time graph will be equal to the impulse of any object.

2.2.12: Conservation of momentum

The law of conservation of momentum applies to any system where no external forces act. This is often exemplified through the us of two colliding objects and their resultant velocity and direction must be calculated.

2.2.14: Newton's third law of motion

Newton's third law states that every action has an opposite and equal reaction. One example of Newton's third law is the flight of birds. As a bird flaps it's wings to push air down the same pressure is applied by the air on the bird upwards, this enables the bird to fly.

2.3: Work and Power

2.3.1: Work

The work done in a s specific motion is defined as the product of the force applied over the distance moved. w=Fs. If the force is however not applied in the same direction as the movement the following equation must be used. w=Fscos(a), where a is the angle at which the force is applied.

In any force displacement graph the work done is equal to the area underneath the curve.

2.3.4: Kinetic Energy

Kinetic energy is the energy possessed by an object as a result of its velocity. It can be found using the equation below.

$$ke = \frac{1}{2}mv^2$$

In the above equation, m is the mass of the object in motion and v is the velocity of it.

2.3.5: Gravitational Potential Energy

Gravitational potential energy is the energy possessed by an object as a result of its location within an area where it experiences a gravitational pull. It can be expressed using the below equation.

$$pe = mg\Delta h$$

In the above equation, m is equal to the mass of the object, g is the gravitational field strength and h is the altitude of the object.

2.3.6: Conservation of Energy

"The amount of energy in an isolated system is the same all the time. Additionally, energy may neither be created not destroyed." This statement is the basic law of the conservation of energy, in essence initial energy=final energy.

2.3.7: Types and Conversion of Energy

There are many forms of energy below are a a few.

Energy	
Kinetic Energy	Any object in motion will possess kinetic energy
Gravitational Potential Energy	Energy that exists as the result of the location of an object
Chemical Energy	Energy possessed due to the ability of an object to undergo chemical reactions
Strain Energy	Energy released when atoms in an object are allowed to rearrange, for example in a rubber band.
Nuclear Energy	Energy held within the nucleus of an atom that can be released when the state of the atom is altered
Thermal Energy	Energy possessed by an object due to its temperature

Energy can be converted in many ways, some examples are through a battery where chemical energy is turned into electrical energy, friction where kinetic energy is converted into thermal energy and a microphone which converts sound into electrical energy.

2.3.8: Types of collisions

Collisions			
Elastic collisions	Momentum is conserved	Kinetic energy is conserved	Can only occur at very small scale as energy is otherwise lost due to heat and light
Inelastic collisions	Momentum is conserved	Kinetic energy is not conserved	All visible collisions are inelastic

2.3.9: Power

Power is the rate at which work is done.

$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

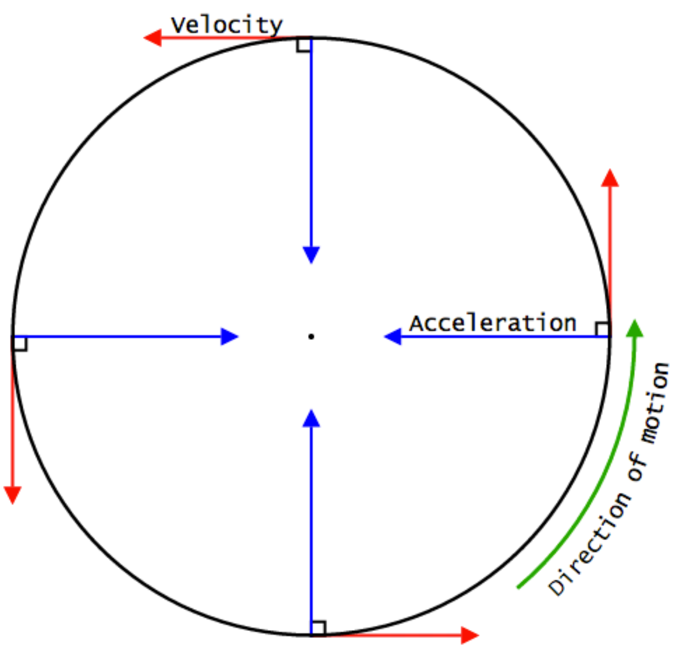
2.3.10: Efficiency

Efficiency is measured as the percentage of input energy which is returned as useful work from a system. For example a small percentage of the energy put into a car in the form of petrol will be wasted through the production of sound rather than mechanical power to move the car forwards.

$$\text{Efficiency} = \frac{\text{Useful Energy Out}}{\text{Total Energy In}}$$

2.4: Uniform Circular Motion

2.4.1: Diagram



In the above diagram speed is constant while the velocity changes as it is a vector and the direction is under constant change. Some examples of this phenomena is satellites where the centre seeking force is the gravitational pull, a car driving in a circle experiences the same force from friction between the tires and the ground.

2.4.2: Centripetal Acceleration

The magnitude of the acceleration toward the centre during circular motion can be found using the below equation. (Centripetal means centre seeking)

$$a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$$

2.4.4: Solving Questions

In the data booklet there are two listed equations, the one mentioned above and the equation for angular velocity, seen below. Omega is the angular velocity measured in rad/s.

$$\omega = \frac{2\pi}{t}$$

Topic 3: Thermal Physics

3.1: Thermal Concepts

The most important concept in thermal physics is that temperature will always flow from a hot object to a cold one. Once these two objects are at the same temperature they are said to be in thermal equilibrium. In thermal physics Kelvin is often used instead of Celsius. This is because the Kelvin scale begins at 0K which is absolute zero, the coldest temperature attainable by any material.

$$\text{Kelvin} = \text{Celsius} + 273$$

3.1.3: Internal Energy

The internal energy of a substance is determined by two factors, the kinetic and potential energy of its molecules.

Internal Energy	
Kinetic Energy	The kinetic energy of the particles is determined by their individual translational (movement) and rotational (Rotating... DUH!) kinetic energy.
Potential Energy	Potential energy of the particles comes from their respective intermolecular forces, this energy is from the work required to pull the particles apart.

3.1.4: Macroscopic Thermal Measurements

Measurements	
Temperature	Scalar quantity, measures how hot something is (measured in Kelvin)
Internal Energy	Total Kinetic and Potential energy of a substance (measured in Joules)
Thermal Energy	Energy that is given to a substance when it is heated (measured in Joules)

3.1.5: Mole & Molar Mass

Mole	Amount of substance, in a certain number of particles (avogadro's constant)
Molar Mass	The mass of one mole of a specific substance.

Avogadro's constant is the number of atoms in one mole, 6.02×10^{23}, the number of atoms in 0.012 kg of carbon-12.

3.2: Thermal Properties of Matter

3.2.1: Specific Heat Capacity

Specific Heat Capacity (c)	The amount of thermal energy required to raise the temperature of 1 kg of a substance by 1K ($1^{o}C$)	$Q = mc\Delta T$ Thermal Energy= mass x specific heat capacity x change in temp.
Thermal Capacity	The amount of thermal energy required to raise the temperature of a body by 1K ($1^{o}C$)	$Q = C\Delta T$ Energy= Heat capacity x change in temperature

3.2.3: States of Matter

Solid	Particles are in order, only movement is in the form of vibration, strong intermolecular forces, shape and volume are constant.
Liquid	Particles are in some order, particles can vibrate and slide around each other, moderately strong intermolecular forces, volume is constant but shape is not.
Gas	Particles are in disorder, particles can move freely, very weak intermolecular forces, shape and volume are both variable.

3.2.4: Changing states of matter

The state of matter can change due to outside forces. If a solid is heated until the point where the particles contain sufficient energy to weaken the bonds between them they material will melt. When a liquid is heated the energy will be used to break intermolecular bonds creating a gas.

When a material is changing matter it will not be heating up as all the energy will be used to weaken or break intermolecular bonds.

3.2.6: Evaporation vs. Boiling

Evaporation, unlike boiling, occurs at all temperatures, but the rate of evaporation increases as temperatures increases. Boiling occurs only when the liquid has reached a temperature of 100°C. Evaporation occurs only at the surface of a liquid while boiling occurs everywhere. Boiling is an endothermic (takes in energy) reaction while evaporation is exothermic as only the most energetic molecules are released. Boiling occurs when a liquid is heated from the bottom while evaporation occurs when the liquid is heated from the top.

3.2.7: Specific Latent Heat

The specific latent heat of a substance is the energy required for a specific mass of a substance to change state. It can be calculated using the below equation, in which Q is the energy required, m is the mass of substance and L is the latent heat in J/kg.

$$Q = mL$$

3.2.9: Pressure (for gases)

Pressure can be defined as the force exerted by a gas on the sides of its container. Measured in Nm^{-2}.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

3.2.10: Kinetic Model of an Ideal Gas

In order to more easily measure and predict the behavior of gases scientists have developed the kinetic model of ideal gases. This model makes several assumptions about the behavior of gases.

Assumptions:

1. Gas molecules are assumed to behave in an idealized way, that is, Newton's laws of mechanics apply to the motion of individual molecules.
2. It is assumed that intermolecular forces are negligibly small.
3. Molecules are assumed to be spherical and possess negligible volume (when compared with gas as a whole)
4. Molecules are assumed to be moving randomly.
5. Collisions between molecules are assumed to be elastic.
6. The time for a collision to take place is also assumed to be negligible.

Temperature is a measure of the average random kinetic energy of an ideal gas.

3.2.12: Macroscopic Behavior of an Ideal Gas

When investigating a gas at the macroscopic level several things about the gas can change.

Possible Changes:

1. An increase in the number of molecules, this will cause more collisions and therefore more powerful collisions with the sides of the container.
2. When volume is decreased pressure will increase as there will be an increase in the number of collisions causing stronger and more frequent collisions with the container sides.
3. When temperature is increased there will be an increase in pressure because gas molecules will be moving faster and collide with more force with the container sides.

Topic 4: Oscillations and Waves

4.1: Kinematics of Simple Harmonic Motion

An oscillating object is an object which is moving back and forth with a constant time period.

4.1.2: Definitions	
Displacement	**Distance** travelled from equilibrium point
Amplitude	Maximum value of **Displacement**
Frequency	The number of **oscillations** per second, Hz
Period	The time taken for one **oscillation.**
Phase Difference	A way of comparing different oscillating objects, often in terms of **wavelengths**

4.1.3: Simple Harmonic Motion

Simple harmonic motion is defined by two principles:
1. The force or acceleration is always directed towards the centre of motion
2. The force of acceleration is proportional to the distance from the equilibrium point

$$a = -\omega^2 x$$

$$\text{acceleration= -(angular frequency)}^2 \times \text{displacement}$$

There are other equations which can be used to find displacement or velocity along different waves, these equations can be seen below. These are all in RADIANS.

$$v = v_0 \sin(\omega t)$$
$$\mathrm{v} = \mathrm{v}_0 \cos(\omega t)$$
$$v = \pm\omega(x_0^2 - x^2)$$
$$x = x_0 \cos(\omega t)$$
$$x = x_0 \sin(\omega t)$$

4.2: Energy Changes During Simple Harmonic Motion

During simple harmonic motion energy is continously transferred between potential and kinetic energy. In a pendulum for example an object is gaining potential and losing kinetic energy as it is moving away from the equilibrium point.

To find the amount of different forms of energy in simple harmonic motion the below equations can be used. E_T is the total energy.

$$E_T = \frac{1}{2} m\omega^2 x_0^2$$

$$E_K = \frac{1}{2} m\omega^2 (x_0^2 - x^2)$$

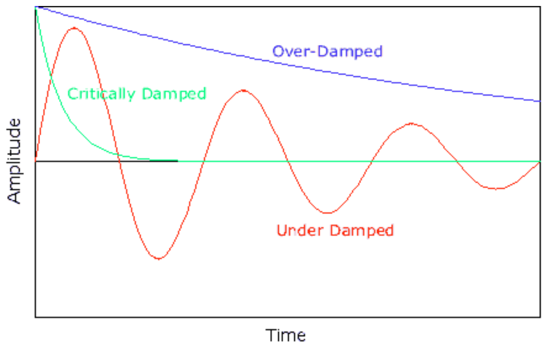
$$E_P = \frac{1}{2} m\omega^2 x^2$$

4.3: Forced Oscillations and Resonance

4.3.1: Damping

Damping is the use of a force in the opposite direction of the motion of an object in simple harmonic motion. It causes the amplitude of an oscillation to decrease.

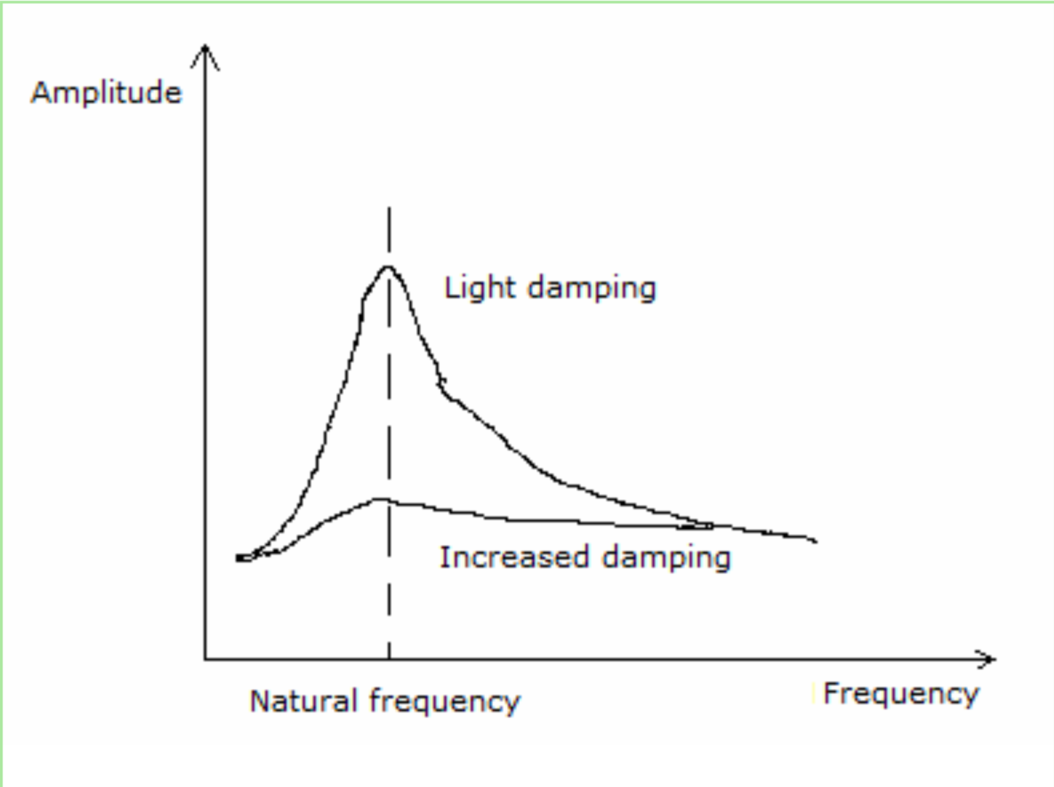
Damping is used in bridges, swing doors and car suspensions etc. There are three forms of damping:

Damping		
Under Damped	Occurs when the damping force is small so the amplitude is only slightly decreased each oscillation	
Critically Damped	Occurs when the damping force is sufficiently large, it decreases the amplitude rapidly and causes it to stop at 0.	
Over Damped	Occurs when the damping force is large, this causes the amplitude to decrease very slowly.	

4.3.3: Natural Frequency & Forced Oscillation

The natural frequency is the frequency that an object will oscillate at when displaced from its equilibrium.

A forced oscillation is when an object is made to oscillate due to an external force.



The above diagram illustrates the amplitude of an object undergoing forced oscillation.

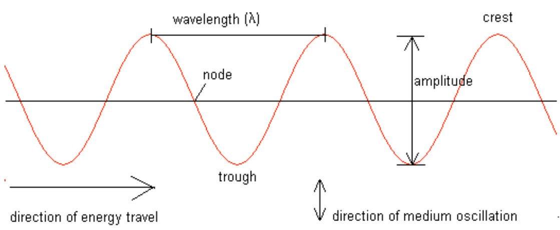
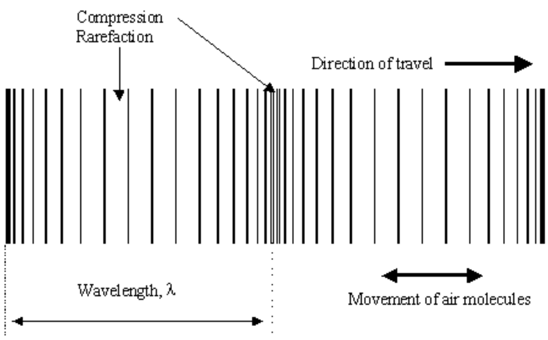
4.3.5: Resonance

Resonance is when an object is oscillating at its natural frequency, hence with a large amplitude.

Resonance can be very damaging to bridges and airplanes as it can cause them to break apart. It can however be good to have resonance in musical instruments as it enables them to play loudly.

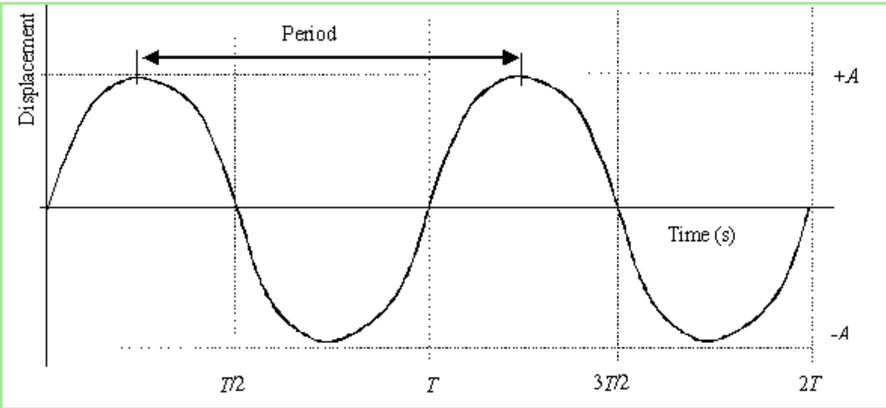
4.4: Wave Characteristics

All waves posses certain characteristics:
1. All waves transfer energy
2. The substance that the wave moves through does not move
3. They all possess SHM

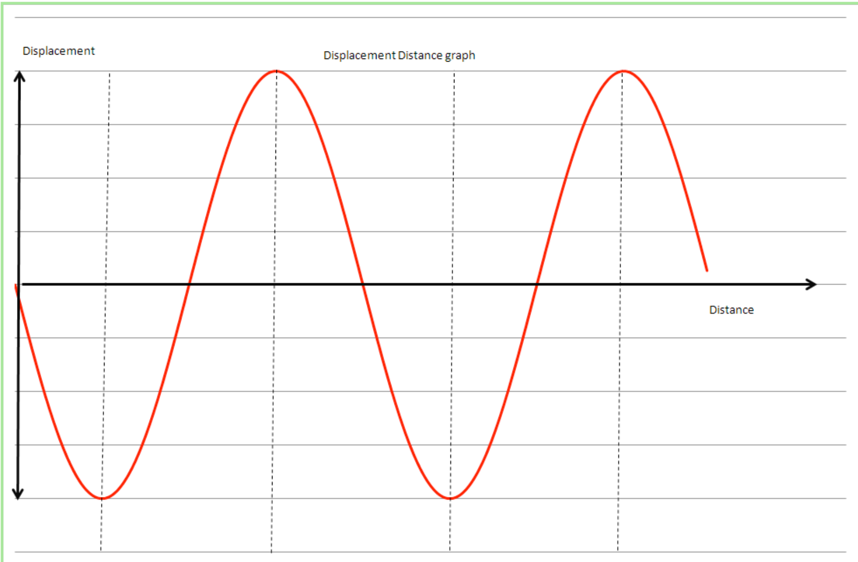
Waves		
Transverse Wave	Oscillations are at a right angle to the direction of energy transfer e.g. Water Waves, Vibrations along a string	
Longitudinal Wave	Oscillations are parallel to the direction of energy transfer e.g. Sound Waves, Seismic Waves	

Wave Characteristics Definitions	
Wave Front	Highlights the part of the waves moving together. e.g. all crests
Rays	Rays highlight the direction in which a wave is moving
Crest	The highest point on a transverse wave
Trough	The lowest point on a transverse wave
Compression	The point of highest pressure on a longitudinal wave
Rarefaction	The point of lowest pressure on a longitudinal wave
Wave Speed	The speed at which an oscillation passes a stationary point
Intensity	Power that the wave carries per oscillation, proportional to the square of the amplitude.

Different graphs of waves can be drawn, for example a displacement time graph, below, can be used to show how a point along a waves moves with time.



A displacement position graph, below, can be used to show how points along a graph possess different displacement at any point.

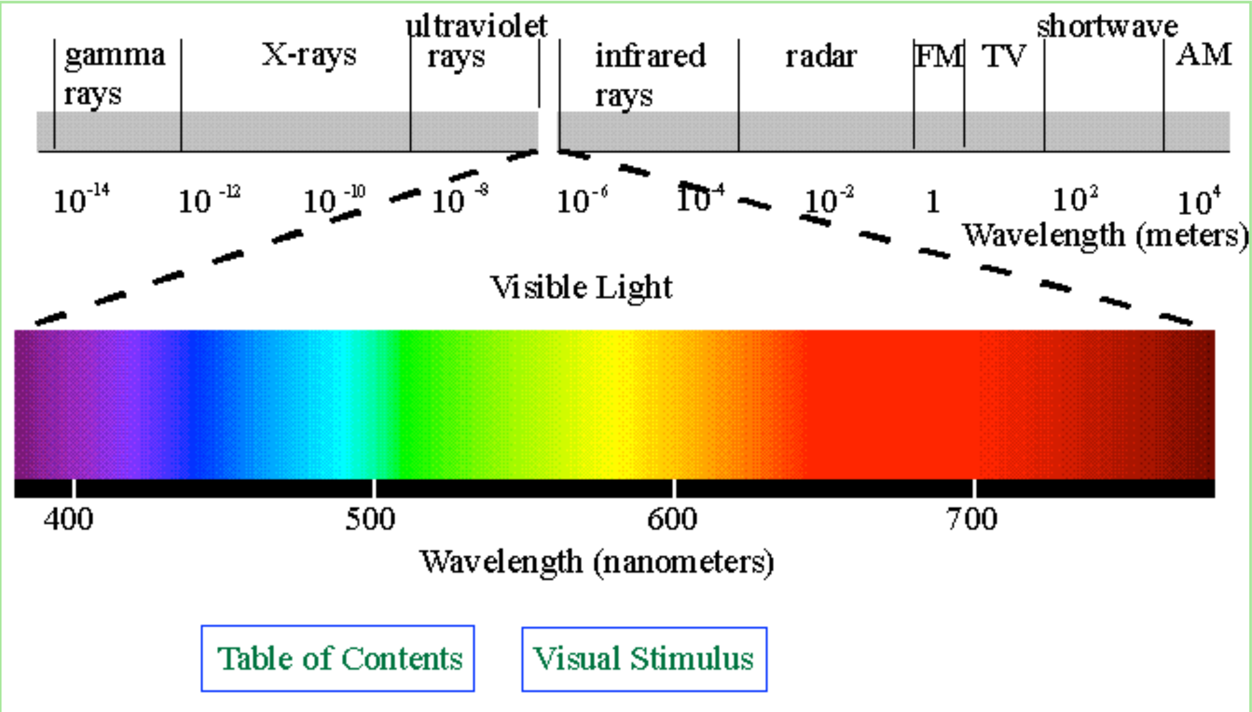


$$v = f\lambda$$

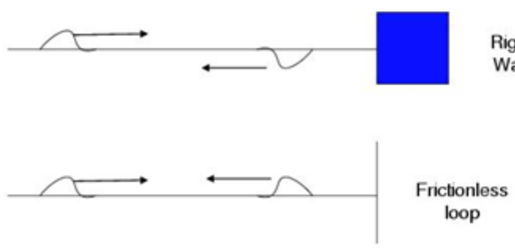
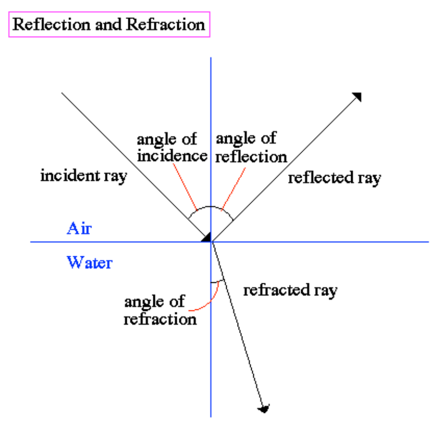
The above equation is the equation which can be used to find, velocity, frequency or wavelength of any wave.

4.4.9: Electromagnetic Waves

All waves along the electromagnetic spectrum travel at the same speed (speed of light) in a vacuum.

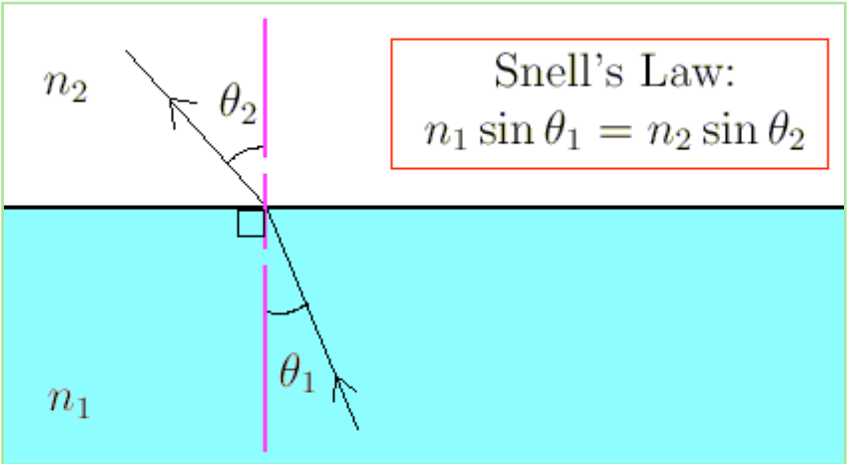


4.5: Wave Properties

Reflection and Refraction of Waves		
Reflection	When a wave reflects off a surface, can be seen in diagram to the right.	
Refraction	When light is incident on a refractive material	

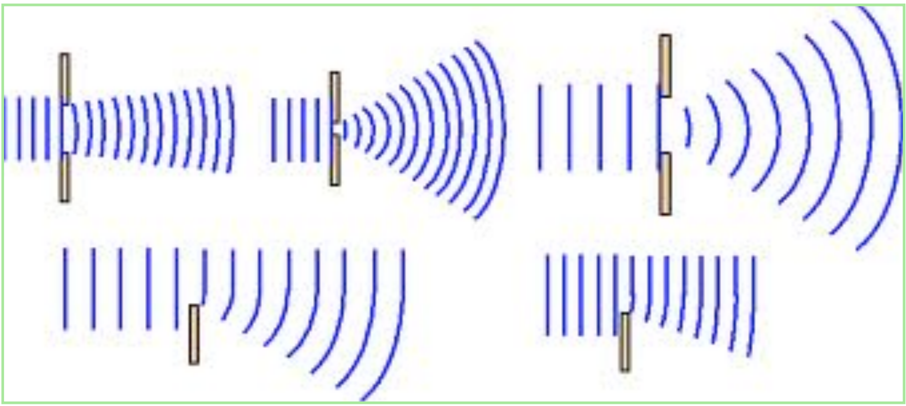
4.5.2: Snell's Law

Snell's law states that there is a relationship between the angle of incidence, the refractive index of the two materials and the angle of refraction.



4.5.3: Diffraction

When a wave passes by an obstacle or passes through an aperture it will diffract and spread out. Maximum diffraction occurs when the wavelength is equal to the slit width.



Diffraction occurs in a range of situations, for example in a harbor, and when sounds pass by corners so you can hear things you can't see.

Interference & Superposition	
Constructive Interference	When two waves interfere and are moving in the same direction, the resultant displacement is the sum of the two displacements
Destructive Interference	When two waves meet and are displaced in opposite directions, this causes them to partially cancel out, the sum is the resultant displacement
Superposition	The superposition of two waves is the sum of their displacement

Topic 5: Electrical Currents

5.1: Electric Measurements

Electrical Currents Definitions	
Electric Potential Difference	The potential difference between two points on a circuit is equal to the work done per unit charge to move a small positive charge between these points. Measured in Volts. $$\Delta V = \frac{\Delta E}{q}$$
Electronvolt 1eV	The amount of energy acquired by an electron when it is accelerated through a potential difference of 1 Volt. 1 eV = $1.6\text{x}10^{-19}$J
Electric Current	Electric current is a flow of charge, either due to electrons moving through a metal or through ions moving in a solution or gas. Electrons in metals flow as electrons move through a lattice of positive metal ions. Metals can conduct as some of the electrons in metals can move freely. Measured in Amperes. $$I = \frac{\Delta q}{\Delta t}$$
Resistance	Resistance is a measure of how easily charge can flow in a material. The resistance is defined as the ratio of the potential difference across a material to the current flowing through it. $$R = \frac{V}{I}$$
Electromotive Force (emf)	Emf is the work (or energy) per unit charge made available by an electrical source. Emf is the maximum potential difference that an electric source can supply.

5.1.7: Resistance

Resistance depends on 3 factors:
1. Length of material which current is moving through
2. Cross sectional Area of the material which the current is moving through
3. The resistivity of the material which the current is moving through.

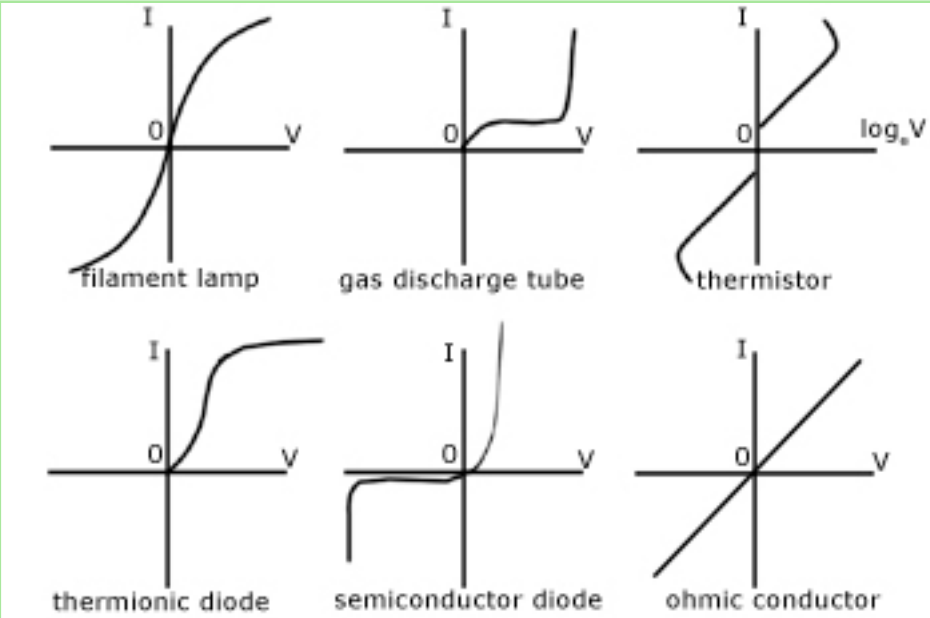
Resistivity is a measure of how good of a conductor a material is. Good conductors have low resistivity. Measured in Ohm Meters.
Resistance of an object can therefore be calculated using the following equation (where rho is the resistivity):

$$R = \frac{\rho L}{A}$$

5.1.8: Ohm's Law

Ohm's Law states that ohmic materials are materials where voltage is proportional to current. Ohmic materials do not change temperature when a current is passed through them.

Non-Ohmic materials heat up when a current is passed through them.
Below are diagrams showing the relationship between voltage and current for several conductors.



5.1.10: Power

Electrical Power is the rate that an electrical device uses energy.

$$P = VI = I^2R = \frac{V^2}{R}$$

These equations can be derived from the below working:

$$P = \frac{W}{t} \qquad W = Vq \quad \longrightarrow \quad I = \frac{q}{t} \qquad P = \frac{Vq}{t} = IV$$

And as R=V/I. All of the above equations can be derived.

5.2: Electric Circuits

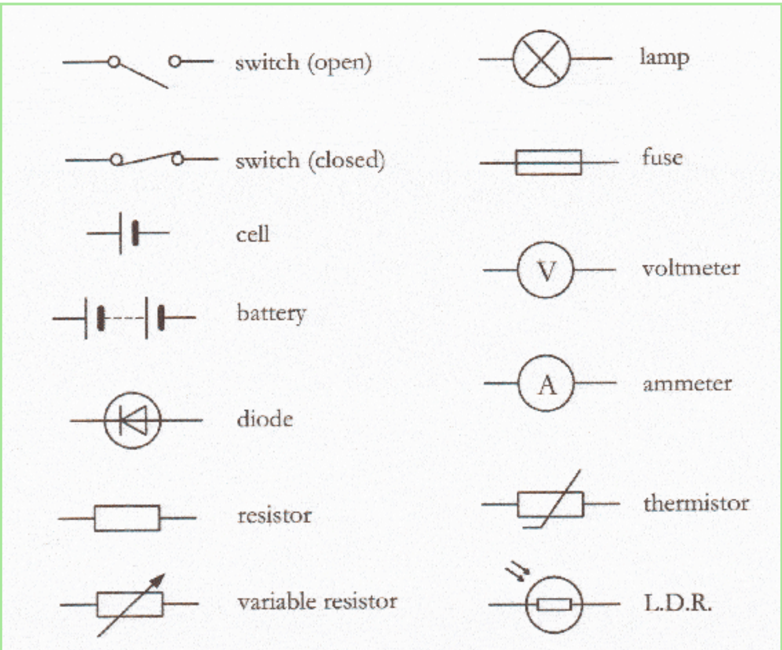
5.2.2: Internal Resistance

Internal resistance is the concept that a cell itself has resistance that the current needs to pass through. This can be proven as the cell heats up and this resistance increases.

5.2.3: Resistance Equations

Resistance Equation	
Series	$R_{Total} = R_1 + R_2 + R_3 + \ldots$
Parallel	$\frac{1}{R_{Total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$

5.2.4: Circuit Diagrams



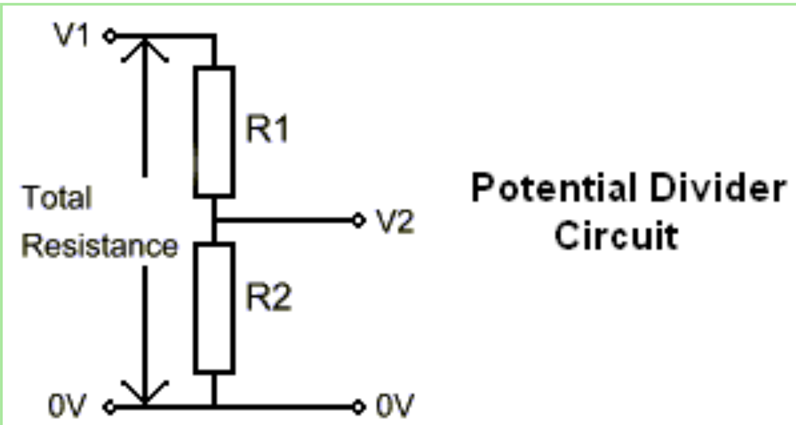
Strain Gauge, a resistor that can be pulled and when it does its resistance increases.

5.2.5: Ammeter and Voltmeter

Ammeter & Voltmeter	
Ammeter	Measures the current at a point in a circuit. Should be connected in series. Should ideally have 0 resistance so no p.d. is dropped across it.
Voltmeter	Measures the voltage across a part of a circuit. Should be connected in parallel. A voltmeter should have a very high almost infinite resistance.

5.2.6: Potential Divider

Resistors connected in parallel can be used to control voltages. By changing the ratio of the resistors it is possible to vary how much potential is dropped across either R_1 or R_2. This can be used to supply different objects by the same cell without supplying to much current to the various objects.



5.2.7: Sensors in Circuits

Sensors can be used to activate different parts of a circuit at any time. For example a light sensor can be used to activate lights only at night. A Light Dependent Resistor will have lower resistance with higher light intensity.

Topic 6: Fields & Forces

6.1: Gravitational Force and Field

Newton's Universal law of gravitation states "Every mass attracts every other mass with a force proportional to the product of their masses and inversely proportional to the square of their separation"

$$F \propto \frac{m_1 m_2}{r^2}$$

$$F = \frac{G m_1 m_2}{r^2}$$

$$G = 6.67 \times 10^{-11} Nm^2 kg^{-2}$$

6.1.2: Gravitational Field Strength

Gravitational field strength is defined as the force per unit mass acting on a small test mass placed at a point in a field. Measured in $Nkg^{-1}ms^{-2}$

$$g = \frac{F}{m} = \frac{\frac{G m_1 m_2}{r^2}}{m} = \frac{Gm}{r^2}$$

Planets are surrounded by a radial field where masses will experience a force. This force becomes less as you get further away from the planet, the potential energy increases as an object moves further away as it can travel further. When it is an infinite distance away it however the potential becomes 0 as the planet has no effect on the mass.

The equation for change in potential energy when moving in relation to a planet is equal to:

$$\Delta V = \frac{w}{m}$$

For an object to reach the point where the potential is 0 and it no longer experiences a force it must leaver the planet with a specific velocity, escape velocity.

$$\text{Energy Required} = \frac{GMm}{r}$$

$$\frac{1}{2}mv^2 = \frac{GMm}{r}$$

$$v = \sqrt{\frac{2GM}{r}}$$

6.2: Electric Force and Field

Charge exists either as positive or negative charge. According to the law of conservation of charge, charge always remains constant within an isolated system.

A conductor is a material or object which can easily carry a charge. This is because it has free electrons within itself which can carry the charge. Metals are often conductors.

Insulators are materials or objects which do not carry a charge. Most materials are insulators.

6.2.4: Coulomb's Law

Every charge attracts or repels every other charge with a force proportional to the product of their charges and inversely proportional to the square of their separation.

$$F \propto \frac{q_1 q_2}{r^2} \quad F = \frac{k q_1 q_2}{r^2} \quad k = 8.99 \times 10^9 \, Nm^2 C^{-2}$$

6.2.5: Electric Field Strength

Similar to gravitational field strength, electric field strength is the force per unit charge acting on a small positive test charge placed at that point. Electric field strength is calculated using the below equation:

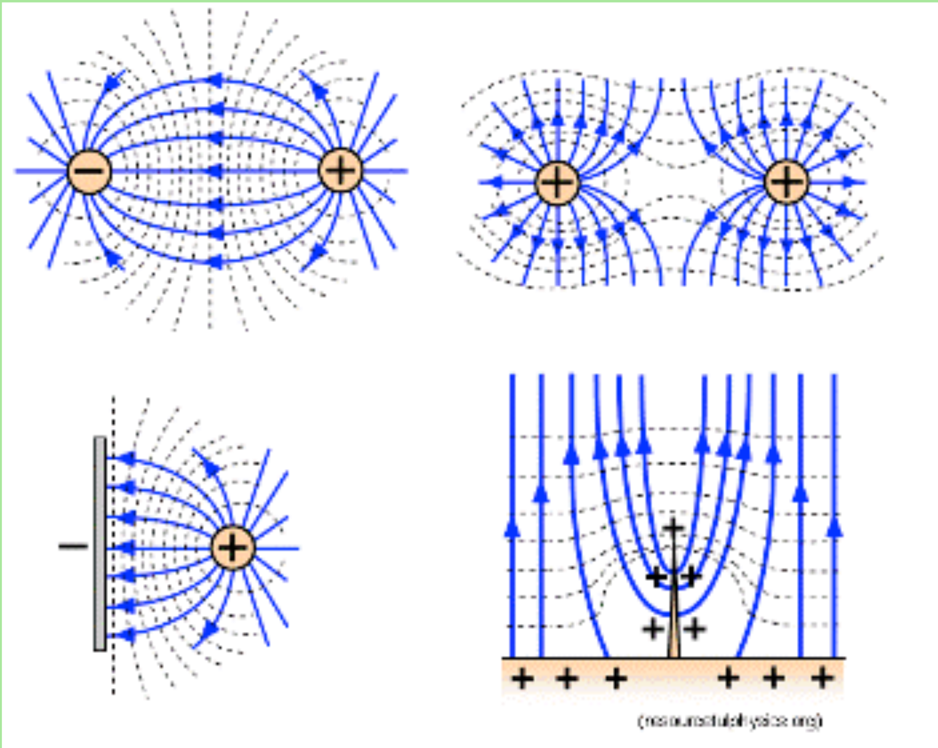
$$E = \frac{F}{q} = \frac{\frac{k q_1 q_2}{r^2}}{q} = \frac{kq}{r^2}$$

A change in the potential energy of a test charge in a field can be measured using the below equation:

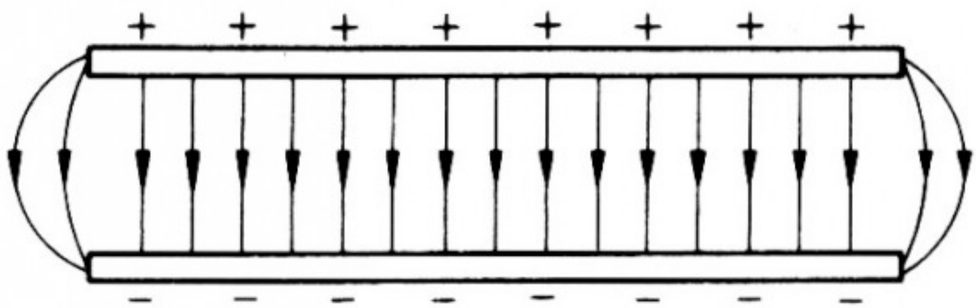
$$\Delta V = \frac{(-)kq}{r}$$

The negative signifies that since charge can be both negative and positive.

6.2.7: Electric Field Diagrams



The dotted lines are lines where the field strength is equal. (On the below diagrams the lines on the sides are caused by the edge effect)

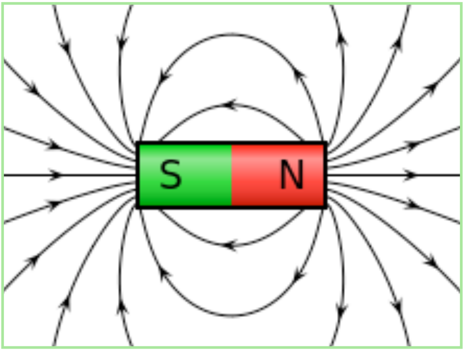


The above diagram shows a uniform electric field. To find the electric field strength between these two plates the following equation can be used:

$$E = \frac{V}{d}$$

E is the electric field strength (Vm^{-1} or NC^{-1}), V is the potential difference between the two plates and d is there separation.

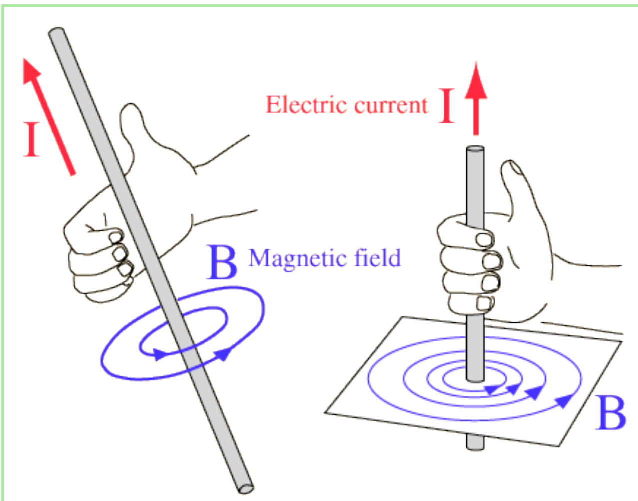
6.3: Magnetic Force & Field



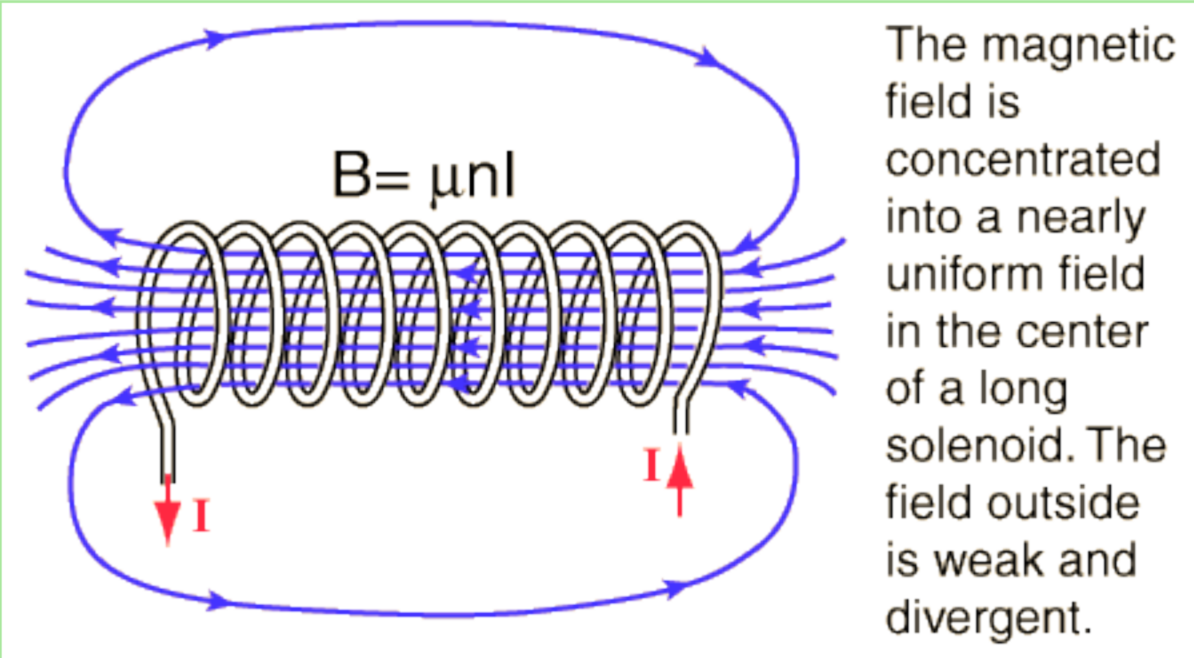
Magnetism is the phenomena that causes certain materials to be able to attract or repel each other. A moving current will also give rise to a magnetic field.
There are three elements that can be magnetic:
1. Iron
2. Nickel
3. Cobalt

Magnetism	
Hard Magnetic (Permanent)	Difficult to magnetize and demagnetize
Soft Magnetic (Temporary)	Easy to magnetize and demagnetize

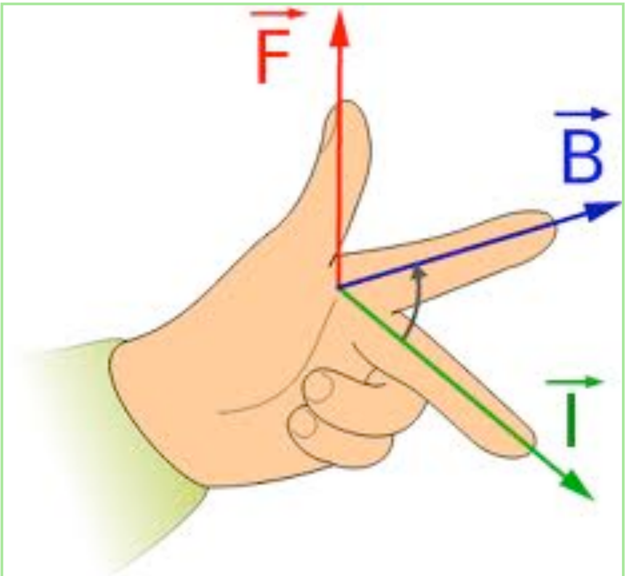
A current carrying wire will give rise to the magnetic field seen below (this is known as the grip rule)



Similarly a solenoid with a current through it will generate a magnetic field as seen in the diagram below.



When a charge is moving through a magnetic field it will thus experience a force. To find the direction of this force Fleming's left hand rule can be used.



The above rule can be used when investigating the direction in which a charged particle will experience a force when moving through a magnetic field (B). I is the direction of current and F is the force.

When a current carrying wire moves through a magnetic field it will experience a force. This force can be calculated by using the following equation.

$$F = BIL\sin\theta$$

In this equation F is the force experienced, B is the magnetic flux density of the magnetic field and I is the current in the wire, L is the length of the wire and theta is the angle between the wire and the field.

When an charged particle is moving through a magnetic field another equation can however be used, it is stated below.

$$F = BQv\sin\theta$$

F is similarly to before the force experienced by the object, B is the magnetic flux density, Q is the charge of the object, v is the velocity of the object and theta is the angle between the field and the movement of the object. The left hand rule can after this be used to find the direction of the force. Remember that current is the flow of negative charge.

6.3.5: Definitions of a Magnetic Field

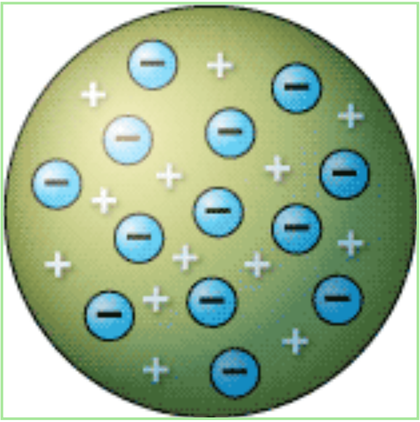
Magnitude of a magnetic field is the strength of the field, measured by it's magnetic flux density.

The direction of a magnetic field is from north pole to south pole. The direction determines how objects within the field will react to the field.

Topic 7: Atomic and Nuclear Physics

7.1: The Atom

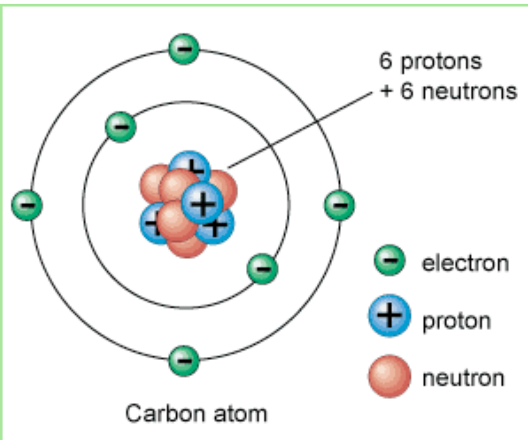
In historic times atoms were described as being made of a so called plum pudding model, seen below. This was however disproved by Rutherford.



Rutherford was able to disprove this method through several observations he made when performing the now famous 'Rutherford experiment' where he fired alpha particles through a gold leaf with a detector behind to detect wether any alpha particles flew through.

Observation	Conclusions
Most alpha particles went straight through	Most of atom must be empty space
Some positive alpha particles experienced large deflections	Matter in the atom must be positive
Very few alphas returned	Matter must be concentrated into very small space

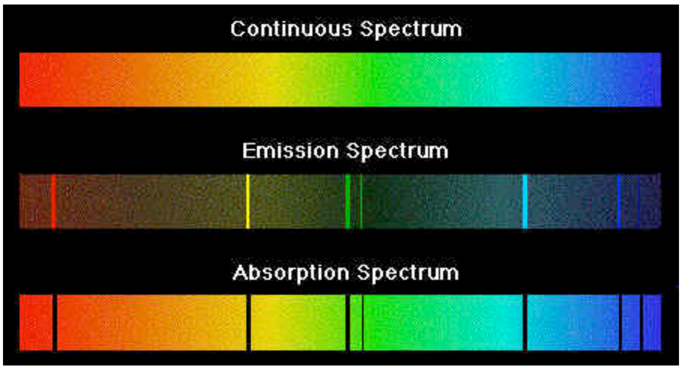
Through this experiment Rutherford could thus disprove the plum pudding model, and the current atomic model was developed.



This model, often called the Bohr model is however severely limited as it is only accurate for hydrogen.

7.1.4: Atomic Energy Levels

As seen by the Bohr model of the atom electrons are circling in layers around the nucleus, these different layers are referred to as atomic energy levels. The existence of these levels has been proven through the fact that when an element is heated it will give off light. This can be said to prove the existence of energy levels as the release of certain frequencies of light is due to electrons moving between energy levels. Energy levels correspond to specific energy levels and in order for an electron to move to a specific level it must be given the precise difference in energy from it's current state to it's new state. This is often achieved by shining light on a tube of the gas form of the element in question. When however investigating the emission spectrum a charge can be applied across a gas of the element to be investigated. This will result in the excitement and then relaxation of electrons, causing emission of specifically charged photons, as seen on the below spectra.



The release of this photon of a specific energy will correspond to a specific wavelength of light. To calculate this wavelength the below calculation must be made. Values of energy levels are often measured in electronvolts. To convert between eV and J you must multiply by 1.6×10^{-19} and divide by the same number to go the other way.

$$E = hf$$

$$\text{Energy} = \text{Planck's Constant} \times \text{Frequency}$$

$$c = f\lambda$$

$$\text{Speed of light} = \text{frequency} \times \text{wavelength}$$

This calculation to find the wavelength of the emitted light from an atom has proven the existence of energy levels.

7.1.5: The Nucleus

Definitions	
Nuclide	A nuclide is a specific nucleon, determined by it's number of neutrons and protons
Isotope	Isotopes are different versions of the same element, differing only in the number of neutrons that it possesses
Nucleon	A nucleon is either of the two components of a nucleus, a proton or a neutron
Nucleon Number (A=Z+N)	The nucleon number of an element is the number of protons and neutrons in a stable nucleus
Proton Number (Z)	The proton number of an element is the number of protons in the nucleus of an atom of this element.
Neutron Number (N)	The neutron number is the number of neutrons in the nucleus of an atom of a specific element.

Inside the nucleus nucleons are kept together due to short range nuclear interactions, forcing the neutrons and protons together. This force that keeps the nucleons together causes the masses of bound together nucleons to be less than if they were separated. It is this phenomena that enables nuclear power.

7.2: Radioactive Decay

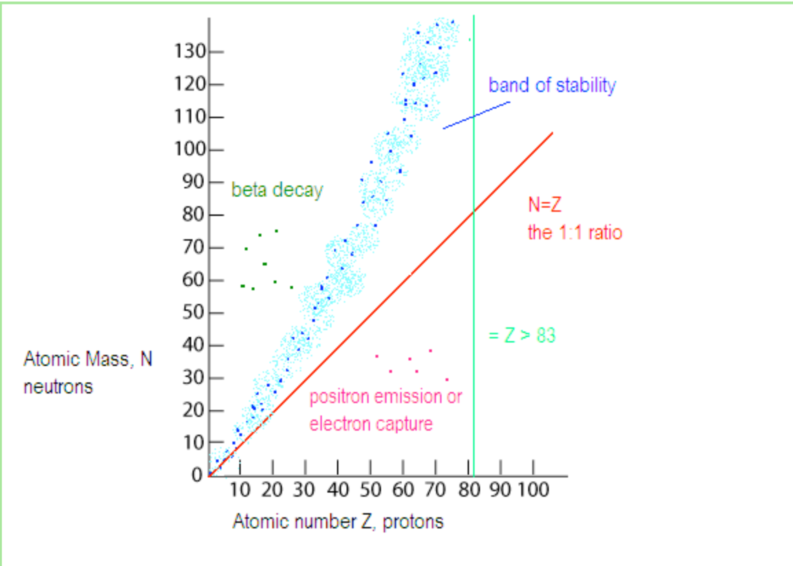
There are four types of radiation, these are listed in the table below.

Types of Radiation		
Alpha (α)	Alpha radiation is the release of a helium nucleus from an unstable nucleus.	$^{210}_{84}\mathrm{Po} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{206}_{82}\mathrm{Pb}$
Beta⁻ (β⁻)	Beta minus radiation is the release of an electron from the nucleus of an element. This release is enabled through the creation of a proton from a neutron.	$^{14}_{6}\mathrm{C} \rightarrow {}^{0}_{-1}\beta^{-} + {}^{14}_{7}\mathrm{N} + {}^{0}_{0}\overline{\upsilon}_e$ The creation release of this electron in one direction causes an electron flavored anti neutrino to be launched in the opposite direction, in order to keep momentum constant
Beta⁺ (β⁺)	Beta plus radiation is similar to beta minus but instead of releasing an electron, a positron is released.	$^{70}_{31}\mathrm{Ga} \rightarrow {}^{0}_{1}e^{+} + {}^{70}_{30}\mathrm{Zn} + {}^{0}_{0}\upsilon_e$ Beta plus radiation causes the release of electron flavored neutrino.

Types of Radiation		
Gamma (ɣ)	Gamma radiation is caused by the decay of a nucleus from one energy level to another. This causes the release of a high energy electromagnetic wave (>10keV)	Gamma rays that are emitted have discrete energy levels and thus nuclear energy levels are also discrete.

All of these types are ionizing radiation, particles that have sufficient energy to liberate electrons from their atoms, causing the atom to become ionized. Alpha particles are very ionizing but because of their large size they can easily be stopped by a few centimeters of air or a sheet of paper. Beta radiation is less ionizing but because of its very high speed it is able to penetrate more. Gamma radiation is also ionizing and it is very hard to stop, it requires thick sheets of lead to shield from gamma radiation.

Exposure to ionizing radiation can be very harmful as particles causing electrons to be liberated can cause cancer and other severe conditions. In the short term this radiation can cause skin damage and damage to the reproductive organs. In the long term however it may cause cancer and hereditary issues.

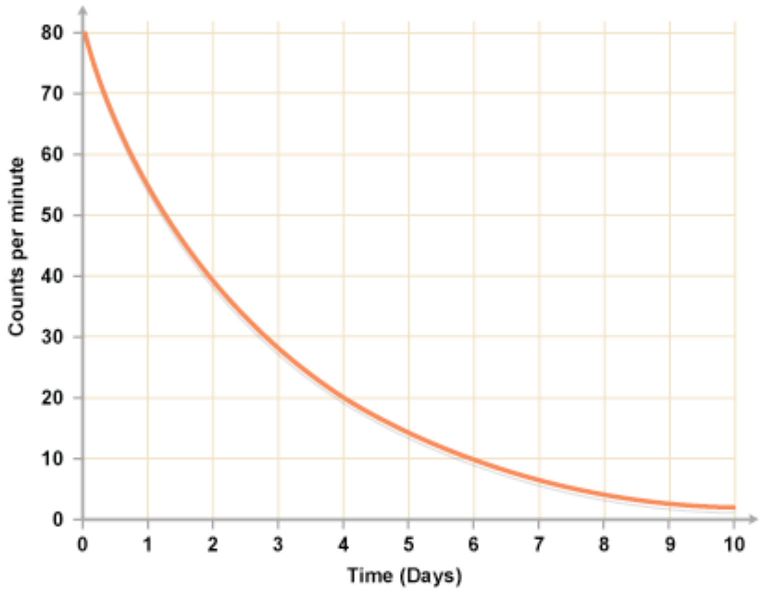


The above graph shows a graph of most elements. As seen on the graph the number of neutrons increases exponentially the larger the nucleus. This causes large nuclei to become unstable as the forces keeping the nucleus together become weaker as the nucleus grows, no longer enabling it to remain stable. Elements along the top of this graph often undergo alpha radiation, while elements to the left of the stable line will undergo beta minus and elements to the right will undergo beta plus.

7.2.6: Half-Life

Half-life is defined as the time taken for half the remaining radioactive nuclei of a substance to decay or as the time taken for the activity of a radioactive substance to halve.

As radioactive decay is a random process half life can not always with complete accuracy predict the behavior of a radioactive sample. The rate of decay does however always decrease.



The above graph of the activity of a specific radioactive element can be used to calculate the half life by finding the time taken for the activity to halve, in this case 2 days.

When working with half-life the following equation is useful:

$$N = N_0 e^{-\lambda t}$$

In this equation, N is the number of atoms remaining, N_0 is the original number of atoms, lambda is the decay constant and t is the time taken. In order to find the time of one half life the below derivation can be performed.

$$N = N_0 e^{-\lambda t}$$

$$1 = 2e^{-\lambda t_{1/2}}$$

$$\frac{1}{2} = e^{-\lambda t_{1/2}}$$

$$\ln\left(\frac{1}{2}\right) = \ln\left(e^{-\lambda t_{1/2}}\right)$$

$$\ln\left(\frac{1}{2}\right) = -\lambda t_{1/2}$$

$$\ln\left(2^{-1}\right) = -\lambda t_{1/2}$$

$$-\ln(2) = -\lambda t_{1/2}$$

$$t_{1/2} = \frac{\ln(2)}{\lambda}$$

7.3: Nuclear Reactions

An artificial transmutation is the process by which an atom changes into an atom of a different element. This can occur as a result of exposure to radioactivity as the atom may have been exposed to and thus been hit by radioactive products, such as alpha or beta particles. This situation can be described using a nuclear equation:

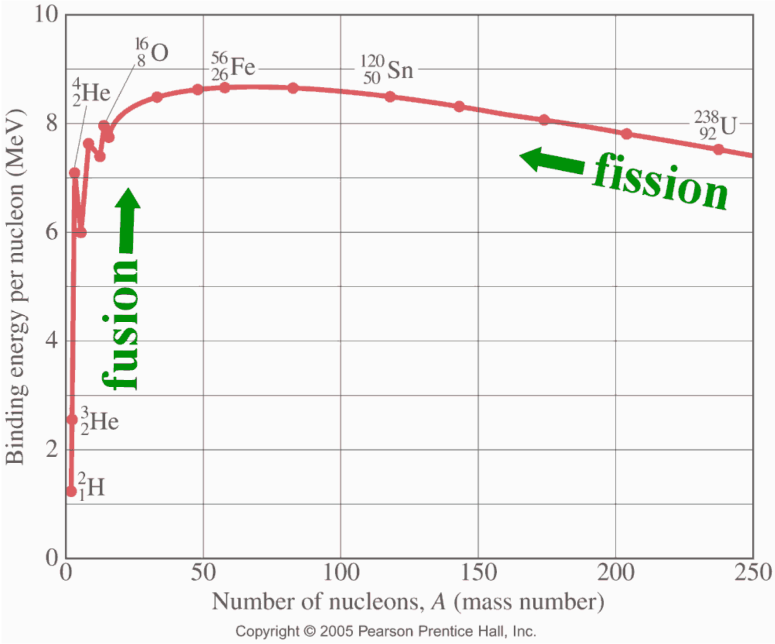
$$^{14}_{7}N + ^{4}_{2}\alpha \rightarrow ^{14}_{8}O + ^{1}_{1}H$$

The term unified atomic mass unit is a measurement of the mass of objects at very small scale.

$$E=mc^2$$

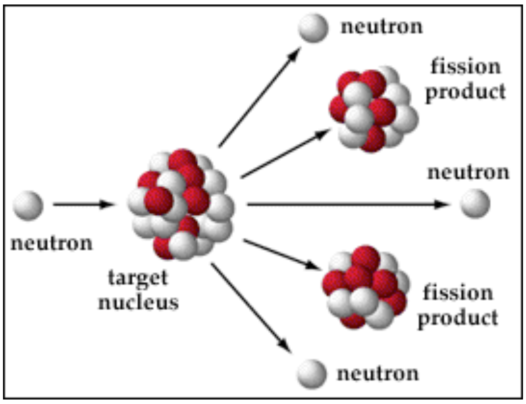
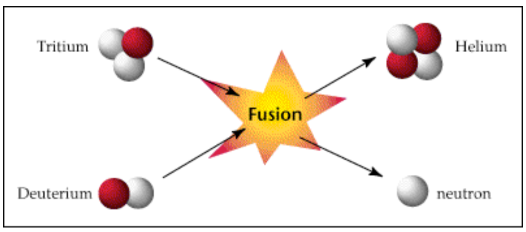
The Einstein mass energy equivalence relationship is a very useful. The equation creates a way in which mass can be represented as energy, this is based on the energy that would be released if all the intermolecular bonds in a substance was broken. When discussing this relationship there is one critical value, 931.5 $MeVc^{-2}$. This number represents the mass of 1 atomic mass unit, in terms of energy and the speed of light. This can be used wen finding for example the binding energy of a nucleus. The binding energy is found in atomic mass units. This is then multiplied by 931.5. This will then give you the binding energy in terms of MeV.

Definitions	
Mass Defect	Mass defect is the difference in mass between an atom and the constituent parts of this atom. This is what enables energy to be released from nuclear reactions.
Binding Energy	Binding energy is the energy which holds a nucleus together, it is equal to the mass defect.
Binding Energy Per Nucleon	The binding energy per nucleon is what it sounds like...

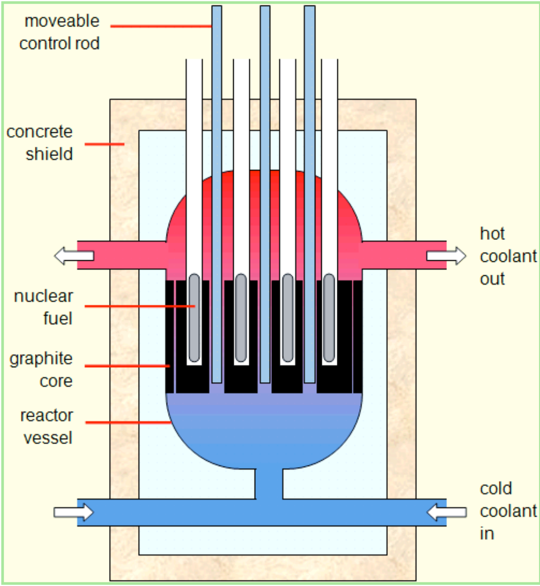


The above graph shows the relationship between the binding energy per nucleon and number of nucleons for all elements. The two arrows also indicated the directions in which fusion and fission can occur.

Fission and Fusion

Definitions		
Fission		Fission occurs as a neutron is fired onto a target nucleus. This nucleus is because of this impact split into two new nuclei as well as releasing a few solitary neutrons. These neutrons will then continue to hit other nuclei increasing the reaction. In order to keep a fission reaction under control it is necessary to absorb some of the neutrons, this is done using Boron or Cadmium.
Fusion		Fusion works by the joining of hydrogen isotopes, which at very high temperatures can bond and will form helium and neutrons. Not yet possible on earth due to the high temperatures required.

The graph seen previously with the bonding energy per nucleon can be used to illustrate the energy released during a nuclear reaction, as the energy per nucleon increases energy will be released, this enables energy to be retrieved.



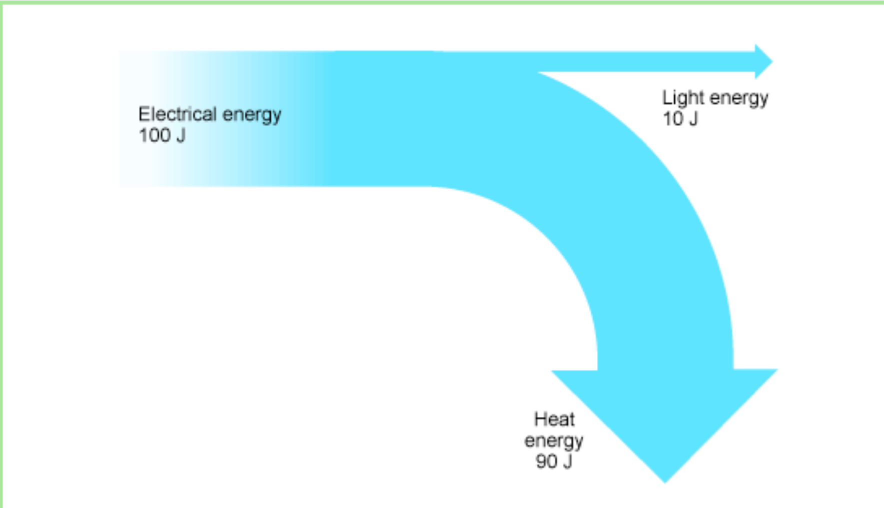
This diagram illustrates the structure of a nuclear fission reactor. The graphite core is in place to slow down the neutrons as they have to strike the fuel nuclei at a specific speed for the reaction to take place.

Topic 8: Energy, power and climate change

8.1: Energy degradation and power generation

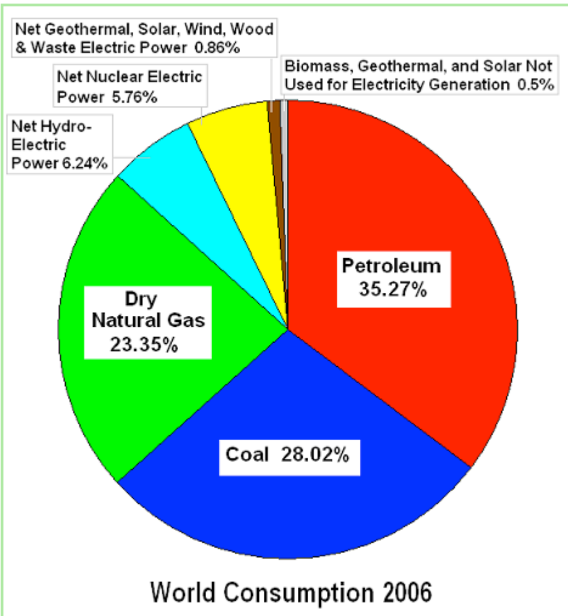
When producing energy the most common method is to heat up water which is then used to turn a steam turbine to generate electricity.

Degraded energy is the process through which energy is lost due to heat, light, sound or other methods to the surrounding environment when electricity is produced.

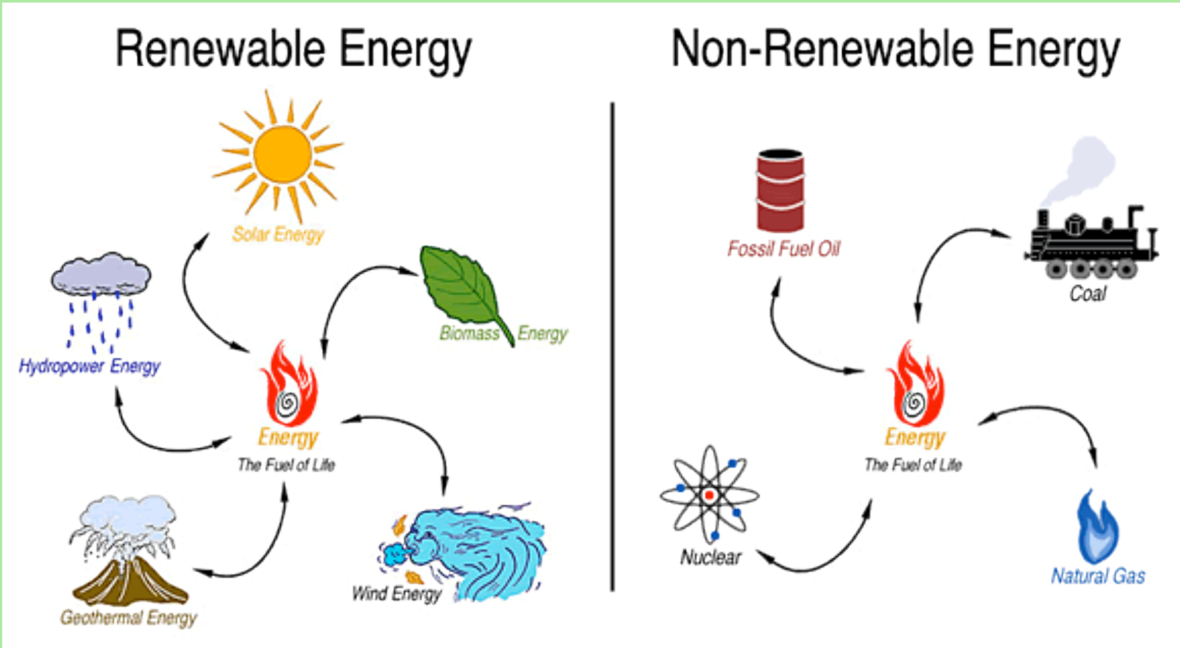


The above diagram is known as a Sankey diagram, it represents how energy can be lost during the production or use of electricity. In this situation it is apparent that 90% of the input energy is output as heat and 10% is output as light.

8.2: World energy sources



The above chart illustrates the relative amount of resource use for the production of electricity on earth.



The above diagram illustrates the different energy sources used to produce electricity, those on the right are non-renewable, meaning that there is only a finite amount of it available on earth, those on the left are available in unlimited amounts. Biomass, fossil fuels and natural gas also release CO_2 when burnt to produce electricity.

Energy density is the amount of energy per kg of a specific fuel. It is measured in JKg^{-1}. The cost of fuels is often closely related to its energy density as fuels with high energy densities are more desirable.

Advantages & Disadvantages of different fuels		
Coal	Inexpensive Relatively easy to collect	Releases large amounts of air pollution Causes acid rain and global warming Heavy and difficult to transport
Nuclear	Fuel is inexpensive High energy density No greenhouse gas release	Very high capital cost Difficult long term storage of fuel Very dangerous if incident occurs
Hydroelectric	Very inexpensive after initial investment	Very location dependent Effects wildlife Potential collapse very dangerous
Gas/Oil	Easy to obtain High energy density	Major contributor to greenhouse effect Large price swings dependent on demand

Wind	Free fuel source	Expensive equipment to maintain Very climate dependent Limited energy production
Solar	Free fuel source	Very climate dependent Rare materials needed in production of equipment Large land area for small amounts of energy generation
Biomass	Early life of industry Job creation as small plants must be used	Inefficient when small plants are used Global warming contributor

8.3: Fossil fuel power production

Fossil fuels have historically been widely used, both because of their ease of extraction but also because they have a high energy density.

The use of fossil fuels to produce electricity is however quite inefficient because of the sheer mass of fuel which must be transported. Fossil fuel power plants have an efficiency around 40%.

8.4: Non-fossil fuel power production

In a nuclear power plant energy is released due to the collision between neutrons and nuclei which due to the collision splits. This process releases energy which heats water surrounding the reactor which is then used to produce electricity. The reaction is kept in control by using control rods which absorb some of the neutrons in order to prevent a runaway reaction, the type of reaction desired in a nuclear weapon.

The fuel enrichment which is done before uranium can be used in a nuclear reactor involves placing the fuel in a centrifuge where the lighter Uranium-235 collects together apart from the Uranium-238 which is not desired. The Uranium can through this process become more than the required proportion of 3.5% Uranium-235, as opposed to the prioo 0.7%.

The moderator, often heavy water, is a liquid which is placed within the core of the nuclear reactor, it works to slow down the neutrons, this is required as the neutrons have to hit the nuclei at a specific velocity in order for a successful reaction to take place. The faster neutrons are likely to be captured by uranium-238 and produce plutonium-239. Plutonium-239 is however also a viable nuclear fuel which has a low critical mass (see later)

The heat exchanger is a device where hot water comes in and the energy from it is transferred to cold water, the cold, now warm water can then be used to power a generator to create electricity.

Critical mass is the minimum amount of fuel required in order to sustain a nuclear reaction.

The use of nuclear power to generate electricity has however been greatly contested because of the risks which it brings. The four main issues are:

1. The risk of a meltdown, which may cause severe damage to surrounding areas and health risks for hundreds of years
2. Nuclear waste is difficult to transport and store due to its large health risks
3. The mining of uranium can also like most mining be very dangerous.
4. A nuclear energy program can also be used as a cover-up by a country to produce nuclear weapons

Nuclear fusion is not yet possible on earth due to the very high temperature needed to maintain a successful reaction.

8.4: Solar Power

There are two ways of retrieving electricity directly from the sun, the first method is to use a photovoltaic cell. A photovoltaic cell is able to directly transfer solar energy into electricity but it is expensive to build. A solar heating panel however works by heating water with the energy which it receives, this energy can in turn be used to power a steam turbine and produce electricity.

Solar power is however very dependent on seasonal and regional changes, as the northern hemisphere for example has less incident light in the winter, due to the slant of the earth.

8.4: Hydroelectric Power

There are three main processes through which electricity can be produced from the motion of water. The first method is through the use of a dam where water can be backed up and released through turbines which generate electricity. Electricity can also be produced from the movement of tides by using underwater propellers which can generate electricity from the movement of currents. A third method through which electricity can be produced is the use of a "wave-snake", in practice a tube which lays on top of the ocean and moves due to the waves pushing pistons within it back and forth, a motion which can generate electricity.

In any hydroelectric scheme the main process which is taking place is the transfer of kinetic energy into electrical energy.

The power produced by a hydroelectric dam can be calculated as below (rho is density, V is volume, E_p is potential energy, g is acceleration due to gravity, m is mass, h is heigh, P is power and t is time):

$$E_p = mgh$$
$$\rho = m/V$$

$$E_p = \rho V g h$$
$$P = E/t$$
$$P = \rho V g h / t$$

8.4: Wind Power

A wind generator consists of a propeller which due to the force of the wind will turn, this will cause the production of electricity in a generator. Thus transferring kinetic energy into electrical energy.

To calculate the energy available to a wind power plant the below calculation and simplification can be made.

$$Volume = velocity \times Area$$
$$E_K = \tfrac{1}{2} m v^2$$
$$m = \rho V$$
$$E_K = \tfrac{1}{2} \rho V v^2$$
$$E_K = \tfrac{1}{2} \rho A v^3$$

This equation can be used to find the energy produced by a wind mill, when the air continues on the other side the change in velocity should be considered.

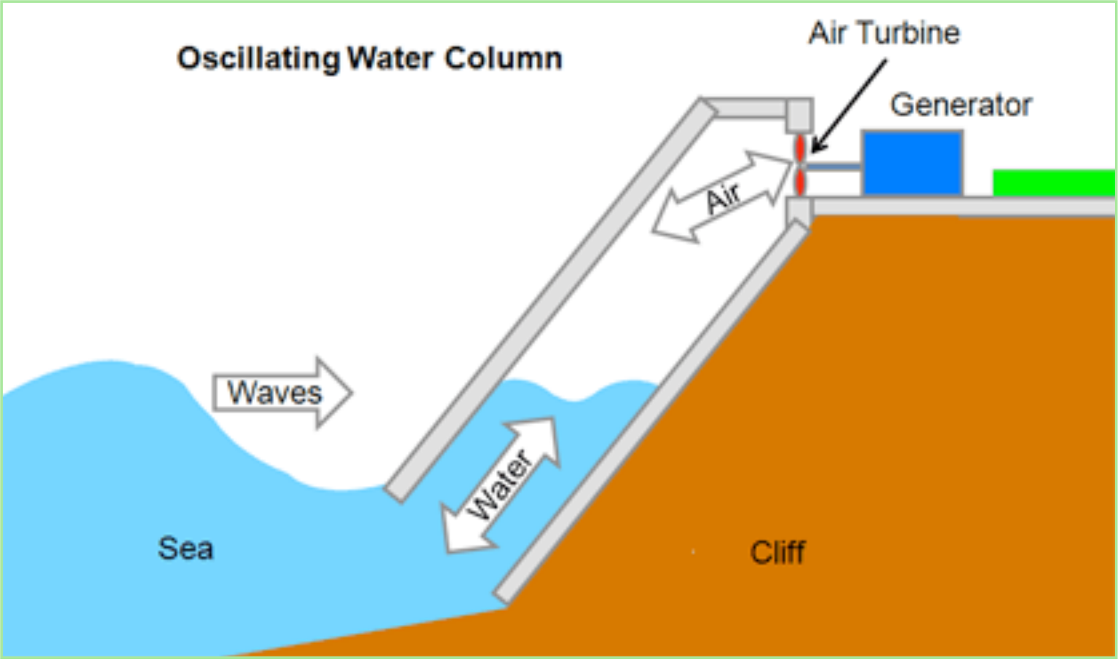
8.4: Wave Power

When looking at wave power the potential energy that a wave possesses because of its amplitude is the most important consideration. The water drops on average half of the amplitude when the wave moves. The below derivation illustrates this energy retrieval.

$$V = A\lambda L$$
$$E_p = mgh$$
$$E_p = \rho V g h$$
$$E_p = \rho A \lambda L g h$$
$$E_p = \rho A \lambda L g \tfrac{A}{2}$$
$$E_p = \tfrac{1}{2} \rho A^2 \lambda L g$$
$$P = \frac{\tfrac{1}{2} \rho A^2 \lambda L g}{t}$$
$$P = \tfrac{1}{2} \rho A^2 v L g$$

In the above equation, V is volume, A is amplitude (of half the wave), lambda is the wavelength and L is the three dimensional depth of the wave.

On method through which wave power power can be extracted is through an Oscillating Water Column (OWC). An OWC can be seen below:



This machine works by the wave pushing water into the column compressing the air which in turn turns a turbine which generates electricity.

8.5: Greenhouse Effect

To find the amount of light which is incident on the earth the below calculation can be performed.

Solar Energy Output= $3.9\times10^{26}Js^{-1}$

Surface area of sphere around sun at distance of earth:$4\pi R^2$

$SA=4\pi\left(1.5\times10^{11}\right)^2$

$SA=2.83\times10^{23}$

Energy output per $\text{m}^2 = \dfrac{3.9\times10^{26}}{2.83\times10^{23}}$

$E=1400Wm^{-2}$

Cross sectional area of earth=πr^2

$A=\pi\times\left(6.4\times10^6\right)^2$

$A=1.29\times10^{14}$

Power hitting Earth=$1400\times1.29\times10^{14}$

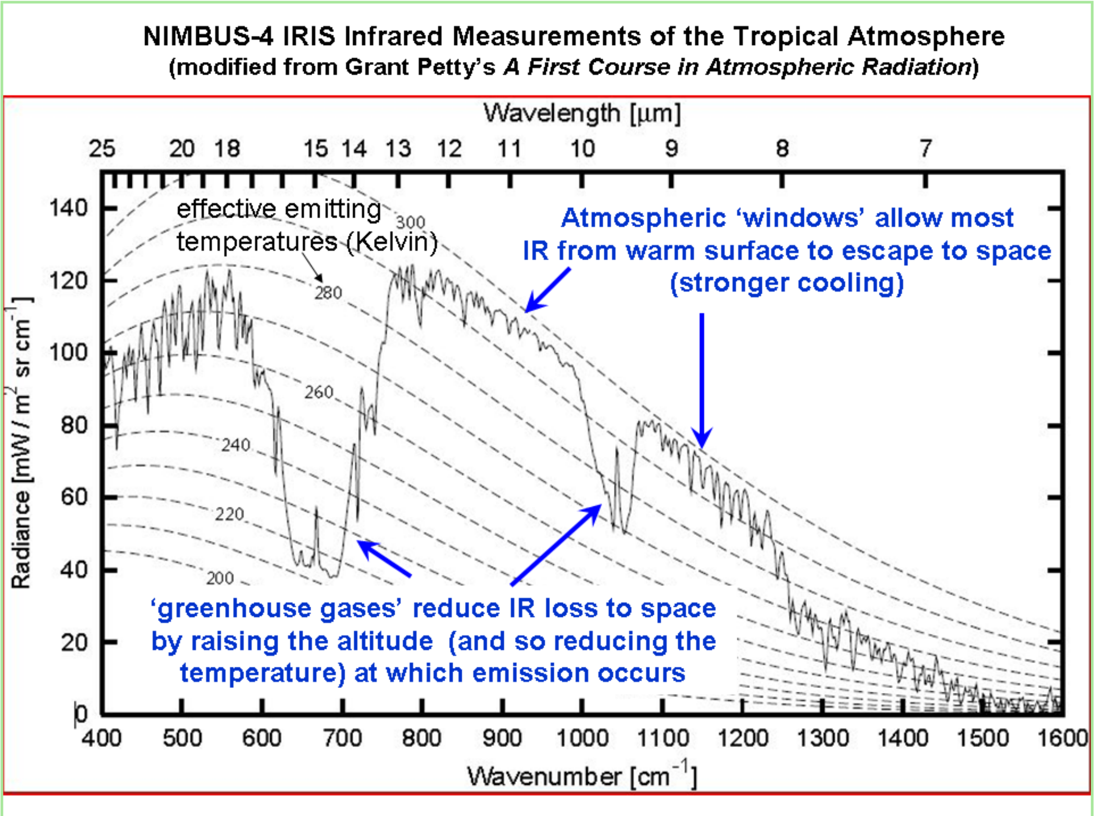
$P=1.8\times10^{17}$

The albedo of a celestial body is the fraction of incoming light that is directly reflected away. The albedo for Earth is approximately 0.3. The albedo of a body depends heavily on the material that the planet is covered in, as the reflectiveness of the surface determines albedo. For example glaciers will keep the albedo high as they reflect a lot of incoming light.

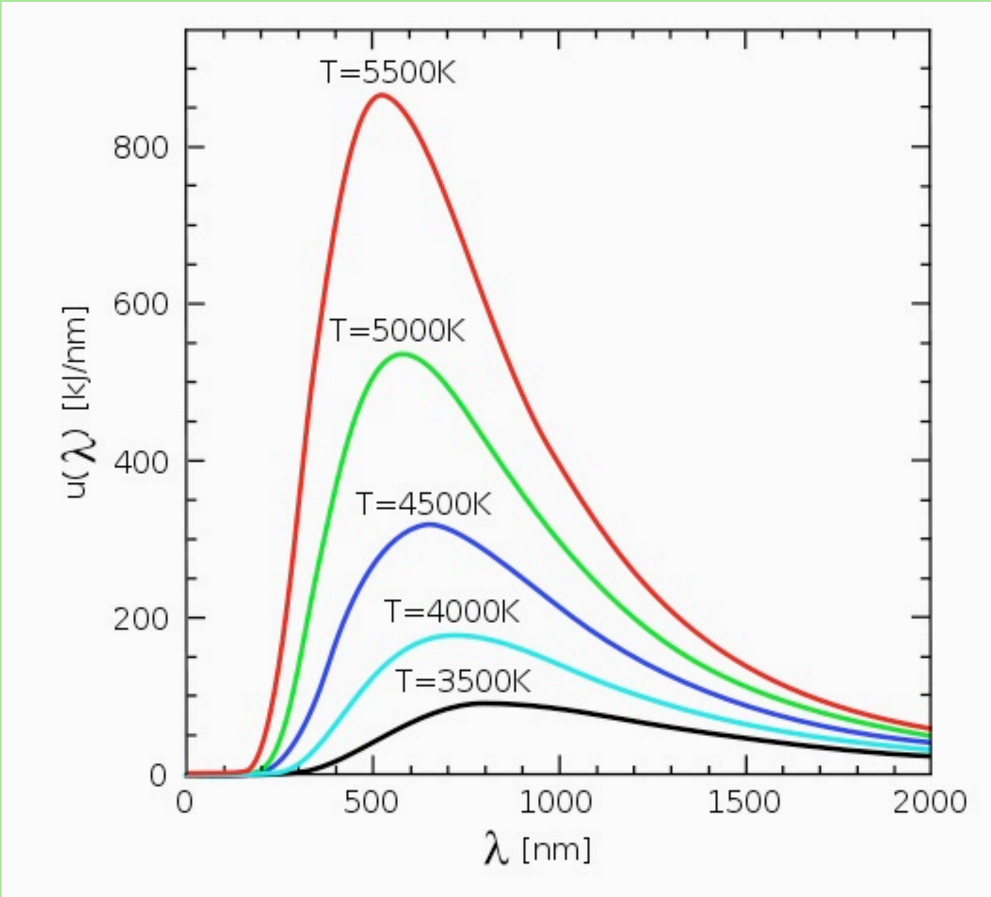
The greenhouse effect is primarily caused by the earths ability to keep some of the energy which is incident on it as a result of gases in the atmosphere.

The main gases that contribute to the greenhouse effect are, CH_4 (Methane), H_2O (Water vapor), CO_2 (Carbon Dioxide) and N_2O (Nitrous Oxide). These gases are released naturally (CO_2 and H_2O) but some are also released due to human environmental interference, for example we release more CO_2 today than ever before.

The above gases are able to retain energy on earth due to their ability to absorb infrared radiation. The gases are hit by the radiation, this causes them to vibrate, and light in the infrared region in particular is able to vibrate these molecules at their natural frequency which enables them to absorb the light.



The above graph shows the relationship between the wavelengths of light incident and the ability of greenhouse gases to absorb the light, and as shown by this graph greenhouse gases absorb infrared in the wavelength 13-18μm the best.



A black body is a an object that absorbs and emits all types of radiation. The graph above shows the emission spectrum of a black body at different temperatures. The peak at each temperature is known as the 'most prevalent wavelength'. Wein's Law is a rule that states that the most prevalent wavelength emitted by a black body is equal to:

$$\lambda_{\max} = \frac{2.90 \times 10^{-3}}{T}$$

The Stefan Boltzmann law relates the Power emitted by a planet to various other factors, such as emissivity, surface area, and temperature, it is written below:

$$\text{Power=Emissivity} \times \text{Stefan Boltzmann Constant} \times \text{Surface Area} \times \text{Temperature}^4$$

$$P = \varepsilon \sigma A T^4$$

Emissivity is the fraction of a black body that a planet is. For Earth: 0.7.

Surface Heat Capacity is a measurement for how much energy is required to raise the temperature of one unit area of a planets surface by 1°. The equation can be seen below:

$$\text{Surface Heat Capacity=}\frac{\text{Heat energy}}{\text{Surface Area} \times \Delta\text{Temperature}}$$

$$C_s = \frac{Q}{A \Delta T}$$

8.6: Global Warming

There have been several explanations provided that aim to explain increasing temperatures on earth, a few are: Change in composition of greenhouse gases, increased solar flare activity, cyclical changes in Earth’s orbit and volcanic activity.

The enhanced greenhouse effect is an influence that humans have had on Earth as the greenhouse effect is a good thing while the enhanced greenhouse effect can be damaging. One contribution that humans have had to this effect is the increased combustion of fossil fuels, a combustion which has caused more greenhouse gases to be released into the atmosphere.

Three processes that help increase the rate of global warming are:
1. Melting of ice and snow caps, alters the albedo and thus increases heat absorption
2. Temperature increases decreases the solubility of CO_2 in the sea which increases the amount of CO_2 in the atmosphere.
3. Deforestation decreases carbon fixation.

The coefficient of volume expansion is a way to measure the increase in volume of a substance per degree of temperature rise.

Water levels are likely to rise from an increase in earths temperature for two reasons:
1. Increased expansion
2. Melting ice and snow caps.

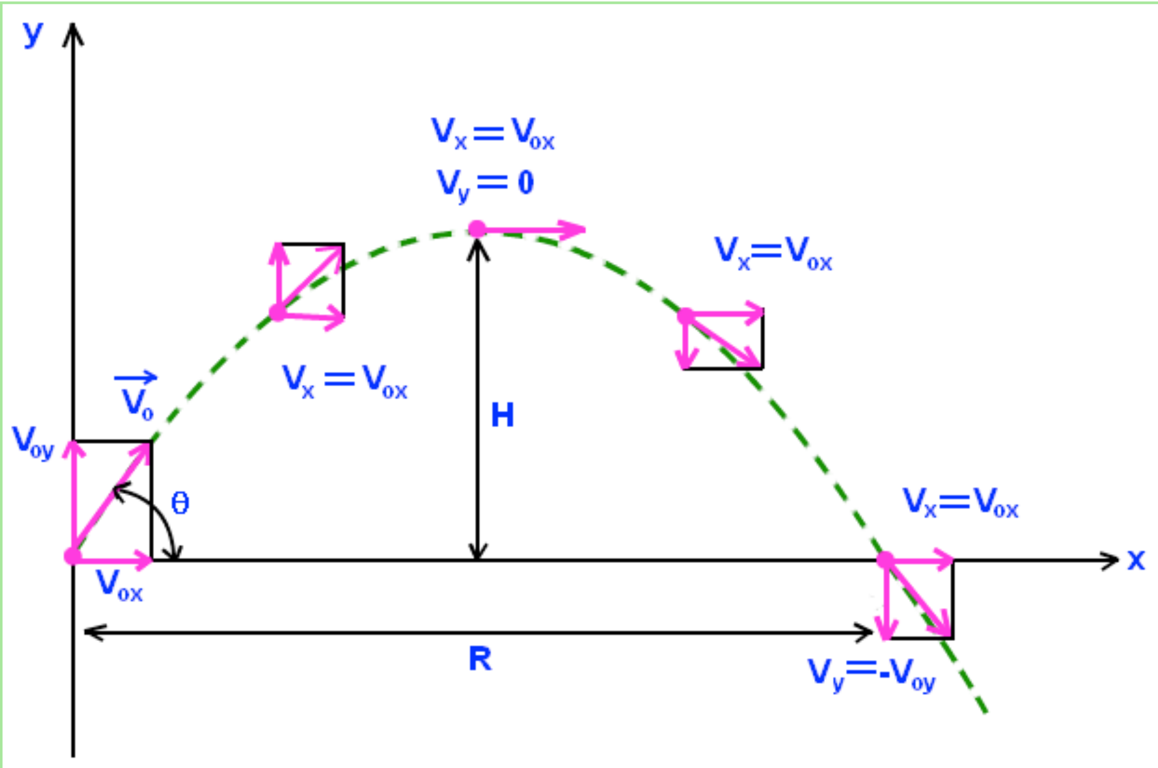
The enhanced greenhouse effect is the major cause of global climate change. Several methods to decrease it’s effects have however been proposed:
1. Increasing power production efficiency
2. Replacing coal and oil with natural gas (which releases less greenhouse gases)
3. Carbon dioxide capture and storage
4. Use of hybrid vehicles

There have been many international meetings and protocols established such as:
1. Intergovernmental Panel on Climate Change (IPCC)
    a. A scientific intergovernmental body established to monitor worldwide data on climate change
2. Kyoto Protocol
    a. An international protocol established to force ratifying countries to limit greenhouse gas emissions
3. Asia-Pacific Partnership on Clean Development and Climate (APPCDC)
    a. An international voluntary partnership between a select number of countries that works to improve energy efficient technology.

Topic 9: Motion in fields

9.1: Projectile Motion

In a uniform field the vertical and horizontal components of motion are independent. If you drop one ball and throw another horizontally from a helicopter they will land at the same time.



The above graph shows an object undergoing projectile motion in the absence of air resistance. If air resistance is present the path would be shorter and steeper.

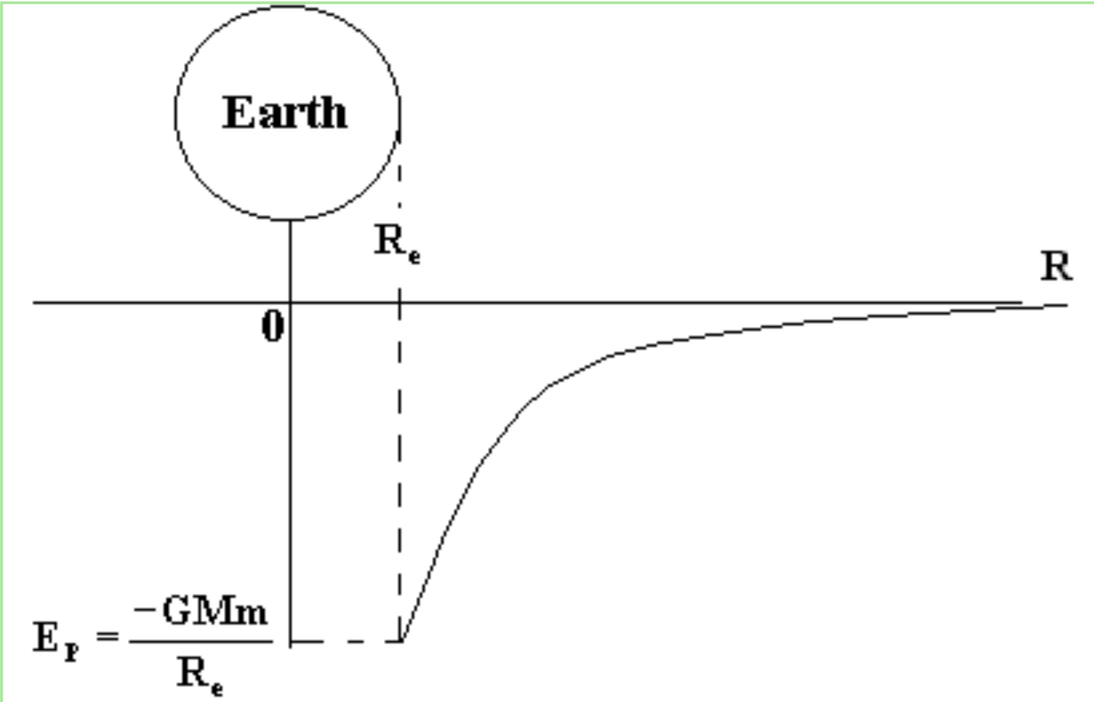
9.2: Gravitational field, potential and energy

Definitions	
Gravitational Potential	Potential energy per unit mass at one point in a gravitational field.
Gravitational Potential Energy	Is the energy possessed by an object due to it's location in the gravitational field of a planet.

Gravitational potential can be calculated by either of the two expressions below.

$$V = \frac{-Gm}{r} \qquad \Delta V = \frac{W}{m}$$

The below graph shows the potential gravitational potential of an object in relation to its distance from earth:



The potential energy can then be calculated using the equation above. Around planets there is a similar kind of circular field that circles an electric charge, thus equipotential lines can be drawn around one or more objects. Escape velocity have been discussed earlier but is required for this unit.

9.3: Electric field, potential and energy

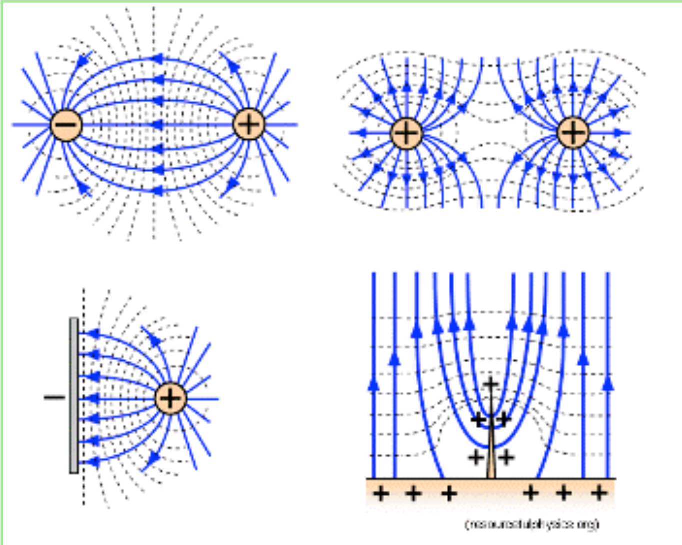
Definitions	
Electric Potential	Potential energy per unit charge at one point in a electric field.
Gravitational Potential Energy	Is the energy possessed by a charge due to it's location in the electric field of another charge.

The equation for electric potential is stated below:

$$\Delta V = \frac{W}{q}$$

$$V = \frac{(-)kq}{r}$$

The below diagram shows equipotential field lines for a few electric charges:



9.4: Orbital Motion

The force of gravity provides the centripetal force which enables circular orbital motion. The derivation of Kepler’s third law can be seen below:

$$\text{Centripetal Force} = \frac{mv^2}{r} = \frac{GMm}{r^2}$$

$$\frac{mv^2}{r} = \frac{GMm}{r^2}$$

$$v^2 = \frac{GM}{r} \qquad \text{v} = \left(\frac{2\pi r}{T}\right)$$

$$v^2 = \left(\frac{(2\pi r)^2}{T^2}\right)$$

$$v^2 = \left(\frac{4\pi^2 r^2}{T^2}\right)$$

$$GM = \frac{4\pi^2 r^3}{T^2}$$

$$T^2 = \frac{4\pi^2 r^3}{GM}$$

$$T^2 \propto r^3$$

To find the energy of an orbiting object the below calculations can be made:

We know: $E_P = -\frac{GMm}{r}$

To find Kinetic Energy: $F = \frac{GMm}{r^2} = \frac{mv^2}{r}$

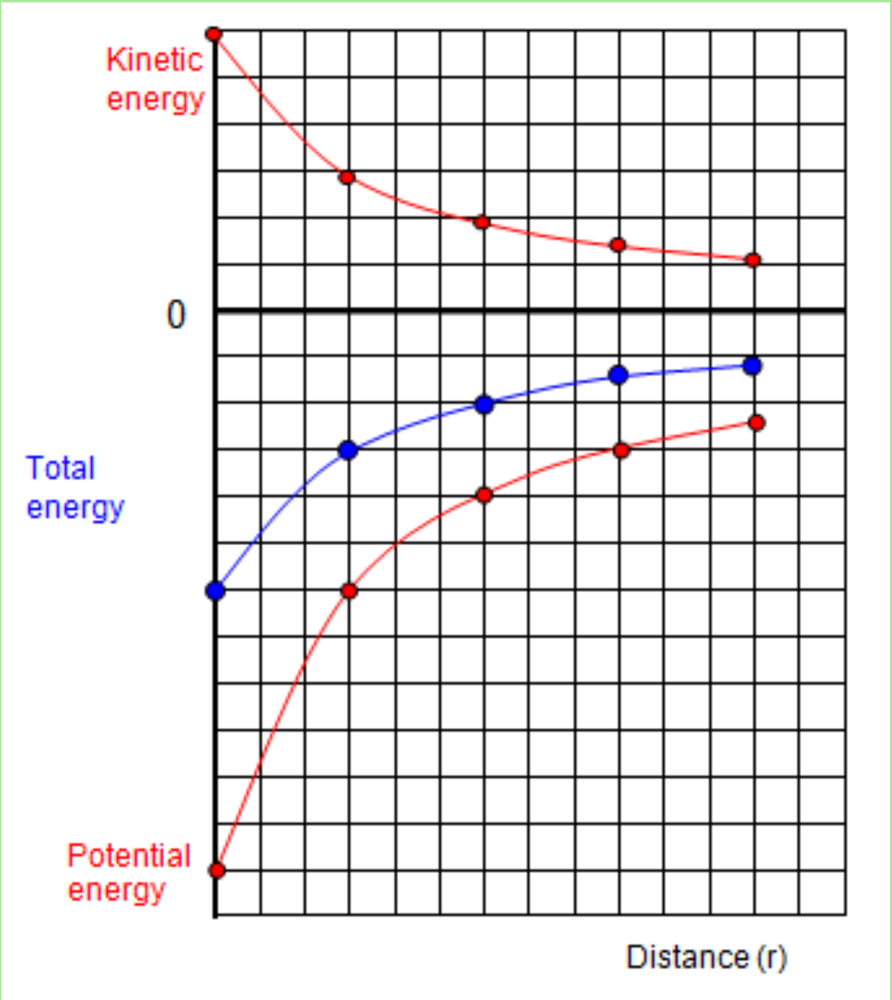
$\frac{GMm}{2r} = \frac{mv^2}{2} =$ Kinetic Energy

Total energy=Potential+Kinetic

$E = -\frac{GMm}{r} + \frac{GMm}{2r}$

$E = -\frac{GMm}{2r}$

The below graph shows the variation in different forms of energy as a satellite moves away from a planet.



In space humans will experience weightlessness, this is due to the fact that you will be falling constantly thus creating the sensation of weightlessness.

Topic 10: Thermal Physics

10.1: Thermodynamics

Ideal Gas:

The equation for an idea gas is equal to:

$$PV = nRT$$

Where P is pressure, V is volume, n is the number of moles of substance, R is the ideal gas constant (8.314 J/molK) and T is the temperature.

An ideal gas is ruled by a set of assumptions about the movement of particles in a gas that makes it easier to predict and calculate the behavior of this gas. The assumptions made are:
1. Gas molecules are assumed to behave in an idealized way, that is, Newton's laws of mechanics apply to the motion of individual molecules.
2. It is assumed that intermolecular forces are negligibly small.
3. Molecules are assumed to be spherical and possess negligible volume (when compared with gas as a whole)
4. Molecules are assumed to be moving randomly.
5. Collisions between molecules are assumed to be elastic.
6. The time for a collision to take place is also assumed to be negligible.

A real gas may however not follow these assumptions but the similarity is sufficiently close for a comparison to be made.

Absolute zero or 0K is a temperature at which particle motion no longer occurs as the energy possessed by particles is insufficient for motion to occur. Nothing can ever achieve a temperature lower than 0K.

10.2: Processes

When changing the attributes of a gas the relationship below may be used:

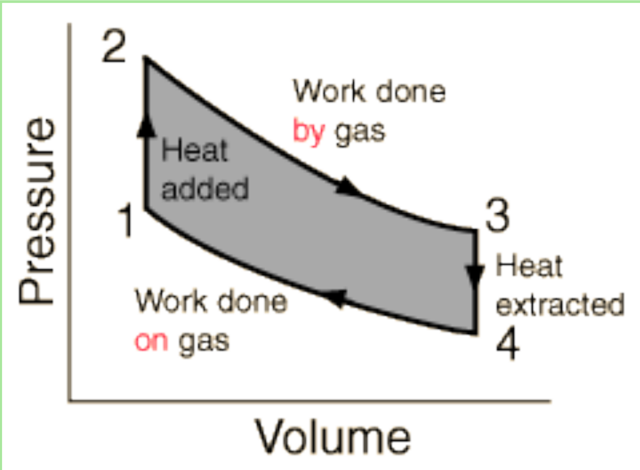
$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

The first law of thermodynamics states that the internal energy of a closed is equal to the amount of heat supplied to the system minus the amount of work done by the system on it's surroundings:

Heat energy exchanged (J)=Internal energy (J) +Work done by gas (J)

$$Q = \Delta U + W$$

This first law of thermodynamics is very similar to the law of conservation of energy as it proposes that the energy of a system cannot increase or decrease unless energy is being transferred to and from outside the system.



The above diagram shows a PV graph of a gas. To calculate the work done at any part of this diagram one can multiply the Pressure and Volume changes, this will give you work done. There are a few special transformations that can take place on a diagram such as the one above they are:

Special Cases	
Isochoric change of state	When a gas changes state while volume is constant, shown on the graph as a vertical shift
Isobaric change of state	Occurs when a gas changes state while the pressure remains constant, illustrated by a horizontal line.
Isothermal change of state	Occurs when a gas changes state while temperature remains constant illustrated by a curved line on the graph
Adiabatic change of state	An adiabatic change of state occurs when no energy leaves or enters the system. Thus when the change in internal energy is equal to the work done by the gas.

10.3: Second law of thermodynamics and entropy

The second law of thermodynamics states that energy cannot randomly transfer from a region of low temperature to a region of high temperature.

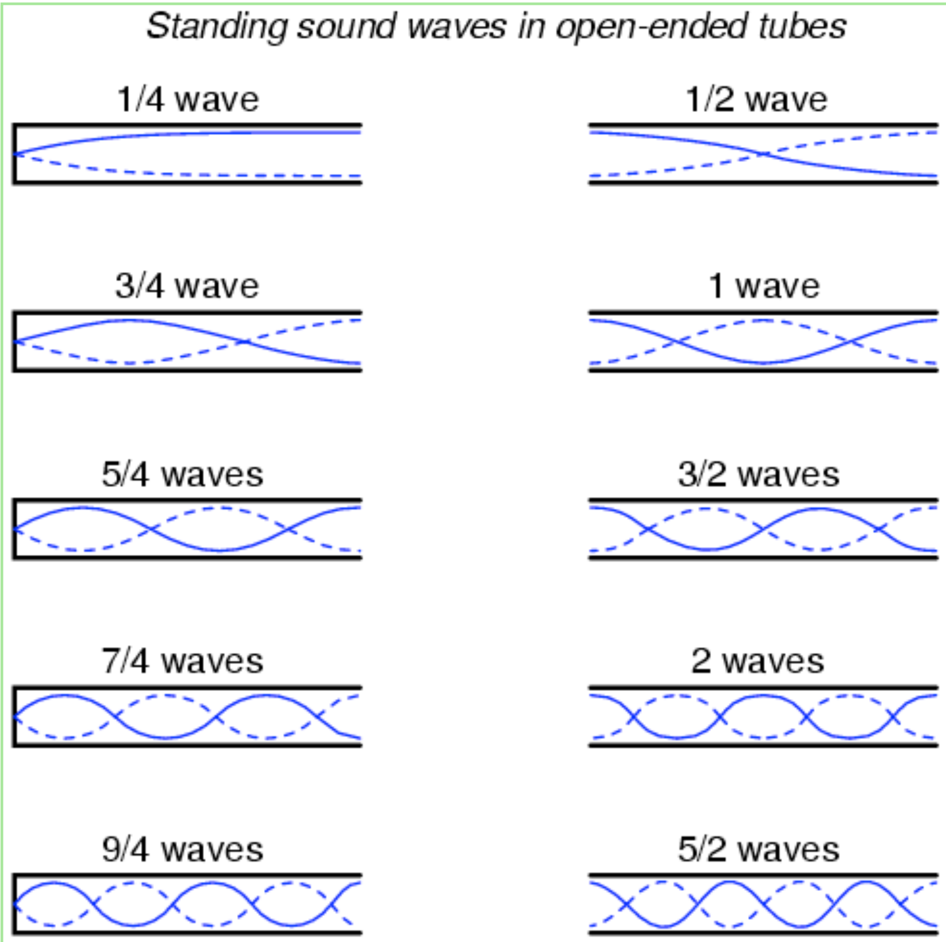
Entropy is a property that expresses that the amount of disorder in a system can only increase due to natural causes. The overall level of entropy in the universe is constantly increasing. Local levels of entropy can however increase due to human or animal influence.

Topic 11: Wave Phenomena

11.1: Standing Waves

Standing waves are different to traveling waves for three main reasons:
1. There is no energy transfer
2. Amplitude varies from particle to particle
3. Phase is the same for neighboring particles

Below are some standing waves:



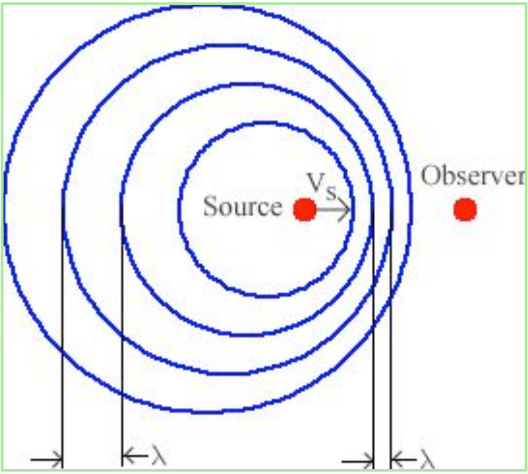
Standing waves can be created as a result of the superposition of two waves with the same speed, frequency and amplitude traveling in opposite directions.

A Place along a standing wave where there is no motion is called a **node**
A Place along a standing wave where there is maximum motion is called an **antinode**

Problems involving standing waves can often be solved using the equation for waves linking velocity, wavelength and frequency.

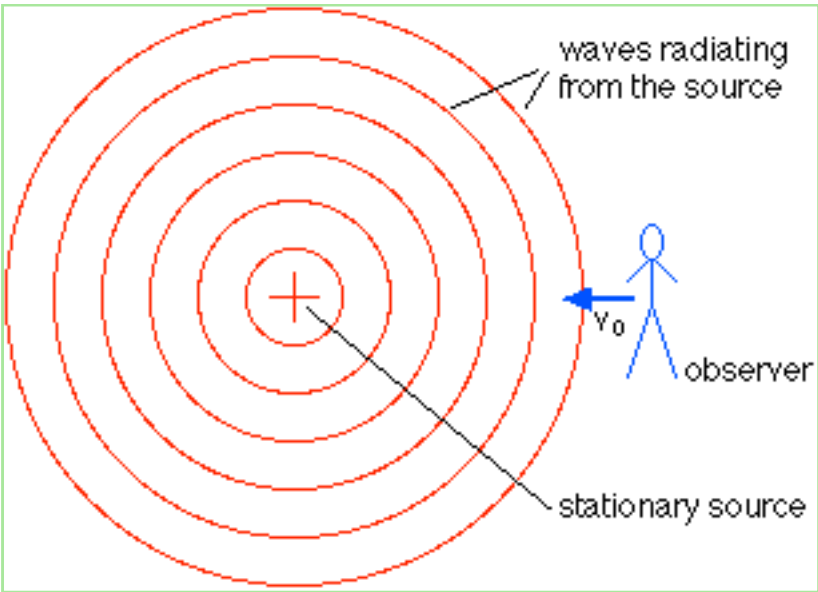
11.2: Doppler Effect

The Doppler effect is described as the apparent change in frequency of a wave when there is a difference in the motion between the emission of the wave and the observer.



The above diagram illustrates how a moving source emits light that appears to have a different wavelength as it moves towards an observer.

The below diagram shows how a moving observer will perceive the waves emitted by a source:



As illustrated by this diagram, the observer moving towards the source will see each wave faster than they were radiated, thus the wavelength appears lower.

When calculating the effect on frequency due to the doppler effect the following equations can be used.

$$\text{Moving Source: } f' = f\left(\frac{v}{v \pm u_s}\right)$$

$$\text{Moving Observer: } f' = f\left(\frac{v \pm u_o}{v}\right)$$

In this equation, f' is the observed frequency, f is the emitted frequency, v is the speed of the wave, u_s is the speed of the source and u_o is the speed of the observer.In the above equation use addition when the source is moving away and subtraction when it is moving towards the observer. For the lower equation use addition when the observer is moving towards the source and subtraction when it is moving away.

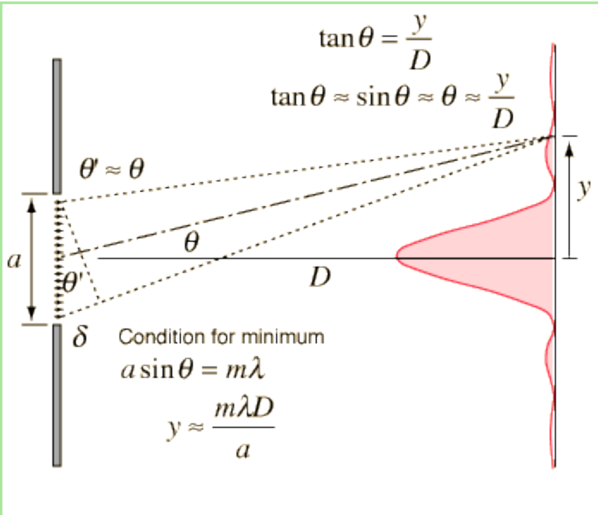
When investigating the doppler effect with a electromagnetic wave the below approximation can be used:

$$\Delta f = \frac{v}{c} f$$

In this equation, v is equal to the speed of the object which is moving, and c is the speed of light. This simplification is possible due to the sheer magnitude of the speed of light.

The doppler effect has a variety of uses such as to measure the speed of a moving car.

11.3: Diffraction



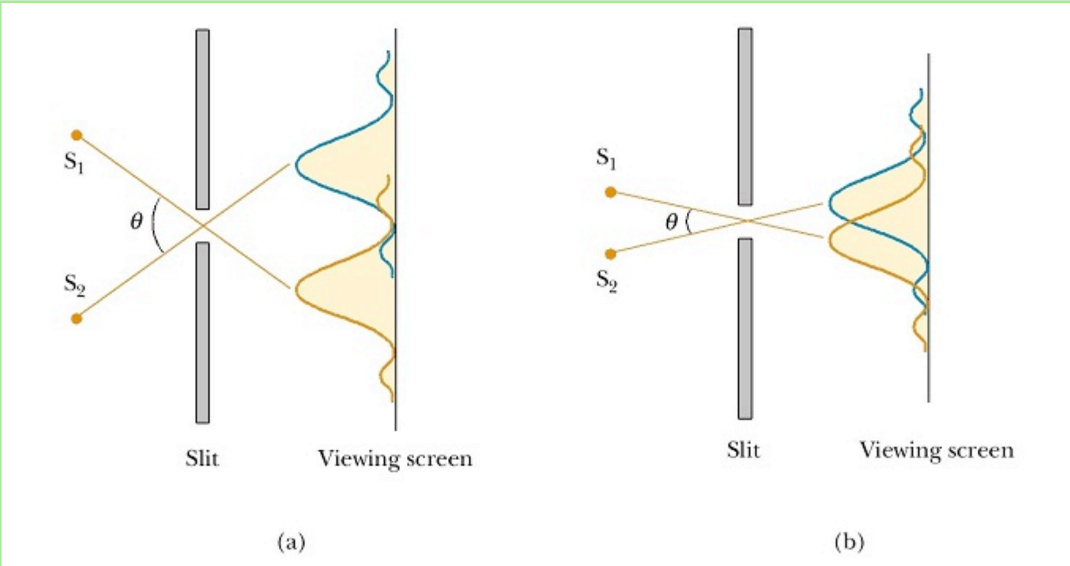
The above diagram shows how the intensity of diffracted light differs depending on the angle from the slit which it has diffracted. Huygen's Principle states that "Every point on a wavefront acs as a source of secondary circular wavelets" this is the phenomena that occurs when light passes through a single slit as shown above.

When investigating the location of the first minimum of a diffraction pattern the below equation can be used:

$$\theta = \frac{\lambda}{b}$$

In this equation, b is equal to a on the diagram. This equation can be derived as the difference in distance between D and the line to the first minimum is so minute. When working with a circular aperture rather than a single slit the fraction in the above equation should be multiplied by 1.22.

11.4: Resolution

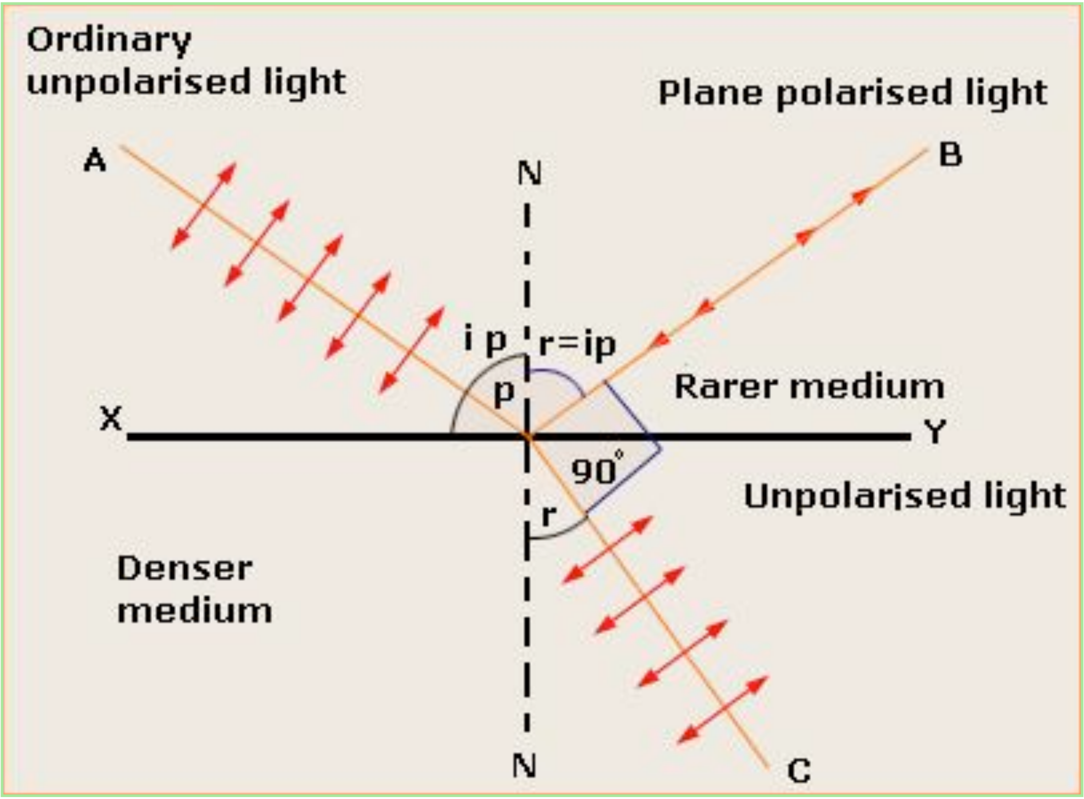


The above diagram illustrates how light from two sources undergoing diffraction may interact on a viewing screen. The Rayleigh Criterion states "The central maximum of one pattern must fall on (or beyond) the first minimum of the other pattern". This criterion is what determines whether two independent light sources will be separable when viewed through a slit.

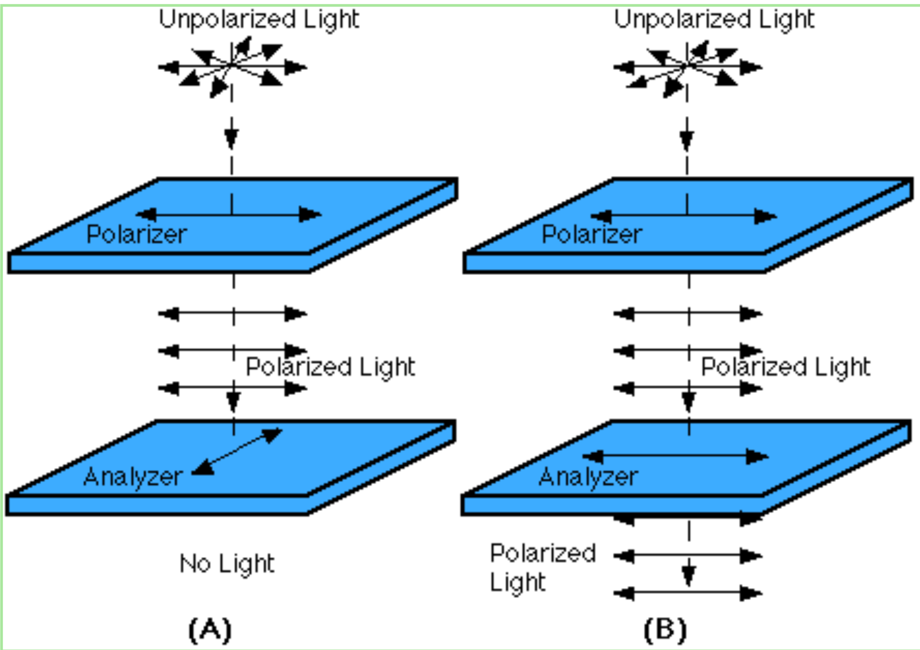
The ability for two light sources to be differentiated between has been critical in the development of technologies such as microscopes and DVD's, this is due to the fact that these technologies requires light to be interpreted and presented.

11.5: Polarization

Polarized light is light which waves only travel in one plane. This is unlike regular electromagnetic light where a magnetic and electric field are at 90 degrees to each other. Polarization of light can occur through different processes. Firstly it can happen due to reflection. When light reflects off a reflective surface only light which is parallel to the reflective surface will be reflected.



The above diagram shows how light incident on a reflective surface has been polarized. There is an angle at which the incident light becomes perfectly polarized, this angle is known as Brewster's angle. And it occurs when the angle between the reflected and refracted ray is 90 degrees.



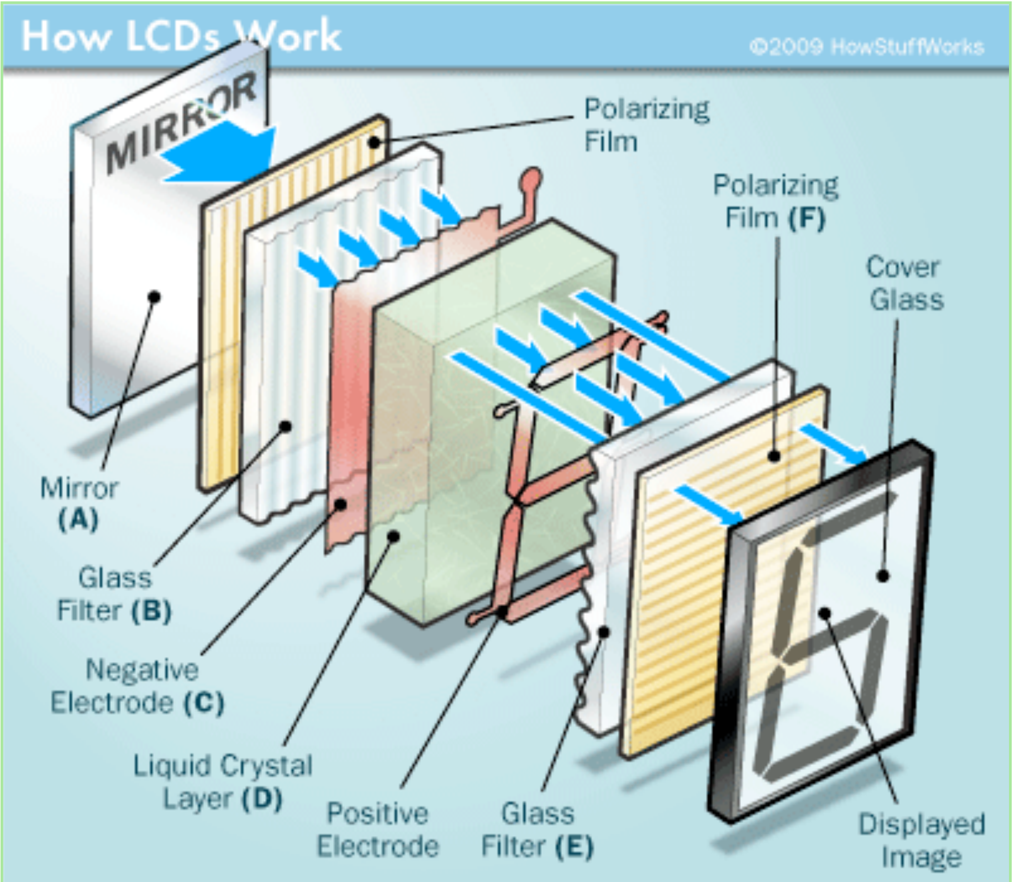
The above diagram shows the difference between a polarizer and an analyzer. A polarizer is a screen which allows light in a certain plane through. An analyzer is however angled differently to the polarizer and thus only some, or no light will be able to pass through. There is an equation which allows the intensity of light after it has passed through a polarizer and an analyzer this equation is known as Malus' law. Malus' law can be seen below:

$$I = I_0 \cos^2 \theta$$

In this equation I is final intensity, I_0 is the original intensity and theta is the difference in angle between the polarizer and analyzer.

An optically active substance is a substance which can alter the plane of polarization of light. Polarization can be used to investigate concentration of a substance if this substance is an optically active substance as such a substance will rotate light differently depending on the concentration. Polarization can also be used to analyze stress levels in for example plastics as these parts of the plastic will rotate light differently.

In an LCD (Liquid Crystal Display) polarization of light can be used to change the plane of polarization of light and thus display contents on a screen. This works by using electrically activated polarizers.



Topic 12: Electromagnetic Induction

12.1: Induced electromotive force (emf)

When a conductor moves in relation to a magnetic field, an electromotive force will be induced. When a wire performs this action there are three variable that determine the strength of the induced electromotive force. These variable are bound by the below equation:

$$emf = Blv$$

In this equation B is the strength of the magnetic field, *l* is the length of the wire and v is the speed of the wire. The resulting electromotive force is measured in Volts. The induced electromotive force being 'created' when a wire is moved through a field arises from the electrons inside the conductor experiences a force due to the motion within the field. As the wire is moved down the field these electrons cause a virtual current to be transferred upwards, the positive nuclei however cause a virtual current to be transferred downwards. This in turn results in force on electrons along the wire. The eventual movement of the electrons causes a potential difference to be induced.

The following derivation can be performed to find the above equation:

$$F_{Electric} = F_{Magnetic}$$
$$F_E = Ee = \frac{V}{l}e$$
$$F_M = Bqv$$
$$Bqv = \frac{V}{l}e$$
$$Bqlv = Ve$$
$$Blv = V$$

Definitions	
Magnetic Flux	Magnetic flux is the strength of a magnetic field, in graphical representation a magnetic field is stronger when the field lines are closer together
Magnetic Flux Linkage	Flux linkage is the amount of flux which a wire can 'cut' hence the more turns of wire the more linkage

An emf can only be induced when a conductive material experiences a force in a direction, hence a conductor with constant velocity will not experience the induction of an electromotive force.

Faraday's Law:
Faraday's law states that the induced e.m.f. in a coil is equal to the rate of change of the flux linkage of the coil.

Lenz's Law:
Lenz's Law states that the direction of the induced e.m.f. is such that if a complete circuit were available, the current direction would oppose the change that caused the induced e.m.f. This means that the object will experience a force in the opposite direction of motion.

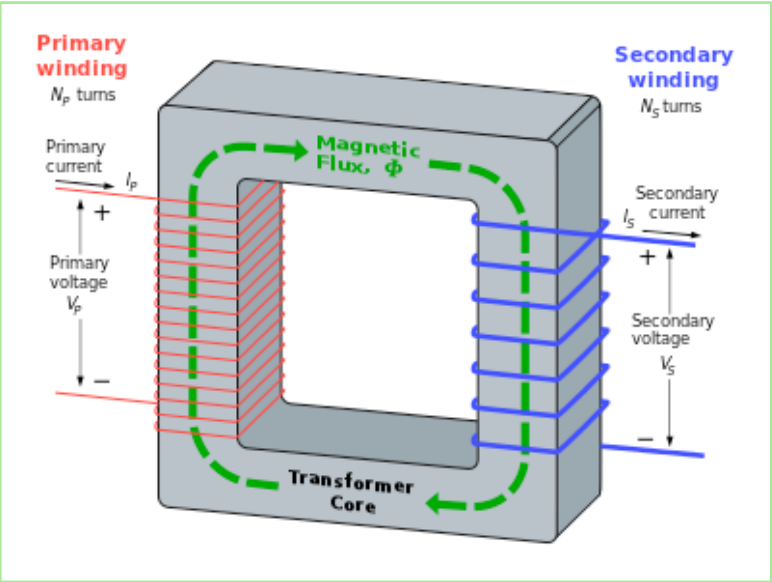
12.2: Alternating Current

When a coil rotates within a magnetic field the amount of flux linked is changing continously, forming a sinusoidal graph. This motion is the basis of a generator, that due to the motion of a coil in a field can generate an alternating current.

A faster rotating coil will mean that the rate of change of the flux linked is greater, hence the produced current will be greater.

r.m.s. is a measure for the voltage of mains power supply, r.m.s. is measured by squaring the voltage at all points and then finding the square root of the average of these points. This will give you the correct voltage value. This will be greater than the mean value for mains electricity (which is 0, due to sinusoidal wave around x-axis) but it will be less than the peak value. This can be practiced on page 172 in the physics textbook.

Transformer:



The above diagram shows a transformer. A transformer works by an alternating voltage being placed across the primary coil. This voltage will induce a voltage on the secondary coil. By changing the number of coils on either side of the core the r.m.s. value of the output current can be altered. A transformer works due to the below steps:
1. Alternating voltage input on primary creates an alternating magnetic field.
2. The core ensures that most of the flux created links with the secondary coil.

3. The changing magnetic field means that that the flux linkage constantly changes across the secondary.
4. The change in flux linkage causes an alternating voltage to be induced across the secondary
5. Increasing the number of turns on the secondary increases the flux linkages so the voltage induced will increase.

There are two types of transformers, a step-up and a step-down. A step-up will increase the voltage and a step-down will decrease the voltage.

The following relationship between voltage and the number of turns can thus be established:

$$\frac{V_{Secondary}}{V_{primary}} = \frac{N_{Secondary}}{N_{primary}}$$

Although seemingly breaking the law of conservation of energy a transformer is able to perform these transformations due to the fact that the current changes as well as the voltage. The below relationship can hence be produced between power input and output.

$$P_{in} = P_{out}$$
$$V_s I_s = V_p I_p$$

12.3: Transmission of Electrical Power

When energy is transferred across power lines energy is lost, this is due to the fact that all transmission lines have resistance , this resistance causes the lines to heat up and hence dissipate power. This resistance can however be decreased by increasing the width of the wire, this is however more expensive and hence the decision between the cost of thicker wire vs. the cost of energy lost to the environment must be made.

Because of this issue, transformers are used for the transmission of energy across power lines. Resistance in a wire only affects the current traveling across it and hence if a lower current is used in transmission less energy will be wasted. This can be achieved by using powerful transformers that can increase the voltage before energy is transmitted across the power lines, thus decreasing the current. This high voltage is then stepped down to safe levels before being used in homes.

Losses can however also occur in the transformer itself through processes such as:
1. Heating in coils
2. The core would heat up wasting significant energy
3. Losses due to magnetic flux 'escaping'

The use of high voltage power lines can however lead to potential health issues as a result of the electromagnetic radiation that they emit.

Topic 13: Quantum and Nuclear Physics

The photoelectric effect:

The photoelectric effect is the emission of electrons from a surface when it is exposed to light or ultraviolet radiation. These electrons require energy in order to leave the surface of the object however. There is thus a threshold energy that the electrons need in order to leave the surface. The wave model of light however fails to explain how this is occurs as the traditional model works by assuming that the energy incident is constant.

Because of this the concept of a photon was created. A photon is a single 'particle' of light. The energy of a photon is given by the equation:

$$E = hf$$

Where *h* is planck's constant (6.63×10^{-34}Js) and f is the frequency of light, in Hz.
When photons are incident on an object it is therefore possible for the electrons of the material to absorb photons, as the electron gains the energy hf. The energy required for an electron to be released from the material is known as the 'work function', W. The work function can be calculated using the equation below:

$$\frac{1}{2}mv^2 = hf - W$$

This is the equation as all the incident energy which is not used to 'release' the electron is transferred into kinetic energy of the electron.

Wave-Particle Duality:

The existence of this duality suggests that matter can behave like a wave. The de Broglie hypothesis states that all matter has a probability wave. The wavelength can be calculated from the momentum of the particle using the below equation:

$$p = \frac{h}{\lambda}$$

The information from this equation is often displayed as a wave function where the amplitude of the wave represents the probability that the particle exists in any given region.

The de Broglie hypothesis has been proved using the Davisson-Germer Experiment, this experiment was performed by firing a beam of electrons onto a nickel plate. The electrons scattered and by looking at the angles that they scattered at and the energy that they possessed it could be determined that the electrons experienced constructive interference.

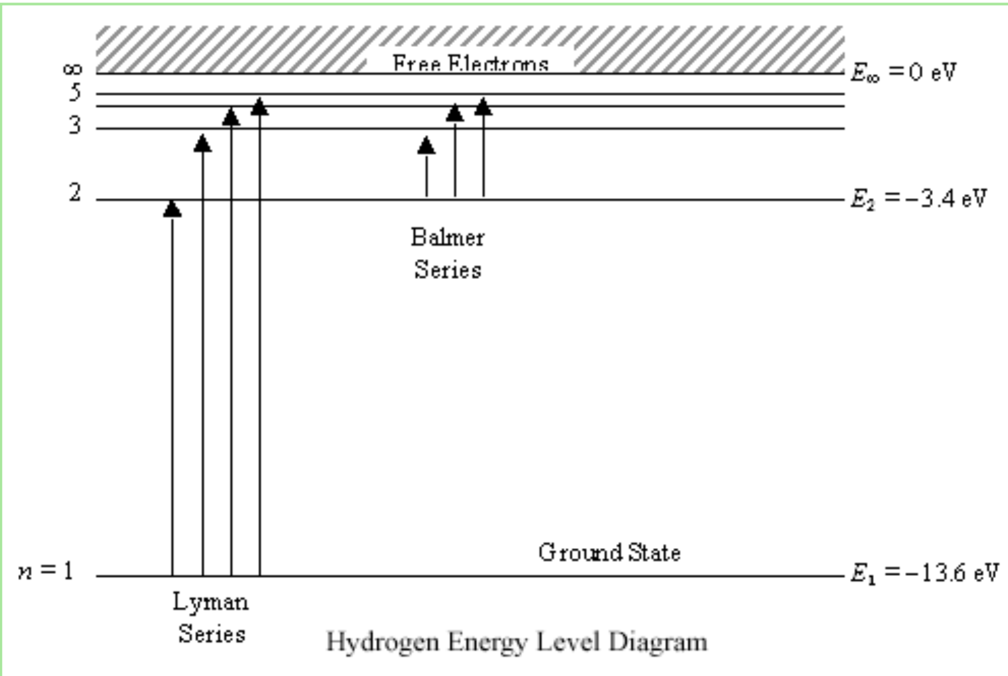
Atomic Spectra and Atomic Energy States:

When an element is exposed to light or is heated up it will radiate light, each element will radiate light. The light that an element radiates can be observed through an emission spectrum. These spectra can be observed by heating up an element in a tube and passing the radiated light through a thin slit. This will produce a line spectra.

Absorption spectra are diagrams that illustrate a continuos spectra with a few frequencies of light missing. This diagram can be created by shining white light on a gas of an element and observing the light that passes through through a slit.

These line spectra can be used to prove that the quantization of electrons in an atom exists. This is due to the fact that light of specific frequencies is radiated hence only certain amounts of energy can have been absorbed by the atom.

In the atom electrons can only possess certain amounts of energy, hence if a photon with a specific amount of energy is incident on an electron it will absorb the energy and move up to a higher energy state. Later if an electron moves down an energy level it will release a photon with the same amount of energy.



The above diagram shows these energy levels and their respective values.

The electron in a box can be used to explain the existence of atomic energy levels, pg.216 in book.

The Schrödinger model of model of the hydrogen atom explains where electrons exists as follows:
Electrons are continuos standing waves that depending on the energy level has different number of periods represented. The probability of the existence of an electron at a specific point in an energy level can be found by using the square of the amplitude of the wave in this location. The wavelength of the electron can be found by the below equation:

$$\lambda = \frac{2L}{N}$$

Where L is the length of the representative box an N is the energy level.

Heisenberg's Uncertainty Principle:

Heisenberg's uncertainty principle is a way to describe the uncertainty by which momentum and location of a particle. The equation can be seen below:

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

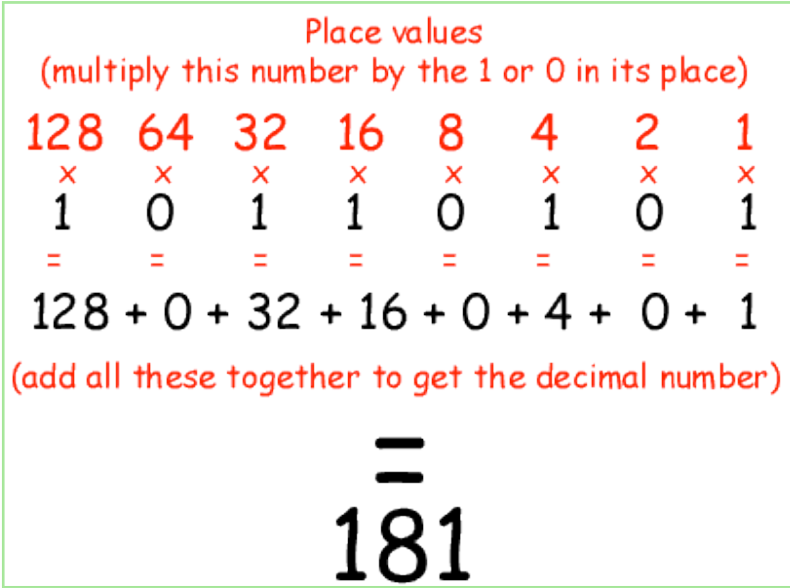
The x and p represent location and momentum and they can never both be known, as one become more certain the other becomes less.

13.2: Nuclear Physics (discussed earlier in topic 7)

Topic 14: Digital Technology

14.1: Analogue and Digital Signals

When converting signal digitally binary numbers are used, binary numbers are numbers which consist solely of 1's and 0's. A binary number can be evaluated as below:

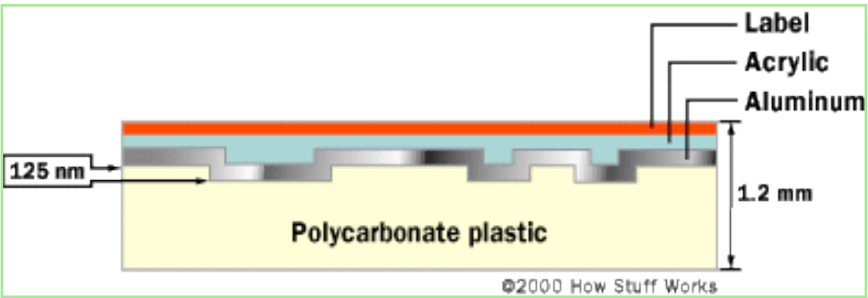


Storage of Data:

Data can be stored in several ways, both in analogue and digital form. For example:
- DVD - Digital
- Vinyls - Analogue
- Hard Disk - Digital

CDs:

A Compact Disc (CD) can be used to store digital files. It is constructed as below:



A laser is shown on the CD as it spins, when the laser is reflected off the edge of a 'bump' on the disc (each bump is the height of 1/4 of the wavelength of the light). negative interference will occur. This negative interference will be detected by the reader which will read this as a binary 1. When constructive interference occurs it will be read as binary 0.

A CD can store approximately 700MB of data in a spiral track which are 1.6micrometers apart, pits are a minimum of 0.83micrometers long and 1.5micrometers apart.

Advantages of Digital Storage:

1. Easier to reproduce data
2. Quality is consistent and does not degrade
3. Retrieval speed is higher
4. Data is more portable

Implications:

1. More data stored, know more about people
2. Environmental damage due to excessive storage
3. Expensive

14.2: Data Capture; digital imaging using charge-coupled devices (CCD's)

Capacitance:

Capacitance is the ability to store a charge. Achieved by using capacitors
Equation for the charge across a capacitor is:

$$q = CV$$

In the above equation, q is the charge stored, C is the capacitance (F), and V is the potential difference.

CCD's:

A CCD is a silicon chip which is divided into sections, each section is a small capacitor which can store a charge.

Through the photoelectric effect a charge can be built up on the pixels of the CCD as light is incident on them.

Once an image has been taken an electrode can measure the potential difference across each pixel and this information together with the location of the pixel can be used to convert this to a binary signal representing location and color of a pixel and hence a picture can be produced.

Quantum Efficiency:

Quantum efficiency can be defined as the number of photoelectrons that are released for every photon which is incident on the pixel. This is often discussed as a percentage.

Magnification:

Magnification is the ratio between the length of an image on a CCD and in reality.

Resolution:

Two points on an object may be resolved if they are separated by at least one pixel (or 2 pixel lengths)

Advantages:

A CCD is better for film for a variety of reasons:
1. Reproducibility of image
2. Speed of photo taking
3. Quality of image

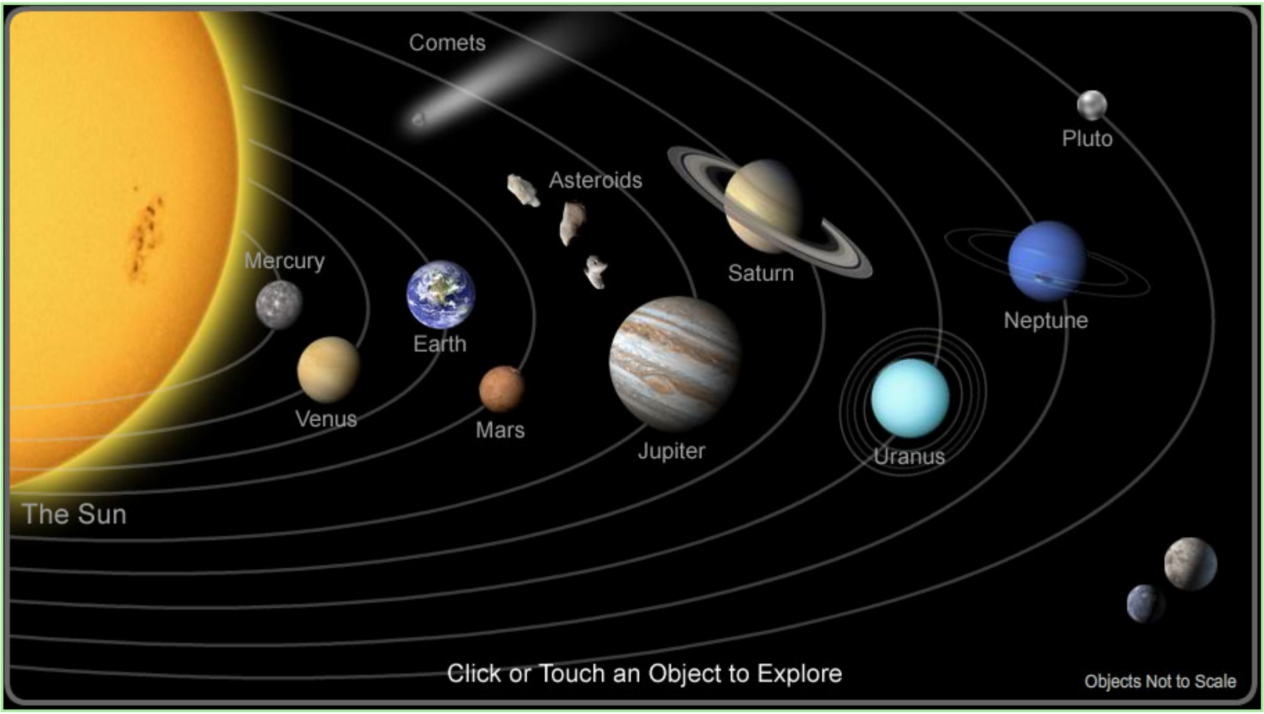
A CCD can be used on a variety of tools, such as: Digital Cameras, Telescopes etc.

Option E: Astrophysics

E1: Introduction to the universe

The universe is a collection of a vast number of galaxies, each galaxy consisting of countless solar systems, each solar system consisting of a star with orbiting planets.

Our Solar System:



Distribution of Stars:

Stars in the galaxy are arranged in different ways, there are stellar clusters, a small number of stars that interact with each other due to gravity. A stellar constellation are however collections of stars that appear close when viewed from earth although they may be located very far away from each other.

Light Year:

A light year is a measure of distance which is equal to the distance that light will travel in one year (9.46×10^{15}m). The closest star (Proxima Centauri) is 4.27 light years away. Distances between stars within a galaxy are much smaller that distances between galaxies.

The night sky will change in appearance at different locations and seasons at earth as the earth rotates and changes angle towards the sun and the rest of space.

E2: Stellar Radiation and Stellar Types

Stars gain the energy that they radiate from fusion. The most common reaction that takes place in a star is the fusion between hydrogen atoms that creates helium. This releases large amounts of energy that is radiated out into space.

A stable star, one that does not expand or contract and keeps a constant temperature can be said to be in a thermal and hydrostatic equilibrium. As it does not expand or contract the pressure that it exerts due to the reactions that are taking place inside must therefore equal in force the gravitational pressure from outside.

Luminosity:

The luminosity (L) of a star is the total power that it radiates.

The apparent brightness (b) of a star depends on the power received from the star over a given area on earth, it depends on the distance away that the star is as well as its luminosity.

These two variables can be bound by the equation:

$$L = \frac{b}{4\pi r^2}$$

Where 'r' is the distance between the two objects.

Wien's Law:

Wien's Law links the temperature of a star with the wavelength of a light it will emit. This relationship can be written as below:

$$\lambda_{\max} = \frac{2.90 \times 10^{-3}}{T}$$

Where T is the temperature in Kelvin and lambda is the wavelength in meters.

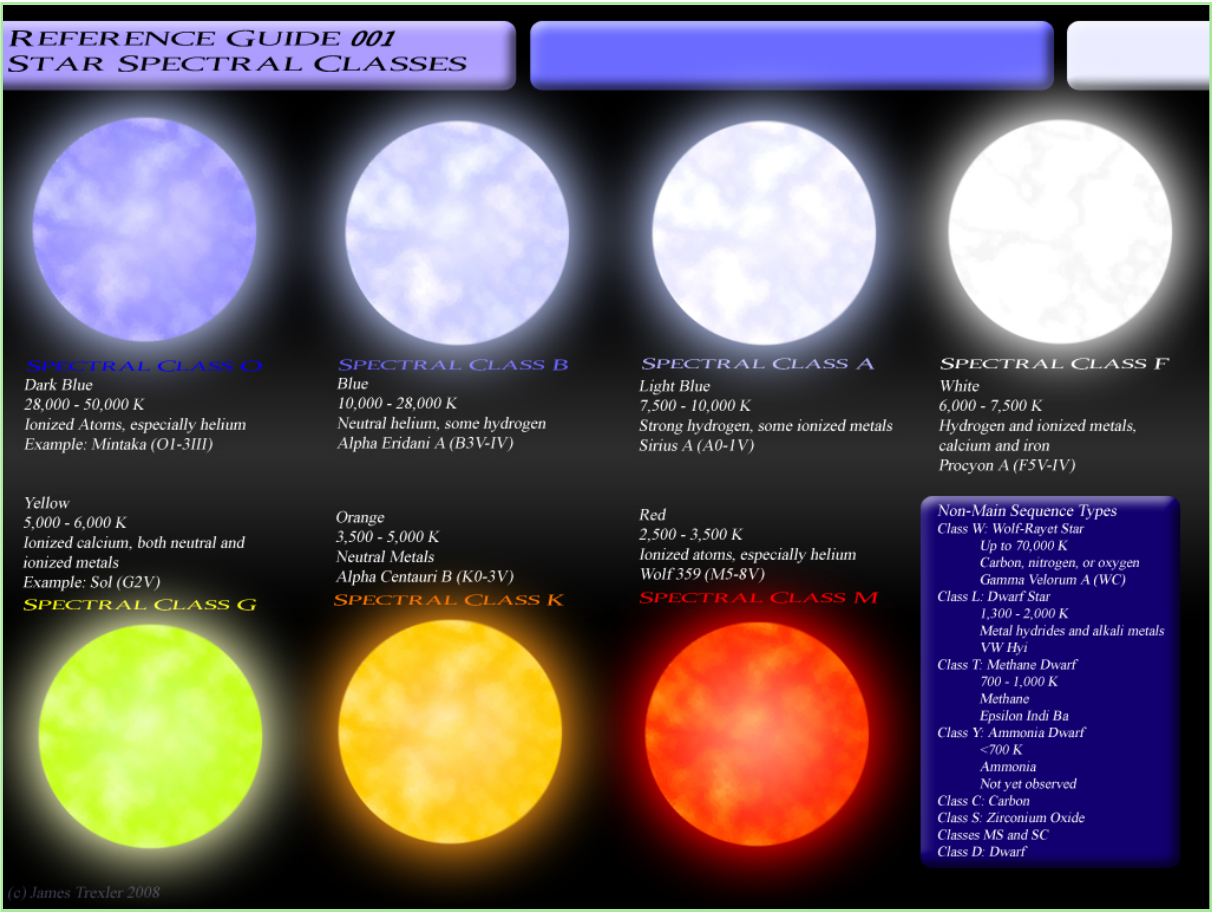
Stefan-Boltzmann Law:

Stefan-Boltzmann Law enables the surface area of a star to be calculated given that the temperature and luminosity is known. The relationship can be seen below, σ is equal to the Stefan Boltzmann constant ($5.67\text{x}10^{-8}$):

$$L = \sigma A T^4$$

Stellar Spectra:

By analyzing the spectrums of light radiated by stars they can be grouped into divisions. There are 7 categories, seen below:



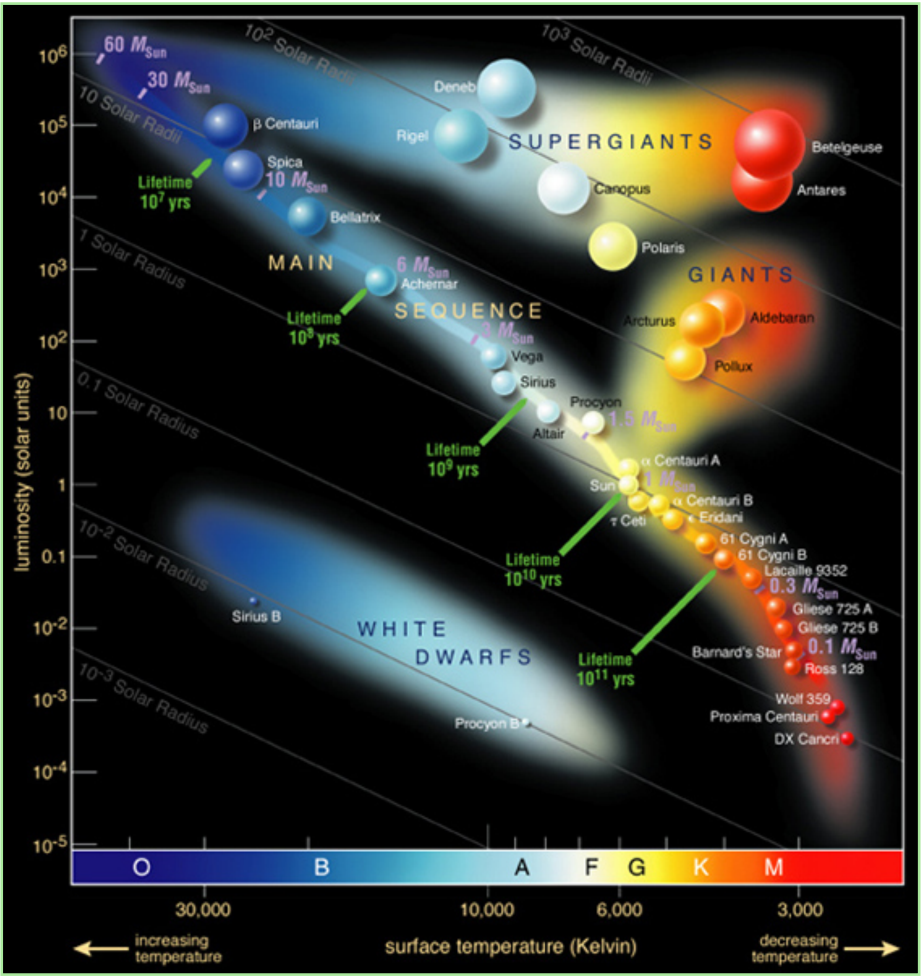
Types of Stars:

Star Types	
Cepheids	A cepheid star changes in size and luminosity in regular intervals, often less than a month
Red Giants	A red giant is in stellar class K and M and have relatively low surface temperatures but are very large
Red Supergiants	An exaggerated red giant
White Dwarfs	A white dwarf has a very high surface temperature but are not very large

There are also as well as solo stars, binary stars. Binary stars are two or more stars that are in orbit around each other. Due to this they may look like they are becoming more and less luminous in cycles.

Hertzsprung-Russell Diagram:

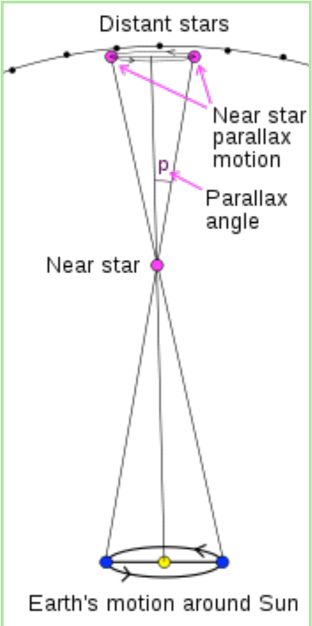
The Hertzsprung-Russell diagram can be used to classify stars, seen below:



E3: Stellar Distances

Parallax Method:

Parsec, is a measurement of distance equal to 3.25ly.
Below is a diagram showing how the distance to a star can be measured by using the parallax method.



The parallax angle can be measured by comparing the apparent location of a star at two moments 6 months apart. The found angle can then be used to calculate the distance to the star. The found angle must however first be converted from degrees into arcsec, one arcsec is equal to 1/3600 of one degree.

$$d = \frac{1}{p}$$

The distance found from the equation above will be the distance to the star measured in parsecs.

Stellar Parallax is however only an efficient method of measuring the distance to a star when it is just a few hundred parsecs away as the angles become far to small to measure after that distance.

Absolute and Apparent Magnitudes:

When comparing the brightness of different stars they are compared using the magnitude scale. The brightness of a star is recorded as a number, a bright star is rated as a 1 and a dim star as a 6. The difference between these two is approximately 100 times. Hence each step along this scale the brightness may be divided 2.512, or $100^{0.2}$. Apparent magnitude is noted as m.

Absolute magnitude (M) is the magnitude of a star if the observer was located 10pc away. The same scale is however also used for absolute magnitudes and the below equation can hence be produced:

$$m - M = 5\log\left(\frac{d}{10}\right)$$

In order to find the distance it can be arranged as:

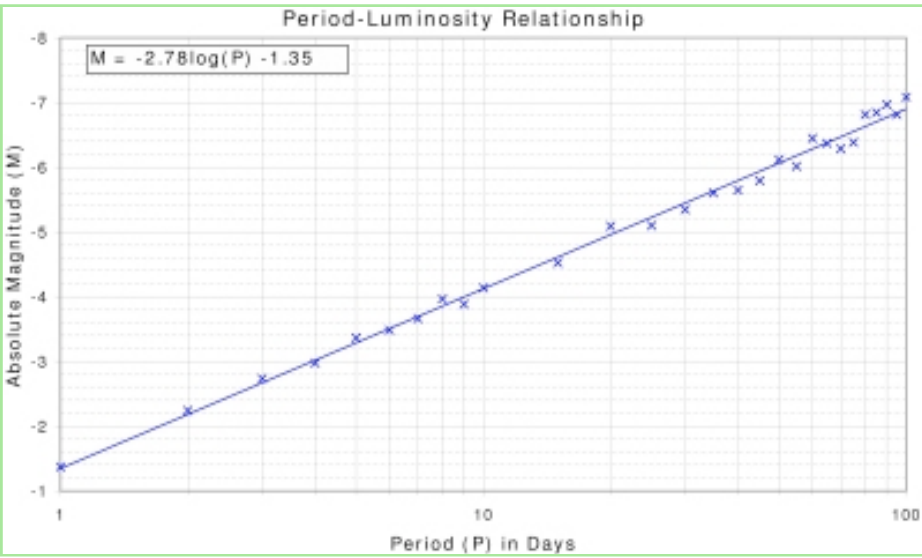
$$d = 10^{\frac{(m-M+5)}{5}}$$

Spectroscopic Parallax:

When a star is over 1000pc away it becomes feasible to use spectroscopic parallax. By examining the the emission spectrum of the star the temperature and spectral type can be found and hence by using the HR diagram the luminosity can also be found. The above equation can then be used to calculate the distance to the star. This is only reliable when stars are closer that 10Mpc.

Cepheid Variables:

When stars are further away than 10Mpc, it becomes acceptable to use cepheid variables to calculate the distance. It has been proven that cepheid stars with a longer period of oscillation will have a greater absolute magnitude. Hence if you want to find the distance to a star which is close to a cepheid you can find the distance to the cepheid and assume that it will be close. Below is a graph of the relationship between period of oscillation and absolute magnitude for cepheid stars.



E4: Cosmology

Olbers' Paradox:

Newton's model of the universe states that the universe is infinite in all directions. Heinrick Olbers however realized that this must mean that there is an infinite number of stars in each direction, and hence the night sky would be bright white due to the infinite number of stars. It has therefore been determined that the universe must be expanding.

The Big Bang Model:

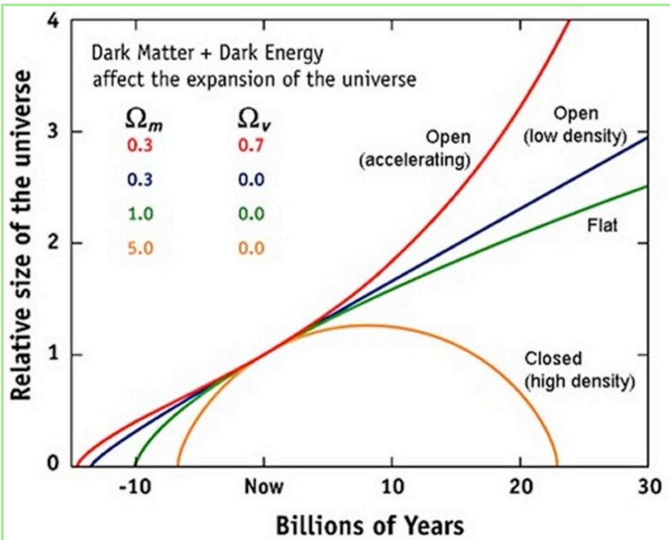
The redshift that we can experience when looking at far away galaxies suggests that they are moving away from us, hence the universe must be expanding. The universe is however not expanding into a void but rather is expanding space itself, universe is a sheet of rubber being pulled in all directions.

As all stellar bodies are moving away from each other they must have in the past been closer together, this is what lies behind the big bang theory. Einstein has been able to prove that not only space but also time began with the big bang.

Background radiation from the big bang can still be found today, this background radiation is in the form of microwaves. This means that these waves must have expanded together with space as they are longer now than they were then.

Development of the Universe:

There are three different possibilities for what could happen to the universe in the future, they can be seen below:



We are currently at the point where the different possibilities intersect. If the average density of the universe is a certain value then the force of gravity will continously slow down the rate of expansion but will take an infinite time to reach 0, hence the 'flat' universe. If the density is lower, there will be an open universe and if it greater the universe will collapse in on itself and it will be a closed universe.
It is however very difficult to determine the density of the universe because of it's sheer size and the existence of dark matter, very dense matter which can't be directly observed. Because of this it is currently believed that the universe is open.