AS Physics

Unit 1

Particles, Quantum Phenomena and Electricity

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Unit 1	Constituents of the Atom	
Lesson 1		
Learning Outcomes	To be know the constituents of the atom with their masses and charges	
	To be able to calculate the specific charge of the constituents	
	To be able to explain what isotopes and ions are	N. DWYER

Constituents of the Atom

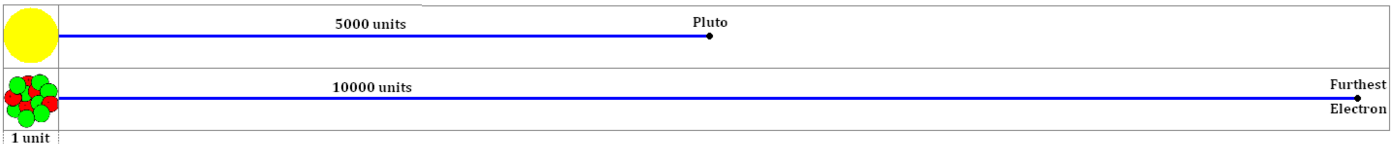
The Nuclear Model *(Also seen in GCSE Physics 1 and 2)*

Constituent	Charge (C)	Mass (kg)
Proton	1.6×10^{-19}	1.673×10^{-27}
Neutron	0	1.675×10^{-27}
Electron	$- 1.6 \times 10^{-19}$	9.1×10^{-31}

We know from Rutherford's experiment that the structure of an atom consists of positively charged protons and neutral neutrons in one place called the nucleus. The nucleus sits in the middle of the atom and has negatively charged electrons orbiting it. At GCSE we used charges and masses for the constituents relative to each other, the table above shows the actual charges and masses.

Almost all of the mass of the atom is in the tiny nucleus which takes up practically no space when compared to the size of the atom. If we shrunk the Solar System so that the Sun was the size of a gold nucleus the furthest electron would be twice the distance to Pluto.

If the nucleus was a full stop it would be 25 m to the first electron shell, 100 to the second and 225 to the third.



Notation *(Also seen in GCSE Physics 2)*

We can represent an atom of element X in the following way: $\,^{A}_{Z}X$

Z is the proton number. This is the number of protons in the nucleus. In an uncharged atom the number of electrons orbiting the nucleus is equal to the number of protons.

In Chemistry it is called the atomic number

A is the nucleon number. This is the total number of nucleons in the nucleus (protons + neutrons) which can be written as A = Z + N.

In Chemistry it is called the atomic mass number

N is the neutron number. This is the number of neutrons in the nucleus.

Isotopes *(Also seen in GCSE Physics 1 and 2)*

Isotopes are different forms of an element. They always have the same number of protons but have a different number of neutrons. Since they have the same number of protons (and electrons) they behave in the same way chemically.

Chlorine If we look at Chlorine in the periodic table we see that it is represented by $\,^{35.5}_{17}Cl$. How can it have 18.5 neutrons? It can't! There are two stable isotopes of Chlorine, $\,^{35}_{17}Cl$ which accounts for ~75% and $\,^{37}_{17}Cl$ which accounts for ~25%. So the average of a large amount of Chlorine atoms is $\,^{35.5}_{17}Cl$.

Specific Charge

Specific charge is another title for the charge-mass ratio. This is a measure of the charge per unit mass and is simply worked out by worked out by dividing the charge of a particle by its mass.

You can think of it as a how much charge (in Coulombs) you get per kilogram of the 'stuff'.

Constituent	Charge (C)	Mass (kg)	Charge-Mass Ratio (C kg^{-1}) or (C/kg)	
Proton	1.6×10^{-19}	1.673×10^{-27}	$1.6 \times 10^{-19} \div 1.673 \times 10^{-27}$	9.58×10^{7}
Neutron	0	1.675×10^{-27}	$0 \div 1.675 \times 10^{-27}$	0
Electron	(-) 1.6×10^{-19}	9.1×10^{-31}	$1.6 \times 10^{-19} \div 9.11 \times 10^{-31}$	(-) 1.76×10^{11}

We can see that the electron has the highest charge-mass ratio and the neutron has the lowest.

Ions *(Also seen in GCSE Physics 2)*

An atom may gain or lose electrons. When this happens the atoms becomes electrically charged (positively or negatively). We call this an ion.

If the atom gains an electron there are more negative charges than positive, so the atom is a negative ion.

Gaining one electron would mean it has an overall charge of -1, which actually means -1.6×10^{-19}C.

Gaining two electrons would mean it has an overall charge of -2, which actually means -3.2×10^{-19}C.

If the atom loses an electron there are more positive charges than negative, so the atom is a positive ion.

Losing one electron would mean it has an overall charge of +1, which actually means $+1.6 \times 10^{-19}$C.

Losing two electrons would mean it has an overall charge of +2, which actually means $+3.2 \times 10^{-19}$C.

Unit 1	Particles and Antiparticles	
Lesson 2		
Learning Outcomes	To know what is the difference between particles and antiparticles	
	To be able to explain what annihilation is	
	To be able to explain what pair production is	N. DWYER

Antimatter

British Physicist Paul Dirac predicted a particle of equal mass to an electron but of opposite charge (positive). This particle is called a positron and is the electron's *antiparticle*.

Every particles has its own antiparticle. An antiparticle has the same mass as the particle version but has opposite charge. An antiproton has a negative charge, an antielectron has a positive charge but an antineutron is also uncharged like the particle version.

American Physicist Carl Anderson observed the positron in a cloud chamber, backing up Dirac's theory.

Anti particles have opposite Charge, Baryon Number, Lepton Number and Strangeness.

If they are made from quarks the antiparticle is made from antiquarks

Annihilation

Whenever a particle and its antiparticle meet they annihilate each other.

Annihilation is the process by which mass is converted into energy, particle and antiparticle are transformed into two photons of energy.

Mass and energy are interchangeable and can be converted from one to the other. Einstein linked energy and mass with the equation:

$$\boxed{E = mc^2}$$

You can think of it like money; whether you have dollars or pounds you would still have the same amount of money. So whether you have mass or energy you still have the same amount.

The law of conservation of energy can now be referred to as the conservation of mass-energy.

The total mass-energy before is equal to the total mass-energy after.

Photon

Max Planck had the idea that light could be released in 'chunks' or packets of energy. Einstein named these wave-packets photons. The energy carried by a photon is given by the equation:

$$\boxed{E = hf}$$

Since $c = f\lambda$ we can also write this as: $\boxed{E = \frac{hc}{\lambda}}$

How is there anything at all?

When the Big Bang happened matter and antimatter was produced and sent out expanding in all directions. A short time after this there was an imbalance in the amount of matter and antimatter. Since there was more matter all the antimatter was annihilated leaving matter to form protons, atoms and everything around us.

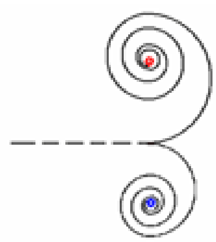
Pair Production

Pair production is the opposite process to annihilation, energy is converted into mass. A single photon of energy is converted into a particle-antiparticle pair. (This happens to obey the conservation laws)

This can only happen if the photon has enough mass-energy to "pay for the mass".

Let us image mass and energy as the same thing, if two particles needed 10 "bits" and the photon had 8 bits there is not enough for pair production to occur.

If two particles needed 10 bits to make and the photon had 16 bits the particle-antiparticle pair is made and the left over is converted into their kinetic energy.



If pair production occurs in a magnetic field the particle and antiparticle will move in circles of opposite direction but only if they are charged. (The deflection of charges in magnetic fields will be covered in Unit 4: Force on a Charged Particle)

Pair production can occur spontaneously but must occur near a nucleus which recoils to help conserve momentum. It can also be made to happen by colliding particles. At CERN protons are accelerated and fired into each other. If they have enough kinetic energy when they collide particle-antiparticle pair may be created from the energy.

The following are examples of the reactions that have occurred:

$p + p \rightarrow p + p + p + \overline{p}$ $\quad$ $p + p \rightarrow p + p + \pi^+ + \pi^-$ $\quad$ $p + p \rightarrow p + p + n + \overline{n}$

In all we can see that the conservation laws of particle physics are obeyed.

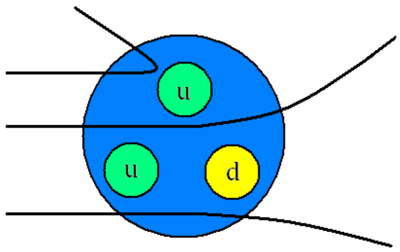
Unit 1	# Quarks	
Lesson 3		
Learning Outcomes	To know what quarks are and where they are found	
	To be able to explain how they were discovered	
	To know the properties of each type of quark	N. DWYER

Rutherford *Also seen in GCSE Physics 2*

Rutherford fired a beam of alpha particles at a thin gold foil. If the atom had no inner structure the alpha particles would only be deflected by very small angles. Some of the alpha particles were scattered at large angles by the nuclei of the atoms. From this Rutherford deduced that the atom was mostly empty space with the majority of the mass situated in the centre. Atoms were made from smaller particles.

Smaller Scattering

In 1968 Physicists conducted a similar experiment to Rutherford's but they fired a beam of high energy electrons at nucleons (protons and neutrons). The results they obtained were very similar to Rutherford's; some of the electrons were deflected by large angles. If the nucleons had no inner structure the electrons would only be deflected by small angles. These results showed that protons and neutrons were made of three smaller particles, each with a fractional charge.



Quarks

These smaller particles were named quarks and are thought to be fundamental particles (not made of anything smaller). There are six different quarks and each one has its own antiparticle.
We need to know about the three below as we will be looking at how larger particles are made from different combinations of quarks and antiquarks.

Quark	Charge (Q)	Baryon Number (B)	Strangeness (S)
d	-⅓	+⅓	0
u	+⅔	+⅓	0
s	-⅓	+⅓	-1

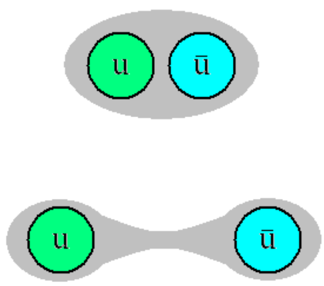
Anti Quark	Charge (Q)	Baryon Number (B)	Strangeness (S)
$\bar{d}$	+⅓	-⅓	0
$\bar{u}$	-⅔	-⅓	0
$\bar{s}$	+⅓	-⅓	+1

The other three are Charm, Bottom and Top. You will not be asked about these three

Quark	Charge	Baryon No.	Strangeness	Charmness	Bottomness	Topness
d	-⅓	+⅓	0	0	0	0
u	+⅔	+⅓	0	0	0	0
s	-⅓	+⅓	-1	0	0	0
c	+⅔	+⅓	0	+1	0	0
b	-⅓	+⅓	0	0	-1	0
t	+⅔	+⅓	0	0	0	+1

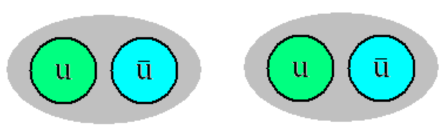
The Lone Quark?

Never! Quarks never appear on their own. The energy required to pull two quarks apart is so massive that it is enough to make two new particles. A quark and an antiquark are created, another example of pair production.
A particle called a neutral pion is made from an up quark and an antiup quark. Moving these apart creates another up quark and an antiup quark. We now have two pairs of quarks.
Trying to separate two quarks made two more quarks.



Particle Classification

Now that we know that quarks are the smallest building blocks we can separate all other particles into two groups, those made from quarks and those that aren't made from quarks.
Hadrons – Heavy and made from smaller particles
Leptons – Light and not made from smaller particles



Unit 1	Hadrons	
Lesson 4		
Learning Outcomes	To know what a hadron is and the difference between the two types	
	To know the properties common to all hadrons	
	To know the structure of the common hadrons and which is the most stable	N. DWYER

Made from Smaller Stuff

Hadrons, the Greek for ‘heavy’ are not fundamental particles they are all made from smaller particles, quarks.
The properties of a hadron are due to the combined properties of the quarks that it is made from.
There are two categories of Hadrons: Baryons and Mesons.

Baryons *Made from three quarks*

Proton	Charge (Q)	Baryon Number (B)	Strangeness (S)
u	+⅔	+⅓	0
u	+⅔	+⅓	0
d	-⅓	+⅓	0
p	**+1**	**+1**	**0**

Neutron	Charge (Q)	Baryon Number (B)	Strangeness (S)
d	-⅓	+⅓	0
u	+⅔	+⅓	0
d	-⅓	+⅓	0
n	**0**	**+1**	**0**

The proton is the only stable hadron, all others eventually decay into a proton.

Mesons *Made from a quark and an antiquark*

Pion Plus	Charge (Q)	Baryon Number (B)	Strangeness (S)
u	+⅔	+⅓	0
$\bar{d}$	+⅓	-⅓	0
π^+	**+1**	**0**	**0**

Pion Minus	Charge (Q)	Baryon Number (B)	Strangeness (S)
$\bar{u}$	-⅔	-⅓	0
d	-⅓	+⅓	0
π^-	**-1**	**0**	**0**

Pion Zero	Charge (Q)	Baryon Number (B)	Strangeness (S)
u	+⅔	+⅓	0
$\bar{u}$	-⅔	-⅓	0
π^0	**0**	**0**	**0**

Pion Zero	Charge (Q)	Baryon Number (B)	Strangeness (S)
d	-⅓	+⅓	0
$\bar{d}$	+⅓	-⅓	0
π^0	**0**	**0**	**0**

Kaon Plus	Charge (Q)	Baryon Number (B)	Strangeness (S)
u	+⅔	+⅓	0
$\bar{s}$	+⅓	-⅓	+1
K^+	**+1**	**0**	**+1**

Kaon Minus	Charge (Q)	Baryon Number (B)	Strangeness (S)
$\bar{u}$	-⅔	-⅓	0
s	-⅓	+⅓	-1
K^-	**-1**	**0**	**-1**

Kaon Zero	Charge (Q)	Baryon Number (B)	Strangeness (S)
d	-⅓	+⅓	0
$\bar{s}$	+⅓	-⅓	+1
K^0	**0**	**0**	**+1**

AntiKaon Zero	Charge (Q)	Baryon Number (B)	Strangeness (S)
$\bar{d}$	+⅓	-⅓	0
s	-⅓	+⅓	-1
$\bar{K}^0$	**0**	**0**	**-1**

Anti Hadrons

Anti hadrons are made from the opposite quarks as their Hadron counterparts, for example a proton is made from the quark combination uud and an antiproton is made from the combination $\bar{u}\bar{u}\bar{d}$
We can see that a π^+ and a π^- are particle and antiparticle of each other.

Anti Proton	Charge (Q)	Baryon Number (B)	Strangeness (S)
$\bar{u}$	-⅔	-⅓	0
$\bar{u}$	-⅔	-⅓	0
$\bar{d}$	+⅓	-⅓	0
$\bar{p}$	**-1**	**-1**	**0**

Anti Neutron	Charge (Q)	Baryon Number (B)	Strangeness (S)
$\bar{d}$	+⅓	-⅓	0
$\bar{u}$	-⅔	-⅓	0
$\bar{d}$	+⅓	-⅓	0
$\bar{n}$	**0**	**-1**	**0**

You need to know all the quark combination shown on this page as they may ask you to recite any of them.

Unit 1	Leptons	
Lesson 5		
Learning Outcomes	To be able to explain what a lepton is	
	To know the properties common to all leptons	
	To be able to explain the conservation laws and be able to use them	N. DWYER

Fundamental Particles

A fundamental particle is a particle which is not made of anything smaller. Baryons and Mesons are made from quarks so they are not fundamental, but quarks themselves are. The only other known fundamental particles are Bosons (see Lesson 6: Forces and Exchange Particles) and Leptons.

Leptons

Leptons are a family of particles that are much lighter than Baryons and Mesons and are not subject to the strong interaction. There are six leptons in total, three of them are charged and three are uncharged.

The charged particles are electrons, muons and tauons. The muon and tauon are similar to the electron but bigger. The muon is roughly 200 times bigger and the tauon is 3500 times bigger (twice the size of a proton).

Each of the charged leptons has its own neutrino. If a decay involves a neutrino and a muon, it will be a muon neutrino, not a tauon neutrino or electron neutrino.

The neutrino is a chargeless, almost massless particle. It isn't affected by the strong interaction or EM force and barely by gravity. It is almost impossible to detect.

Lepton		Charge (Q)	Lepton Number (L)
Electron	e^-	-1	+1
Electron Neutrino	ν_e	0	+1
Muon	μ^-	-1	+1
Muon Neutrino	ν_μ	0	+1
Tauon	τ^-	-1	+1
Tauon Neutrino	ν_τ	0	+1

Anti Lepton		Charge (Q)	Lepton Number (L)
Anti Electron	e^+	+1	-1
Anti Electron Neutrino	$\bar{\nu}_e$	0	-1
Anti Muon	μ^+	+1	-1
Anti Muon Neutrino	$\bar{\nu}_\mu$	0	-1
Anti Tauon	τ^+	+1	-1
Anti Tauon Neutrino	$\bar{\nu}_\tau$	0	-1

Conservation Laws

For a particle interaction to occur the following laws must be obeyed, if either is violated the reaction will never be observed (will never happen):

Charge: Must be conserved (same total value before as the total value after)
Baryon Number: Must be conserved
Lepton Number: Must be conserved
Strangeness: Conserved in EM and Strong Interaction. Doesn't have to be conserved in Weak Interaction

Examples

In pair production a photon of energy is converted into a particle and its antiparticle

	γ	→	e^-	+	e^+				
Q	0	→	-1	+	+1	0	→	0	Conserved
B	0	→	0	+	0	0	→	0	Conserved
L	0	→	+1	+	-1	0	→	0	Conserved
S	0	→	0	+	0	0	→	0	Conserved

Let us look at beta plus decay as we knew it at GCSE. A neutron decays into a proton and releases an electron.

	n	→	p	+	e^-				
Q	0	→	+1	+	-1	0	→	0	Conserved
B	+1	→	+1	+	0	+1	→	+1	Conserved
L	0	→	0	+	+1	0	→	+1	Not Conserved
S	0	→	0	+	0	0	→	0	Conserved

This contributed to the search for and discovery of the neutrino.

Number Reminders

There may be a clue to the charge of a particle; π^+, K^+ and e^+ have a positive charge.
It will only have a baryon number if it **IS** a baryon. Mesons and Leptons have a Baryon Number of zero.
It will only have a lepton number if it **IS** a lepton. Baryons and Mesons have a Lepton Number of zero.
It will only have a strangeness if it is made from a strange quark. Leptons have a strangeness of zero.

Unit 1	Forces and Exchange Particles	
Lesson 6		
Learning Outcomes	To know the four fundamental forces, their ranges and relative strengths	
	To know what each force does and what it acts on	
	To be able to explain what exchange particles are	N. DWYER

The Four Interactions

There are four forces in the universe, some you will have come across already and some will be new:
The electromagnetic interaction causes an attractive or repulsive force between charges.
The gravitational interaction causes an attractive force between masses.
The strong nuclear interaction causes an attractive (or repulsive) force between quarks (and so hadrons).
The weak nuclear interaction does not cause a physical force, it makes particles decay. 'Weak' means there is a low probability that it will happen.

Interaction/Force	Range	Relative Strength	
Strong Nuclear	$\sim 10^{-15}$m	1	(1)
Electromagnetic	∞	$\sim 10^{-2}$	(0.01)
Weak Nuclear	$\sim 10^{-18}$m	$\sim 10^{-7}$	(0.0000001)
Gravitational	∞	$\sim 10^{-36}$	(0.000000000000000000000000000000000001)

Exchange Particles

In 1935 Japanese physicist Hideki Yukawa put forward the idea that the interactions/forces between two particles were caused by 'virtual particles' being exchanged between the two particles.
He was working on the strong nuclear force which keeps protons and neutrons together and theorised that they were exchanging a particle back and forth that 'carried' the force and kept them together. This is true of all the fundamental interactions.
The general term for exchange particles is *bosons* and they are fundamental particles like quarks and leptons.

Ice Skating Analogy

Imagine two people on ice skates that will represent the two bodies experiencing a force.
If A throws a bowling ball to B, A slides back when they release it and B moves back when they catch it.
Repeatedly throwing the ball back and forth moves A and B away from each other, the force causes repulsion.
The analogy falls a little short when thinking of attraction, but bear with it.
Now imagine that A and B are exchanging a boomerang (bear with it), throwing it behind them pushes A towards B, B catches it from behind and moves towards A. The force causes attraction.

Which Particle for What Force

Each of the interactions/forces has its own exchange particles.

Interaction/Force	Exchange Particle			What is acts upon
Strong Nuclear	Gluons between quarks	Pions between Baryons		Nucleons (Hadrons)
Electromagnetic	Virtual Photon			Charged particles
Weak Nuclear	W^+	W^-	Z^0	All particles
Gravitational	Graviton			Particles with masses

Borrowing Energy to Make Particles

The exchange particles are made from 'borrowed' energy, borrowed from where? From nowhere! Yukawa used the Heisenberg Uncertainty Principle to establish that a particle of mass-energy ΔE could exist for a time Δt as long as $\boxed{\Delta E.\Delta t \leq h}$ where h is Planck's constant. This means that a heavy particle can only exist for a short time while a lighter particle may exist for longer.

h is Planck's Constant, h = 6.63 x 10^{-34} J s.

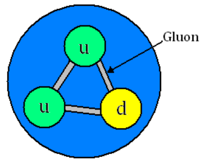
In 1947 the exchange particle of the strong nuclear interaction were observed in a cloud chamber.

Lending Money Analogy

Think of making exchange particles in terms of lending somebody some money.
If you lend somebody £50 you would want it paid back fairly soon.
If you lend somebody 50p you would let them have it for longer before paying you back.

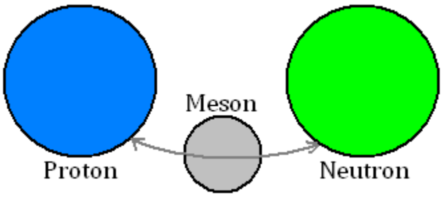
Unit 1	The Strong Interaction	
Lesson 7		
Learning Outcomes	To know why a nucleus doesn’t tear itself apart	
	To know why a nucleus doesn’t collapse in on itself	
	To know why the neutron exists in the nucleus	N. DWYER

The Strong Interaction



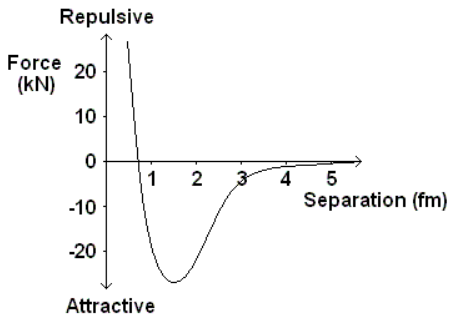
The strong nuclear force acts between quarks. Since Hadrons are the only particles made of quarks only they experience the strong nuclear force.
In both Baryons and Mesons the quarks are attracted to each other by exchanging virtual particles called ‘gluons’.

On a larger scale the strong nuclear force acts between the Hadrons themselves, keeping them together. A pi-meson or pion (π) is exchanged between the hadrons. This is called the residual strong nuclear force.



Force Graphs

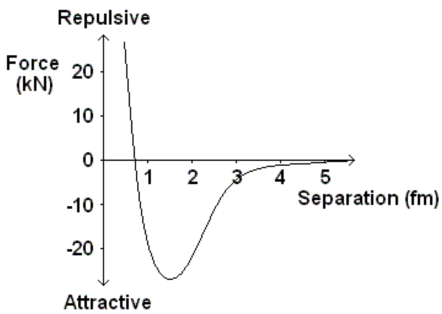
Neutron-Neutron or Neutron-Proton



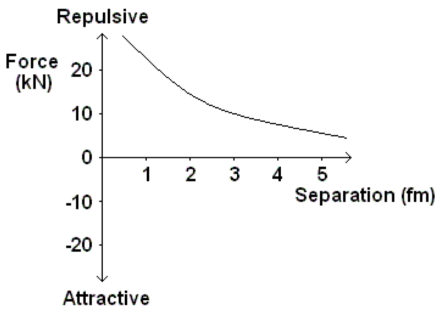
Here is the graph of how the force varies between two neutrons or a proton and a neutron as the distance between them is increased.
We can see that the force is very strongly repulsive at separations of less than 0.7 fm (x 10^{-15} m). This prevents all the nucleons from crushing into each other.
Above this separation the force is strongly attractive with a peak around 1.3 fm. When the nucleons are separated by more than 5 fm they no longer experience the SNF.

Proton-Proton

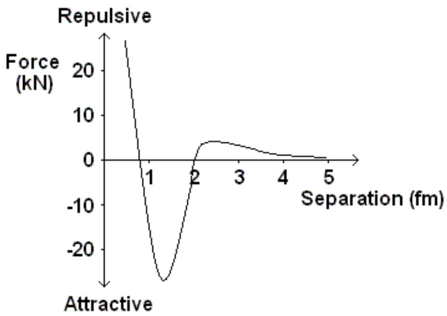
The force-separation graphs for two protons is different. They both attract each other due to the SNF but they also repel each other due to the electromagnetic force which causes two like charges to repel.



Graph A



Graph B

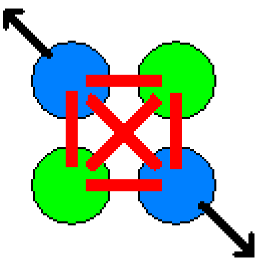


Graph C

Graph A shows how the strong nuclear force varies with the separation of the protons
Graph B shows how the electromagnetic force varies with the separation of the protons
Graph C shows the resultant of these two forces: repulsive at separations less than 0.7 fm, attractive up to 2 fm when the force becomes repulsive again.

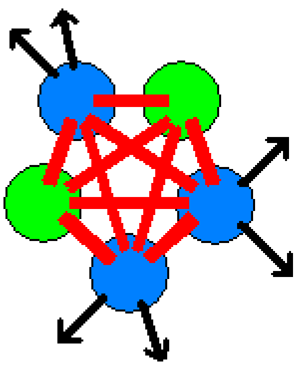
Neutrons – Nuclear Cement

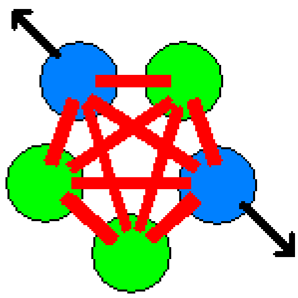
In the lighter elements the number of protons and neutrons in the nucleus is the same. As the nucleus gets bigger more neutrons are needed to keep it together.



Adding another proton means that all the other nucleons feel the SNF attraction. It also means that all the other protons feel the EM repulsion.

Adding another neutron adds to the SNF attraction between the nucleons but, since it is uncharged, it does not contribute to the EM repulsion.





Unit 1	The Weak Interaction	
Lesson 8		
Learning Outcomes	To be able to write the equation for alpha and beta decay	
	To know what a neutrino is and why is must exist	
	To be able to state the changes in quarks during beta plus and beta minus decay	N. DWYER

Alpha Decay

When a nucleus decays in this way an alpha particle (a helium nucleus) is ejected from the nucleus.

$${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha \qquad \text{or} \qquad {}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

All the emitted alpha particles travelled at the same speed, meaning they had the same amount of energy. The law of conservation of mass-energy is met, the energy of the nucleus before the decay is the same as the energy of the nucleus and alpha particle after the decay.

Alpha decay is NOT due to the weak interaction but Beta decay IS

Beta Decay and the Neutrino

In beta decay a neutron in the nucleus changes to a proton and releases a beta particle (an electron).
The problem with beta decay was that the electrons had a range of energies so the law of conservation of mass-energy is violated, energy disappears. There must be another particle being made with zero mass but variable speeds, the neutrino.

We can also see from the particle conservation laws that this is a forbidden interaction: $n \rightarrow p + e^-$

Charge	Q: 0 → +1–1	0 → 0	Charge is conserved
Baryon Number	B: +1 → +1+0	1 → 1	Baryon number is conserved
Lepton Number	L: 0 → 0+1	0 → 1	Lepton number is NOT conserved

Beta Minus (β⁻) Decay

In neutron rich nuclei a neutron may decay into a proton, electron and an anti electron neutrino.

$$\boxed{n \rightarrow p + e^- + \overline{\nu_e}}$$

Charge	Q: 0 → +1–1+0	0 → 0	Charge is conserved
Baryon Number	B: +1 → +1+0+0	1 → 1	Baryon number is conserved
Lepton Number	L: 0 → 0+1–1	0 → 0	Lepton number is conserved

In terms of quarks beta minus decay looks like this: $dud \rightarrow uud + e^- + \overline{\nu_e}$ which simplifies to:

$$\boxed{d \rightarrow u + e^- + \overline{\nu_e}}$$

Charge	Q: – ⅓ → +⅔–1+0	– ⅓ → – ⅓	Charge is conserved
Baryon Number	B: +⅓ → +⅓+0+0	⅓ → ⅓	Baryon number is conserved
Lepton Number	L: 0 → 0+1–1	0 → 0	Lepton number is conserved

Beta Plus (β⁺) Decay

In proton rich nuclei a proton may decay into a neutron, positron and an electron neutrino.

$$\boxed{p \rightarrow n + e^+ + \nu_e}$$

Charge	Q: +1 → 0+1+0	1 → 1	Charge is conserved
Baryon Number	B: +1 → +1+0+0	1 → 1	Baryon number is conserved
Lepton Number	L: 0 → 0–1+1	0 → 0	Lepton number is conserved

In terms of quarks beta plus decay looks like this: $uud \rightarrow dud + e^+ + \nu_e$ which simplifies to:

$$\boxed{u \rightarrow d + e^+ + \nu_e}$$

Charge	Q: +⅔ → –⅓+1+0	⅔ → ⅔	Charge is conserved
Baryon Number	B: +⅓ → +⅓+0+0	⅓ → ⅓	Baryon number is conserved
Lepton Number	L: 0 → 0–1+1	0 → 0	Lepton number is conserved

Strangeness

The weak interaction is the only interaction that causes a quark to change into a different type of quark. In beta decay up quarks and down quarks are changed into one another. In some reactions an up or down quark can change into a strange quark meaning strangeness is not conserved.
During the weak interaction there can be a change in strangeness of ±1.

Unit 1	Feynman Diagrams	
Lesson 9		
Learning Outcomes	To know what a Feynman diagram shows us	
	To be able to draw Feynman diagrams to represent interactions and decays	
	To be able to state the correct exchange particle	N. DWYER

Feynman Diagrams

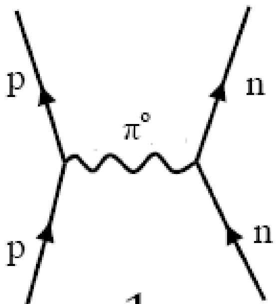
An American Physicist called Richard Feynman came up with a way of visualising forces and exchange particles. Below are some examples of how Feynman diagrams can represent particle interactions.

The most important things to note when dealing with Feynman diagrams are the arrows and the exchange particles, the lines do not show us the path that the particles take only which come in and which go out.

The arrows tell us which particles are present before the interaction and which are present after the interaction.

The wave represents the interaction taking place with the appropriate exchange particle labelled.

Examples



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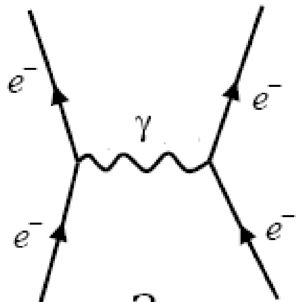

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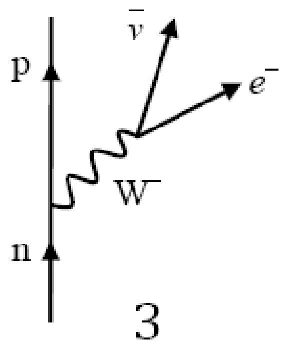

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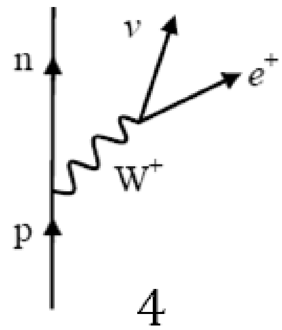

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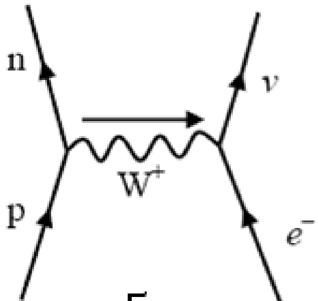
Diagram 1 represents the strong interaction. A proton and neutron are attracted together by the exchange of a neutral pion.

Diagram 2 represents the electromagnetic interaction. Two electrons repel each other by the exchange of a virtual photon.

Diagram 3 represents beta minus decay. A neutron decays due to the weak interaction into a proton, an electron and an anti electron neutrino

Diagram 4 represents beta plus decay. A proton decays into a neutron, a positron and an electron neutrino.



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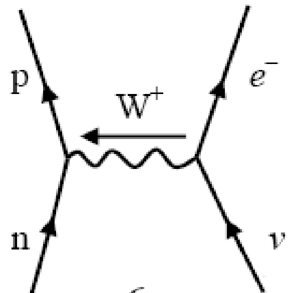

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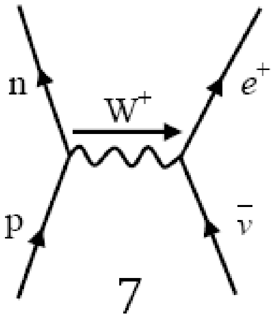

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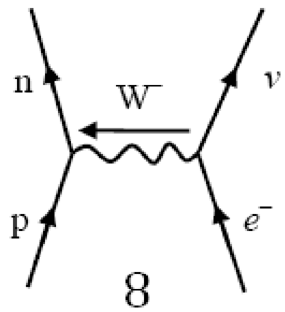

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Diagram 5 represents electron capture. A proton captures an electron and becomes a neutron and an electron neutrino.

Diagram 6 represents a neutrino-neutron collision. A neutron absorbs a neutrino and forms a proton and an electron.

Diagram 7 represents an antineutrino-proton collision. A proton absorbs an antineutrino and emits a neutron and an electron.

Diagram 8 represents an electron-proton collision. They collide and emit a neutron and an electron neutrino.

Getting the Exchange Particle

The aspect of Feynman diagrams that students often struggle with is labelling the exchange particle and the direction to draw it. Look at what you start with:

If it is positive and becomes neutral you can think of it as throwing away its positive charge so the boson will be positive. This is the case in electron capture.

If it is positive and becomes neutral you can think of it as gaining negative to neutralise it so the boson will be negative. This is the case in electron-proton collisions.

If it is neutral and becomes positive we can think of it either as gaining positive (W+ boson) or losing negative (W– boson in the opposite direction).

Work out where the charge is going and label it.

Unit 1	The Photoelectric Effect	
Lesson 10		
Learning Outcomes	To know what the photoelectric effect is and how frequency and intensity affect it	
	To be able to explain what photon, photoelectron, work function and threshold frequency are	
	To be able to calculate the kinetic energy of a photoelectron	N. DWYER

Observations

When light fell onto a metal plate it released electrons from the surface straight away. Increasing the intensity increased the number of electrons emitted. If the frequency of the light was lowered, no electrons were emitted at all. Increasing the intensity and giving it more time did nothing, no electrons were emitted.

If Light was a Wave…

Increasing the intensity would increase the energy of the light. The energy from the light would be evenly spread over the metal and each electron would be given a small amount of energy. Eventually the electron would have enough energy to be removed from the metal.

Photon

Max Planck had the idea that light could be released in 'chunks' or packets of energy. Einstein named these wave-packets photons. The energy carried by a photon is given by the equation:

$\boxed{E = hf}$ Since $c = f\lambda$ we can also write this as: $\boxed{E = \frac{hc}{\lambda}}$

Explaining the Photoelectric Effect

Einstein suggested that one photon collides with one electron in the metal, giving it enough energy to be removed from the metal and then fly off somewhere. Some of the energy of the photon is used to break the bonds holding the electron in the metal and the rest of the energy is used by the electron to move away (kinetic energy). He represented this with the equation: $\boxed{hf = \phi + E_K}$

hf represents the energy of the photon, ϕ is the work function and E_K is the kinetic energy.

Work Function, ϕ

The work function is the amount of energy the electron requires to be completely removed from the surface of the metal. This is the energy <u>just</u> to remove it, not to move away.

Threshold Frequency, f_0

The threshold frequency is the minimum frequency that would release an electron from the surface of a metal, any less and nothing will happen.

Since $hf = \phi + E_K$, the minimum frequency releases an electron that is not moving, so $E_K = 0$

$hf_0 = \phi$ which can be rearranged to give: $\boxed{f_0 = \frac{\phi}{h}}$

Increasing the intensity increases the number of photons the light sources gives out each second.
If the photon has less energy than the work function an electron can not be removed. Increasing the intensity just sends out more photons, all of which would still not have enough energy to release an electron.

Graph

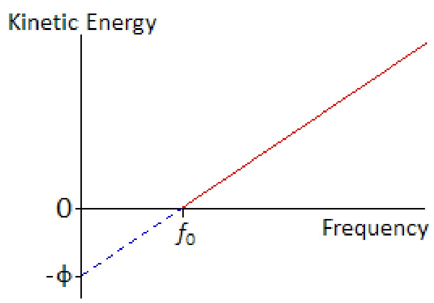
If we plot a graph of the kinetic energy of the electrons against frequency we get a graph that looks like this:

Start with $hf = \phi + E_K$ and transform into $y = mx + c$.

E_K is the y-axis and f is the x- axis.

This makes the equation become: $E_K = hf - \phi$

So the **gradient represents Planck's constant** and the **y-intercept represents (–) the work function**.



Nightclub Analogy

We can think of the photoelectric effect in terms of a full nightclub; let the people going into the club represent the photons, the people leaving the club represent the electrons and money represent the energy.
The club is full so it is one in and one out. The work function equals the entrance fee and is £5:
If you have £3 you don't have enough to get in so noone is kicked out.
If 50 people arrive with £3 no one has enough, so one gets in and noone is kicked out.
If you have £5 you have enough to get in so someone is kicked out, but you have no money for booze.
If 50 people arrive with £5 you all get in so 50 people are kicked out, but you have no money for booze.
If you have £20 you have enough to get in so someone is kicked out and you have £15 to spend on booze.
If 50 people arrive with £20 you all get in so 50 people are kicked out and you have £15 each to spend on booze.

Unit 1	# Excitation, Ionisation and Energy Levels	
Lesson 11		
Learning Outcomes	To know how Bohr solved the falling electron problem	
	To be able to explain what excitation, de-excitation and ionisation are	
	To be able to calculate the frequency needed for excitation to a certain level	N. DWYER

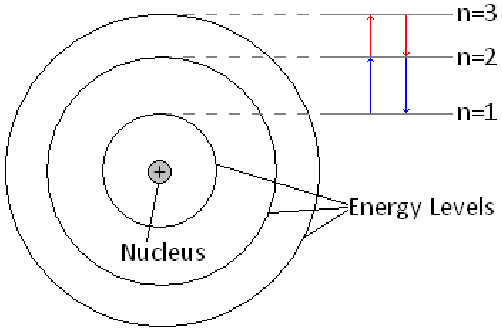
The Electronvolt, eV

The Joule is too big use on an atomic and nuclear scale so we will now use the electronvolt, represented by eV. One electronvolt is equal to the energy gained by an electron of charge *e*, when it is accelerated through a potential difference of 1 volt. 1eV = 1.6 x 10^{-19}J 1J = 6.25 x 10^{18}eV

eV → J multiply by *e* J → eV divide by *e*

The Problem with Atoms

Rutherford's nuclear model of the atom leaves us with a problem: a charged particle emits radiation when it accelerates. This would mean that the electrons would fall into the nucleus.



Bohr to the Rescue

Niels Bohr solved this problem by suggesting that the electrons could only orbit the nucleus in certain 'allowed' energy levels. He suggested that an electron may only transfer energy when it moves from one energy level to another. A change from one level to another is called a 'transition'.

To move up and energy level the electron must gain the exact amount of energy to make the transition.

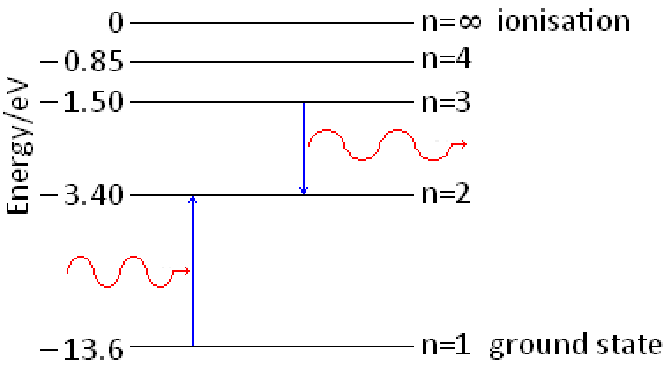
It can do this by another electron colliding with it or by absorbing a photon of the exact energy.

When moving down a level the electron must lose the exact amount of energy when making the transition.

It releases this energy as a photon of energy equal to the energy it loses.

$$\boxed{\Delta E = hf = E_1 - E_2}$$

E_1 is the energy of the level the electron starts at and E_2 is the energy of the level the electron ends at



Excitation

When an electron gains the exact amount of energy to move up one or more energy levels

De-excitation

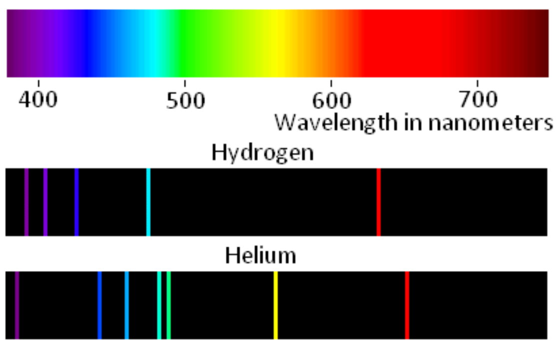
When an electron gives out the exact amount of energy to move back down to its original energy level

Ionisation

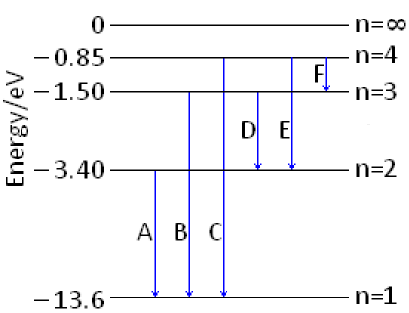
An electron can gain enough energy to be completely removed from the atom.

The ground state and the energy levels leading up to ionisation have negative values of energy, this is because they are compared to the ionisation level. Remember that energy must be given to the electrons to move up a level and is lost (or given out) when it moves down a level.

Line Spectra



Atoms of the same element have same energy levels. Each transition releases a photon with a set amount of energy meaning the frequency and wavelength are also set. The wavelength of light is responsible for colour it is. We can analyse the light by using a diffraction grating to separate light into the colours that makes it up, called its *line spectra*. Each element has its own line spectra like a barcode.



To the above right are the line spectra of Hydrogen and Helium.

We can calculate the energy difference that created the colour.

If we know the energy differences for each element we can work out which element is responsible for the light and hence deduce which elements are present.

We can see that there are 6 possible transitions in the diagram to the left, A to F.

D has an energy difference of 1.9 eV or 3.04 x 10^{-19} J which corresponds to a frequency of 4.59 x 10^{14} Hz and a wavelength of 654 nm – red.

Unit 1	Wave-Particle Duality	
Lesson 12		
Learning Outcomes	To know how to calculate the de Broglie wavelength and what is it	
	To be able to explain what electron diffraction shows us	
	To know what wave-particle duality is	N. DWYER

De Broglie

In 1923 Louis de Broglie put forward the idea that 'all particles have a wave nature' meaning that particles can behave like waves.
This doesn't sound too far fetched after Einstein proved that a wave can behave like a particle.
De Broglie said that all particles could have a wavelength. A particle of mass, m, that is travelling at velocity, v, would have a wavelength given by:

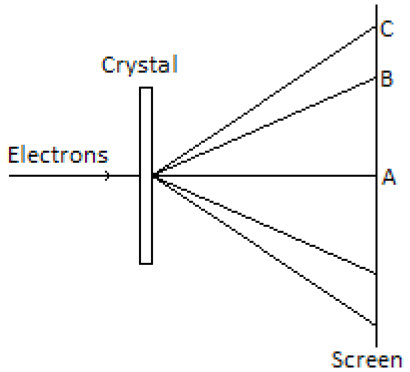
$\boxed{\lambda = \frac{h}{mv}}$ which is sometime written as $\boxed{\lambda = \frac{h}{p}}$ where p is momentum

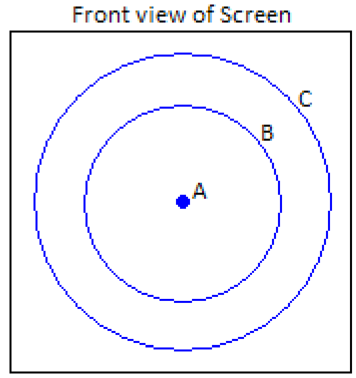
This wavelength is called the de Broglie wavelength. The modern view is that the de Broglie wavelength is linked to the probability of finding the particle at a certain point in space.

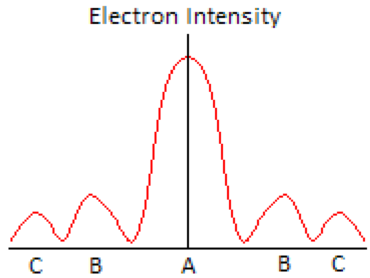
De Broglie wavelength is measured in metres, m

Electron Diffraction

Two years after de Broglie came up with his particle wavelengths and idea that electrons could diffract, Davisson and Germer proved this to happen.
They fired electrons into a crystal structure which acted as a diffraction grating. This produced areas of electrons and no electrons on the screen behind it, just like the pattern you get when light diffracts.







Electron Wavelength

We can calculate the de Broglie wavelength of an electron from the potential difference, V, that accelerated it.
Change in electric potential energy gained = eV

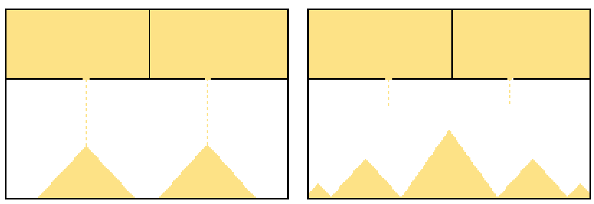
This is equal to the kinetic energy of the electron $$eV = \frac{1}{2}mv^2$$

The velocity is therefore given by: $$\sqrt{\frac{2eV}{m}} = v$$

We can substitute this into $\lambda = \frac{h}{mv}$ to get: $$\boxed{\lambda = \frac{h}{\sqrt{2meV}}}$$

Sand Analogy

If we compare a double slit electron diffraction to sand falling from containers we can see how crazy electron diffraction is. Imagine two holes about 30cm apart that sand is dropping from. We would expect to find a maximum amount of sand under each hole, right? This is not what we find! We find a maximum in between the two holes. The electrons are acting like a wave.



Wave-Particle Duality

Wave-particle duality means that waves sometimes behave like particles and particles sometimes behave like waves. Some examples of these are shown below:

Light as a Wave

Diffraction, interference, polarisation and refraction all prove that light is a wave and will be covered in Unit 2.

Light as a Particle

We have seen that the photoelectric effect shows that light can behave as a particle called a photon.

Electron as a Particle

The deflection by an electromagnetic field and collisions with other particles show its particle nature.

Electron as a Wave

Electron diffraction proves that a particle can show wave behaviour.

Unit 1	QVIRt	
Lesson 13		
Learning Outcomes	To be able to explain what current, charge, voltage/potential difference and resistance are	
	To know the equations that link these	
	To know the correct units to be use in each	N. DWYER

Definitions *(Also seen in GCSE Physics 2)*

Current, I

Electrical current is the rate of flow of charge in a circuit. Electrons are charged particles that move around the circuit. So we can think of the electrical current is the rate of the flow of electrons, not so much the speed but the number of electrons moving in the circuit. If we imagine that electrons are Year 7 students and a wire of a circuit is a corridor, the current is how many students passing in a set time.

Current is measured in Amperes (or Amps), A

Charge, Q

The amount of electrical charge is a fundamental unit, similar to mass and length and time. From the data sheet we can see that the charge on one electron is actually -1.60 x 10^{-19} C. This means that it takes 6.25 x 10^{18} electrons to transfer 1C of charge.

Charge is measured in Coulombs, C

Voltage/Potential Difference, V

Voltage, or potential difference, is the work done per unit charge.
1 unit of charge is 6.25 x 10^{18} electrons, so we can think of potential difference as the energy given to each of the electrons, or the pushing force on the electrons. It is the p.d. that causes a current to flow and we can think of it like water flowing in a pipe. If we make one end higher than the other end, water will flow down in, if we increase the height (increase the p.d.) we get more flowing. If we think of current as Year 7s walking down a corridor, the harder we push them down the corridor the more we get flowing.

Voltage and p.d. are measured in Volts, V

Resistance, R

The resistance of a material tells us how easy or difficult it is to make a current flow through it. If we think of current as Year 7s walking down a corridor, it would be harder to make the Year 7s flow if we added some Year 11 rugby players into the corridor. Increasing resistance lowers the current.

Resistance is measured in Ohms, Ω

Time, t

You know, time! How long stuff takes and that.

Time is measured in seconds, s

Equations

There are three equations that we need to be able to explain and substitute numbers into.

1

$$\boxed{I = \frac{\Delta Q}{\Delta t}}$$

This says that the current is the rate of change of charge per second and backs up or idea of current as the rate at which electrons (and charge) flow.
This can be rearranged into

$$\Delta Q = I \Delta t$$

which means that the charge is equal to how much is flowing multiplied by how long it flows for.

2

$$\boxed{V = \frac{E}{Q}}$$

This says that the voltage/p.d. is equal to the energy per charge. *The 'push' of the electrons is equal to the energy given to each charge (electron).*

3

$$\boxed{V = IR}$$

This says that increasing the p.d. increases the current. *Increasing the 'push' of the electrons makes more flow.* It also shows us that for constant V, if R increases I gets smaller. *Pushing the same strength, if there is more blocking force less current will flow.*

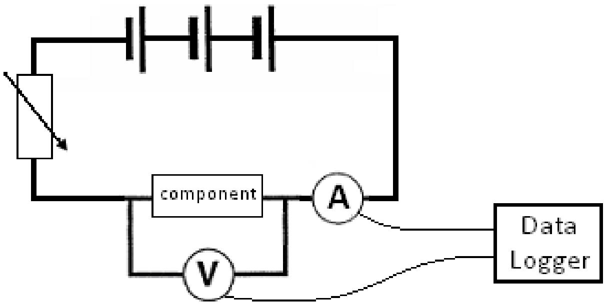
Unit 1	Ohm’s Laws and I-V Graphs	
Lesson 14		
Learning Outcomes	To be able to sketch and explain the I-V graphs of a diode, filament lamp and resistor	
	To be able to describe the experimental set up and measurements required to obtain these graphs	
	To know how the resistance of an LDR and Thermistor varies	N. DWYER

Ohm’s Law *(Also seen in GCSE Physics 2)*

After the last lesson we knew that a voltage (or potential difference) causes a current to flow and that the size of the current depends on the size of the p.d.

For something to obey Ohm’s law the current flowing is proportional to the p.d. pushing it. $V=IR$ so this means the resistance is constant. On a graph of current against p.d. this appears as a straight line.

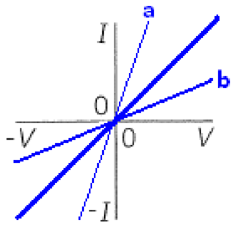
Taking Measurements



To find how the current through a component varies with the potential difference across it we must take readings. To measure the potential difference we use a voltmeter connected in parallel and to measure the current we use an ammeter connected in series.

If we connect the component to a battery we would now have one reading for the p.d. and one for the current. But what we require is a *range* of readings. One way around this would be to use a range of batteries to give different p.d.s. A better way is to add a variable resistor to the circuit, this allows us to use one battery and get a range of readings for current and p.d. To obtain values for current in the negative direction we can reverse either the battery or the component.

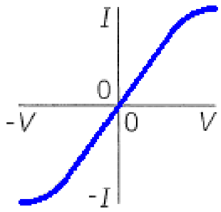
I-V Graphs *(Also seen in GCSE Physics 2)*



Ohmic Resistor

Resistor

This shows that when p.d. is zero so is the current. When we increase the p.d. in one direction the current increases in that direction. If we apply a p.d. in the reverse direction a current flows in the reverse direction. The straight line shows that current is proportional to p.d. and it obeys Ohm’s law. Graph **a** has a lower resistance than graph **b** because for the same p.d. less current flows through **b**.

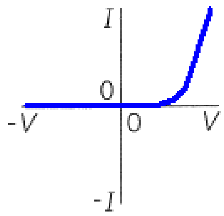


Filament Lamp

Filament Lamp

At low values the current is proportional to p.d. and so, obeys Ohm’s law.

As the potential difference and current increase so does the temperature. This increases the resistance and the graph curves, since resistance changes it no longer obeys Ohm’s law.



Semiconducting Diode

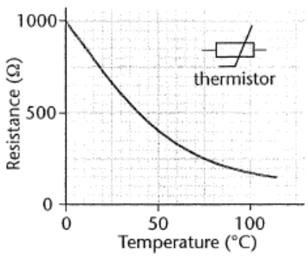
Diode

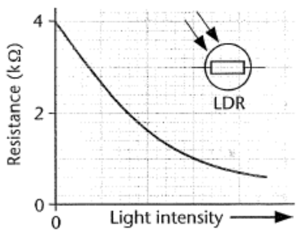
This shows us that in one direction increasing the p.d. increases the current but in the reverse direction the p.d. does not make a current flow. We say that it is forward biased. Since resistance changes it does not obey Ohm’s law.

Three Special Resistors *(Also seen in GCSE Physics 2)*

Variable Resistor

A variable resistor is a resistor whose value can be changed.





Thermistor

The resistance of a thermistor varied with temperature. At low temperatures the resistance is high, at high temperatures the resistance is low.

Light Dependant Resistor (L.D.R)

The resistance of a thermistor varied with light intensity. In dim light the resistance is high and in bright light the resistance is low.

Unit 1	# Resistivity and Superconductivity
Lesson 15	
Learning Outcomes	To be able to state what affects resistance of a wire and explain how they affect it
	To be able to describe the experimental set up required to calculate resistivity and define it
	To be able to explain superconductivity and state its uses — N. DWYER

Resistance

The resistance of a wire is caused by free electrons colliding with the positive ions that make up the structure of the metal. The resistance depends upon several factors:

Length, l **Length increases – resistance increases**

The longer the piece of wire the more collisions the electrons will have.

Area, A **Area increases – resistance decreases**

The wider the piece of wire the more gaps there are between the ions.

Temperature **Temperature increases – resistance increases**

As temperature increases the ions are given more energy and vibrate more, the electrons are more likely to collide with the ions.

Material

The structure of any two metals is similar but not the same, some metal ions are closer together, others have bigger ions.

Resistivity, ρ

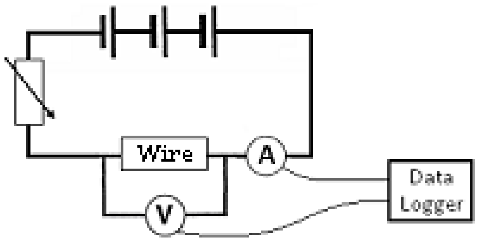
The resistance of a material can be calculate using $\boxed{R = \rho \frac{l}{A}}$ where ρ is the resistivity of the material.

Resistivity is a factor that accounts for the structure of the metal and the temperature. Each metal has its own value of resisitivity for each temperature. For example, the resistivity of copper is 1.7×10^{-8} Ωm and carbon is 3×10^{-5} Ωm at room temperature. When both are heated to 100°C their resistivities increase.

Resistivity is measured in Ohm metres , Ωm

Measuring Resistivity

In order to measure resistivity of a wire we need to measure the length, cross-sectional area (using Area = πr^2) and resistance. Remember, to measure the resistance we need to measure values of current and potential difference using the set up shown on the right



We then rearrange the equation to $\boxed{\rho = \frac{RA}{l}}$ and substitute values in

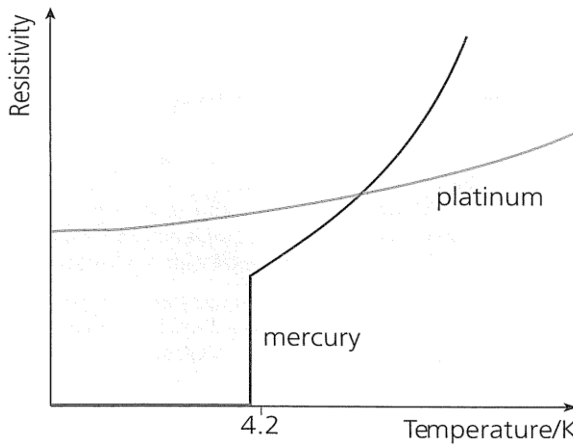
Superconductivity

The resistivity (and so resistance) of metals increases with the temperature. The reverse is also true that, lowering the temperature lowers the resistivity.

When certain metals are cooled below a *critical temperature* their resistivity drops to zero. The metal now has zero resistance and allows massive currents to flow without losing any energy as heat. These metals are called superconductors.

When a superconductor is heated above it's critical temperature it loses its superconductivity and behaves like other metals.

The highest recorded temperature to date is –196°C, large amounts of energy are required to cool the metal to below this temperature.



Uses of Superconductors

High-power electromagnets

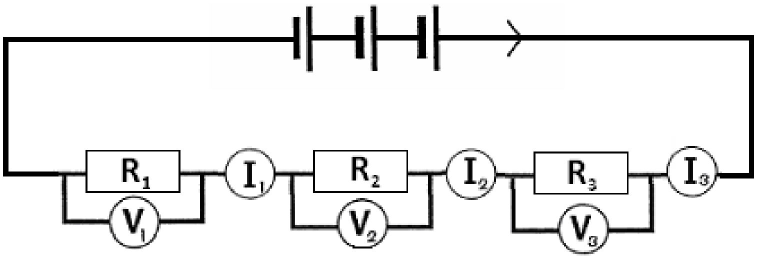
Power cables

Magnetic Resonance Imaging (MRI) scanners

Unit 1	Series and Parallel Circuits	
Lesson 16		
Learning Outcomes	To be able to calculate total current in series and parallel circuits	
	To be able to calculate total potential difference in series and parallel circuits	
	To be able to calculate total resistance in series and parallel circuits	N. DWYER

Series Circuits *(Also seen in GCSE Physics 2)*

In a series circuit all the components are in one circuit or loop. If resistor 1 in the diagram was removed this would break the whole circuit.



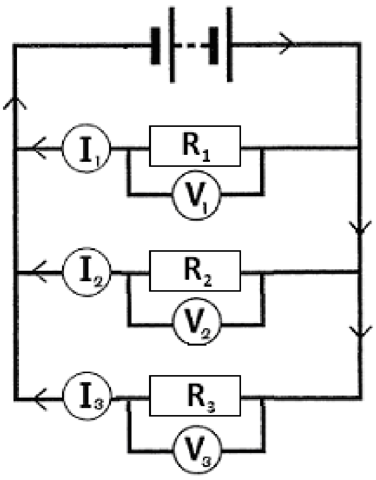
The total current of the circuit is the same at each point in the circuit. $\boxed{I_{TOTAL} = I_1 = I_2 = I_3}$

The total voltage of the circuit is equal to the sum of the p.d.s across each resistor. $\boxed{V_{TOTAL} = V_1 + V_2 + V_3}$

The total resistance of the circuit is equal to the sum of the resistance of each resistor. $\boxed{R_{TOTAL} = R_1 + R_2 + R_3}$

Parallel Circuits *(Also seen in GCSE Physics 2)*

Components in parallel have their own separate circuit or loop. If resistor 1 in the diagram was removed this would only break that circuit, a current would still flow through resistors 2 and 3.



The total current is equal to the sum of the currents through each resistor.

$$\boxed{I_{TOTAL} = I_1 + I_2 + I_3}$$

The total potential difference is equal to the p.d.s across each resistor.

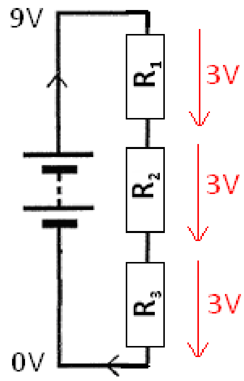
$$\boxed{V_{TOTAL} = V_1 = V_2 = V_3}$$

The total resistance can be calculated using the equation:

$$\boxed{\frac{1}{R_{TOTAL}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

Water Slide Analogy

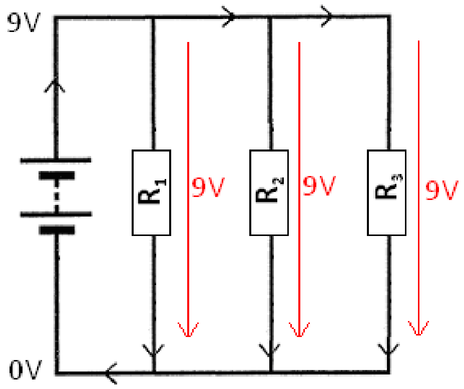
Imagine instead of getting a potential difference we get a height difference by reaching the top of a slide. This series circuit has three connected slides and the parallel circuit below has three separate slides that reach the bottom.



Voltages/P.D.s

In series we can see that the total height loss is equal to how much you fall on slide 1, slide 2 and slide 3 added together. This means that the total p.d. lost must be the p.d. given by the battery. If the resistors have equal values this drop in potential difference will be equal.

In parallel we see each slide will drop by the same height meaning the potential difference is equal to the total potential difference of the battery.



Currents

If we imagine 100 people on the water slide, in series we can see that 100 people get to the top. All 100 must go down slide 1 then slide 2 and final slide 3, there is no other option. So the current in a series circuit is the same everywhere.

In parallel we see there is a choice in the slide we take. 100 people get to the top of the slide but some may go down slide 1, some down slide 2 and some down slide 3. The total number of people is equal to the number of people going down each slide added together, and the total current is equal to the currents in each circuit/loop.

Unit 1	Energy and Power	
Lesson 17		
Learning Outcomes	To know what power is and how to calculate the power of an electrical circuit	
	To know how to calculate the energy transferred in an electrical circuit	
	To be able to derive further equations or use a series of equations to find the answer	N. DWYER

Power *(Also seen in GCSE Physics 1)*

Power is a measure of how quickly something can transfer energy. Power is linked to energy by the equation:

$$\boxed{Power = \frac{Energy}{time}}$$

Power is measured in Watts, W
Energy is measured in Joules, J
Time is measured in seconds, s

New Equations

If we look at the equations from the QVIRt lesson we can derive some new equations for energy and power.

Energy

$V = \frac{E}{Q}$ can be rearranged into $E = VQ$ and we know that $Q = It$ so combining these equations we get a new one to calculate the energy in an electric circuit:

$E = VQ$ <---------------------- $Q = It$ so $\boxed{E = VIt}$ (1)

Power

If we look at the top equation, to work out power we divide energy by time:

$\frac{E}{t} = \frac{VIt}{t}$ which cancels out to become $\boxed{P = VI}$ (2)

If we substitute $V = IR$ into the last equation we get another equation for power:

$P = IV$ <---------------------- $V = IR$ so $\boxed{P = I^2R}$ (3)

We can also rearrange $V = IR$ into $I = \frac{V}{R}$ and substitute this into $P = VI$ to get our last equation for power:

$P = VI$ <---------------------- $I = \frac{V}{R}$ so $\boxed{P = \frac{V^2}{R}}$ (4)

Energy again

Two more equations for energy can be derived from the equation at the top and equations 3 and 4
Energy = Power x time

$Pt = I^2Rt$ Equation 3 becomes $\boxed{E = I^2Rt}$ (5)

$Pt = \frac{V^2}{R}t$ Equation 4 becomes $\boxed{E = \frac{V^2}{R}t}$ (6)

Fuses *(Also seen in GCSE Physics 2)*

Electrical devices connected to the Mains supply by a three-pin plug have a fuse as part of their circuit. This is a thin piece of wire that melts if the current through it exceeds its maximum tolerance. The common fuses used are 3A, 5A and 13A. A 100W light bulb connected to the UK Mains would have a 240V potential difference across it. Using $P = IV$ we can see that the current would be 0.42A so a 2A fuse would be the best to use.

Applications

The starter motor of a motor car needs to transfer a lot of energy very quickly, meaning its needs a high power. Millions of Joules are required in seconds; since the voltage of the battery is unchanging we need current in the region of 160A which is enormous.
The power lines that are held by pylons and form part of the National Grid are very thick and carry electricity that has a very high voltage. Increasing the voltage lowers the current so if we look at the equation $E = I^2Rt$ we can see that this lowers the energy transferred to the surroundings.

Unit 1	EMF and Internal Resistance	
Lesson 18		
Learning Outcomes	To know what emf and internal resistance are	
	To know how to measure internal resistance	
	To be able sketch and interpret a V-I graph, labelling the gradient and y-intercept	N. DWYER

Energy in Circuits

In circuits there are two fundamental types of component: energy *givers* and energy *takers*.

Electromotive Force (emf), ε

Energy givers provide an electromotive force, they force electrons around the circuit which transfer energy.

The size of the emf can be calculate using: $\boxed{\varepsilon = \frac{E}{Q}}$

This is similar to the equation we use to find voltage/potential difference and means the energy given to each unit of charge. We can think of this as the energy given to each electron.

The emf of a supply is the p.d. across its terminals when no current flows

EMF is measured in Joules per Coulomb, JC^{-1} or Volts, V

Energy takers have a potential difference across them, transferring energy from the circuit to the component.

emf = energy giver p.d. = energy taker

Energy is conserved in a circuit so energy in = energy out, or:

$$\boxed{\textit{The total of the emfs = The total of the potential differences around the whole circuit}}$$

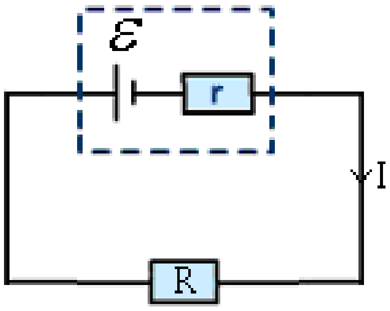
Internal Resistance, r

The chemicals inside a cell offer a resistance to the flow of current, this is the internal resistance on the cell.

Internal Resistance is measured in Ohms, Ω

Linking emf and r

If we look at the statement in the box above and apply it to the circuit below, we can reach an equation that links emf and *r*.



Total emfs = total potential differences

ε = (p.d. across r) + (p.d. across R) {Remember that V=IR}

ε = (I x r) + (I x R)

ε = Ir + IR

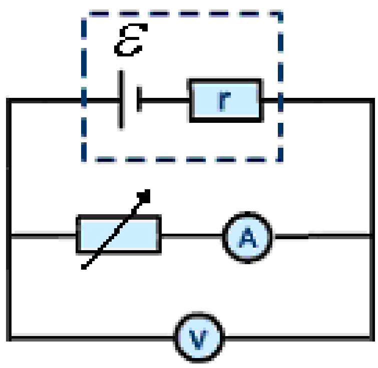
$\boxed{\varepsilon = I(r+R)}$

The terminal p.d. is the p.d. across the terminals of the cell when a current is flowing

ε = internal p.d + terminal p.d.

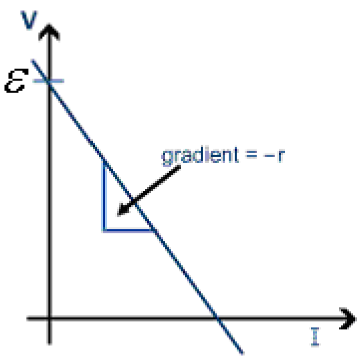
So the above equation can be written as $\boxed{\varepsilon = Ir + V}$ where V is the terminal p.d.

Measuring emf and r



We can measure the emf and internal resistance of a cell by measuring the current and voltage as shown on the right, the variable resistor allows us to get a range of values. If we plot the results onto a graph of voltmeter reading against ammeter reading we get a graph that looks like the one below.

Graphs have the general equation of y = mx+c, where y is the vertical (upwards) axis, x is the horizontal (across) axis, m is the gradient of the line and c is where the line intercepts (cuts) the y axis.



If we take $\varepsilon = Ir + V$ and arrange it into y= mx + c

y axis = V and x axis = I

$\varepsilon = Ir + V$ → $V = -Ir + \varepsilon$ → $V = -r\,I + \varepsilon$

y =m x +c

So we can see that the:

y-intercept represents the emf

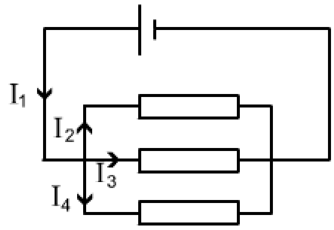
and

gradient represents (–)internal resistance

Unit 1	**Kirchhoff and Potential Dividers**	
Lesson 19		
Learning Outcomes	To know Kirchhoff's laws and be able to apply them to questions	
	To know what a potential dividers is and be able to calculate the output voltage	
	To be able to explain an application of a potential divider	N. DWYER

Kirchhoff's Laws

Kirchhoff came up with two (some may say rather obvious) laws concerning conservation in electrical circuits.

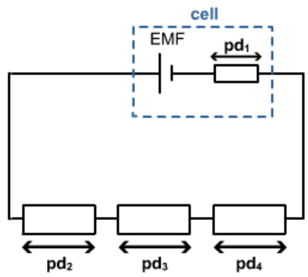


Captain Obvious' First Law

Electric charge is conserved in all circuits, all the charge that arrives at a point must leave it.

Current going in = current going out.

In the diagram we can say that: $I_1 = I_2 + I_3 + I_4$



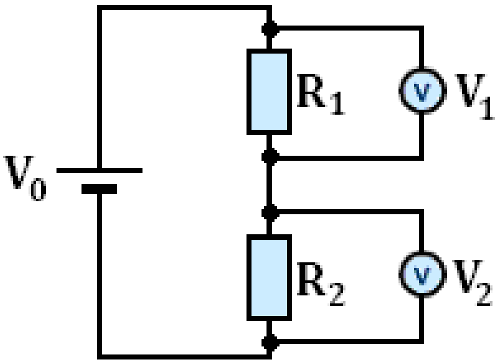
Captain Obvious' Second Law

Energy is conserved in all circuits, for any complete circuit the sum of the emfs is equal to the sum of the potential differences.

Energy givers = energy takers.

In the diagram we can say that: $\varepsilon = pd_1 + pd_2 + pd_3 + pd_4$.

Potential Dividers



A potential divider is used to produce a desired potential difference, it can be thought of as a potential selector.

A typical potential divider consists of two or more resistors that share the emf from the battery/cell.

The p.d.s across R_1 and R_2 can be calculated using the following equations:

$$\boxed{V_1 = V_0 \frac{R_1}{R_1 + R_2}} \qquad \boxed{V_2 = V_0 \frac{R_2}{R_1 + R_2}}$$

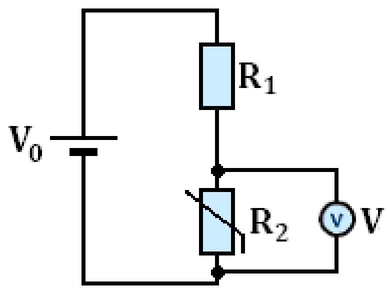
This actually shows us that the size of the potential difference is equal to the input potential multiplied by what proportion of R_1 is of the total resistance.
If R_1 is 10 Ω and R_2 is 90 Ω, R_1 contributes a tenth of the total resistance so R_1 has a tenth of the available potential. This can be represented using:

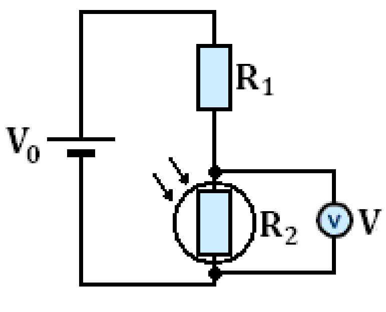
$$\boxed{\frac{R_1}{R_2} = \frac{V_1}{V_2}}$$

The ratio of the resistances is equal to the ratio of the output voltages.

Uses

In this potential divider the second resistor is a thermistor. When the temperature is low the resistance (R_2) is high, this makes the output voltage high. When the temperature is high the resistance (R_2) is low, this makes the output voltage low. A use of this would be a cooling fan that works harder when it is warm.





In the second potential divider the second resistor is a Light Dependant Resisitor. When the light levels are low the resistance (R_2) is high, making the output voltage high. When the light levels increase the resistance (R_2) decreases, this makes the output voltage decrease. A use of this could be a street light sensor that lights up when the surrounding are dark.

Unit 1	Alternating Current	
Lesson 20		
Learning Outcomes	To know what peak current/voltage is and to be able to identify it	
	To know what peak-to-peak current/voltage is and to be able to identify it	
	To know what r.m.s. values are and to be able to calculate them	N. DWYER

ACDC Definitions *(Also seen in GCSE Physics 2)*

Direct Current

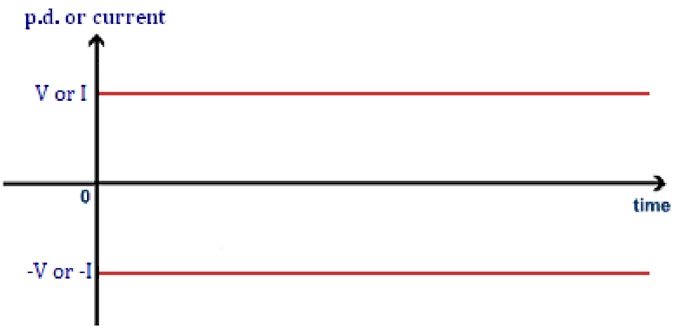
Cells and batteries are suppliers of direct current; they supply an emf in one direction.

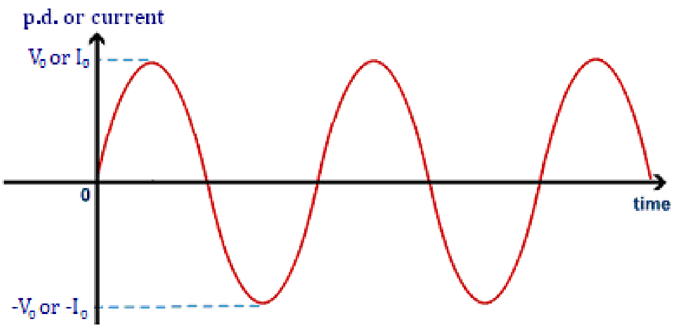
In the graph below we can see that the current and voltage are constant. The bottom line shows that when the battery or cell is reversed the voltage and current are constants in the other direction

Alternating Current

The Mains electricity supplies an alternating current; it supplies an emf that alternates from maximum in one direction to maximum in the other direction.

In the graph below we see the voltage and current start at zero, increase to a maximum in the positive direction, then fall to zero, reach a maximum in the negative direction and return to zero. This is one cycle.

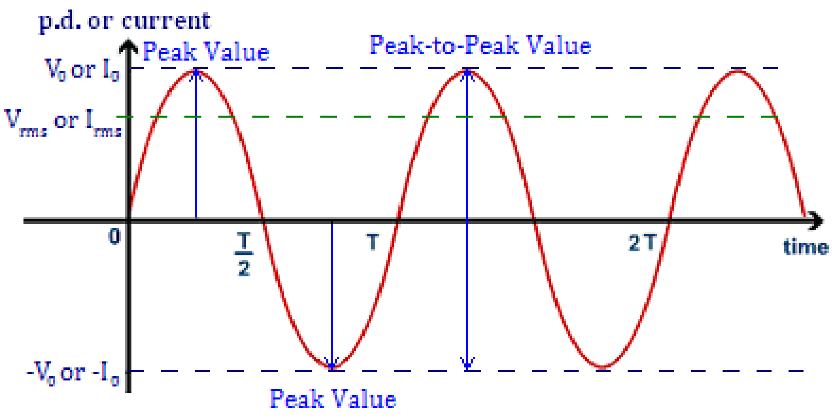




Alternating Current Definitions

Peak Value

The peak value of either the current or the potential difference is the maximum in either direction. It can be measured from the wave as the amplitude, the distance from 0 to the top (or bottom) of the wave. We denote peak current with I_0 and peak p.d. with V_0.



Peak-to-Peak Value

The peak-to-peak value of either the current or potential difference is the range of the values. This is literally the distance from the peak above the zero line to the peak below the line.

Time Period

In an a.c. current or p.d. this is the time taken for one complete cycle (or wave).

Frequency

As with its use at GCSE, frequency is a measure of how many complete cycles that occur per second.

Frequency is measured in Hertz, Hz.

Root Mean Squared, r.m.s.

Since the current and p.d. is constantly changing it is impossible to assign them a fixed value over a period of time, the average would be zero. The r.m.s. current produces the same heating effect in a resistor as the equivalent d.c. for example 12V dc = 12Vrms ac

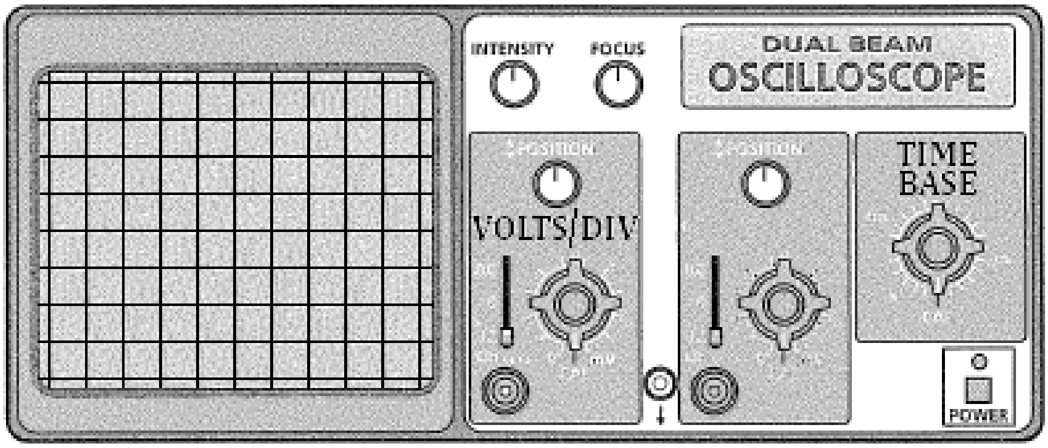
$$\boxed{I_{rms} = \frac{I_0}{\sqrt{2}}}$$ which can be rearranged to give $$\boxed{I_0 = I_{rms}\sqrt{2}}$$

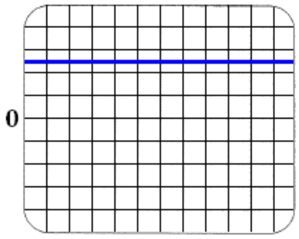
$$\boxed{V_{rms} = \frac{V_0}{\sqrt{2}}}$$ which can also be rearranged to give $$\boxed{V_0 = V_{rms}\sqrt{2}}$$

Unit 1	The Oscilloscope	
Lesson 21		
Learning Outcomes	To know what are the main controls of the oscilloscope	
	To be able to determine the voltage and current using an oscilloscope	
	To be able to determine the time period and frequency using an oscilloscope	N. DWYER

The Oscilloscope

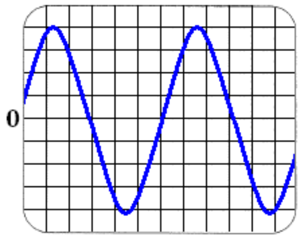
An oscilloscope can be used to show the sizes of voltages and currents in both d.c. and a.c. circuits. This is what a typical oscilloscope looks like. A trace would be seen on the grid display.





D.C. Traces *(Also seen in GCSE Physics 2)*

If we connected a battery or cell to an oscilloscope, we would see a trace similar to the one shown here. The current of a d.c. supply is constant, this means the voltage is constant.
We see a straight line.



A.C. Traces *(Also seen in GCSE Physics 2)*

If we connect anything that draws power from the Mains to an oscilloscope we will see a similar trace to the one shown here. The current is constantly changing from maximum flow in one direction to maximum flow in the other direction; this means the voltage is doing the same.
We see a wave.

Controls

There are two main controls that we use are the volts/div and time base dials:
The volts/div (volts per division) dial allows you to change how much each vertical square is worth.
The time base dial allows you to change how much each horizontal square is worth.

Voltage

We can measure the voltage of a d.c. supply by counting the number or vertical squares from the origin to the line and then multiplying it by the volts/div. In the trace the line is 2.5 squares above 0, if each square is worth 5 volts the voltage is (2.5 x 5) 12.5 volts.
We can measure the peak voltage of an a.c. supply by counting how many vertical squares from the centre of the wave to the top and then multiplying it by the volts/div (how much voltage each square is worth). In the trace the peak voltage is 4 squares high, if each square is worth 5 volts the voltage is (4 x 5) 20 volts.

Time and Frequency

We can measure the time for one period (wave) by counting how many horizontal squares one wavelength is and then multiplying it by the time base (how much time each square is worth).
In the trace above one wave is 6 squares long, if each square is worth 0.02 seconds the time for one wave is 0.12 seconds.
We can calculate the frequency (how many waves or many times this happens per second) using the equation:

$$\boxed{f = \frac{1}{T}} \quad \text{and} \quad \boxed{T = \frac{1}{f}}$$

If the time period is 0.12 seconds, the frequency is 8.33Hz

Frequency is measured in Hertz, Hz

Unit 2	Scalars and Vectors	
Lesson 1		
Learning Outcomes	To know the difference between scalars and vectors and be able to list some examples of each	
	To be able to add vectors by scale drawing	
	To be able to add negative vectors by scale drawing	N. DWYER

What is a Vector?

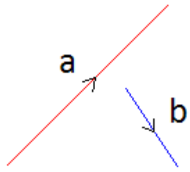
A vector is a physical quantity that has both magnitude (size) and direction.

Examples of Vectors: Displacement, velocity, force, acceleration and momentum.

What is a Scalar?

A scalar is a physical quantity that has magnitude only (it doesn't act in a certain direction).

Examples of Scalars: Distance, speed, energy, power, pressure, temperature and mass.



Vector Diagrams

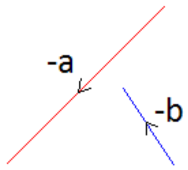
A vector can be represented by a vector diagram as well as numerically:

The length of the line represents the magnitude of the vector.

The direction of the line represents the direction of the vector.

We can see that vector **a** has a greater magnitude than vector **b** but acts in a different direction.

A negative vector means a vector of equal magnitude but opposite direction.



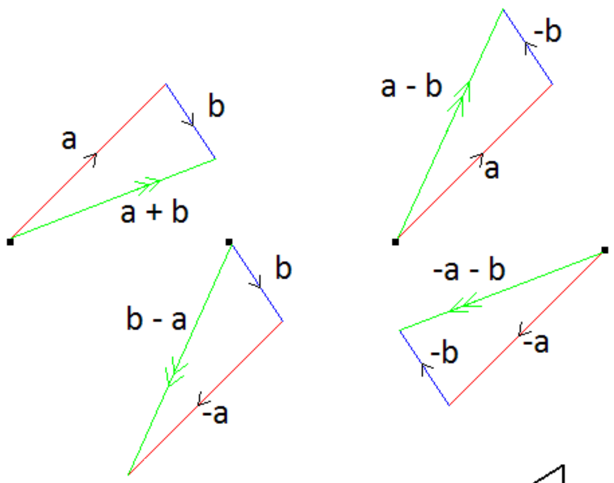
Adding Vectors

We can add vectors together to find the affect that two or more would have if acting at the same time. This is called the resultant vector. We can find the resultant vector in four ways: Scale drawing, Pythagoras, the Sine and Cosine rules and Resolving vectors (next lesson).

Scale Drawing

To find the resultant vector of **a** + **b** we draw vector **a** then draw vector **b** from the end of **a**. The resultant is the line that connects the start and finish points.

The resultants of **a** + **b, b** – **a, a** – **b,** – **a** – **b** and would look like this:

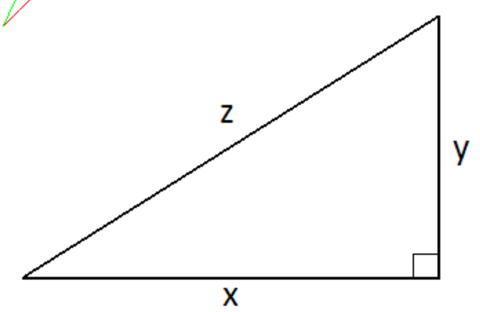


If the vectors were drawn to scale we can find the resultant by measuring the length of the line and the angle.

Pythagoras

If two vectors are perpendicular to each other the resultant can be found using Pythagoras:

Vector **z** is the resultant of vectors **x** and **y**.



Since **x** and **y** are perpendicular $z^2 = x^2 + y^2 \rightarrow z = \sqrt{x^2 + y^2}$

We can also use this in reverse to find **x** or **y**:

$$z^2 = x^2 + y^2 \rightarrow z^2 - y^2 = x^2 \rightarrow \sqrt{z^2 - y^2} = x$$

$$z^2 = x^2 + y^2 \rightarrow z^2 - x^2 = y^2 \rightarrow \sqrt{z^2 - x^2} = y$$

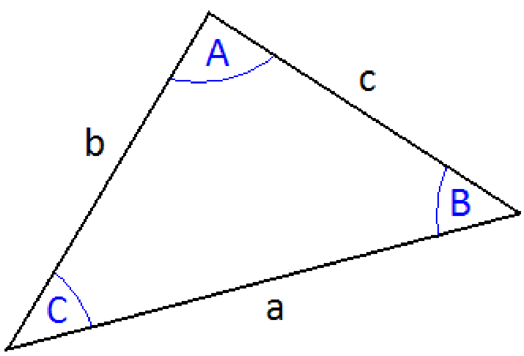
Sine and Cosine Rules

The sine rule relates the angles and lengths using this equation:

$$\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}$$

The Cosine rule relates them using these equations:

$$a^2 = b^2 + c^2 - 2bc\cos A$$
$$b^2 = a^2 + c^2 - 2ac\cos B$$
$$c^2 = a^2 + b^2 - 2ab\cos C$$

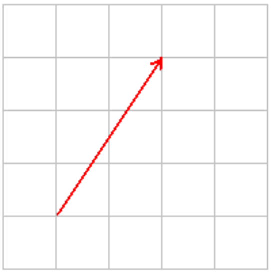


Unit 2	Resolving Vectors	
Lesson 2		
Learning Outcomes	To be able to resolve vectors into their vertical and horizontal components	
	To be able to add vectors and find the resultant by resolving them	
	To know what equilibrium is and how it is achieved	N. DWYER

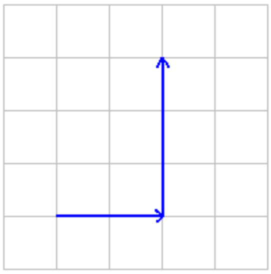
In the last lesson we looked at how we could add vectors together and find the resultant. In this lesson we will first look at 'breaking down' the vectors and then finding the equilibrium.

Resolving Vectors

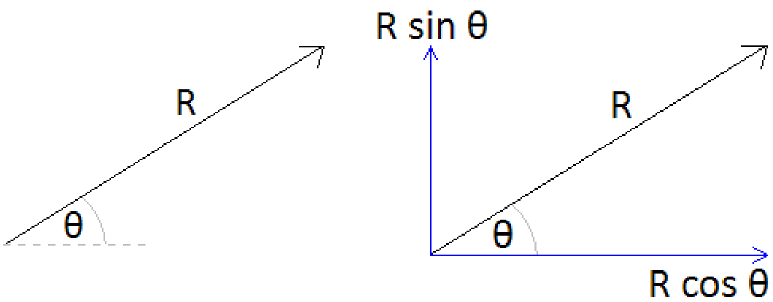
A vector can be 'broken down' or *resolved* into its vertical and horizontal components.



We can see that this vector can be resolved into two perpendicular components, in this case two to the right and three up.
This is obvious when it is drawn on graph paper but becomes trickier when there isn't a grid and still requires an element of scale drawing.

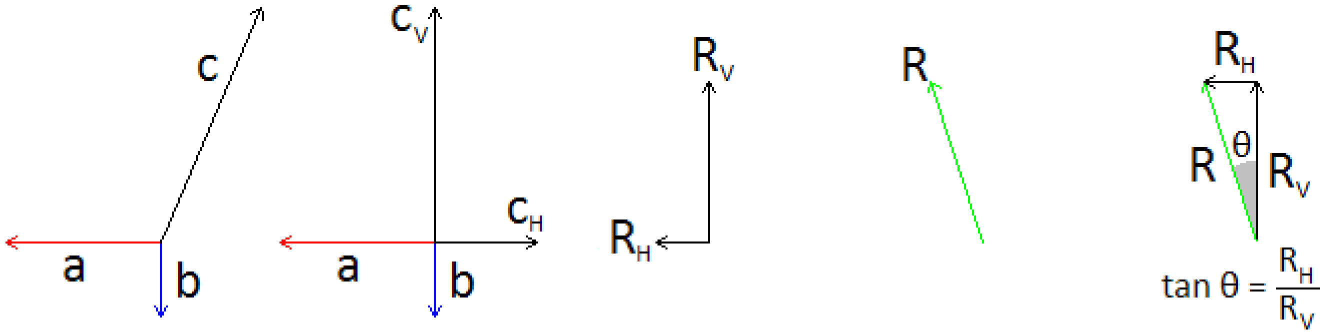


We can calculate the vertical and horizontal components if we know the magnitude and direction of the vector. In other words; we can work out the across and upwards bits of the vector if we know the length of the line and the angle between it and the horizontal or vertical axis.



Adding Resolved Vectors

Now that we can resolve vectors into the vertical and horizontal components it is made from we can add them together. Look at this example of multiple vectors acting (**A**).

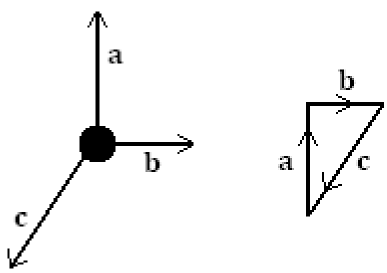


A **B** **C** **D** **E**

If we resolve the vector **c** we get (**B**). We can now find the resultant of the horizontal components and the resultant of the vertical components (**C**). We can then add these together to find the resultant vector (**D**) and the angle can be found using trigonometry (**E**)

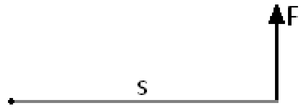
Equilibrium

When all the forces acting on a body cancel out equilibrium is reached and the object does not move. As you sit and read this the downwards forces acting on you are equally balanced by the upwards forces, the resultant it that you do not move.
With scale drawing we can draw the vectors, one after the other. If we end up in the same position we started at then equilibrium is achieved.
With resolving vectors we can resolve all vectors into their vertical and horizontal components. If the components up and down are equal and the components left and right are equal equilibrium has been reached.



Unit 2	Moments	
Lesson 3		
Learning Outcomes	To be able to calculate the moment of a single and a pair of forces	
	To be able to explain what the centre of mass and gravity are	
	To be able to explain how something balances and becomes stable	N. DWYER

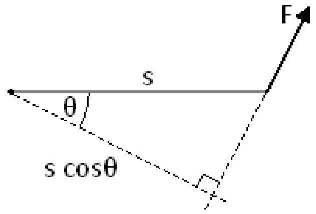
Moments *(Also seen in GCSE Physics 3)*



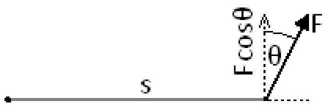
The moment of a force is its turning affect about a fixed point (pivot).
The magnitude of the moment is given by:

moment = force x perpendicular distance from force to the pivot

$$\boxed{moment = Fs}$$



In this diagram we can see that the force is not acting perpendicularly to the pivot.
We must find the perpendicular or closest distance, this is $s\cos\theta$.
The moment in this case is given as: $\boxed{moment = Fs\cos\theta}$

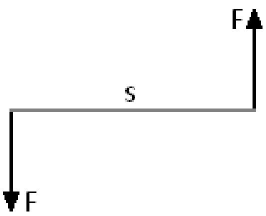


We could have also used the value of s but multiplied it by the vertical component of the force. This would give us the same equation. $\boxed{moment = F\cos\theta . s}$

Moments are measured in Newton metres, Nm

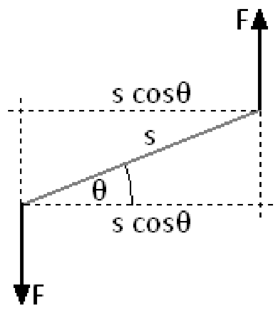
Couples

A couple is a pair of equal forces acting in opposite directions. If a couple acts on an object it rotates in position. The moment of a couple is called the torque.



The torque is calculated as: torque = force x perpendicular distance between forces

$$\boxed{torque = Fs}$$



In the diagram to the right we need to calculate the perpendicular distance, $s\cos\theta$.

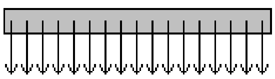
So in this case: $\boxed{torque = Fs\cos\theta}$

Torque is measured in Newton metres, Nm

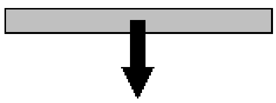
Centre of Mass *(Also seen in GCSE Physics 3)*

If we look at the ruler to the right, every part of it has a mass. To make tackling questions easier we can assume that all the mass is concentrated in a single point.

Centre of Gravity



The centre of gravity of an object is the point where all the weight of the object appears to act. It is in the same position as the centre of mass.
We can represent the weight of an object as a downward arrow acting from the centre of mass or gravity. This can also be called the line of action of the weight.

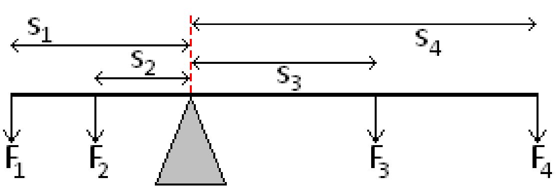


Balancing *(Also seen in GCSE Physics 3)*

When an object is balanced:

$$\boxed{\text{the total moments acting clockwise} = \text{the total moments acting anticlockwise}}$$

An object suspended from a point (e.g. a pin) will come to rest with the centre of mass directly below the point of suspension.
If the seesaw to the left is balanced then the clockwise moments must be equal to the anticlockwise moments.



Clockwise moment due to 3 and 4

$$moment = F_3 s_3 + F_4 s_4$$

Anticlockwise moments due to 1 and 2

$$moment = F_1 s_1 + F_2 s_2$$

So $$F_3 s_3 + F_4 s_4 = F_1 s_1 + F_2 s_2$$

Stability *(Also seen in GCSE Physics 3)*

The stability of an object can be increased by lowering the centre of mass and by widening the base.
An object will topple over if the line of action of the weight falls outside of the base.

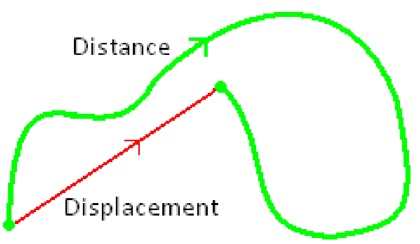
Unit 2	**Velocity and Acceleration**	
Lesson 4		
Learning Outcomes	To be able to calculate distance and displacement and explain what they are	
	To be able to calculate speed and velocity and explain what they are	
	To be able to calculate acceleration and explain uniform and non-uniform cases	N. DWYER

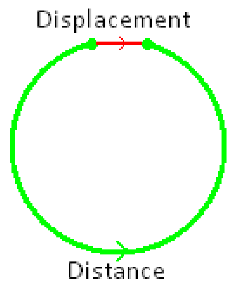
Distance *(Also seen in Physics 2)*

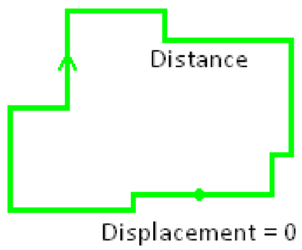
Distance is a scalar quantity. It is a measure of the total length you have moved.

Displacement *(Also seen in Physics 2)*

Displacement is a vector quantity. It is a measure of how far you are from the starting position.







If you complete a lap of an athletics track: distance travelled = 400m
displacement = 0

Distance and Displacement are measured in metres, m

Speed *(Also seen in Physics 2)*

Speed is a measure of how the distance changes with time. Since it is dependent on speed it too is a scalar.

$$\boxed{speed = \frac{\Delta d}{\Delta t}}$$

Velocity *(Also seen in Physics 2)*

Velocity is measure of how the displacement changes with time. Since it depends on displacement it is a vector too.

$$\boxed{v = \frac{\Delta s}{\Delta t}}$$

Speed and Velocity are is measured in metres per second, m/s

Time is measured in seconds, s

Acceleration *(Also seen in Physics 2)*

Acceleration is the rate at which the velocity changes. Since velocity is a vector quantity, so is acceleration. With all vectors, the direction is important. In questions we decide which direction is positive (e.g. → +ve)

If a moving object has a positive velocity:
* a positive acceleration means an increase in the velocity
* a negative acceleration means a decrease in the velocity (it begins the 'speed up' in the other direction)

If a moving object has a negative velocity:
* a positive acceleration means an increase in the velocity (it begins the 'speed up' in the other direction)
* a negative acceleration means a increase in the velocity

If an object accelerates from a velocity of u to a velocity of v, and it takes t seconds to do it then we can write the equations as $\boxed{a = \frac{(v-u)}{t}}$ it may also look like this $\boxed{a = \frac{\Delta v}{\Delta t}}$ where Δ means the 'change in'

Acceleration is measured in metres per second squared, m/s^2

Uniform Acceleration

In this situation the acceleration is constant – the velocity changes by the same amount each unit of time.
For example: If acceleration is 2m/s^2, this means the velocity increases by 2m/s every second.

Time (s)	0	1	2	3	4	5	6	7
Velocity (m/s)	0	2	4	6	8	10	12	14
Acceleration (m/s^2)		2	2	2	2	2	2	2

Non-Uniform Acceleration

In this situation the acceleration is changing – the velocity changes by a different amount each unit of time.
For example:

Time (s)	0	1	2	3	4	5	6	7
Velocity (m/s)	0	2	6	10	18	28	30	44
Acceleration (m/s^2)		2	4	6	8	10	12	14

Unit 2	Motion Graphs	
Lesson 5		
Learning Outcomes	To be able to interpret displacement-time and velocity-time graphs	
	To be able to represent motion with displacement-time and velocity-time graphs	
	To know the significance of the gradient of a line and the area under it	N. DWYER

Before we look at the two types of graphs we use to represent motion, we must make sure we know how to calculate the gradient of a line and the area under it.

Gradient

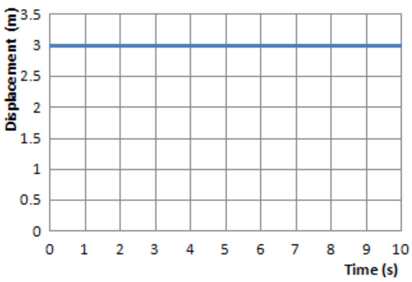
We calculate the gradient by choosing two points on the line and calculating the change in the y axis (up/down) and the change in the x axis (across).

$$\boxed{gradient = \frac{\Delta y}{\Delta x}}$$

Area Under Graph

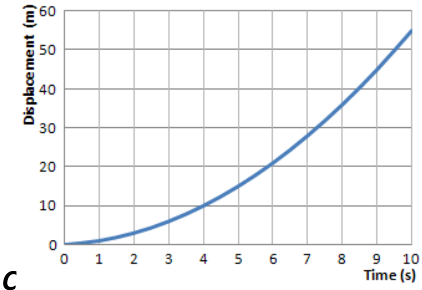
At this level we will not be asked to calculate the area under curves, only straight lines.
We do this be breaking the area into rectangles (base x height) and triangles (½ base x height).

Displacement-Time Graphs *(Also seen in GCSE Physics 2)*



A

B

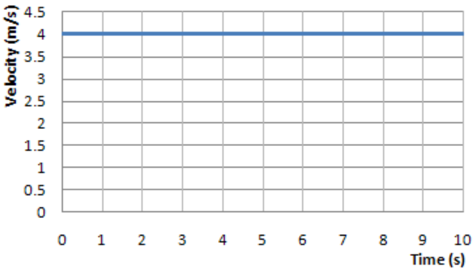


C

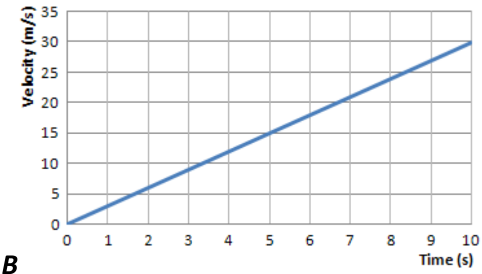
Graph A shows that the displacement stays at 3m, it is stationary.
Graph B shows that the displacement increases by the same amount each second, it is travelling with constant velocity.
Graph C shows that the displacement covered each second increases each second, it is accelerating.

Since $gradient = \frac{\Delta y}{\Delta x}$ and y = displacement and x = time → $gradient = \frac{\Delta s}{\Delta t}$ → $\boxed{gradient = velocity}$

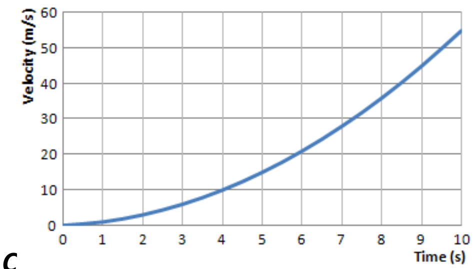
Velocity- Time Graphs *(Also seen in GCSE Physics 2)*



A



B

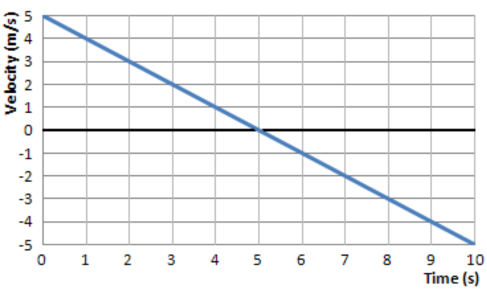


C

Graph A shows that the velocity stays at 4m/s, it is moving with constant velocity.
Graph B shows that the velocity increases by the same amount each second, it is accelerating by the same amount each second (uniform acceleration).
Graph C shows that the velocity increases by a larger amount each second, the acceleration is increasing (non-uniform acceleration).

Since $gradient = \frac{\Delta y}{\Delta x}$ and y = velocity and x = time → $gradient = \frac{\Delta v}{\Delta t}$ → $\boxed{gradient = acceleration}$

area = base x height → area = time x velocity → $\boxed{area = displacement}$



This graph show the velocity decreasing in one direction and increasing in the opposite direction.
If we decide that ←is negative and →is positive then the graph tells us:
The object is initially travels at 5 m/s →
It slows down by 1m/s every second
After 5 seconds the object has stopped
It then begins to move ←
It gains 1m/s every second until it is travelling at 5m/s ←

Unit 2	Equations of Motion	
Lesson 6		
Learning Outcomes	To be able to use the four equations of motion	
	To know the correct units to be used	
	To be able to find the missing variable:, s u v a or t	N. DWYER

Defining Symbols

Before we look at the equations we need to assign letters to represent each variable

Displacement	= ***s***	m	metres
Initial Velocity	= ***u***	m/s	metres per second
Final Velocity	= ***v***	m/s	metres per second
Acceleration	= ***a***	m/s^2	metres per second per second
Time	= ***t***	s	seconds

Equations of Motion

Equation 1

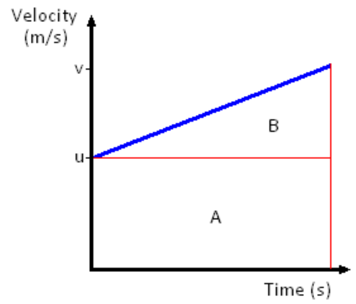
If we start with the equation for acceleration $a = \frac{(v-u)}{t}$ we can rearrange this to give us an equation 1

$at = (v-u)$ → $at + u = v$ $\boxed{v = u + at}$

Equation 2

We start with the definition of velocity and rearrange for displacement

velocity = displacement / time → displacement = velocity x time



In situations like the graph to the right the velocity is constantly changing, we need to use the average velocity.

displacement = average velocity x time

The average velocity is give by: average velocity = $\frac{(u+v)}{2}$

We now substitute this into the equation above for displacement

displacement = $\frac{(u+v)}{2}$ x time → $s = \frac{(u+v)}{2}t$ $\boxed{s = \tfrac{1}{2}(u+v)t}$

Equation 3

With Equations 1 and 2 we can derive an equation which eliminated *v*. To do this we simply substitute $v = u + at$ into $s = \tfrac{1}{2}(u+v)t$

$s = \tfrac{1}{2}(u + (u+at))t$ → $s = \tfrac{1}{2}(2u + at)t$ → $s = \tfrac{1}{2}(2ut + at^2)$ $\boxed{s = ut + \tfrac{1}{2}at^2}$

This can also be found if we remember that the area under a velocity-time graph represents the distance travelled/displacement. The area under the line equals the area of rectangle A + the area of triangle B.

Area = Displacement = *s* = $ut + \tfrac{1}{2}(v-u)t$ since $a = \frac{(v-u)}{t}$ then $at = (v-u)$ so the equation becomes

$s = ut + \tfrac{1}{2}(at)t$ which then becomes equation 3

Equation 4

If we rearrange equation 1 into $t = \frac{(v-u)}{a}$ which we will then substitute into equation 2:

$s = \tfrac{1}{2}(u+v)t$ → $s = \tfrac{1}{2}(u+v)\frac{(v-u)}{a}$ → $as = \tfrac{1}{2}(u+v)(v-u)$ →

$2as = (v^2 + uv - uv - u^2)$ → $2as = v^2 - u^2$ $\boxed{v^2 = u^2 + 2as}$

Any question can be solved as long as three of the variables are given in the question.
Write down all the variables you have and the one you are asked to find, then see which equation you can use.
These equations can only be used for motion with UNIFORM ACCELERATION.

Unit 2	# Terminal Velocity and Projectiles	
Lesson 7		
Learning Outcomes	To know what terminal velocity is and how it occurs	
	To be know how vertical and horizontal motion are connected	
	To be able to calculate the horizontal and vertical distance travelled by a projectile	N. DWYER

Acceleration Due To Gravity *(Also seen in GCSE Physics 2)*

An object that falls freely will accelerate towards the Earth because of the force of gravity acting on it.
The size of this acceleration does not depend mass, so a feather and a bowling ball accelerate at the same rate. On the Moon they hit the ground at the same time, on Earth the resistance of the air slows the feather more than the bowling ball.
The size of the gravitational field affects the magnitude of the acceleration. Near the surface of the Earth the gravitational field strength is 9.81 N/kg. This is also the acceleration a free falling object would have on Earth. In the equations of motion ***a* = *g* = 9.81 m/s.**

Mass is a property that tells us how much matter it is made of.

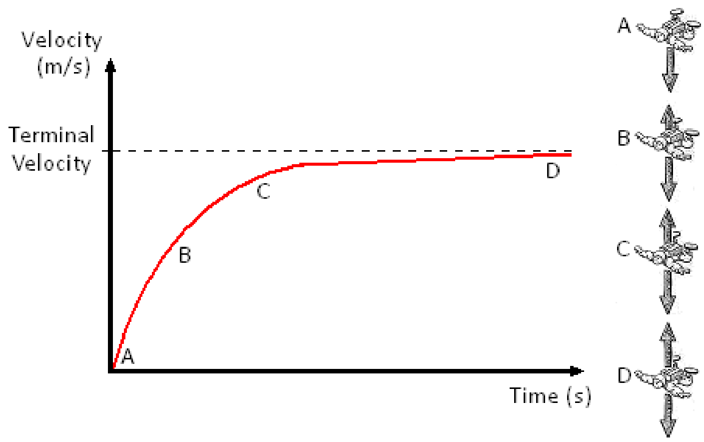
Mass is measured in kilograms, kg

Weight is a force caused by gravity acting on a mass:
weight = mass x gravitational field strength $\boxed{w = mg}$

Weight is measured in Newtons, N

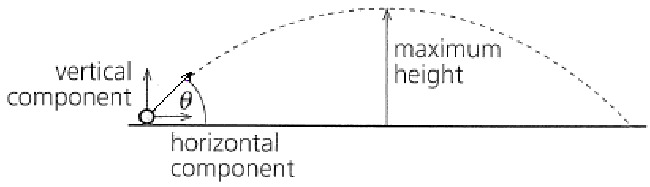
Terminal Velocity *(Also seen in GCSE Physics 2)*

If an object is pushed out of a plane it will accelerate towards the ground because of its weight (due to the Earth's gravity). Its velocity will increase as it falls but as it does, so does the drag forces acting on the object (air resistance). Eventually the air resistance will balance the weight of the object. This means there will be no overall force which means there will be no acceleration. The object stops accelerating and has reached its terminal velocity.



Projectiles

An object kicked or thrown into the air will follow a parabolic path like that shown to the right.
If the object had an initial velocity of u, this can be resolved into its horizontal and vertical velocity (as we have seen in Lesson 2)



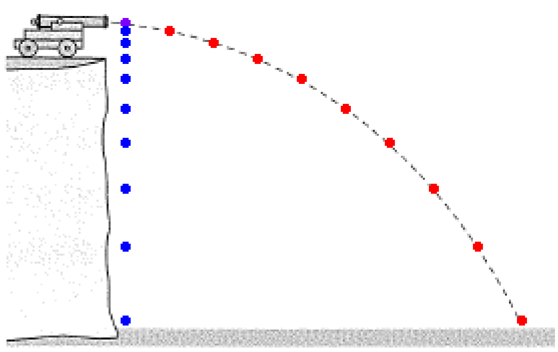
The horizontal velocity will be $u\cos\theta$ and the vertical velocity will be $u\sin\theta$. With these we can solve projectile questions using the equations of motion we already know.

Horizontal and Vertical Motion

The diagram shows two balls that are released at the same time, one is released and the other has a horizontal velocity. We see that the ball shot from the cannon falls at the same rate at the ball that was released. This is because the horizontal and vertical components of motion are independent of each other.

Horizontal: The horizontal velocity is constant; we see that the fired ball covers the same horizontal (across) distance with each second.
Vertical: The vertical velocity accelerates at a rate of g ($9.81 m/s^2$). We can see this more clearly in the released ball; it covers more distance each second.

The horizontal velocity has no affect on the vertical velocity. If a ball were fired from the cannon at a high horizontal velocity it would travel further but still take the same time to reach the ground.



Unit 2	Newton's Laws	
Lesson 8		
Learning Outcomes	To know and be able to use Newton's 1st law of motion, where appropriate	
	To know and be able to use Newton's 2nd law of motion, where appropriate	
	To know and be able to use Newton's 3rd law of motion, where appropriate	N. DWYER

Newton's 1st Law

An object will remain at rest, or continue to move with uniform velocity, unless it is acted upon by an external resultant force.

Newton's 2nd Law

The rate of change of an object's linear momentum is directly proportional to the resultant external force. The change in the momentum takes place in the direction of the force.

Newton's 3rd Law

When body A exerts a force on body B, body B exerts an equal but opposite force on body A.

Force is measured in Newtons, N

Say What?

Newton's 1st Law

If the forward and backward forces cancel out, a stationary object will remain stationary.
If the forward forces are greater than the backwards forces, a stationary object will begin to move forwards.
If the forward and backward forces cancel out, a moving object will continue to move with constant velocity.
If the forward forces are greater than the backward forces, a moving object will speed up.
If the backward forces are greater than the forward forces, a moving object will slow down.

Newton's 2nd Law

The acceleration of an object increases when the force is increased but decreases when the mass is increased:

$a = \frac{F}{m}$ but we rearrange this and use $\boxed{F = ma}$

Newton's 3rd Law

Forces are created in pairs.
As you sit on the chair your weight pushes down on the chair, the chair also pushes up against you.
As the chair rests on the floor its weight pushes down on the floor, the floor also pushes up against the chair.
The forces have the same size but opposite directions.

Riding the Bus

Newton's 1st Law

You get on a bus and stand up. When the bus is stationary you feel no force, when the bus accelerates you feel a backwards force. You want to stay where you are but the bus forces you to move. When the bus is at a constant speed you feel no forwards or backwards forces. The bus slows down and you feel a forwards force. You want to keep moving at the same speed but the bus is slowing down so you fall forwards. If the bus turns left you want to keep moving in a straight line so you are forced to the right (in comparison to the bus). If the bus turns right you want to keep moving in a straight line so you are forced left (in comparison to the bus).

Newton's 2nd Law

As more people get on the bus its mass increases, if the driving force of the bus's engine is constant we can see that it takes longer for the bus to gain speed.

Newton's 3rd Law

As you stand on the bus you are pushing down on the floor with a force that is equal to your weight. If this was the only force acting you would begin to move through the floor. The floor is exerting a force of equal magnitude but upwards (in the opposite direction).

Taking the Lift

Newton's 1st Law

When you get in the lift and when it moves at a constant speed you feel no force up or down. When it sets off going up you feel like you are pushed down, you want to stay where you are. When it sets off going down you feel like you are lighter, you feel pulled up.

Newton's 2nd Law

As more people get in the lift its mass increases, if the lifting force is constant we can see that it takes longer for the lift to get moving. Or we can see that with more people the greater the lifting force must be.

Newton's 3rd Law

As you stand in the lift you push down on the floor, the floor pushes back.

Unit 2	# Work, Energy and Power	
Lesson 9		
Learning Outcomes	To be able to calculate work done (including situations involving an inclined plane)	
	To be able to calculate the power of a device	
	To be able to calculate efficiency and percentage efficiency	N. DWYER

Energy *(Also seen in GCSE Physics 1)*

We already know that it appears in a number of different forms and may be transformed from one form to another. But what is energy? **Energy is the ability to do work**.

We can say that the work done is equal to the energy transferred

Work done = energy transferred $\boxed{W = E}$

Work Done *(Also seen in GCSE Physics 2)*

In Physics we say that work is done when a force moves through a distance and established the equation

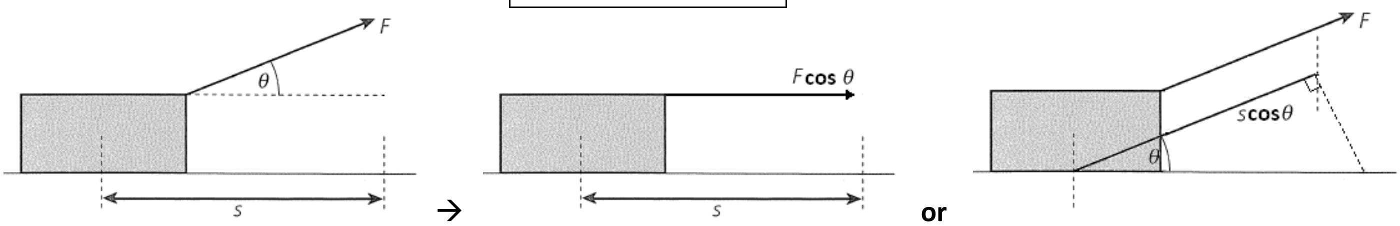
Work Done = Force x Distance moved in the direction of the force $\boxed{W = Fs}$

Work Done is measured in Joules, J
Force is measured in Newtons, N
Distance is measured in metres, m

The distance moved is not always in the direction of the force. In the diagram we can see that the block moves in a direction that is θ away from the 'line of action' of the force. To calculate the work done we must calculate the distance we move in the direction of the force or the size of the force in the direction of the distance moved. Both of these are calculated by resolving into horizontal and vertical components.

Work Done = Force x Distance moved in the direction of the force
Work Done = Size of Force in the direction of movement x Distance moved

$$\boxed{\text{Work Done} = Fs\cos\theta}$$



Power *(Also seen in GCSE Physics 1 and AS Unit 1)*

Power is a measure of how quickly something can transfer energy. Power is linked to energy by the equation:

Power is measured in Watts, W
Energy is measured in Joules, J
Time is measured in seconds, s

$$\boxed{Power = \frac{EnergyTransferred}{timetaken}} \quad \boxed{P = \frac{\Delta E}{\Delta t}}$$

But Work Done = Energy Transferred so we can say that power is a measure of how quickly work can be done.

$$\boxed{Power = \frac{WorkDone}{timetaken}} \quad \boxed{P = \frac{\Delta W}{\Delta t}}$$

Now that we can calculate Work Done we can derive another equation for calculating power:

We can substitute $W = Fs$ into $P = \frac{W}{t}$ to become $P = \frac{Fs}{t}$ this can be separated into $P = F\frac{s}{t}$.

$\frac{s}{t} = v$ so we can write $\boxed{P = Fv}$

Velocity is measured in metres per second, m/s or ms^{-1}

Efficiency *(Also seen in GCSE Physics 1)*

We already know that the efficiency of a device is a measure of how much of the energy we put in is wasted.

$$\text{Efficiency} = \frac{\text{useful energy transferred by the device}}{\text{total energy supplied to the device}}$$ this will give us a number less than 1

Useful energy means the energy transferred for a purpose, the energy transferred into the desired form.

Since power is calculated from energy we can express efficiency as:

$$\text{Efficiency} = \frac{\text{useful output power of the device}}{\text{input power to the device}}$$ again this will give us a number less than 1

To calculate the efficiency as a percentage use the following:

percentage efficiency = efficiency x 100%

Unit 2	Conservation of Energy	
Lesson 10		
Learning Outcomes	To be able to calculate gravitational potential energy	
	To be able to calculate kinetic energy	
	To be able to solve problems involving the conversion of energy	N. DWYER

Energy Transformations *(Also seen in GCSE Physics 1)*

We already know that energy cannot be created or destroyed, only transformed from one type to another and transferred from one thing to another. Eg a speaker transforms electrical energy to sound energy with the energy itself is being transferred to the surroundings.

An isolated (or closed) system means an energy transformation is occurring where none of the energy is lost to the surroundings. In reality all transformations/transfers are not isolated, and all of them waste energy to the surroundings.

Kinetic Energy *(Also seen in GCSE Physics 2)*

Kinetic energy is the energy a moving object has. Let us consider a car that accelerates from being stationary (u=0) to travelling at a velocity v when a force, F, is applied.

The time it takes to reach this velocity is give by $v = u + at \rightarrow v = at \rightarrow t = \frac{v}{a}$

The distance moved in this time is given by $s = \frac{1}{2}(u+v)t \rightarrow s = \frac{1}{2}(v)t \rightarrow s = \frac{1}{2}(v)\frac{v}{a} \rightarrow s = \frac{1}{2}\frac{v^2}{a}$

Energy transferred = Work Done, Work Done = Force x distance moved and Force = mass x acceleration

$E = W \rightarrow E = Fs \rightarrow E = mas \rightarrow E = ma\frac{1}{2}\frac{v^2}{a}$ $\boxed{E_K = \frac{1}{2}mv^2}$

Velocity is measured in metres per second, m/s
Mass is measured in kilograms, kg
Kinetic Energy is measured in Joules, J

Gravitational Potential Energy

This type of potential (stored) energy is due to the position of an object. If an object of mass m is lifted at a constant speed by a height of h we can say that the acceleration is zero. Since $F=ma$ we can also say that the overall force is zero, this means that the lifting force is equal to the weight of the object → $F=mg$

We can now calculate the work done in lifting the object through a height, h.

$WD = Fs \rightarrow WD = (mg)h \rightarrow WD = mgh$

Since work done = energy transferred $\boxed{\Delta E_P = mg\Delta h}$

Height is a measure of distance which is measured in metres, m
Gravitational Potential Energy is measured in Joules, J

Work Done against….

In many situations gravitational potential energy is converted into kinetic energy, or vice versa. Some everyday examples of this are:

Swings and pendulums If we pull a pendulum back we give it GPE, when it is released it falls, losing its GPE but speeding up and gaining KE. When it passes the lowest point of the swing it begins to rise (gaining GPE) and slow down (losing KE).

Bouncing or throwing a ball Holding a ball in the air gives it GPE, when we release this it transforms this into KE. As it rises it loses KE and gains GPE.

Slides and ramps A ball at the top of a slide will have GPE. When it reaches the bottom of the slide it has lost all its GPE, but gained KE.

In each of these cases it appears as though we have lost energy. The pendulum doesn't swing back to its original height and the ball never bounces to the height it was released from. This is because work is being done against resistive forces.

The swing has to overcome air resistance whilst moving and the friction from the top support.

The ball transforms some energy into sound and overcoming the air resistance.

Travelling down a slide transforms energy into heat due to friction and air resistance

The *total* energy before a transformation = The *total* energy after a transformation

Unit 2	Hooke's Law	
Lesson 11		
Learning Outcomes	To be able to state Hooke's Law and explain what the spring constant is	
	To be able to describe how springs behave in series and parallel	
	To be able to derive the energy stored in a stretched material	N. DWYER

Hooke's Law

If we take a metal wire or a spring and hang it from the ceiling it will have a natural, unstretched length of l metres. If we then attach masses to the bottom of the wire is will begin to increase in length (stretch). The amount of length it has increased by we will call the extension and represent by e.

If the extension increases proportionally to the force applied it follows Hooke's Law:

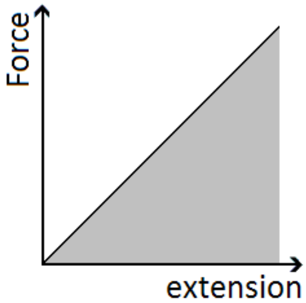
The force needed to stretch a spring is directly proportional to the extension of the spring from its natural length

So it takes twice as much force to extend a spring twice as far and half the force to extend it half as far.

We can write this in equation form: $F \propto e$ or $\boxed{F = ke}$

Here k is the constant that shows us how much extension in length we would get for a given force. It is called...

The Spring Constant



The spring constant gives us an idea of the stiffness (or stretchiness) of the material.

If we rearrange Hooke's Law we get: $k = \dfrac{F}{e}$

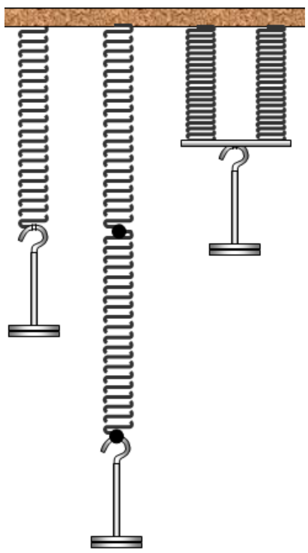
If we record the length of a spring, add masses to the bottom and measure its extension we can plot a graph of force against extension. The gradient of this graph will be equal to the spring constant.

A small force causes a large extension the spring constant will be *small – very stretchy*

A large force causes a small extension the spring constant will be *large – not stretchy*

Spring Constant is measured in Newtons per metre, N/m

Springs in Series



The combined spring constant of spring A and spring B connected in series is given by:

$\dfrac{1}{k_T} = \dfrac{1}{k_A} + \dfrac{1}{k_B}$ If A and B are identical this becomes:

$$\frac{1}{k_T} = \frac{1}{k} + \frac{1}{k} \rightarrow \frac{1}{k_T} = \frac{2}{k} \rightarrow k_T = \frac{k}{2}$$

Since this gives us a smaller value for the spring constant, applying the same force produces a larger extension. *It is stretchier*

Springs in Parallel

The combined spring constant of spring A and spring B connected in parallel is:

$k_T = k_A + k_B$ so if A and B are identical this becomes:

$$k_T = k + k \rightarrow k_T = 2k$$

Since this gives us a larger value for the spring constant applying the same force produces a smaller extension. *It is less stretchy*

Energy Stored *(Elastic Strain Energy)*

We can calculate the energy stored in a stretched material by considering the work done on it.

We defined work done as the force x distance moved in the direction of the force or $W = Fs$

Work done is equal to the energy transferred, in this case transferred to the material, so: $E = Fs$

The distance moved is the extension of the material, e, making the equation: $E = Fe$

The force is not constant; it increases from zero to a maximum of F. The average force is given by: $\dfrac{(F-0)}{2}$

If we bring these terms together we get the equation $E = \dfrac{(F-0)}{2}e$ which simplifies to: $\boxed{E = \tfrac{1}{2}Fe}$

This is also equal to the area under the graph of force against extension.

We can write a second version of this equation by substituting our top equation of $F = ke$ into the one above.

$$E = \tfrac{1}{2}Fe \rightarrow E = \tfrac{1}{2}(ke)e \rightarrow \boxed{E = \tfrac{1}{2}ke^2}$$

Unit 2	Stress and Strain	
Lesson 12		
Learning Outcomes	To know what stress is, be able to explain it, calculate it and state its units	
	To know what strain is, be able to explain it, calculate it and state its units	
	To be able to calculate the elastic strain energy per unit volume	N. DWYER

Deforming Solids

Forces can be used to change the speed, direction and shape of an object. This section of Physics looks at using forces to change of shape of a solid object, either temporarily or permanently.

If a pair of forces are used to *squash* a material we say that they are *compressive* forces.

If a pair of forces is used to *stretch* a material we say that they are *tensile* forces.

Tensile Stress, σ

Tensile stress is defined as the force applied per unit cross-sectional area (which is the same as pressure). This is represented by the equations:

$$stress = \frac{F}{A} \qquad \boxed{\sigma = \frac{F}{A}}$$

The largest tensile stress that can be applied to a material before it breaks is called the ultimate tensile stress (UTS). Nylon has an UTS of 85 MPa whilst Stainless steel has a value of 600 MPa and Kevlar a massive 3100 MPa

Stress is measured in Newtons per metre squared, N/m^2 or N m^{-2}

Stress can also be measured in Pascals, Pa

A tensile stress will cause a tensile strain. *Stress causes Strain*

Tensile Strain, ε

Tensile strain is a measure of how the extension of a material compares to the original, unstretched length. This is represented by the equations:

$$strain = \frac{e}{l} \qquad \boxed{\varepsilon = \frac{e}{l}}$$

Steel wire will undergo a strain of 0.01 before it breaks. This means it will stretch by 1% of its original length then break. Spider silk has a breaking strain of between 0.15 and 0.30, stretching by 30% before breaking

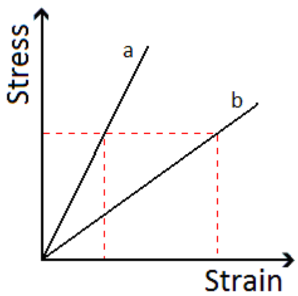
Strain has no units, it is a ratio of two lengths

Stress-Strain Graphs

A stress-strain graph is very useful for comparing different materials.

Here we can see how the strain of two materials, **a** and **b**, changes when a stress is applied.

If we look at the dotted lines we can see that the same amount of stress causes a bigger strain in **b** than in **a**. This means that **b** will increase in length more than **a** (compared to their original lengths).



Elastic Strain Energy

We can build on the idea of energy stored from the previous lesson now that we know what stress and strain are. We can work out the amount of elastic strain energy that is stored *per unit volume* of the material.

It is given by the equation: $\boxed{E = \tfrac{1}{2} stress \times strain}$

There are two routes we can take to arrive at this result:

Equations

If we start with the equation for the total energy stored in the material: $E = \tfrac{1}{2} Fe$

The volume of the material is given by: $V = Al$

Now divide the total energy stored by the volume: $E = \dfrac{\tfrac{1}{2} Fe}{Al}$ which can be written as: $E = \tfrac{1}{2} \dfrac{F}{A} \dfrac{e}{l}$

If we compare the equation to the equations we know for stress and strain we see that: $E = \tfrac{1}{2} stress \times strain$

Graphs

The area under a stress-strain graph gives us the elastic strain energy per unit volume (m^3). The area is given by:

$A = \tfrac{1}{2} base \times height \quad \rightarrow \quad A = \tfrac{1}{2} strain \times stress$ or $A = \tfrac{1}{2} stress \times strain \quad \rightarrow \quad E = \tfrac{1}{2} stress \times strain$

Unit 2	# Bulk Properties of Solids	
Lesson 13		
Learning Outcomes	To be able to calculate density and explain what it is	
	To be able to explain what elastic, plastic, yield point, breaking stress, stiff, ductile and brittle are	
	To be able to label these qualities on stress-strain graphs	N. DWYER

Density, ρ

Density is the *mass per unit volume of a material*, a measure of how much mass each cubic metre of volume contains. Density if given by the equation:

$$\rho = \frac{m}{V}$$

Where ρ is density, m is mass in kilograms and V is volume in metres cubed.

Density is measured in kilograms per metre cubed, kg/m^3 or $kg\ m^{-3}$

Elasticity

Materials extend in length when a stress is applied to them (masses hung from them). A material can be described as elastic if it returns to its original length when the stress is removed. They obey Hooke's Law as extension is proportional to the force applied.

Limit of Proportionality, P

Up to this point the material obeys Hooke's Law; extension is proportional to the force applied.

Elastic Limit, E

The elastic limit is the final point where the material will return to its original length if we remove the stress which is causing the extension (take the masses off). There is no change to the shape or size of the material. We say that the material acts plastically beyond its elastic limit.

Yield Point, Y

Beyond the elastic limit a point is reached where small increases in stress cause a massive increase in extension (strain). The material will not return to its original length and behaves like a plastic.

Plasticity

Materials extend in length when a stress is applied to them (masses hung from them). A material can be described as plastic if it does not return to its original length when the stress is removed. There is a permanent change to its shape

Breaking Stress – Ultimate Tensile Strength, UTS

This is the maximum amount of stress that can be applied to the material without making it break. It is sometimes referred to as the strength of the material.

Breaking Point, B

This is (surprisingly?) the point where the material breaks.

Stiffness

If different materials were made into wires of equal dimensions, the stiffer materials bend the least.
Stiff materials have low flexibility

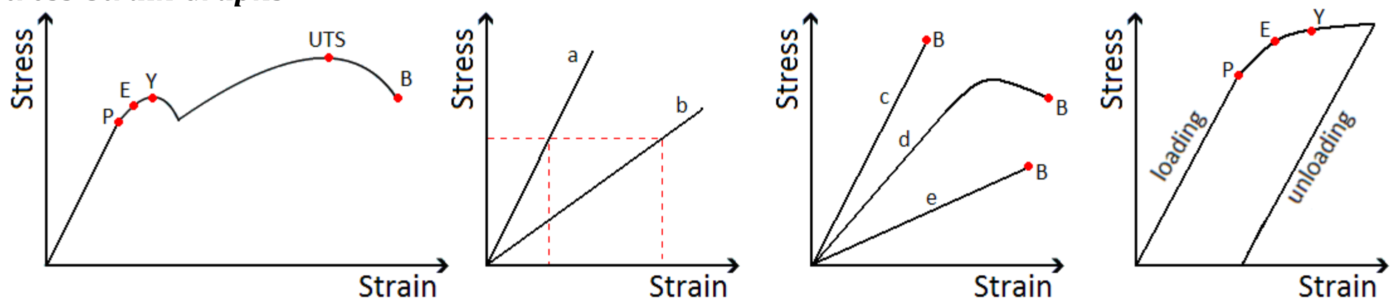
Ductility

A ductile material can be easily and permanently stretched. Copper is a good example, it can easily be drawn out into thin wires. This can be seen in graph **d** below.

Brittleness

A brittle material will extend obeying Hooke's Law when a stress is applied to it. It will suddenly fracture with no warning sign of plastic deformation. Glass, pottery and chocolate are examples of brittle materials.

Stress-Strain Graphs



In the first graph we see a material that stretches, shows plastic behaviour and eventually breaks.
In the second graph we can see that material **a** is stiffer than material **b** because the same stress causes a greater strain in **b**.
In the third graph we see materials **c** and **e** are brittle because they break without showing plastic behaviour.
The fourth graph shows how a material can be permanently deformed, the wire does not return to its original length when the stress is removed (the masses have been removed).

Unit 2	The Young Modulus	
Lesson 14		
Learning Outcomes	To know what the Young Modulus is, be able to explain it, calculate it and state its units	
	To be able to describe an experiment for finding the Young Modulus	
	To be able to calculate the Young Modulus from a stress-strain graph	N. DWYER

The Young Modulus, E

The Young Modulus can be thought of as the stiffness constant of a material, a measure of how much strain will result from a stress being applied to the material. It can be used to compare the stiffness of different materials even though their dimensions are not the same.
The Young Modulus only applies up to the limit of proportionality of a material.

$YoungModulus = \dfrac{stress}{strain}$ or in equation terms we have $E = \dfrac{\sigma}{\varepsilon}$

We have equations for stress $\sigma = \dfrac{F}{A}$ and strain $\varepsilon = \dfrac{e}{l}$ which makes the equation look like this: $E = \dfrac{\left(\frac{F}{A}\right)}{\left(\frac{e}{l}\right)}$

An easier way of writing this is $E = \left(\dfrac{F}{A}\right) \times \left(\dfrac{l}{e}\right)$ which becomes: $\boxed{E = \dfrac{Fl}{Ae}}$

The Young Modulus is measured in Newtons per metre squares, N/m^2 or N m^{-2}

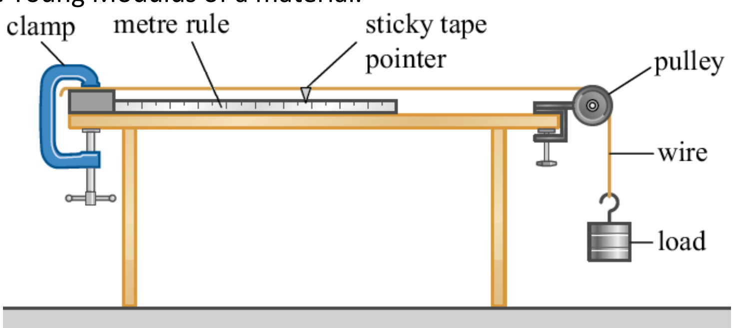
Stress-Strain Graphs

The Young Modulus of a material can be found from its stress-strain graph.

Since $gradient = \dfrac{\Delta y}{\Delta x}$, this becomes $gradient = \dfrac{stress}{strain}$ for our graph. Our top equation stated that $YoungModulus = \dfrac{stress}{strain}$ so we see that the gradient of a stress-strain graph gives us the Young Modulus.
This only applied to the straight line section of the graph, where gradient (and Young Modulus) are constant.

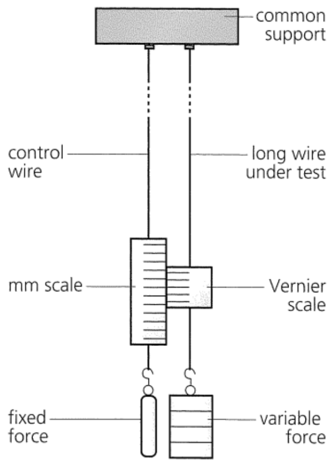
Measuring the Young Modulus

Here is a simple experimental set up for finding the Young Modulus of a material.



- A piece of wire is held by a G-clamp, sent over a pulley with the smallest mass attached to it. This should keep it straight without extending it.
- Measure the length from the clamp to the pointer. This is the original length (unstretched).
- Use a micrometer to measure the diameter of the wire in several places. Use this to calculate the cross-sectional area of the wire.
- Add a mass to the loaded end of the wire.
- Record the extension by measuring how far the pointer has moved from its start position.
- Repeat for several masses but ensuring the elastic limit is not reached.
- Remove the masses, one at a time taking another set of reading of the extension.
- Calculate stress and strain for each mass.
- Plot a graph of stress against strain and calculate the gradient of the line which gives the Young Modulus.

Here is a more precise way of finding the Young Modulus but involves taking the same measurements of extension and force applied.
It is called Searle's apparatus.

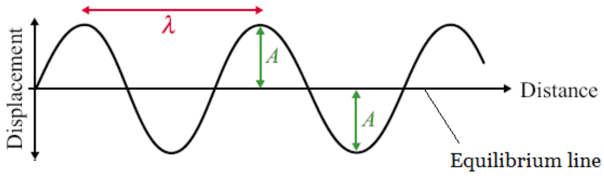


Unit 2	Progressive Waves	
Lesson 15		
Learning Outcomes	To be know the basic measurements of a wave	
	To be able to calculate the speed of any wave	
	To be know what phase and path difference are and be able to calculate them	N. DWYER

Waves

All waves are caused by oscillations and all transfer energy without transferring matter. This means that a water wave can transfer energy to you sitting on the shore without the water particles far out to sea moving to the beach.

Here is a diagram of a wave; it is one type of wave called a transverse wave. A wave consists of something (usually particles) oscillating from an equilibrium point. The wave can be described as progressive; this means it is moving outwards from the source.



We will now look at some basic measurements and characteristics or waves.

Amplitude, A

Amplitude is measured in metres, m

The amplitude of a wave is the maximum displacement of the particles from the equilibrium position.

Wavelength, λ

Wavelength is measured in metres, m

The wavelength of a wave is the length of one whole cycle. It can be measured between two adjacent peaks, troughs or any point on a wave and the same point one wave later.

Time Period, T

Time Period is measured in seconds, s

This is simply the time is takes for one complete wave to happen. Like wavelength it can be measured as the time it takes between two adjacent peaks, troughs or to get back to the same point on the wave.

Frequency, f

Frequency is measured in Hertz, Hz

Frequency is a measure of how often something happens, in this case how many complete waves occur in every second. It is linked to time period of the wave by the following equations: $T = \frac{1}{f}$ and $\boxed{f = \frac{1}{T}}$

Wave Speed, c

Wave Speed is measured in metres per second, m s^{-1}

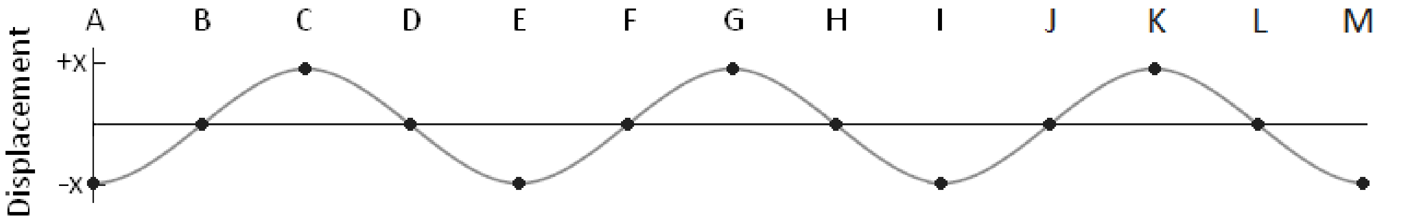
The speed of a wave can be calculated using the following equations: $\boxed{c = f\lambda}$

Here c represents the speed of the wave, f the frequency and λ the wavelength.

Phase Difference

Phase Difference is measured in radians, rad

If we look at two particles a wavelength apart (such as C and G) we would see that they are oscillating in time with each other. We say that they are *completely in phase*. Two points half a wavelength apart (such as I and K) we would see that they are always moving in opposite directions. We say that they are *completely out of phase*. The phase difference between two points depends on what fraction of a wavelength lies between them



	B	C	D	E	F	G	H	I	J	K	L	M
Phase Difference from A (radians)	½π	1π	1½π	2π	2½π	3π	3½π	4π	4½π	5π	5½π	6π
Phase Difference from A (degrees)	90	180	270	360	450	540	630	720	810	900	990	1080

Path Difference

Path Difference is measured in wavelengths, λ

If two light waves leave a bulb and hit a screen the difference in how far the waves have travelled is called the path difference. Path difference is measured in terms of wavelengths.

	B	C	D	E	F	G	H	I	J	K	L	M
Path Difference from A	¼λ	½λ	¾λ	1λ	1¼λ	1½λ	1¾λ	2λ	2¼λ	2½λ	2¾λ	3λ

So two waves leaving A with one making it to F and the other to J will have a path difference of 1 wavelength (1λ).

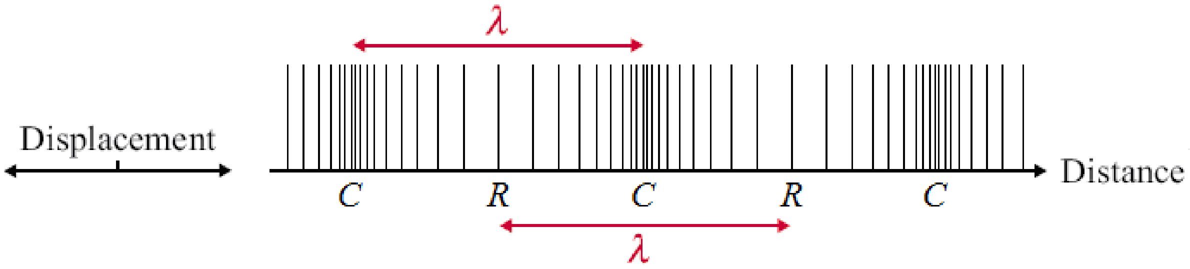
Unit 2	# Longitudinal and Transverse Waves	
Lesson 16		
Learning Outcomes	To be able explain the differences between longitudinal and transverse waves	
	To know examples of each	
	To be explain what polarisation is and how it proves light is a transverse wave	N. DWYER

Waves

All waves are caused by oscillations and all transfer energy without transferring matter. This means that a sound wave can transfer energy to your eardrum from a far speaker without the air particles by the speaker moving into your ear. We will now look at the two types of waves and how they are different

Longitudinal Waves

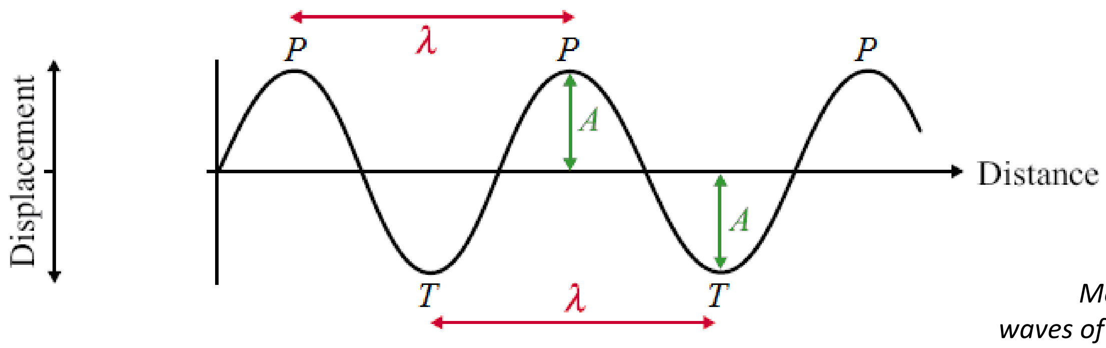
Here is a longitudinal wave; the oscillations are parallel to the direction of propagation (travel).
Where the particles are close together we call a compression and where they are spread we call a rarefaction.
The wavelength is the distance from one compression or rarefaction to the next.
The amplitude is the maximum distance the particle moves from its equilibrium position to the right of left.



<u>Example</u>: sound waves

Transverse Waves

Here is a transverse wave; the oscillations are perpendicular to the direction of propagation.
Where the particles are displaced above the equilibrium position we call a peak and below we call a trough.
The wavelength is the distance from one peak or trough to the next.
The amplitude is the maximum distance the particle moves from its equilibrium position up or down.



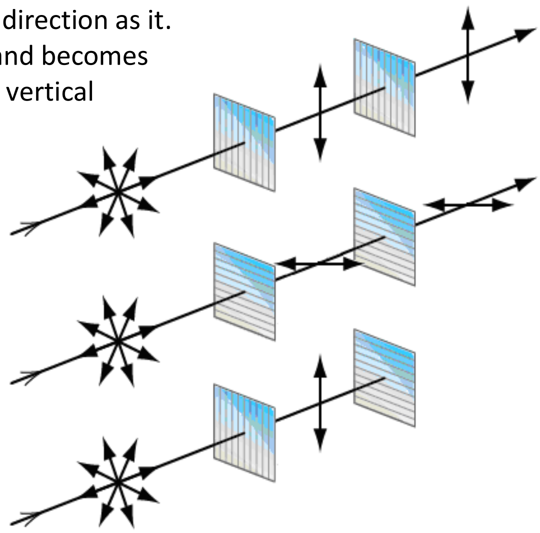
<u>Examples</u>: water waves, Mexican waves and waves of the EM spectrum

EM waves are produced from varying electric and magnetic field.

Polarisation

Polarisation restricts the oscillations of a wave to one plane. In the diagrams the light is initially oscillating in all directions. A piece of Polaroid only allows light to oscillate in the same direction as it.

- In the top diagram the light passes through a vertical plane Polaroid and becomes polarized in the vertical plane. This can then pass through the second vertical Polaroid.
- In the middle diagram the light becomes polarized in the horizontal plane.
- In the bottom diagram the light becomes vertically polarized but this cannot pass through a horizontal plane Polaroid.



This is proof that the waves of the EM spectrum are transverse waves. If they were longitudinal waves the forwards and backwards motion would not be stopped by crossed pieces of Polaroid; the bottom set up would emit light.

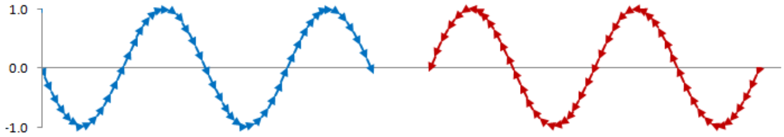
Applications

TV aerials get the best reception when they point to the transmission source so they absorb the maximum amount of the radio waves.

Unit 2	Superposition and Standing Waves	
Lesson 17		
Learning Outcomes	To know and be able to explain what standing waves are and how they are formed	
	To know what nodes and antinodes are	
	To be able to sketch the standing wave produced at different frequencies	N. DWYER

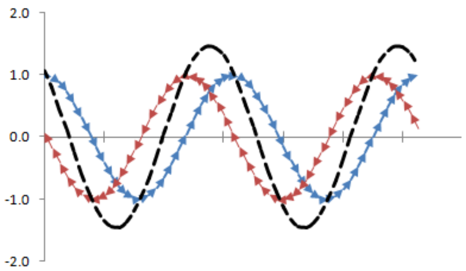
Superposition

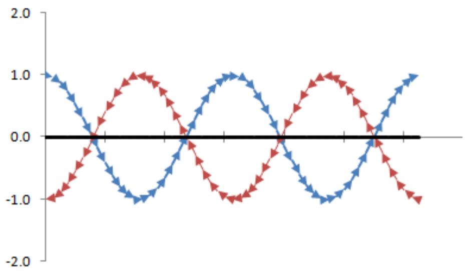
Here are two waves that have amplitudes of 1.0 travelling in opposite directions:

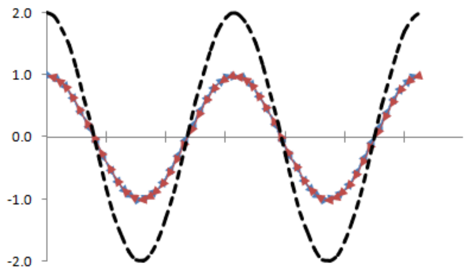


Superposition is the process by which two waves combine into a single wave form when they overlap.

If we add these waves together the resultant depends on where the peaks of the waves are compared to each other. Here are three examples of what the resultant could be: a wave with an amplitude of 1.5, no resultant wave at all and a wave with an amplitude of 2.0

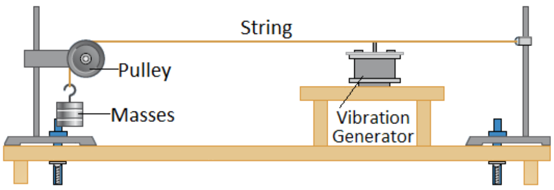


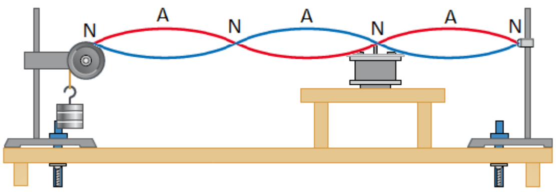




Stationary/Standing Waves

When two similar waves travel in opposite directions they can superpose to form a standing (or stationary) wave. Here is the experimental set up of how we can form a standing wave on a string. The vibration generator sends waves down the string at a certain frequency, they reach the end of the string and reflect back at the same frequency. On their way back the two waves travelling in opposite direction superpose to form a standing wave made up of nodes and antinodes.





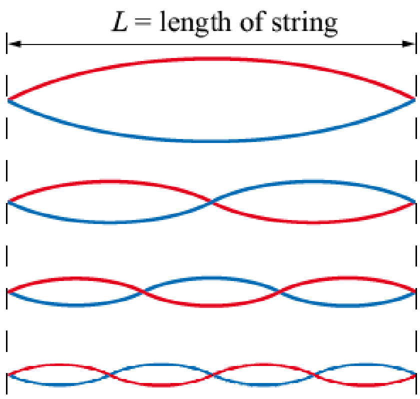
Nodes Positions on a standing wave which do not vibrate. The waves combine to give zero displacement

Antinodes Positions on a standing wave where there is a maximum displacement.

	Standing Waves	Progressive Waves
Amplitude	Maximum at antinode and zero at nodes	The same for all parts of the wave
Frequency	All parts of the wave have the same frequency	All parts of the wave have the same frequency
Wavelength	Twice the distance between adjacent nodes	The distance between two adjacent peaks
Phase	All points between two adjacent nodes in phase	Points one wavelength apart in phase
Energy	No energy translation	Energy translation in the direction of the wave
Waveform	Does not move forward	Moves forwards

Harmonics

As we increase the frequency of the vibration generator we will see standing waves being set up. The first will occur when the generator is vibrating at the fundamental frequency, f_0, of the string.



First Harmonic $f = f_0$ $\lambda = 2L$

2 nodes and 1 antinode

Second Harmonic $f = 2f_0$ $\lambda = L$

3 nodes and 2 antinodes

Third Harmonic $f = 3f_0$ $\lambda = \frac{2}{3}L$

4 nodes and 3 antinodes

Forth Harmonic $f = 4f_0$ $\lambda = \frac{1}{2}L$

5 nodes and 4 antinodes

Unit 2	# Refraction	
Lesson 18		
Learning Outcomes	To be able to calculate the refractive index of a material and to know what it tells us	
	To be able to describe and explain the direction light takes when entering a different material	
	To be able to calculate the relative refractive index of a boundary	N. DWYER

Refractive Index

The refractive index of a material is a measure of how easy it is for light to travel through it. The refractive index of material s can be calculated using:

$$\boxed{n = \frac{c}{c_s}}$$

where n is the refractive index, c is the speed of light in a vacuum and c_s is the speed of light in material s.

Refractive Index, n, has no units

If light can travel at c in material x then the refractive index is: $n = \frac{c}{c_x} \rightarrow n = \frac{c}{c} \rightarrow n = 1$

If light can travel at $c/2$ in material y then the refractive index is: $n = \frac{c}{c_y} \rightarrow n = \frac{c}{c/2} \rightarrow n = 2$

The higher the refractive index the slower light can travel through it

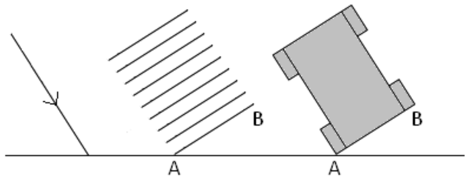
The higher the refractive index the denser the material

Bending Light

When light passes from one material to another it is not only the speed of the light that changes, the direction can change too.

If the ray of light is incident at 90° to the material then there is no change in direction, only speed.

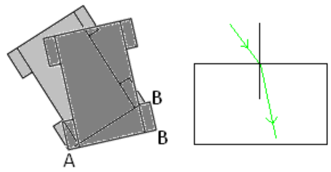
It may help to imagine the front of the ray of light as the front of a car to determine the direction the light will bend. Imagine a lower refractive index as grass and a higher refractive index at mud.



Entering a Denser Material

The car travels on grass until tyre A reaches the mud. It is harder to move through mud so A slows down but B can keep moving at the same speed as before. The car now points in a new direction.

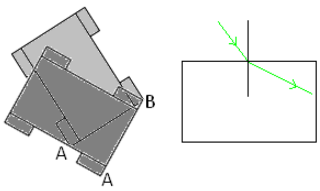
Denser material – higher refractive index – bends towards the Normal



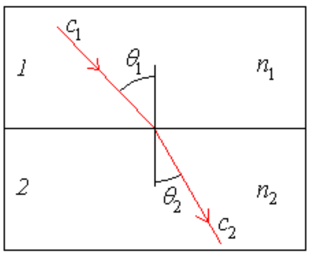
Entering a Less Dense Material

The car travels in mud until tyre A reaches the grass. It is easier to move across grass so A can speed up but B keeps moving at the same speed as before. The car now points in a new direction.

Less dense material – lower refractive index – bends away from the Normal



Relative Refractive Index



Whenever two materials touch the boundary between them will have a refractive index dependent on the refractive indices of the two materials. We call this the relative refractive index.

When light travels from material *1* to material *2* we can calculate the relative refractive index of the boundary using any of the following:

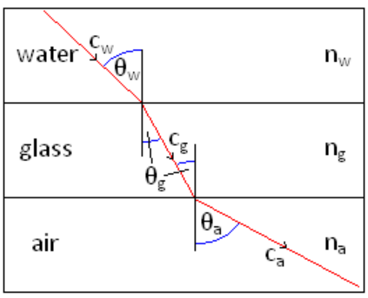
$$\boxed{{}_1n_2 = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\sin\theta_1}{\sin\theta_2}}$$

Relative Refractive Index, $_1n_2$, has no units

Some questions may involve light travelling through several layers of materials. Tackle one boundary at a time.

$${}_wn_g = \frac{n_g}{n_w} = \frac{c_w}{c_g} = \frac{\sin\theta_w}{\sin\theta_g} \text{ ----------------------------> }$$

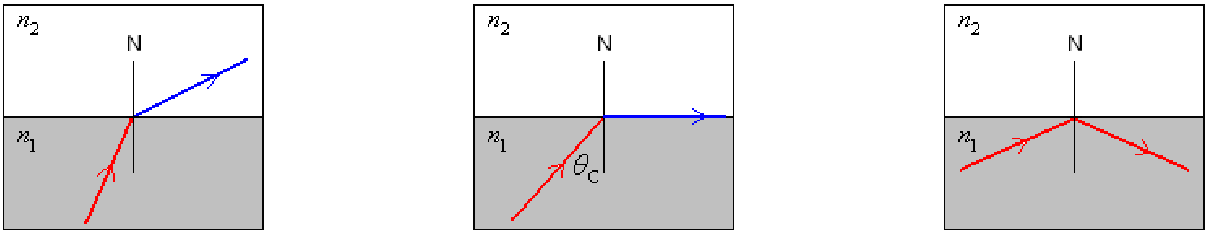
$${}_gn_a = \frac{n_a}{n_g} = \frac{c_g}{c_a} = \frac{\sin\theta_g}{\sin\theta_a} \text{ ----------------------------> }$$



Unit 2	Total Internal Reflection	
Lesson 19		
Learning Outcomes	To know what the critical angle is and be able to calculate it	
	To be able to explain what fibre optics are and how they are used	
	To be able to explain how cladding helps improve the efficiency of a fibre optic	N. DWYER

Total Internal Reflection *(Also seen in GCSE Physics 3)*

We know that whenever light travels from one material to another the majority of the light refracts but a small proportion of the light also reflects off the boundary and stays in the first material.
When the incident ray strikes the boundary at an angle *less than* the critical angle the light refracts into the second material.
When the incident ray strikes the boundary at an angle *equal to* the critical angle all the light is sent along the boundary between the two materials.
When the incident ray strikes the boundary at an angle *greater than* the critical angle all the light is reflected and none refracts, we say it is total internal reflection has occurred.



Critical Angle *(Also seen in GCSE Physics 3)*

We can derive an equation that connects the critical angle with the refractive indices of the materials.

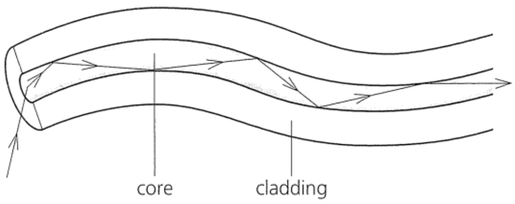
$\dfrac{\sin\theta_1}{\sin\theta_2} = \dfrac{n_2}{n_1}$ but at the critical angle θ_2 is equal to 90° which makes $\sin\theta_2 = 1$ → $\dfrac{\sin\theta_1}{1} = \dfrac{n_2}{n_1}$

θ_1 is the critical angle which we represent as θ_C making the equation: $\boxed{\sin\theta_C = \dfrac{n_2}{n_1}}$

When the second material is air $n_2 = 1$, so the equation becomes: $\boxed{\sin\theta_C = \dfrac{1}{n_1}}$ or $\boxed{n_1 = \dfrac{1}{\sin\theta_C}}$

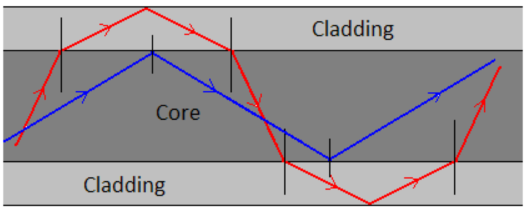
Optical Fibres/Fibre Optics

An optical fibre is a thin piece of flexible glass. Light can travel down it due to total internal reflection. Thier uses include:
*Communication such as phone and TV signals: they can carry more information that electricity in copper wires.
*Medical endoscopes: they allow us to see down them and are flexible so they don't cause injury to the patient.



Cladding

Cladding is added to the outside of an optical fibre to reduce the amount of light that is lost. It does this by giving the light rays a second chance at TIR as seen in the diagram.
It does increase the critical angle but the shortest path through the optical fibre is straight through, so only letting light which stays in the core means the signal is transmitted quicker.



Consider the optical fibre with a refractive index of 1.5…

Without cladding n_2 = 1	$\sin\theta_C = \dfrac{n_2}{n_1}$	$\sin\theta_C = \dfrac{1}{1.5}$	$\theta_C = 41.8°$
With cladding n_2 = 1.4	$\sin\theta_C = \dfrac{n_2}{n_1}$	$\sin\theta_C = \dfrac{1.4}{1.5}$	$\theta_C = 69.0°$

If the cladding had a lower refractive index than the core it is easier for light to travel through so the light would bend away from the normal, *Total Internal Reflection.*
If the cladding had a higher refractive index than the core it is harder for light to travel through so the light would bend towards the normal, *Refraction.*

Unit 2	Interference	
Lesson 20		
Learning Outcomes	To be able to explain what interference and coherence is	
	To be able to explain Young's double slit experiment and a double source experiment	
	To be able to use the equation to describe the appearance of fringes produced	N. DWYER

Interference

Interference is a special case of superposition where the waves that combine are coherent. The waves overlap and form a repeating interference pattern of maxima and minima areas. If the waves weren't coherent the interference pattern would change rapidly and continuously.

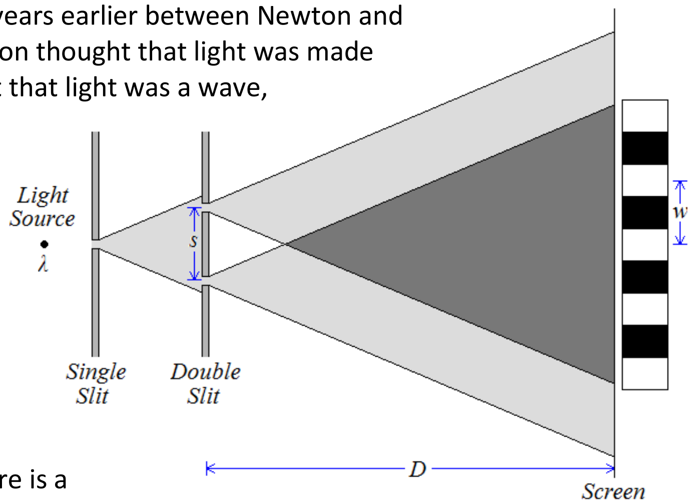
Coherence: Waves which are of the same frequency, wavelength, polarisation and amplitude and in a constant phase relationship. A laser is a coherent source but a light bulb is not.

Constructive Interference: The path difference between the waves is a whole number of wavelengths so the waves arrive in phase adding together to give a large wave. *2 peaks overlap*

Destructive Interference: The path difference between the waves is a half number of wavelengths so the waves arrive out of phase cancelling out to give no wave at all. *A peak and trough overlap*

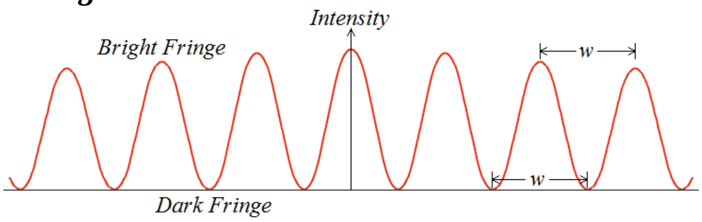
Young's Double Slit Experiment

In 1803 Thomas Young settled a debate started over 100 years earlier between Newton and Huygens by demonstrating the interference of light. Newton thought that light was made up of tiny particles called corpuscles and Huygens thought that light was a wave, Young's interference of light proves light is a wave. Here is Young's double slit set up, the two slits act as coherent sources of waves



Interference occurs where the light from the two slits overlaps. Constructive interference produces bright areas, while deconstructive interference produces dark areas. These areas are called interference fringes.

Fringes

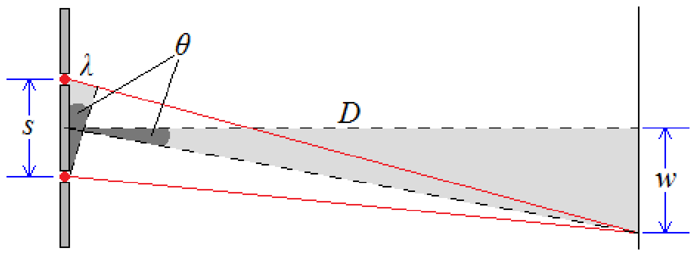


There is a central bright fringe directly behind the midpoint between the slits with more fringes evenly spaced and parallel to the slits.
As we move away from the centre of the screen we see the intensity of the bright fringes decreases.

Double Source Experiment

The interference of sound is easy to demonstrate with two speakers connected to the same signal generator. Waves of the same frequency (coherent) interfere with each other. Constructive interference produces loud fringes, while deconstructive interference produces quiet fringes.

Derivation



We can calculate the separation of the fringes (w) if we consider the diagram to the right which shows the first bright fringe below the central fringe. The path difference between the two waves is equal to one whole wavelength (λ) for constructive interference.
If the distance to the screen (D) is massive compared to the separation of the sources (s) the angle (θ) in the large triangle can be assumed the same as the angle in the smaller triangle.

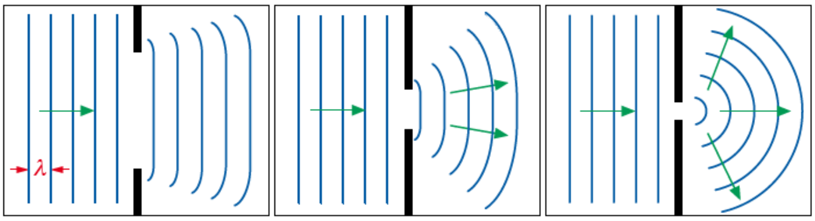
$\sin\theta = \dfrac{Opposite}{Hypotenuse}$ For the small triangle: $\sin\theta = \dfrac{\lambda}{s}$ For the large triangle: $\sin\theta = \dfrac{w}{D}$

Since the angles are the same we can write $\dfrac{w}{D} = \sin\theta = \dfrac{\lambda}{s}$ or $\dfrac{w}{D} = \dfrac{\lambda}{s}$ which rearranges to: $\boxed{w = \dfrac{\lambda D}{s}}$

Fringe Separation, Source Separation, Distance to Screen and Wavelength are measured in metres, m

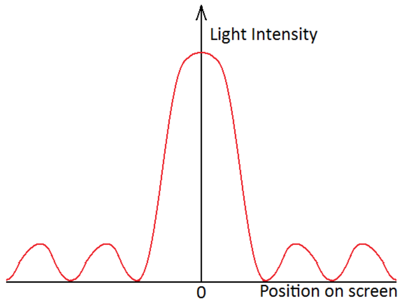
Unit 2	Diffraction	
Lesson 21		
Learning Outcomes	To know what diffraction is and when it happens the most	
	To be able to sketch the diffraction pattern from a single slit and a diffraction grating	
	To be able to derive $d\sin\theta = n\lambda$	N. DWYER

Diffraction



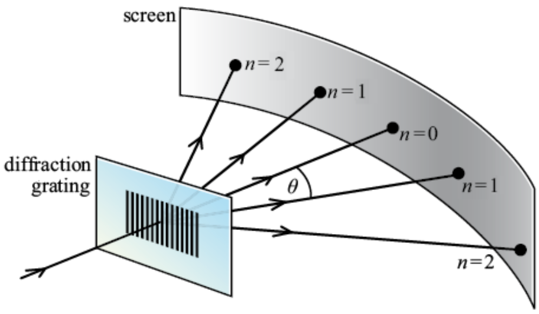
When waves pass through a gap they spread out, this is called diffraction. The amount of diffraction depends on the size of the wavelength compared to the size of the gap.
In the first diagram the gap is several times wider than the wavelength so the wave only spreads out a little.
In the second diagram the gap is closer to the wavelength so it begins to spread out more.
In the third diagram the gap is now roughly the same size as the wavelength so it spreads out the most.

Diffraction Patterns



Here is the diffraction pattern from light being shone through a single slit.
There is a central maximum that is twice as wide as the others and by far the brightest. The outer fringes are dimmer and of equal width.
If we use three, four or more slits the interference maxima become brighter, narrower and further apart.

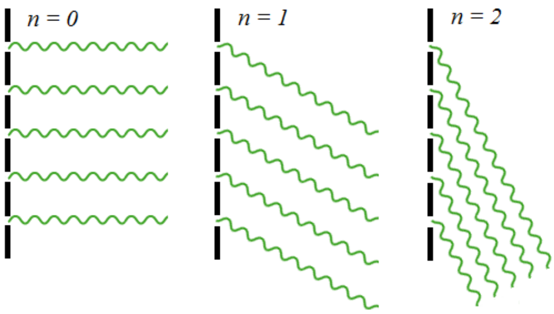
Diffraction Grating



A diffraction grating is a series of narrow, parallel slits. They usually have around 500 slits per mm.
When light shines on the diffraction grating several bright sharp lines can be seen as shown in the diagram to the right.
The first bright line (or interference maximum) lies directly behind where the light shines on the grating. We call this the zero-order maximum. At an angle of θ from this lies the next bright line called the first-order maximum and so forth.

The zero-order maximum ($n=0$)

There is no path difference between neighbouring waves. They arrive in phase and interfere constructively.



The first-order maximum ($n=1$)

There is a path difference of 1 wavelength between neighbouring waves. They arrive in phase and interfere constructively.

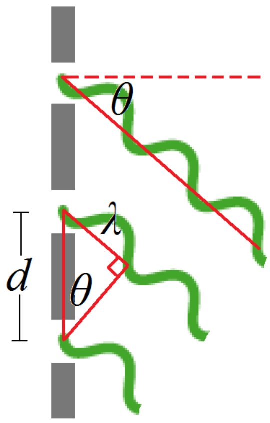
The second-order maximum ($n=2$)

There is a path difference of 2 wavelengths between neighbouring waves. They arrive in phase and interfere constructively.

Between the maxima

The path difference is not a whole number of wavelengths so the waves arrive out of phase and interfere destructively.

Derivation



The angle to the maxima depends on the wavelength of the light and the separation of the slits. We can derive an equation that links them by taking a closer look at two neighbouring waves going to the first-order maximum.
The distance to the screen is so much bigger than the distance between two slits that emerging waves appear to be parallel and can be treated that way.
Consider the triangle to the right.

$$\sin\theta = \frac{Opposite}{Hypotenuse} \rightarrow \sin\theta = \frac{\lambda}{d} \rightarrow d\sin\theta = \lambda$$

For the nth order the opposite side of the triangle becomes $n\lambda$, making the equation:

$$\boxed{d\sin\theta = n\lambda}$$