

SCIENCE CLINIC
DBE ESSENTIALS

GRADE
11



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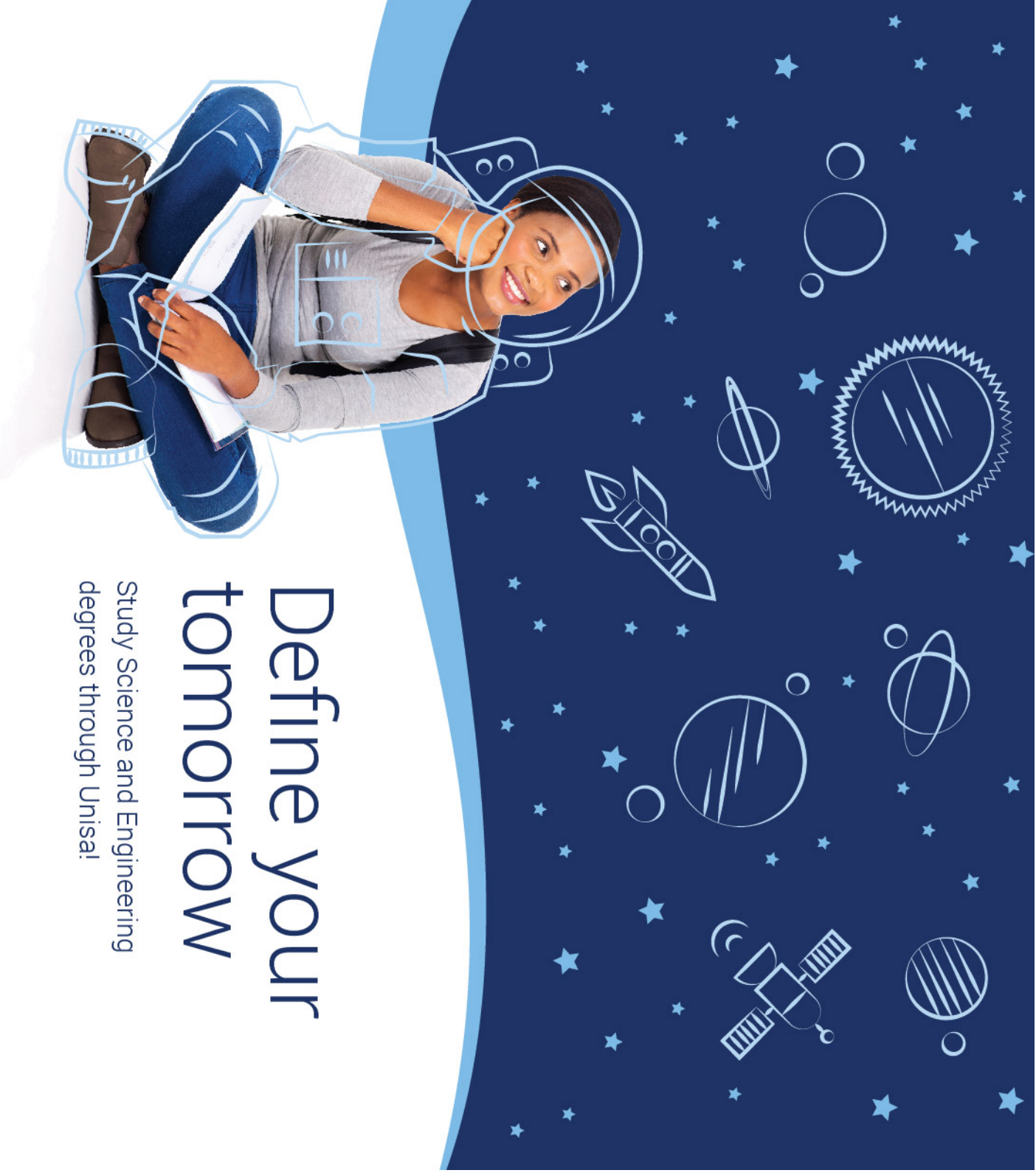
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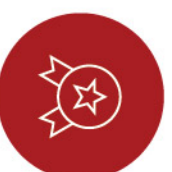
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WHY YOU SHOULD STUDY SCIENCE

Science is amazing! It is also one of the toughest subjects at school. Science-y careers are diverse and exciting, but require years of vigorous academic commitment. If it's so hard to get somewhere with Science, why should you study it? Here's our top reasons for getting your nerd on:

1. **Be a modern-day hero:** The single greatest reason why we should study Science, is to ensure Humanity's sustainable survival on Earth! Ecosystems are in crisis mode, the planetary weather system is changing rapidly, and humanity is failing to coexist in harmony with other species.

World food production has to double in the next thirty years, in order to sustain the growing global population. We are running out of fossil fuels which are critical to the efficiency of our industry, farming and supply chains. Fresh water is becoming increasingly scarce, with many of the World's greatest rivers no longer running into the sea. Diseases are becoming increasingly resistant to antibiotics. The air in many Indian and Chinese cities are verging on unbreathable. The Great Pacific Garbage Patch has become an unfathomable mass of floating junk that is destroying our oceans. The use of fossil fuels is polluting our air and adding to the Greenhouse Effect.

Before you despair, there is a silver lining: every one of these problems can be improved, and even solved, through Science! If you are passionately concerned about this Planet and about a healthy future for Humanity, get stuck into your Science studies and aim for a Science-y career that will equip you to make a difference!

2. **Be smart:** The study of Science encourages problem-solving tenacity that helps you to understand the world around you. I have always explained to my students that Science illuminates one's path, and that going through life without Science is similar to driving your car along dark roads - your headlights might light your way forward, but they don't illuminate the world around you. You travel onwards without ever understanding the context of your journey. Studying Science makes you comfortable with the unknown, and gives you the confidence to say: "I don't know the answers, but I will find out!". Science is gracious to naivety but does not condone the apathy of indifference: it allows you to say "I don't know, but I want to find out", but does not tolerate the attitude of "I don't know and I don't care".

Science is highly structured, but welcomes change - it constantly adjusts its views based on what is observed. This approach teaches you to evolve your thinking by constantly testing and investigating information, which makes you a well-rounded human being and empowers you with an ethical approach to others: it enables you to discern the difference between your opinions and facts, and to acknowledge the opinions and beliefs of others without immediately accepting or rejecting them.

3. **Be adventurous:** Science gets you places! I can only speak from my experience - my engineering background, which is firmly rooted in Science, has opened a door to great adventure and exploration. I have worked on four continents and have been exposed to a diversity of incredible experiences that a 'normal' office job would never allow. Would you like to work in jungles? Study Natural Sciences. A life of studying volcanoes or auroras, perhaps? Study geosciences. Would you like to ply your mind to solving massive problems and driving innovation? Study engineering! Would you like to work with killer whales? Study zoology!

Science-y careers and research allow you visit places that would not be accessible through other fields of study. Whether you want to go to Antarctica or to outer space, Science is the way to get there.

4. **Diversity and flexibility:** From dentistry to plasma physics, Science-y careers offer vast opportunities for professional career development and diversification. Engineers are welcomed into the financial sector, due to their problem-solving ability and analytical way of thinking. Many academic physicists teach, perform ground-breaking research and consult private clients in the same work week. Medical professionals diversify into the legal field to become patent attorneys or medical lawyers. However on the flip side, it's rare for a professional with a 'non-Science-y' background to bridge into the Science-based career fields.

5. **Inventions:** Science-y careers create an intellectual and business environment that is conducive to problem solving and invention. Look at all the exciting inventions of the last twenty years, that have completely transformed our lifestyles. The Internet, the everyday use of GPS, mobile phone technology, PC and touch-screen displays are but a few. This technological progress was made possible due to Science.

Visit online crowdfunding platforms such as Kickstarter and Indiegogo, and appraise the exciting Science-y inventions that are being funded. The tech scene is mushrooming with skunkworks and hackathons that are creating radical innovations. It is an exciting time to be part of Science and technology, and if you want to be at the cusp of making cool things that make a big difference, study Science!

6. **Be a modern-day hero (#2):** South Africa has a growing deficit of expert Science teachers. If you are passionate about Science, and passionate about making a difference, teaching is a massively rewarding career path that is becoming increasingly lucrative. Remember, supply and demand dictate going rates - if there are fewer expert Science teachers around, the demand for expertise leads to increased fees. Become a Science teacher, a thought leader and a role model!
7. **Wealth:** More than a fifth of the planet's wealthiest people on the Forbes 2015 list studied an engineering degree, according to a recent survey by the Approved Index platform. A quarter of the Forbes top-hundred have Science as a foundation for their work.
8. **Discovery:** Science research is a field that allows you to discover the unknown. The deep oceans are unexplored, nanotechnology and photonic crystals have so many secrets, and we're still not sure whether there is any form of life outside near-Earth space. Imagine being the person that publishes a peer-reviewed article to tell the world about a brand new discovery, or a new revelation in our understanding, or a life-altering breakthrough in technology.

This is a call to action for young history-makers, and for a new wave of heroes to save this world and make a difference. I encourage you to become part of it!

James Hayes
Founder – Science Clinic

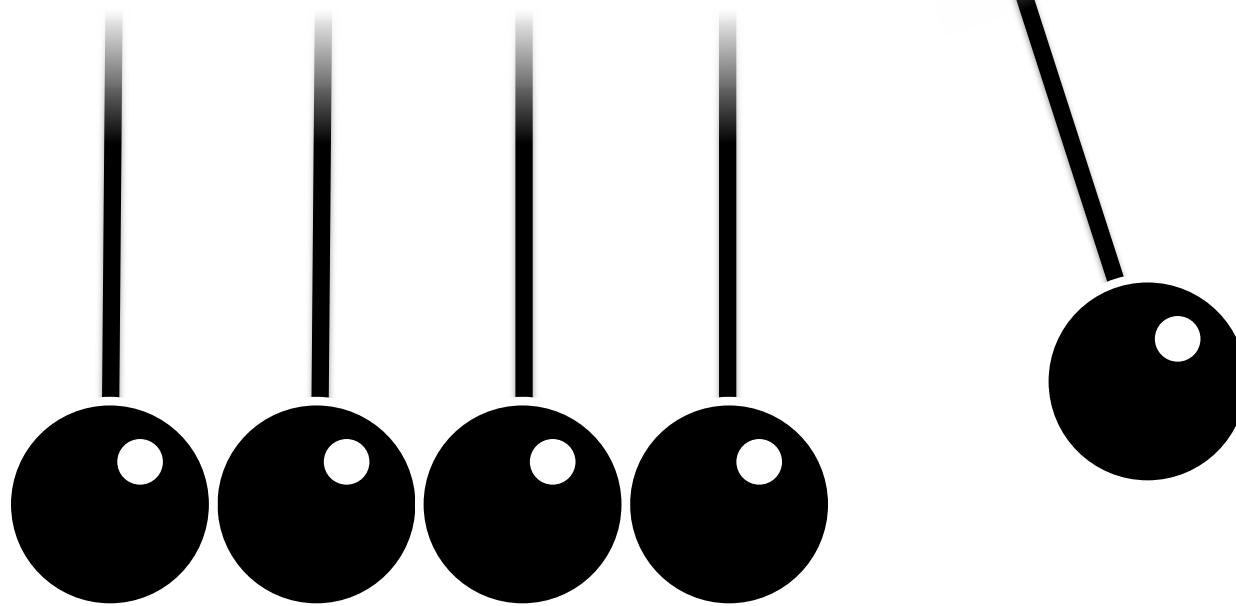
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Grade 11 Physics

The most common quantities, symbols and SI units used in introductory Physics are listed below.
A quantity should not be confused with the unit in which it is measured.

Quantity	Preferred symbol	Alternative symbol	Unit name	Unit symbol
mass	m		kilogram	kg
position	x, y		metre	m
displacement	$\Delta x, \Delta y$	s	metre	m
velocity	v_x, v_y	u, v	metre per second	$\text{m}\cdot\text{s}^{-1}$
initial velocity	v_i	u	metre per second	$\text{m}\cdot\text{s}^{-1}$
final velocity	v_f	v	metre per second	$\text{m}\cdot\text{s}^{-1}$
acceleration	a		metre per second per second	$\text{m}\cdot\text{s}^{-2}$
acceleration due to gravity	g		metre per second per second	$\text{m}\cdot\text{s}^{-2}$
time (instant)	t		second	s
time interval	Δt		second	s
energy	E		joule	J
kinetic energy	K	E_k	joule	J
potential energy	U	E_p	joule	J
work	W		joule	J
work function	W_0		joule	J
power	P		watt	W
momentum	p		kilogram metre per second	$\text{kg}\cdot\text{m}\cdot\text{s}^{-1}$
force	F		newton	N
weight	w	F_g	newton	N
normal force	N	F_N	newton	N
tension	T	F_T	newton	N
friction force	f	F_f	newton	N
coefficient of friction	μ, μ_s, μ_k		(none)	
torque	τ		newton metre	$\text{N}\cdot\text{m}$
wavelength	λ		metre	m
frequency	f	v	hertz or per second	Hz or s^{-1}
period	T		second	s
speed of light	c		metre per second	$\text{m}\cdot\text{s}^{-1}$
refractive index	n		(none)	
focal length	f		metre	m
object distance	s	u	metre	m
image distance	s'	v	metre	m
magnification	m		(none)	
charge	Q, q		coulomb	C
electric field	E		newton per coulomb or volt per metre	$\text{N}\cdot\text{C}^{-1}$ or $\text{V}\cdot\text{m}^{-1}$
electric potential at point P	V_P		volt	V
potential difference	$\Delta V, V$		volt	V
emf	E	$\mathcal{E}$	volt	V
current	I, i		ampere	A
resistance	R		ohm	Ω
internal resistance	r		ohm	Ω
magnetic field	B		tesla	T
magnetic flux	Φ		tesla·metre ² or weber	$\text{T}\cdot\text{m}^2$ or Wb
capacitance	C		farad	F
inductance	L		henry	H

DATA FOR PHYSICAL SCIENCES GRADE 11
PAPER 1 (PHYSICS)

GEGEWENS VIR FISIIESE WETENSKAPPE GRAAD 11
VRAESTEL 1 (FISIKA)

TABLE 1: PHYSICAL CONSTANTS/TABEL 1: FISIIESE KONSTANTES

NAME/NAAM	SYMBOL/SIMBOOL	VALUE/WAARDE
Acceleration due to gravity <i>Swaartekragversnelling</i>	g	9,8 m·s ⁻²
Gravitational constant <i>Swaartekragkonstante</i>	G	6,67 x 10 ⁻¹¹ N·m ² ·kg ⁻²
Radius of Earth <i>Straal van Aarde</i>	R _E	6,38 x 10 ⁶ m
Coulomb's constant <i>Coulomb se konstante</i>	K	9,0 x 10 ⁹ N·m ² ·C ⁻²
Speed of light in a vacuum <i>Spoed van lig in 'n vakuum</i>	c	3,0 x 10 ⁸ m·s ⁻¹
Charge on electron <i>Lading op elektron</i>	e	-1,6 x 10 ⁻¹⁹ C
Electron mass <i>Elektronmassa</i>	m _e	9,11 x 10 ⁻³¹ kg
Mass of the earth <i>Massa van die Aarde</i>	M	5,98 x 10 ²⁴ kg

TABLE 2: FORMULAE/TABEL 2: FORMULES

MOTION/BEWEGING

$v_f = v_i + a \Delta t$	$\Delta x = v_i \Delta t + \frac{1}{2} a \Delta t^2$
$v_f^2 = v_i^2 + 2a \Delta x$	$\Delta x = \left(\frac{v_f + v_i}{2} \right) \Delta t$

FORCE/KRAG

$F_{\text{net}} = ma$	$w = mg$
$F = \frac{Gm_1m_2}{r^2}$	$\mu_s = \frac{f_{s(\text{max})}}{N}$
$\mu_k = \frac{f_k}{N}$	

WAVES, SOUND AND LIGHT/GOLWE, KLANK EN LIG

$v = f \lambda$	$T = \frac{1}{f}$
$n_i \sin \theta_i = n_r \sin \theta_r$	$n = \frac{c}{v}$

ELECTROSTATICS/ELEKTROSTATIKA

$F = \frac{kQ_1Q_2}{r^2}$ ($k = 9,0 \times 10^9 \text{ N}\cdot\text{m}^2\cdot\text{C}^{-2}$)	$E = \frac{F}{q}$
$E = \frac{kQ}{r^2}$ ($k = 9,0 \times 10^9 \text{ N}\cdot\text{m}^2\cdot\text{C}^{-2}$)	$V = \frac{W}{Q}$

ELECTROMAGNETISM/ELEKTROMAGNETISME

$\varepsilon = -N \frac{\Delta\Phi}{\Delta t}$	$\Phi = BA \cos \theta$
--	-------------------------

CURRENT ELECTRICITY/STROOMELEKTRISITEIT

$I = \frac{Q}{\Delta t}$	$R = \frac{V}{I}$
$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \dots$	$R = r_1 + r_2 + r_3 + \dots$
$W = Vq$	$P = \frac{W}{\Delta t}$
$W = VI \Delta t$	$P = VI$
$W = I^2R \Delta t$	$P = I^2R$
$W = \frac{V^2 \Delta t}{R}$	$P = \frac{V^2}{R}$

	Scalar: a physical quantity that has magnitude only Vector: a physical quantity that has both magnitude and direction Resultant vector: the single vector which has the same effect as the original vectors acting together Distance: the length of path travelled (scalar quantity) Displacement: a change in position (vector quantity) Speed: the rate of change of distance (scalar quantity) Velocity: the rate of change of displacement (vector quantity) Acceleration: the rate of change of velocity (vector quantity)
Forces and Vectors	Normal force (F_N): the force or the component of a force which a surface exerts on an object with which it is in contact, and which is perpendicular to the surface Frictional force (F_f): the force that opposes the motion of an object and which acts parallel to the surface Static frictional force (F_s): the force that opposes the tendency of motion of a stationary object relative to a surface. Kinetic frictional force (F_k): the force that opposes the motion of a moving object relative to a surface. Frictional force is proportional to the normal force, is independent of the area of contact, is independent of the velocity of motion Newton's first law of motion: a body will remain in its state of rest or motion at constant velocity unless a non-zero resultant/net force acts on it Newton's second law of motion: when a resultant/net force acts on an object, the object will accelerate in the direction of the force at an acceleration directly proportional to the force and inversely proportional to the mass of the object Newton's third law of motion: when one body exerts a force on a second body, the second body exerts a force of equal magnitude in the opposite direction on the first body Newton's Law of Universal Gravitation: each body in the universe attracts every other body with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres Weight: the gravitational force the Earth exerts on any object on or near its surface
Newton's Laws	
Geometrical Optics	Speed of light (c): the speed of light is constant when travelling through a specific medium. ($c = 3 \times 10^8 \text{ m.s}^{-1}$ in a vacuum) Refraction: a change of wave speed in different media, while the frequency remains constant Refractive index: the ratio of the speed of light in air to the speed of light in a specific medium Optical density: a measure of the speed of light or other electromagnetic wave through a medium Normal: the imaginary line perpendicular to the surface between two different optical media Angle of incidence: the angle between the incident ray and the normal Angle of refraction: the angle between the refracted ray and the normal Snell's law: gives the relationship between the angle of incidence, the angle of refraction and the refractive index when light moves from one medium to another Critical angle: the angle of incidence from which the refractive angle is 90° Total internal reflection: the angle of incidence is greater than the critical angle and no refraction takes place, instead the ray is reflected
2D and 3D Wavefronts	Wavefront: an imaginary line that connects waves that are in phase Huygen's principle: all points of a wavefront act like a point source. Each of these point sources (secondary sources) produce smaller circular wavelets moving forwards with the same speed as the wave. Diffraction: the ability of a wave to spread out in wavefronts as they pass through a small aperture or around a sharp edge
Electrostatics	Coulomb's law: the magnitude of the electrostatic force exerted by one point charge (Q₁) on another point charge (Q₂) is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance (r) between them Electric field: a region of space in which an electric charge experiences a force. The direction of the electric field at a point is the direction that a positive test charge would move if placed at that point. Electric field at a point: The electric field at a point is the electrostatic force experienced per unit positive charge placed at that point.
Electromagnetism	Faraday's law: when a conductor and magnetic field move relative to each other, an emf is induced across the ends of the conductor. The induced emf in the conductor is directly proportional to the rate of change of magnetic flux Ohmic conductor: a conductor that obeys Ohm's law Ohm's law: the potential difference across a conductor is directly proportional to the current in the conductor at constant temperature Non-Ohmic conductor: a conductor which does not obey Ohm's law Internal resistance: resistance of the cell/ battery itself Power: the rate at which electrical energy is converted in an electric circuit and is measured in watts (W) Kilowatt hour (kWh): refers to the use of 1 kilowatt of electricity for 1 hour Emf:
Electric Circuits	

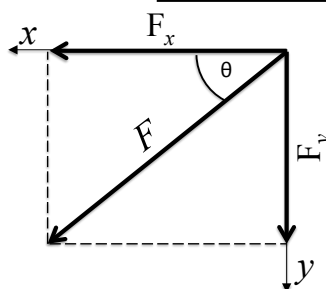
VECTORS IN 2D

RESOLVING INTO COMPONENTS

Diagonal vectors can be broken into components. When vectors are broken into the x - and y -components, we are determining the horizontal (x -axis) and vertical (y -axis) effect of the vector.

$$F_x = F \cos \theta$$

$$F_y = F \sin \theta$$

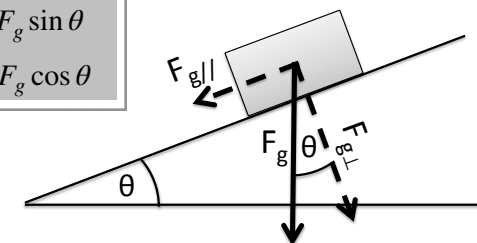


COMPONENTS ON A SLOPE

When forces act on objects on a slope, it is useful to resolve vectors into components that are parallel ($\parallel$) or perpendicular ($\perp$) components. The most common force resolved into components on a slope is weight (F_g).

$$F_{g\parallel} = F_g \sin \theta$$

$$F_{g\perp} = F_g \cos \theta$$



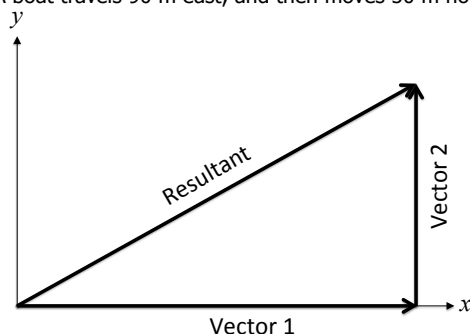
CONSTRUCTING FORCE TRIANGLE

When forces are not co-linear, force triangles can be used to determine resultant forces or the equilibrant. When force triangles are formed, basic geometric rules can be used to determine vectors or resultants.

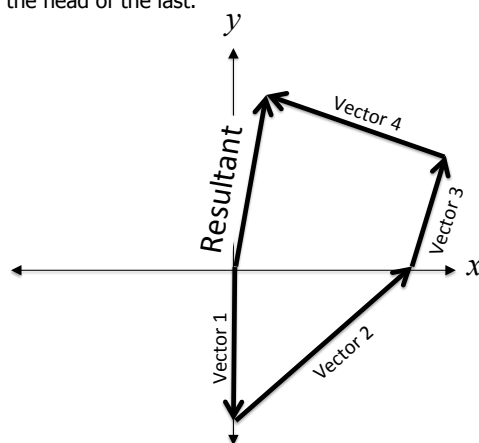
Tail-to-head

Used for consecutive vectors (vectors that occur in sequence).

Eg. A boat travels 90 m east, and then moves 50 m north.



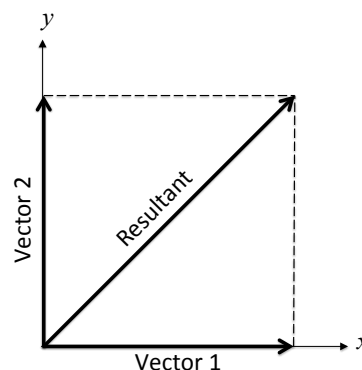
This principle can also be applied to more than 2 vectors taken in order. The resultant is from the tail of the first vector to the head of the last.



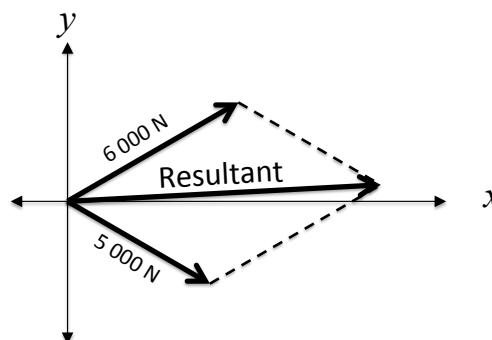
Parallelogram

Used for vectors that act concurrently on the same object.

The resultant is the diagonal of a parallelogram that originates from the tail of the vectors.



Eg. Two tugboats apply a force of 6 000 N and 5 000 N at bearings of 60° and 120° respectively on a cargo ship.



Manipulation

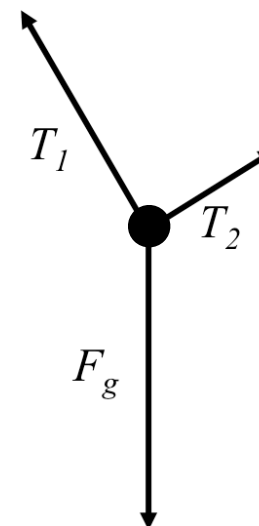
The vector arrows can be manipulated to form a force triangle to determine the resultant forces or an equilibrant.

When manipulating the vector arrows, the following has to remain the same:

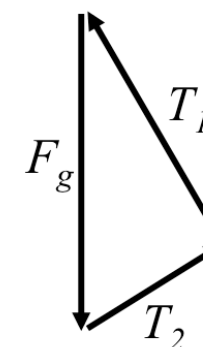
- Length of arrow (magnitude)
- Angle of the arrow (direction)
- The direction of the arrow head

Eg. An object is suspended from a ceiling by 2 cables. Below is a free body diagram as well as a force triangle that can be used to calculate the values of T_1 and T_2 .

Free body diagram



Force triangle



2D VECTORS- RESULTANT AND EQUILIBRANT

EQUILIBRANT: The force that keeps a system in equilibrium.

The equilibrant is equal in magnitude but opposite in direction to the resultant force.

PYTHAGORAS (90° ONLY)

Pythagoras can only be applied to vector triangles that are right angle triangles.

FOR FINDING SIDES:

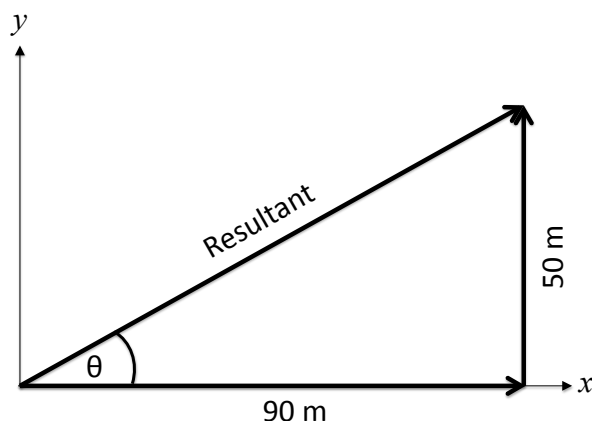
$$R^2 = x^2 + y^2$$

FOR FINDING ANGLES:

$$\sin \theta = \frac{o}{h} \quad \cos \theta = \frac{a}{h} \quad \tan \theta = \frac{o}{a}$$

EXAMPLE:

A boat travels 90 m due east, and then moves 50 m due north. Determine the displacement of the boat.



$$\begin{aligned} R^2 &= x^2 + y^2 \\ R &= \sqrt{90^2 + 50^2} \\ R &= 102,96 \text{ m} \end{aligned}$$

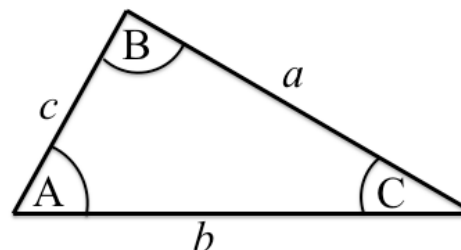
$$\begin{aligned} \tan \theta &= \frac{o}{a} \\ \theta &= \tan^{-1}\left(\frac{50}{90}\right) \\ \theta &= 29,05^\circ \end{aligned}$$

Remember that θ calculated is relative to the x -axis,
 $\therefore$ bearing = $90^\circ - 29,05^\circ = 60,95^\circ$

$\therefore$ Displacement = 102,96 m at a bearing of $60,95^\circ$

SINE-RULE (NON-90°)

The sine-rule can be used to determine sides and angles of vector triangles that are not right angle triangles.



FOR FINDING SIDES:

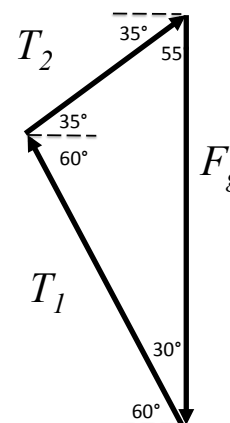
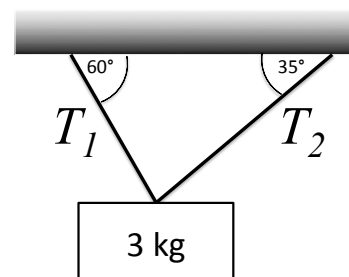
$$\frac{a}{\sin(A)} = \frac{b}{\sin(B)} = \frac{c}{\sin(C)}$$

FOR FINDING ANGLES:

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

EXAMPLE:

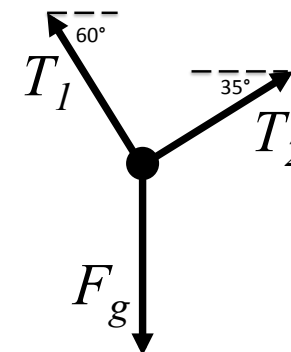
An object is suspended from a ceiling by two cords as shown in the diagram below. Determine the **magnitude** of T_1 and T_2 .



$$\begin{aligned} F_g &= mg \\ &= (3)(9,8) \\ &= 29,4 \text{ N} \end{aligned}$$

$$\begin{aligned} \frac{a}{\sin A} &= \frac{b}{\sin B} \\ \frac{T_1}{\sin 55^\circ} &= \frac{29,4}{\sin 95^\circ} \\ T_1 &= \sin 55^\circ \times \frac{29,4}{\sin 95^\circ} \\ T_1 &= 24,18 \text{ N} \end{aligned}$$

$$\begin{aligned} \frac{a}{\sin A} &= \frac{b}{\sin B} \\ \frac{T_2}{\sin 30^\circ} &= \frac{29,4}{\sin 95^\circ} \\ T_2 &= \sin 30^\circ \times \frac{29,4}{\sin 95^\circ} \\ T_2 &= 14,76 \text{ N} \end{aligned}$$



2D VECTORS- RESULTANT AND EQUILIBRANT

CONSTRUCTION

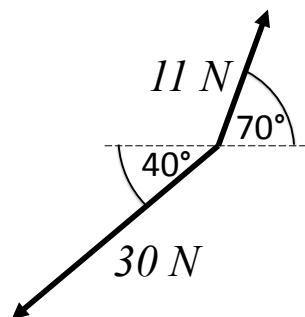
By accurately constructing vector diagrams, the resultant or equilibrant can be determined by measurement. The diagram has to be drawn using a ruler and protractor. The magnitude, represented by the length of the line, is drawn using an appropriate scale, for example:

$$1 \text{ cm} = 1 \text{ N}$$

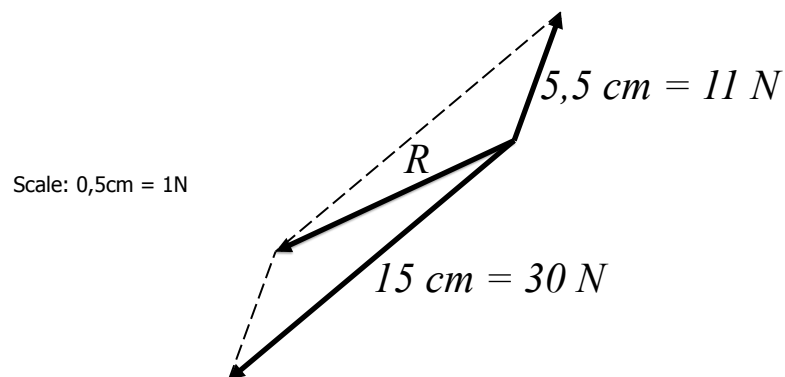
$$1 \text{ mm} = 1 \text{ N}$$

EXAMPLE:

Two forces are applied on an object as shown in the diagram below. Determine the resultant force by construction.



Draw the forces using a specified scale and accurate angle measurements.



By measurement:

Resultant = 10,6cm = 21,20 N at an angle of 25° below the negative x-axis.

(The equilibrant will be 21,20 N at an angle of 25° above the positive x-axis)

COMPONENT ADDITION

The resultant of diagonal forces can be determined using Pythagoras by determining the x-resultant and y-resultant first. This is especially useful for determining resultants when more than 2 forces act on an object and a force triangle can not be used.

Steps to determine resultant using component method:

1. Determine the x- and y-components of each force.
2. Determine the x- and y-resultants of components.
3. Determine the resultant using Pythagoras.
4. Determine the angle using trigonometric principles.

EXAMPLE:

Three forces act on an object as shown in the diagram below. Determine the resultant force on the object.

1. Determine the x- and y-components of each force.

11N force:

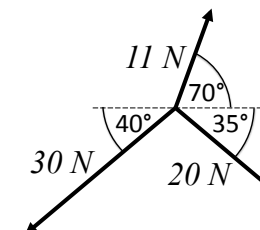
$$\begin{aligned} F_x &= F \cos \theta & F_y &= F \sin \theta \\ &= 11 \cos 70 & &= 11 \sin 70 \\ &= 3,76 \text{ N right } (90^\circ) & &= 10,34 \text{ N up } (0^\circ) \end{aligned}$$

30N force:

$$\begin{aligned} F_x &= F \cos \theta & F_y &= F \sin \theta \\ &= 30 \cos 40 & &= 30 \sin 40 \\ &= 22,98 \text{ N left } (270^\circ) & &= 19,28 \text{ N down } (180^\circ) \end{aligned}$$

20N force:

$$\begin{aligned} F_x &= F \cos \theta & F_y &= F \sin \theta \\ &= 20 \cos 35 & &= 20 \sin 35 \\ &= 16,38 \text{ N right } (90^\circ) & &= 11,47 \text{ N down } (180^\circ) \end{aligned}$$



2. Determine the x- and y-resultants of components.

Take left (270°) as positive

$$\begin{aligned} F_x &= -3,76 + 22,98 - 16,38 \\ &= 2,84 \text{ N left } (270^\circ) \end{aligned}$$

Take down (180°) as positive

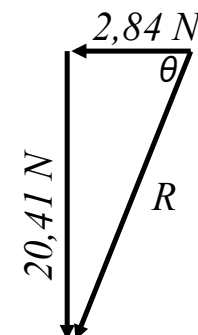
$$\begin{aligned} F_y &= -10,34 + 19,28 + 11,47 \\ &= 20,41 \text{ N down } (180^\circ) \end{aligned}$$

3. Find resultant-Pythagoras.

$$\begin{aligned} R^2 &= x^2 + y^2 \\ R &= \sqrt{2,84^2 + 20,41^2} \\ R &= 20,61 \text{ N} \end{aligned}$$

4. Find angle- trigonometry

$$\begin{aligned} \tan \theta &= \frac{o}{a} \\ \theta &= \tan^{-1} \frac{20,41}{2,84} \\ \theta &= 82,08^\circ \end{aligned}$$



Resultant = 20,61 N at a bearing of 187,92°

NEWTON'S LAWS OF MOTION

FORCES

Non-contact force: A force exerted between objects over a distance without physical contact.	Contact force: A force exerted between objects that are in contact with each other.
Electrostatic force	Applied force (F_A)
Gravitational force (F_g)	Tension (T or F_T)
Magnetic force	Friction (F_f or f_s/f_k)
	Normal force (F_N)

A force is a push or a pull action exerted on an object. This action can be exerted while objects are in contact (contact force) or over a distance (non-contact force).

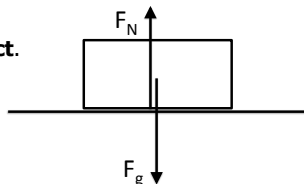
Because forces have magnitude and direction, they are vectors. Force is measured in newton (N). 1 N is the force required to accelerate a 1 kg object at $1 \text{ m}\cdot\text{s}^{-2}$ in the direction of the force. We can therefore say that $1 \text{ N} = 1 \text{ kg}\cdot\text{m}\cdot\text{s}^{-2}$.

Normal force (F_N)

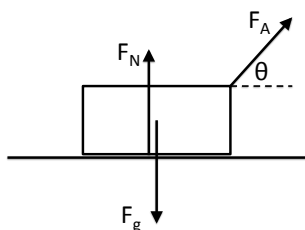
The perpendicular force exerted on by a surface on an object in contact with it.

The normal force is equal to the **perpendicular component** of gravity **if there are no other forces acting on the object**.

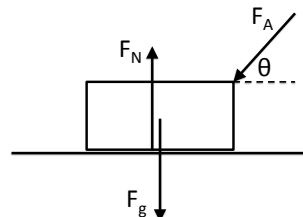
$$F_N = -F_g$$



If alternative forces act on the object, the normal force will change depending on the direction and magnitude of the applied force.



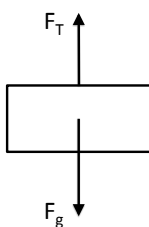
$$\begin{aligned} F_N + F_{Ay} + F_g &= 0 \\ F_N + F_A \sin \theta &= -F_g \end{aligned}$$



$$\begin{aligned} F_N + F_g + F_{Ay} &= 0 \\ F_N &= -F_g - F_A \sin \theta \end{aligned}$$

Objects suspended from a rope/string/cable have no normal force, as there is no surface on which the object rests. The **tension** is equal to the **perpendicular component** of gravity **if there are no other forces acting on the object**.

$$F_T + F_g = 0$$



Friction (F_f or f_s/f_k)

Frictional force due to a surface is the force that opposes the motion of an object in contact with it.

Friction is the parallel component of the contact force on an object by the surface on which it rests. The friction between the contact surfaces are determined by the properties of that surface. The coefficient of friction (μ_s/μ_k) is a description of the roughness of the surface. The rougher the surface, the greater the coefficient of friction.

Static friction (f_s)

Static friction is the **frictional force on a stationary object that opposes the tendency of motion of the object**. The magnitude of the static friction will increase as the parallel component of the applied force is increased, until maximum static friction is reached. $f_s^{\max}$ is the magnitude of friction when the object just starts to move.

$$f_s^{\max} = \mu_s F_N$$

$f_s^{\max}$ = maximum static friction (N)

μ_s = coefficient of friction (no unit)

F_N = normal force (N)

If the applied force is greater than the maximum static friction, the object will start to move.

Kinetic friction (f_k)

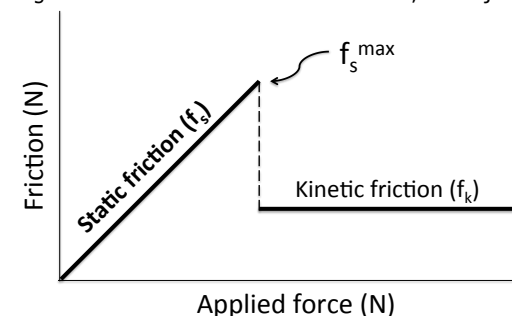
Kinetic friction is the **frictional force on a moving object that opposes the motion of the object**. The magnitude of the kinetic friction is constant for the specific system at all velocities greater than zero, and irrespective of the applied force.

$$f_k = \mu_k F_N$$

f_k = kinetic friction (N)

μ_k = coefficient of friction (no unit)

F_N = normal force (N)



NEWTON'S LAWS OF MOTION

Newton's First Law of Motion

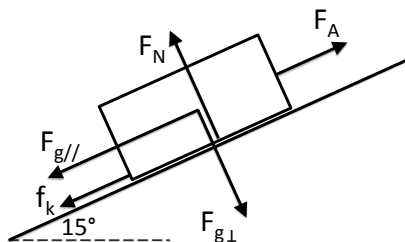
An object continues in a state of rest or uniform (moving with constant) velocity unless it is acted upon by an unbalanced (net or resultant) force.

Newton's First Law is due to inertia- the resistance of an object to change its state of rest of motion.

$$F_{net} = 0 \text{ N}$$

$$a = 0 \text{ m} \cdot \text{s}^{-2}$$

A 3 kg object moves up an incline surface at an angle of 15° with a constant velocity. The coefficient of friction is 0,35. Determine the magnitude of the applied force.



Take downwards as positive:

$$\begin{aligned} F_{net\perp} &= 0 \\ F_N + F_{g\perp} &= 0 \\ F_N &= -F_{g\perp} \\ F_N &= -mg \cos \theta \\ F_N &= -(3)(9,8) \cos 15^\circ \\ F_N &= -28,40 \text{ N} \\ \therefore F_N &= 28,40 \text{ N } \perp \text{ up from slope} \end{aligned}$$

$$\begin{aligned} F_{net\parallel} &= 0 \\ F_A + F_{g\parallel} + f_k &= 0 \\ F_A &= -F_{g\parallel} - f_k \\ F_A &= -mg \sin \theta - \mu_k F_N \\ F_A &= -(3)(9,8) \sin 15^\circ - (0,35)(28,40) \\ F_A &= -17,55 \text{ N} \\ \therefore F_A &= 17,55 \text{ N} \end{aligned}$$

Importance of wearing safety belts:

According to Newton's First Law, an object will remain in motion at a constant velocity unless a non-zero resultant force acts upon it. When a car is in an accident and comes to a sudden stop, the person inside the car will continue with a constant forward velocity. Without a safety belt, the person will make contact with the windscreen of the car, causing severe head trauma. The safety belt acts as an applied force, preventing the forward motion of the person.

Newton's Second Law of Motion

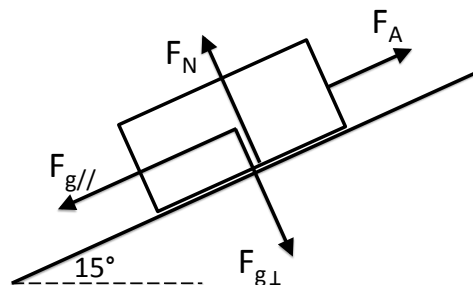
When a net force is applied to an object of mass, it accelerates in the direction of the net force. The acceleration is directly proportional to the net force and inversely proportional to the mass.

Newton's Second Law is dependent on the resultant force- The vector sum of all forces acting on the same object.

$$F_{net} = ma$$

$$a \neq 0 \text{ m} \cdot \text{s}^{-2}$$

A 20 N force is applied to a 5 kg object. The object accelerates up a frictionless incline surface at an angle of 15° . Determine the acceleration of the object.



Take upwards as positive:

$$\begin{aligned} F_{net\parallel} &= ma \\ F_A + F_{g\parallel} &= ma \\ 20 + (5)(-9,8) \sin 15^\circ &= 5a \\ 20 - 12,68 &= 5a \\ a &= \frac{7,32}{5} \\ \therefore a &= 1,46 \text{ m} \cdot \text{s}^{-2} \parallel \text{ up the slope} \end{aligned}$$

Effect of Newton's Second Law on overloading:

According to Newton's Second Law, the acceleration of an object is directly proportional to the applied force and inversely proportional to the mass of the object. If a vehicle is overloaded, the stopping distance will increase which can lead to serious accidents. When brakes are applied, the force (friction) remains the same, but the increase in mass causes a decrease in negative acceleration, increasing the time (and distance) it takes for the vehicle to stop.

Newton's Third Law of Motion

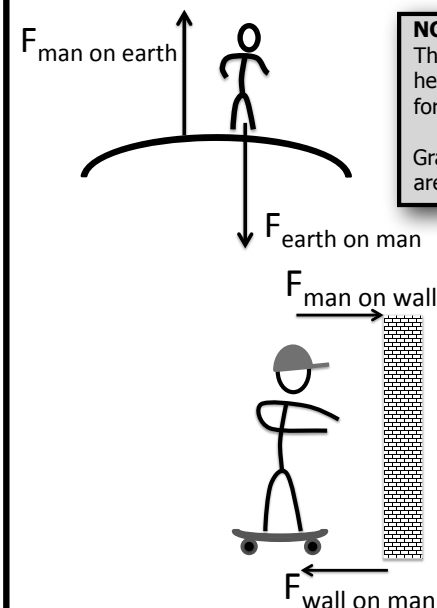
When object A exerts a force on object B, object B simultaneously exerts an oppositely directed force of equal magnitude on object A.

Newton's Third Law describes action-reaction force pairs. These are forces on different objects and can not be added or subtracted.

$$F_{A \text{ on } B} = -F_{B \text{ on } A}$$

Force pairs properties:

- Equal in magnitude
- Opposite in direction
- Acts on different objects (and therefore **DO NOT CANCEL** each other out)



NOTE:

The force pairs shown here are gravitational forces.

Gravity and Normal force are **NOT** force pairs.

Newton's Third Law during an accident

According to Newton's Third Law, the force that two objects exert on each other is equal in magnitude but opposite in direction. If two cars are in an accident, they will both exert the same amount of force on each other irrespective of their masses.

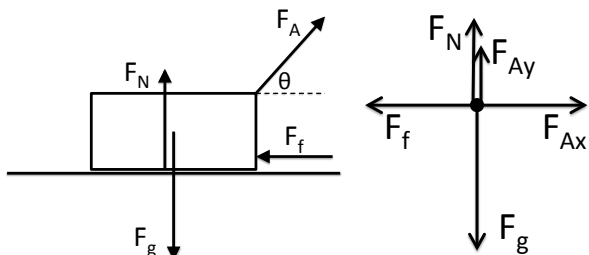
NEWTON'S LAWS OF MOTION

ALL EXAMPLES:
DIRECTION OF MOTION POSITIVE

Horizontal

The vertical resultant = 0 N.
The horizontal resultant determines acceleration.

Pulled at an angle



Horizontal:

$$F_{net} = ma$$

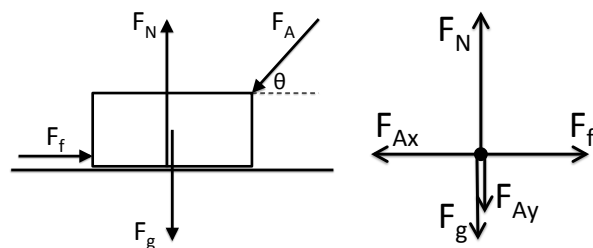
$$F_{Ax} + (-F_f) = ma$$

Vertical:

$$F_{net} = 0$$

$$(-F_g) + F_N + F_{Ay} = 0$$

Pushed at an angle



Horizontal:

$$F_{net} = ma$$

$$F_{Ax} + (-F_f) = ma$$

Vertical:

$$F_{net} = 0$$

$$F_g + (-F_N) + F_{Ay} = 0$$

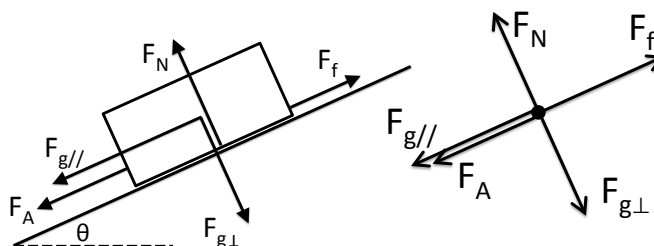
Slopes

The perpendicular ($\perp$) resultant = 0 N.The parallel ($\parallel$) resultant determines acceleration.**REMEMBER: Use components of weight.**

$$F_{g\parallel} = F_g \sin \theta$$

$$F_{g\perp} = F_g \cos \theta$$

Force applied down the slope



Parallel:

$$F_{net} = ma$$

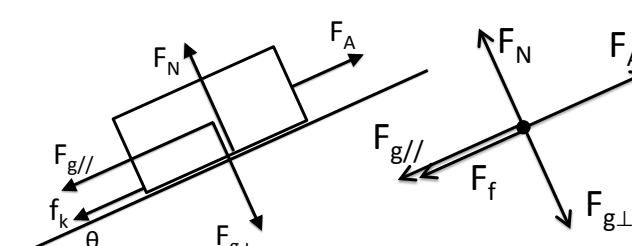
$$F_{g\parallel} + F_A + (-F_f) = ma$$

Perpendicular:

$$F_{net} = 0$$

$$F_{g\perp} + (-F_N) = 0$$

Force applied up the slope



Parallel:

$$F_{net} = ma$$

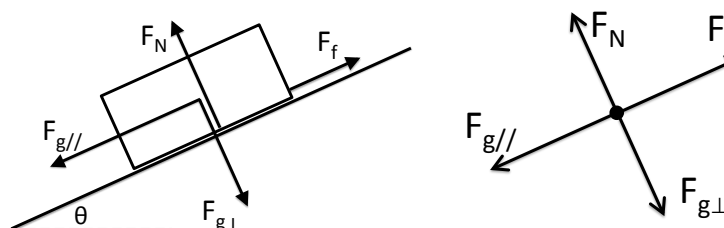
$$-(F_{g\parallel}) + (-F_f) + F_A = ma$$

Perpendicular:

$$F_{net} = 0$$

$$F_{g\perp} + (-F_N) = 0$$

No force applied



Parallel:

$$F_{net} = ma$$

$$F_{g\parallel} + (-F_f) = ma$$

Perpendicular:

$$F_{net} = 0$$

$$F_{g\perp} + (-F_N) = 0$$

Suspended

Horizontal resultant = 0 N.

Vertical resultant determines acceleration.

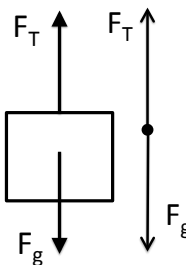
REMEMBER: No normal or friction forces.

Lift stationary/constant velocity

Vertical:

$$F_{net} = 0$$

$$F_g + (-F_T) = 0$$



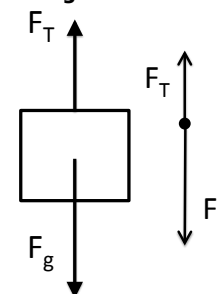
Lift accelerating

Vertical:

$$F_{net} = ma$$

$$F_g + (-F_T) = ma$$

Acceleration will be in the direction of the greatest force.

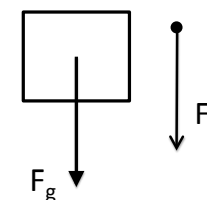


Lift in freefall (cable snap)

Vertical:

$$F_{net} = ma$$

$$F_g = ma$$



NEWTON'S LAWS OF MOTION

ALL EXAMPLES:
DIRECTION OF MOTION POSITIVE

Connected objects

Do separate free body diagrams for each object.

The velocity and acceleration of all objects are equal in magnitude and direction.

Applied forces are applied to only one object at a time.

Simultaneous equations for acceleration and tension are sometimes needed.

REMEMBER:

Ropes/cables- The tension forces on the objects are the same in magnitude but opposite in direction.

Touching objects- Newton's Third Law

Same axis

Can be horizontal (multiple objects on a surface) or vertical (multiple suspended objects).

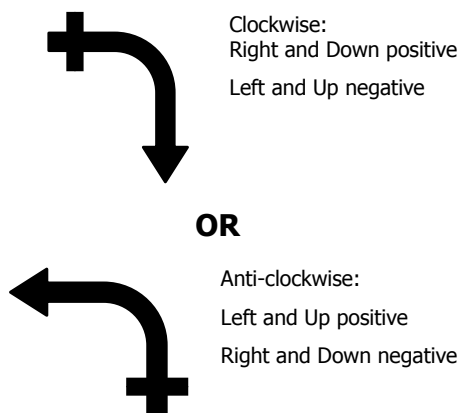
The velocity and acceleration of all objects are equal in magnitude and direction.

Multiple axes

Horizontal (objects on a surface) **AND** vertical (suspended objects).

The velocity and acceleration of all objects are equal in magnitude NOT DIRECTION.

Vector direction on multiple axes

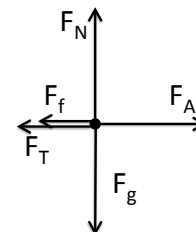
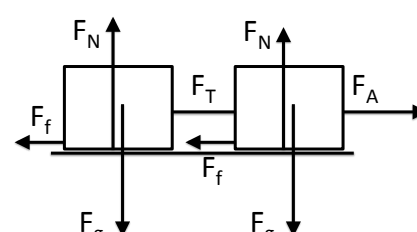
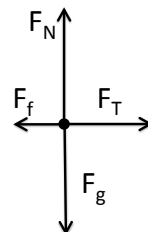


Objects attached by rope/cable

Horizontal:

$$F_{net} = ma$$

$$(-F_f) + F_T = ma$$



Horizontal:

$$F_{net} = ma$$

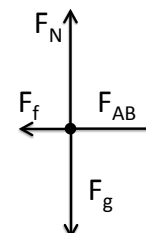
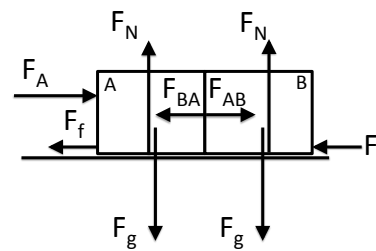
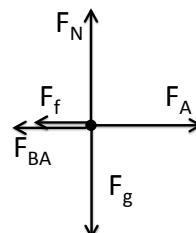
$$F_A + (-F_T) + (-F_f) = ma$$

Objects in contact

Horizontal:

$$F_{net} = ma$$

$$F_A + (-F_{BA}) + (-F_f) = ma$$



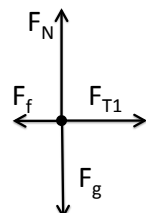
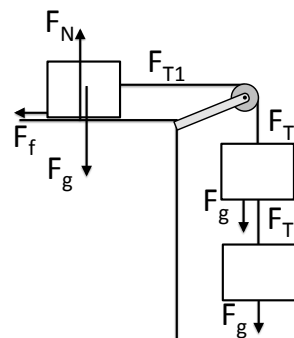
Horizontal:

$$F_{net} = ma$$

$$(-F_f) + F_{AB} = ma$$

Multiple axes

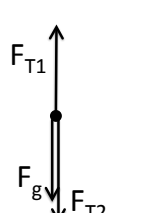
In these examples,
clockwise is positive:
Right positive
Down positive



Horizontal:

$$F_{net} = ma$$

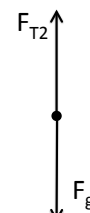
$$F_{T1} + (-F_f) = ma$$



Vertical:

$$F_{net} = ma$$

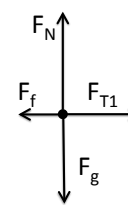
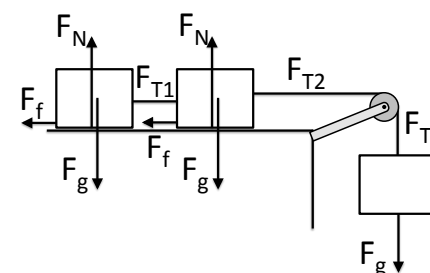
$$F_g + (-F_{T1}) + F_{T2} = ma$$



Vertical:

$$F_{net} = ma$$

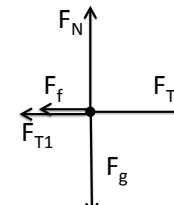
$$F_g + (-F_{T2}) = ma$$



Horizontal:

$$F_{net} = ma$$

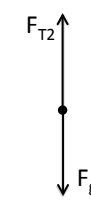
$$F_{T1} + (-F_f) = ma$$



Horizontal:

$$F_{net} = ma$$

$$F_{T2} + (-F_{T1}) + (-F_f) = ma$$



Vertical:

$$F_{net} = ma$$

$$F_g + (-F_{T2}) = ma$$

NEWTON'S LAW OF UNIVERSAL GRAVITATION

Every particle in the universe attracts every other particle with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres.

$$F = \frac{Gm_1m_2}{r^2}$$

F = force of attraction between objects (N)

G = universal gravitational constant ($6,67 \times 10^{-11} \text{ N} \cdot \text{m}^2 \cdot \text{kg}^{-2}$)

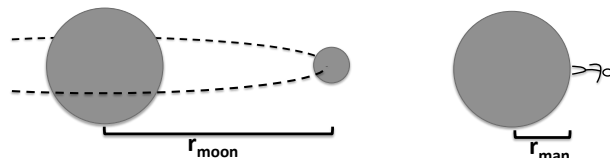
m = object mass (kg)

r = distance between object centers (m)

A uniform sphere of matter attracts a body that is outside the shell as if all the sphere's mass was concentrated at its center.



Thus, the distance is determined between the centers of the two bodies.



NOTE:

The radius of the earth is added to the distance between the earth and the moon.

NOTE:

The radius of object (man) on the earth is negligibly small.

KNOW THE DIFFERENCE!

g vs G

g: Gravitational acceleration ($9,8 \text{ m} \cdot \text{s}^{-2}$ on earth)

g is the acceleration due to gravity on a specific planet.

G: Universal gravitational constant ($6,67 \times 10^{-11} \text{ N} \cdot \text{m}^2 \cdot \text{kg}^{-2}$)

Proportionality constant which applies everywhere in the universe.

Mass vs Weight

Mass (kg)

A scalar quantity of matter which remains constant everywhere in the universe.

Weight (N)

Weight is the gravitational force the Earth exerts on any object. Weight differs from planet to planet. $F_g = mg$. Weight is a vector quantity.

RATIOS

1. Write out the original formula.
2. Manipulate unknown as subject.
3. Substitute changes into formula (Keep symbols!).
4. Simplify ratio number.
5. Replace original formula with unknown symbol.

EXAMPLE:

Two objects, m_1 and m_2 , are a distance r apart and experience a force F . How would this force be affected if:

- a) One mass is doubled and the distance between the masses is halved?

$$\begin{aligned} F &= \frac{Gm_1m_2}{r^2} \\ &= \frac{G(2m_1)m_2}{(\frac{1}{2}r)^2} \\ &= \frac{2}{\frac{1}{4}} \frac{Gm_1m_2}{r^2} \\ &= 8 \left(\frac{Gm_1m_2}{r^2} \right) \end{aligned}$$

Write out the formula

Substitute changes into formula

Simplify ratio number

$$\therefore F_{\text{new}} = 8 F$$

Replace original formula

- b) Both the two masses as well as the distance are doubled?

$$\begin{aligned} F &= \frac{Gm_1m_2}{r^2} \\ &= \frac{G(2m_1)(2m_2)}{(2r)^2} \\ &= \frac{4}{4} \frac{Gm_1m_2}{r^2} \\ &= 1 \left(\frac{Gm_1m_2}{r^2} \right) \end{aligned}$$

Write out the formula

Substitute changes into formula

Simplify ratio number

$$\therefore F_{\text{new}} = 1 F$$

Replace original formula

DETERMINING GRAVITATIONAL ACCELERATION (g)

$$F = m_{\text{object}}g \quad \text{and} \quad F = \frac{Gm_{\text{object}}m_{\text{planet}}}{r_{\text{planet}}^2}$$

$$m_{\text{object}}g = \frac{Gm_{\text{object}}m_{\text{planet}}}{r_{\text{planet}}^2}$$

$$g = \frac{Gm_{\text{planet}}}{r_{\text{planet}}^2}$$

$$\therefore g = \frac{Gm_{\text{planet}}}{r_{\text{planet}}^2}$$

Therefore the gravitational acceleration of an object only depends on the mass and radius of the planet. **Object mass is irrelevant!**

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CALCULATIONS

The force can be calculated using $F = \frac{Gm_1m_2}{r^2}$

REMEMBER:

Mass in **kg**

Radius in **m**

Radius: centre of mass to centre of mass.

Direction is **ALWAYS** attractive.

Both objects experience the same force.
(Newton's Third Law of Motion)

EXAMPLE:

The earth with a radius of $6,38 \times 10^3 \text{ km}$ is $149,6 \times 10^6 \text{ km}$ away from the sun with a radius of $696\,342 \text{ km}$. If the earth has a mass of $5,97 \times 10^{24} \text{ kg}$ and the sun has a mass of $1,99 \times 10^{30} \text{ kg}$, determine the force between the two bodies.

$$\begin{aligned} r &= 6,38 \times 10^3 \text{ km} + 149,6 \times 10^6 \text{ km} + 696\,342 \text{ km} \\ &= 6,38 \times 10^6 \text{ m} + 149,6 \times 10^9 \text{ m} + 696\,342 \times 10^3 \text{ m} \\ &= 1,5 \times 10^{11} \text{ m} \end{aligned}$$

$$F = \frac{Gm_1m_2}{r^2}$$

$$F = \frac{6,67 \times 10^{-11} (5,97 \times 10^{24}) (1,99 \times 10^{30})}{(1,50 \times 10^{11})^2}$$

$$F = 3,52 \times 10^{22} \text{ N attraction}$$

The force of gravitational attraction is a vector, therefore all vector rules can be applied:

- Direction specific
- Can be added or subtracted



Take right as positive:

$$\begin{aligned} F_{\text{net on satellite}} &= F_{\text{m on s}} + F_{\text{e on s}} \\ &= - \left(\frac{Gm_{\text{m}}m_{\text{s}}}{r_{\text{ms}}^2} \right) + \left(\frac{Gm_{\text{e}}m_{\text{s}}}{r_{\text{es}}^2} \right) \end{aligned}$$

ELECTROSTATICS

FLASHBACK!!

Principle of conservation of charge.

$$Q_{\text{new}} = \frac{Q_1 + Q_2}{2}$$

Principle of charge quantization.

$$n = \frac{Q}{q_e}$$

Prefix	Conversion
centi- (cC)	$\times 10^{-2}$
milli- (mC)	$\times 10^{-3}$
micro- (μC)	$\times 10^{-6}$
nano- (nC)	$\times 10^{-9}$
pico- (pC)	$\times 10^{-12}$

COULOMB'S LAW

The force between two charges is directly proportional to the product of the charges and inversely proportional to the distance between the charges squared.

$$F = \frac{kQ_1Q_2}{r^2}$$

F = force of attraction between objects (N)

k = Coulomb's constant ($9 \times 10^9 \text{ N} \cdot \text{m}^2 \cdot \text{C}^{-2}$)

Q = object charge (C)

r = distance between objects (m)

RATIOS

In ratio questions, the same process is used as with Newton's Law of Universal Gravitation.

EXAMPLE:

Two charges experience a force F when held a distance r apart. How would this force be affected if one charge is doubled, the other charge is tripled and the distance is halved.

$$\begin{aligned} F &= \frac{kQ_1Q_2}{r^2} \\ &= \frac{k(2Q_1)(3Q_2)}{(\frac{1}{2}r)^2} \\ &= \frac{6}{\frac{1}{4}} \frac{kQ_1Q_2}{r^2} \\ &= 24 \left(\frac{kQ_1Q_2}{r^2} \right) \\ &= 24F \end{aligned}$$

CALCULATIONS- Electrostatic force

Electrostatic force is a vector, therefore all vector rules can be applied:

- Direction specific
- Can be added or subtracted

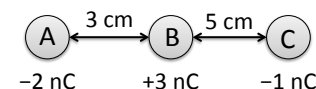
The force can be calculated using

$$F = \frac{kQ_1Q_2}{r^2}$$

- Substitute charge magnitude only.
- Direction determined by charge (like repel, unlike attract).
- Both objects experience the same force (Newton's Third Law of Motion).

1 Dimensional

Determine the resultant electrostatic force on Q_B .



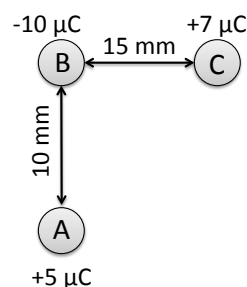
$$\begin{aligned} F_{AB} &= \frac{kQ_AQ_B}{r^2} \\ &= \frac{9 \times 10^9 (2 \times 10^{-9})(3 \times 10^{-9})}{(3 \times 10^{-2})^2} \\ &= 6 \times 10^{-5} \text{ N left (A attracts B)} \end{aligned}$$

$$\begin{aligned} F_{CB} &= \frac{kQ_CQ_B}{r^2} \\ &= \frac{9 \times 10^9 (1 \times 10^{-9})(3 \times 10^{-9})}{(5 \times 10^{-2})^2} \\ &= 1,08 \times 10^{-5} \text{ N right (C attracts B)} \end{aligned}$$

$$\begin{aligned} F_{\text{net}} &= F_{AB} + F_{CB} \\ &= -6 \times 10^{-5} + 1,08 \times 10^{-5} \\ &= -4,92 \times 10^{-5} \\ \therefore F_{\text{net}} &= 4,92 \times 10^{-5} \text{ N left} \end{aligned}$$

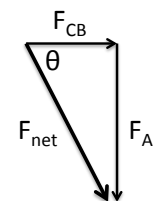
2 Dimensional

Determine the resultant electrostatic force on Q_B .

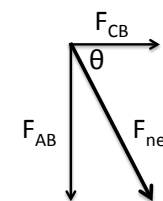


$$\begin{aligned} F_{AB} &= \frac{kQ_AQ_B}{r^2} \\ &= \frac{9 \times 10^9 (5 \times 10^{-6})(10 \times 10^{-6})}{(10 \times 10^{-3})^2} \\ &= 4\,500 \text{ N down (A attracts B)} \end{aligned}$$

$$\begin{aligned} F_{CB} &= \frac{kQ_CQ_B}{r^2} \\ &= \frac{9 \times 10^9 (7 \times 10^{-6})(10 \times 10^{-6})}{(15 \times 10^{-3})^2} \\ &= 2\,800 \text{ N right (C attracts B)} \end{aligned}$$



OR



$$\begin{aligned} \text{PYTHAGORAS :} \\ F_{\text{net}}^2 &= F_{AB}^2 + F_{BC}^2 \\ F_{\text{net}} &= \sqrt{4\,500^2 + 2\,800^2} \\ F_{\text{net}} &= 5\,300 \text{ N} \end{aligned}$$

$$\tan \theta = \frac{o}{a}$$

$$\theta = \tan^{-1} \frac{F_{AB}}{F_{CB}}$$

$$\theta = \tan^{-1} \frac{4\,500}{2\,800}$$

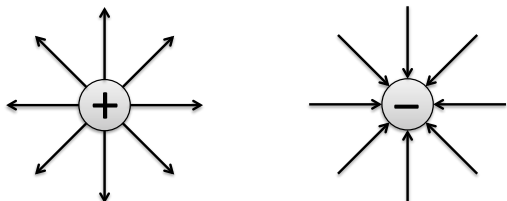
$$\theta = 58,11^\circ$$

$$\therefore F_{\text{net}} = 5\,300 \text{ N at } 58,11^\circ \text{ below the negative y - axis}$$

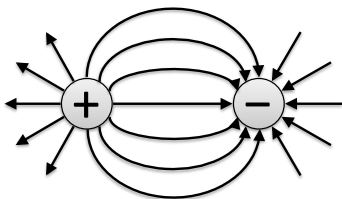
ELECTRIC FIELDS

An electric field is a region of space in which an electric charge experiences a force. The direction of the electric field at a point is the direction that a positive test charge (+1C) would move if placed at that point.

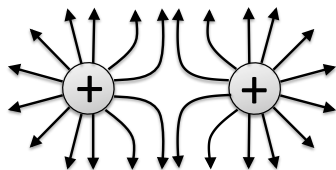
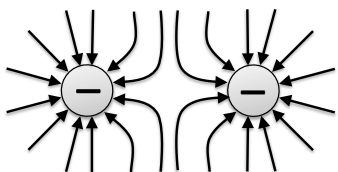
Single point charges



Unlike charges



Like charges



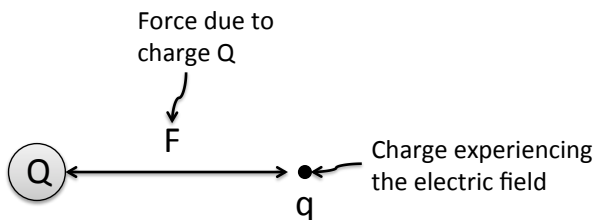
ELECTRIC FIELD STRENGTH

Electric field strength at any point in space is the force per unit charge experienced by a positive test charge at that point.

$$E = \frac{F}{q}$$

E = electric field strength ($\text{N} \cdot \text{C}^{-1}$)
 F = force (N)
 q = charge (C)

q is the charge that experiences the force.



EXAMPLE:

Charge B experiences a force of 2 N due to charge A.
 Determine the electric field strength at point B.



$+2\mu\text{C}$



$-5\mu\text{C}$

$$\begin{aligned} E &= \frac{F}{q} \\ &= \frac{2}{5 \times 10^{-6}} \\ &= 4 \times 10^5 \text{ N} \cdot \text{C}^{-1} \text{ to the right} \end{aligned}$$

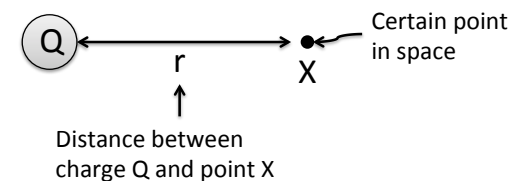
DIRECTION:

Direction that point in space (X) would move IF it was positive.

$$E = \frac{kQ}{r^2}$$

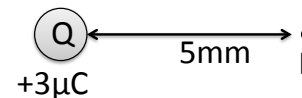
E = electric field strength ($\text{N} \cdot \text{C}^{-1}$)
 k = Coulomb's constant ($9 \times 10^9 \text{ N} \cdot \text{m}^2 \cdot \text{C}^{-2}$)
 Q = object charge (C)
 r = distance between objects (m)

Q is the charge that creates the electric field.



EXAMPLE:

Determine the electric field strength at point P due to charge Q.



$$\begin{aligned} E &= \frac{kQ}{r^2} \\ &= \frac{9 \times 10^9 (3 \times 10^{-6})}{(5 \times 10^{-3})^2} \\ &= 1,08 \times 10^9 \text{ N} \cdot \text{C}^{-1} \text{ to the right} \end{aligned}$$

DIRECTION:

Direction that point in space (X) would move IF it was positive.

NOTE:

Electric field strength is a VECTOR. All vector rules and calculations apply. (linear addition, 2D arrangement, resultant vectors, etc.)

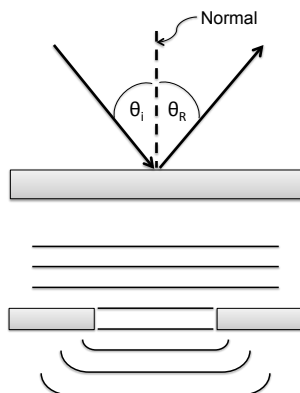
GEOMETRIC OPTICS

When waves reach a change in medium they can undergo:

REFLECTION

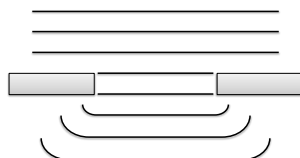
Propagation of light from air into glass and back into air.

Law of reflection: The angle of reflection is equal to the angle of incidence. The incident ray, reflected ray and the normal all lie on the same plane.



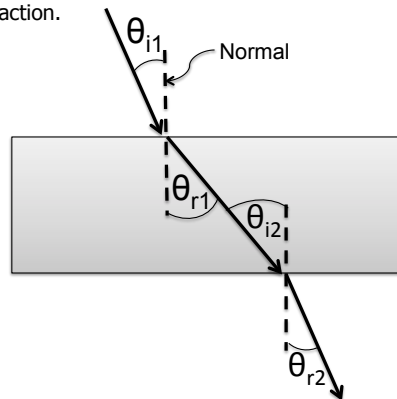
DIFFRACTION

The ability of a wave to spread out in wavefronts as they pass through a small aperture or around a sharp edge.



REFRACTION

When light moves between media of different optical densities, the light undergoes refraction.



Refraction: The bending of light as it moves between two media with different optical densities as a result of the change in wave speed while the frequency remains constant.

Normal: An imaginary line perpendicular to the surface of an object.

Angle of Incidence: Angle between an incident ray and the normal on the surface.

Angle of Reflection: Angle between a reflected ray and the normal on the surface.

OPTICAL DENSITY AND REFRACTIVE INDEX

Optical density

Light can travel through a vacuum at $3 \times 10^8 \text{ m}\cdot\text{s}^{-1}$, but slows down as it moves through a transparent medium. The optical density is a measure of the refracting power of a medium. The higher the optical density, the more the light will be refracted or slowed down as it moves through the medium.

The velocity of light through a medium is inversely proportional to the optical density of the medium. The speed of light in the same medium is constant.

The optical density can be quantified as a refractive index. The refractive index is the ratio of the velocity of light in a vacuum to its velocity in a specified medium and can be determined by:

$$n = \frac{c}{v}$$

n = refractive index (no unit)

c = speed of light in vacuum ($3 \times 10^8 \text{ m}\cdot\text{s}^{-1}$)

v = speed of light through medium ($\text{m}\cdot\text{s}^{-1}$)

Refractive index

The refractive index is defined as the ratio of the speed of light in vacuum (c) to the speed of light in a material (v). The refractive index is directly proportional to the optical density and inversely proportional to the velocity of light through the medium.

Medium	Refractive index
Vacuum	1
Air	$1,0003 \approx 1$
Water	1.33
Crown glass	$1,50 - 1,62$
Diamond	2.42

The refractive index (n) is also a quantitative description of the amount of refraction (bending) that occurs when light moves between media of different refractive indices. The angle of refraction can be determined using Snell's Law. There is a relationship between the angles of incidence and refraction when light travels through the boundary between two different optical media.

SNELL'S LAW

Snell's Law: The ratio of the angle of incidence and the angle of refraction is equivalent to the reciprocal of the ratio of refractive indices.

$$n_i \sin \theta_i = n_r \sin \theta_r$$

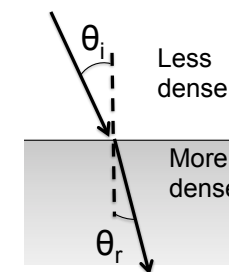
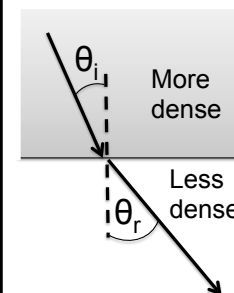
n_i = refractive index (origin medium)

n_r = refractive index (refracted medium)

θ_i = angle of incidence (origin medium)

θ_r = angle of refraction (refracted medium)

Change in optical density	Direction of bend
Less dense to more dense	Towards normal
More dense to less dense	Away from normal



EXAMPLE:

Light moves from air into glass ($n = 1,55$) at an angle of 25° to the normal. Determine the angle of refraction in the glass.

$$\begin{aligned} n_i \sin \theta_i &= n_r \sin \theta_r \\ 1 \sin 25^\circ &= 1,55 \sin \theta_r \\ \frac{1 \sin 25^\circ}{1,55} &= \sin \theta_r \\ \theta_r &= 15,82^\circ \end{aligned}$$

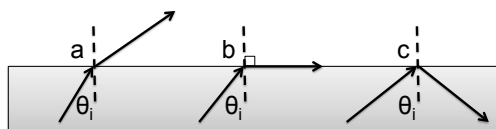
CRITICAL ANGLE

Critical angle: The angle of incidence in the optically denser medium for which the angle of refraction in the optically less dense medium is 90° . The refracted ray travels parallel to the boundary between the media.

$$n_i \sin \theta_i = n_r \sin 90^\circ$$

The relationship between the incident angle and the critical angle determines what will happen to light when it moves between media from a high optical density to a low optical density.

$$\theta_i < \theta_{\text{crit}} \quad \theta_i = \theta_{\text{crit}} \quad \theta_i > \theta_{\text{crit}}$$

a) **Refraction**

$$\theta_i < \theta_{\text{crit}}$$

The light ray is refracted at a variable angle according to Snell's Law.

b) **Refract 90°**

$$\theta_i = \theta_{\text{crit}}$$

The light ray travels along the border between the two media, at an angle of 90° to the normal.

c) **Total Internal Reflection (TIR)**

$$\theta_i > \theta_{\text{crit}}$$

The light ray is reflected internally into the incident medium. The angle of reflection is equal to the angle of incidence.

Conditions for Total Internal Reflection

Total Internal Reflection can only occur if:

- Light moves from a more optically dense to a less optically dense medium.
- The angle of incidence is greater than the critical angle.

Steps to calculate critical angle:

1. Identify the more and less dense media and their respective refractive indices.
2. Write out Snell's Law formula.
3. Assign the bigger refractive index to n_i .
4. Assign the smaller refractive index to n_r .
5. Assign 90° as θ_r .
6. Determine θ_i .

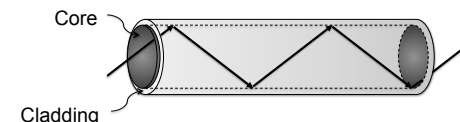
EXAMPLE:

Determine the critical angle if light passes from crown glass ($n = 1,60$) to water ($n = 1,33$).

$$\begin{aligned} n_i \sin \theta_i &= n_r \sin \theta_r \\ 1,60 \sin \theta_i &= 1,33 \sin 90 \\ \sin \theta_i &= \frac{1,33 \sin 90}{1,60} \\ \theta_i &= 56,23^\circ \end{aligned}$$

USES OF TOTAL INTERNAL REFLECTION

Fibre optics



Optical fibers are strands of flexible material strands that allow light to be transmitted over long distances using Total Internal Reflection. Optical fibers consist of an inner glass core with a high refractive index, surrounded by a cladding. The cladding has to have a lower refractive index than the core. Multiple optical fibres can be combined to form a fibre optic cable. Fibre optic cable are primarily used in telecommunications and medicine.

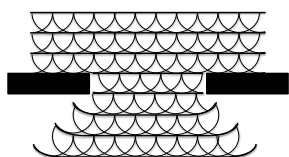
Telecommunications

- Light travels faster than current, therefore signal is faster in fibre optic cables than in copper wires.
- Fibre optic cables are less vulnerable to interception and interference.
- Fibre optic cables have very little resale value, making it less likely to be stolen.

Medicine

- Fibre optics are used in endoscopes.
- Endoscopes consists of 2 flexible fibre optic cables- one to produce light and another to return the image.
- Enables doctors to examine a patient through natural openings in the body such as the mouth, limiting the need for surgery.
- Key-hole surgery can be performed, limiting scarring and recovery time.

HUYGENS PRINCIPLE



Huygens' Principle states that **every point on a wavefront can serve as a point source for secondary, circular wavelets with a speed equal to that of the propagation of the waves**. After a time, t , the new wavefront will be that of a surface tangent to the secondary waves.

A straight wavefront is a result of the superposition of infinite circular waves.

When a wave passes through a small aperture or past a sharp edge, it curves around the corners of the obstacle or aperture. This phenomena is known as diffraction.

According to Huygens' principle, each point on the wavefront is a point source for a new wave, therefore only the wavefront that passes the obstacle is able to continue moving in a straight line. No new point sources are formed in the shadow region, resulting in wavefronts that curve around the edges.

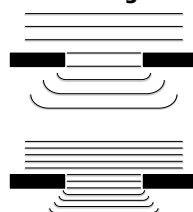
DEGREE OF DIFFRACTION

The degree of diffraction is directly proportional to the wavelength and inversely proportional to the width of the slit according to:

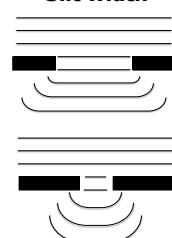
$$\text{Diffraction} \propto \frac{\lambda}{w}$$

A narrower slit and longer wave produces more of a curved pattern, in other words, more diffraction takes place.

Wavelength

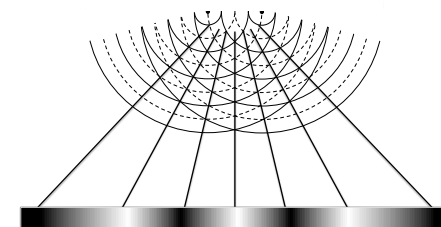


Slit width



DIFFRACTION OF LIGHT

When monochromatic light is passed through a narrow slit, a diffraction pattern forms that consists of alternating light and dark bands. The light bands are as a result of constructive interference. The dark bands form as a result of destructive interference.



Longer wavelengths are diffracted more, therefore red light will diffract more than violet light.

Longer wavelength = more diffraction / wider pattern

Narrower slit = more diffraction / wider pattern

Single slit diffraction pattern:

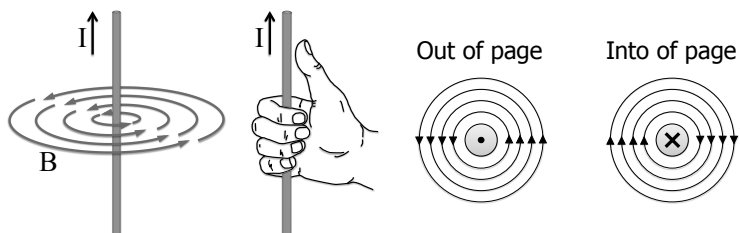


ELECTROMAGNETISM

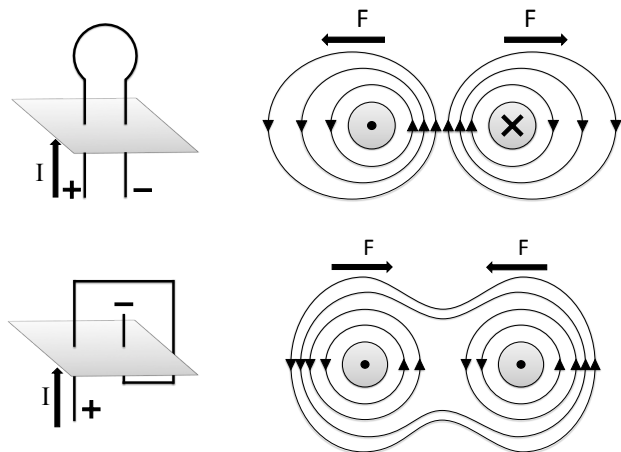
INDUCTION OF A MAGNETIC FIELD

When current passes through a conductor, a magnetic field is induced around the wire.

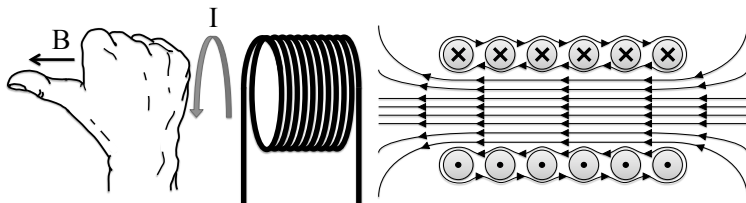
The direction of the magnetic field can be determined by the **right hand thumb rule**. For a straight, single wire, point the thumb of your right hand in the direction of the conventional current and your curled fingers will point in the direction of the magnetic field around the wire.



For a wire loop, the magnetic field is the sum of the individual magnetic fields around the single wires at each end. Use the right hand rule for a single wire at each end of the loop.



For a solenoid, curl your fingers around the solenoid in the direction of the conventional current and your thumb will point in the direction of the North pole. This is known as the **right hand solenoid rule**.



INDUCTION OF AN ELECTRIC CURRENT

When a magnet is brought close to a metal wire, it causes movement of charge in the wire. As a result, an EMF is induced in the wire. Only a **change in magnetic flux** will induce a current.

Faraday's law states that the emf induced is directly proportional to the rate of change of magnetic flux (flux linkage).

Magnetic flux linkage is the product of the number of turns on the coil and the flux through the coil.

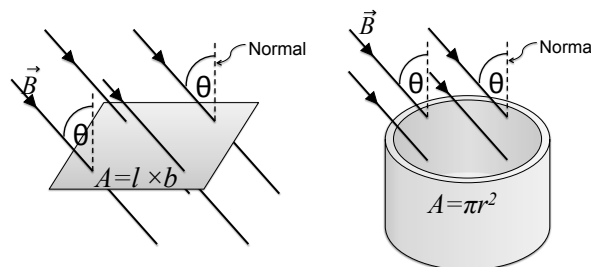
$$\epsilon = \frac{-N\Delta\phi}{\Delta t}$$

ϵ = emf (V)
 N = number of turns/windings in coil
 $\Delta\phi$ = change in magnetic flux (Wb)
 Δt = change in time (s)

The magnetic flux is the result of the product of the perpendicular component of the magnetic field and cross-sectional area the field lines pass through.

$$\phi = BA \cos \theta$$

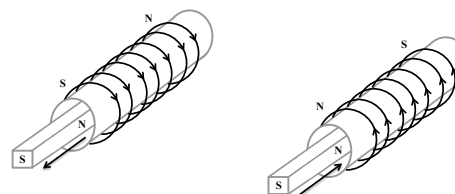
ϕ = magnetic flux (Wb)
 B = magnetic flux density (T)
 A = area (m^2)
 θ = angle between magnetic field line and normal



DIRECTION OF INDUCED CURRENT

As a bar magnet moves into a solenoid the needle of the galvanometer is deflected away from the 0 mark. As the bar magnet is removed, the needle deflects in the opposite direction. The magnetic energy is converted to electrical energy. The direction of the induced current can be determined using **Lenz's law**.

Lenz's Law states that the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnetic flux.



INCREASING THE INDUCED EMF

- Increase the rate of change of magnetic flux, ie. decrease the time it takes to change the flux, ie. increase speed of movement.
- Increase the number of loops in the coil.
- Increase the strength of the magnet.
- Increase the surface area of the loops in the coil.
- Increase the change of flux by changing the angle, θ , from a minimum of 0° to a maximum of 90° .

ENVIRONMENTAL IMPACT OF OVERHEAD CABLES

- Birds fly into power lines as they cannot see them from a distance.
- This places birds at risk of becoming extinct because of the increase in unnatural mortality.
- Trees fall onto power lines and can cause fires to erupt.
- Trees have to be cut down to make space for the power lines.
- There is no evidence that the electromagnetic effect of the power lines has any negative impact on people and the surroundings as the strength of the field is low.
- The electromagnetic effect of the power line can disrupt radio signals and for emergency services, this can be a major problem.

SERIES

If resistors are added in series, the total resistance will increase and the **total** current will decrease provided the emf remains constant.

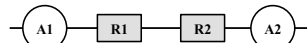
PARALLEL

If resistors are added in parallel, the total resistance will decrease and the **total** current will increase, provided the emf remains constant.

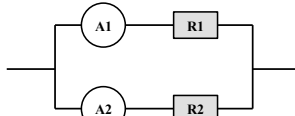
CURRENT is the rate of flow of charge.

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

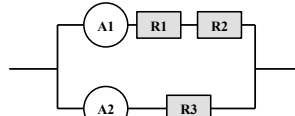
I is the current strength, **Q** the charge in coulombs and **t** the time in seconds. SI unit is ampere (A).



$$I_T = I_1 = I_2$$



$$I_T = I_1 + I_2$$



$$I_T = I_1 + I_2$$

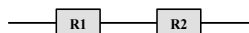
$$I_1 = I_{R1} = I_{R2}$$

RESISTANCE is the material's opposition to the flow of electric current.

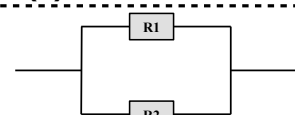
$$V = IR$$

R is the electrical resistance of the conducting material, resisting the flow of charge through it.

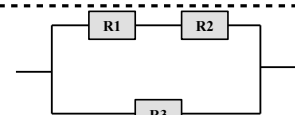
Resistance (R) is the quotient of the **potential difference (V)** across a conductor and the **current (I)** in it. The unit of resistance is called the **ohm (Ω)**.



$$R_s = R_1 + R_2$$



$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$$



$$\frac{1}{R_p} = \frac{1}{R_1 + R_2} + \frac{1}{R_3}$$

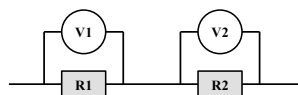
POTENTIAL DIFFERENCE (p.d.) is the **work done per unit positive charge** to move the charge from one point to another. It is often referred to as voltage.

$$V = \frac{W}{Q}$$

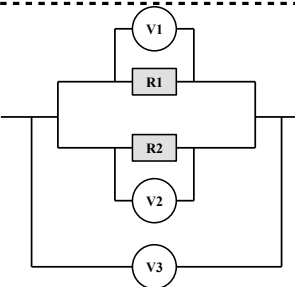
V is Potential difference in V (volts), **W** is Work done or energy transferred in J (joules) and **Q** is Charge in C (coulombs).

NOTE:

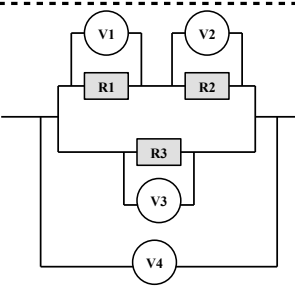
1. Emf ($\mathcal{E}$): voltage across cells when no current is flowing (open circuit).
2. V_{term} or pd: voltage across cells when current is flowing.



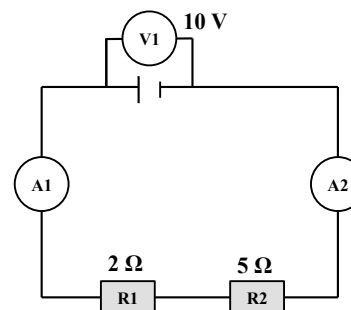
$$V_s = V_1 + V_2$$



$$V_p = V_1 = V_2 = V_3$$



$$V_p = V_3 = V_4 = (V_1 + V_2)$$

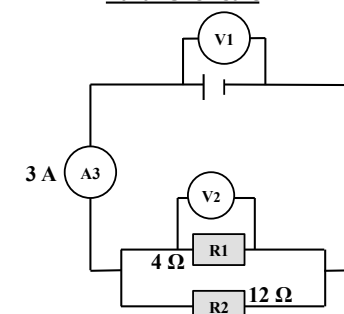
CALCULATIONS (NO INTERNAL RESISTANCE)**Series circuit**

a) Determine the total resistance.

$$\begin{aligned} R_{\text{tot}} &= R_1 + R_2 \\ &= 2 + 5 \\ &= 7 \Omega \end{aligned}$$

b) Determine the reading on A1 and A2.

$$\begin{aligned} V &= IR \\ 10 &= I(7) \\ I &= 1,43 \text{ A} \\ \therefore A1 = A2 &= 1,43 \text{ A} \end{aligned}$$

Parallel circuit

a) Determine the total resistance.

$$\begin{aligned} \frac{1}{R_p} &= \frac{1}{R_1} + \frac{1}{R_2} \\ &= \frac{1}{4} + \frac{1}{12} \\ &= \frac{1}{3} \\ \therefore R_p &= 3 \Omega \end{aligned}$$

b) Determine the reading on V1 and V2.

$$\begin{aligned} V_1 &= IR \\ &= (3)(3) \\ &= 9 \text{ V} \\ \therefore V1 = V2 &= 9 \text{ V} \end{aligned}$$

Combination circuits

Consider the circuit given. (Internal resistance is negligible)

Calculate:

a) the effective resistance of the circuit.

b) the reading on ammeter A1.

c) the reading on voltmeter V1.

d) the reading on ammeter A2.

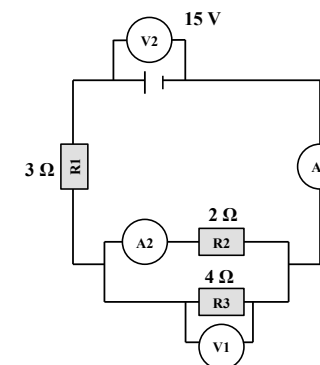
$$\begin{aligned} \frac{1}{R_p} &= \frac{1}{R_2} + \frac{1}{R_3} \\ &= \frac{1}{2} + \frac{1}{4} \\ &= \frac{3}{4} \\ \therefore R_p &= \frac{4}{3} = 1,33 \Omega \end{aligned}$$

$$\begin{aligned} R_{\text{tot}} &= R_{3\Omega} + R_p \\ &= 3 + 1,33 \\ &= 4,33 \Omega \end{aligned}$$

$$\begin{aligned} \text{b) } R_{\text{tot}} &= \frac{V_{\text{tot}}}{I_1} \\ 4,33 &= \frac{15}{I_1} \\ I_1 &= 3,46 \text{ A} \end{aligned}$$

$$\begin{aligned} \text{c) } R_p &= \frac{V_1}{I_1} \\ 1,33 &= \frac{V_1}{3,46} \\ V_1 &= 4,60 \text{ V} \end{aligned}$$

$$\begin{aligned} \text{d) } R_{2\Omega} &= \frac{V_1}{I_2} \\ 2 &= \frac{4,60}{I_2} \\ I_2 &= 2,30 \text{ A} \end{aligned}$$



ELECTRICITY

INTERNAL RESISTANCE

OHM'S LAW

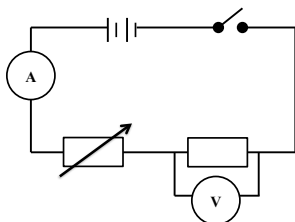
Current through a conductor is directly proportional to the potential difference across the conductor at constant temperature.

$$R = \frac{V}{I}$$

Proof of Ohm's law:

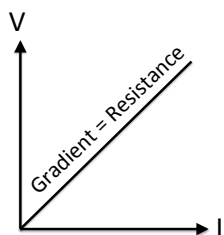
The current in the circuit is changed using the rheostat, thus current is the independent variable and potential difference is the dependent variable. It is important that the temperature of the resistor is kept constant.

The resultant graph of potential difference vs current indicates if the conductor is ohmic or non-ohmic.



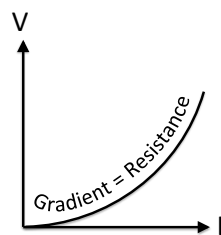
Ohmic conductor

- An Ohmic conductor is a conductor that obeys Ohm's law at all temperatures.
- Constant ratio for $\frac{V}{I}$.
- E.g. Nichrome wire



Non-ohmic conductor

- A Non-ohmic conductor is a conductor that does not obey Ohm's law at all temperatures.
- Ratio for $\frac{V}{I}$ change with change in temperature.
- E.g. Light bulb



POWER

Power is the rate at which work is done.

$$P = \frac{W}{\Delta t}$$

$$P = I^2 R$$

$$P = VI$$

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

P = power (W)

W = work (J)

Δt = time (s)

I = current (A)

V = potential difference (V)

R = resistance (Ω)

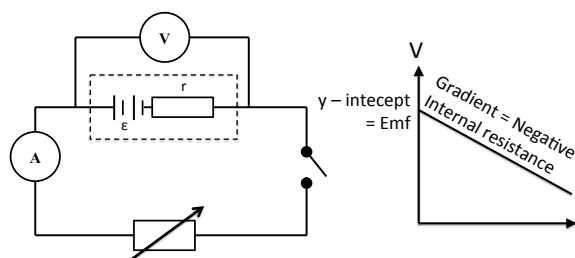
The potential difference across a battery not connected in a circuit is the emf of the battery.

Emf is the total energy supplied per coulomb of charge by the cell.

When connected in a circuit the potential difference drops due to the internal resistance of the cells.

In reality all cells have internal resistance (r). Internal resistors are always considered to be connected in series with the rest of the circuit.

Determining the emf and internal resistance of a cell



Independent variable	Current (I)
Dependent variable	Potential difference (V)
Controlled variable	Temperature

COST OF ELECTRICITY

Electricity is paid for in terms of the amount of energy used by the consumer.

Cost of electricity = power $\times$ time $\times$ cost per unit

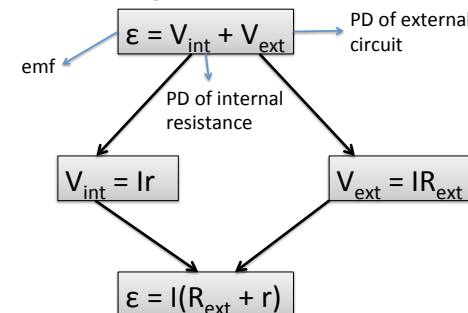
Note:
P in kW
t in hours

Example

A geyser produces 1200 W of power. Calculate the cost of having the geyser switched on for 24 hours, if the price of electricity is 85 c per unit.

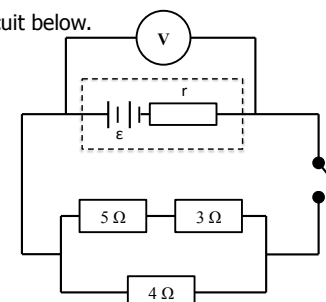
$$\begin{aligned} \text{Cost} &= \text{power} \times \text{time} \times \text{cost per unit} \\ &= (1,2)(24)(0,85) \\ &= \text{R}24,48 \end{aligned}$$

CALCULATIONS (WITH INTERNAL RESISTANCE)



EXAMPLE:

Consider the circuit below.



- When the switch is open the reading on the voltmeter is 12 V.
- When the switch is closed the current through the 3 Ω resistor is 1 A.

- Calculate the total current of the circuit.
- Calculate the internal resistance of the battery.

$$\begin{aligned} R_{top} &= R_{5\Omega} + R_{3\Omega} \\ &= 5 + 3 \\ &= 8 \Omega \\ R_{top} : R_{4\Omega} &= 8 : 4 \\ 8 : 2 &= 4 : 1 \end{aligned}$$

$$\therefore I_{top} : I_{4\Omega} = 1 : 2$$

$$\begin{aligned} I_{4\Omega} &= 2I_{top} \\ &= 2(1) \\ &= 2 \text{ A} \end{aligned}$$

$$\begin{aligned} I_{tot} &= I_{top} + I_{4\Omega} \\ &= 1 + 2 \\ &= 3 \text{ A} \end{aligned}$$

$$\begin{aligned} \text{b) } \frac{1}{R_p} &= \frac{1}{R_{top}} + \frac{1}{R_{4\Omega}} \\ &= \frac{1}{8} + \frac{1}{4} \\ &= \frac{3}{8} \\ R_p &= \frac{8}{3} = 2,67 \Omega \\ \varepsilon &= I(R + r) \\ 12 &= 3(2,67 + r) \\ r &= 1,33 \Omega \end{aligned}$$

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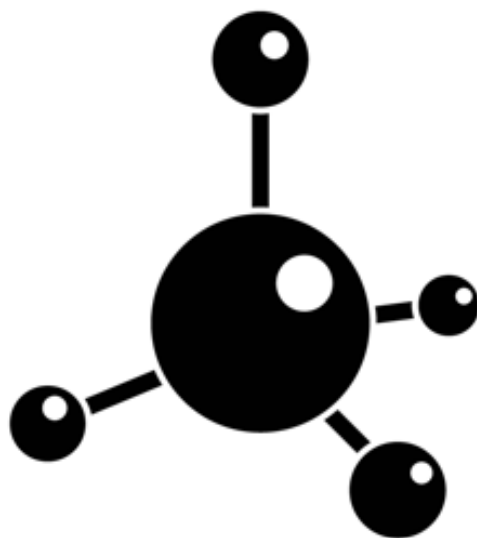
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Grade 11 Chemistry

DATA FOR PHYSICAL SCIENCES GRADE 11
PAPER 2 (CHEMISTRY)

GEGEWENS VIR FISIIESE WETENSKAPPE GRAAD 11
VRAESTEL 2 (CHEMIE)

TABLE 1: PHYSICAL CONSTANTS/TABEL 1: FISIIESE KONSTANTES

NAME/NAAM	SYMBOL/SIMBOOL	VALUE/WAARDE
Avogadro's constant <i>Avogadro-konstante</i>	N_A	$6,02 \times 10^{23} \text{ mol}^{-1}$
Molar gas constant <i>Molêre gaskonstante</i>	R	$8,31 \text{ J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}$
Standard pressure <i>Standaarddruk</i>	$p^\ominus$	$1,013 \times 10^5 \text{ Pa}$
Molar gas volume at STP <i>Molêre gasvolume by STD</i>	V_m	$22,4 \text{ dm}^3\cdot\text{mol}^{-1}$
Standard temperature <i>Standaardtemperatuur</i>	$T^\ominus$	273 K

TABLE 2: FORMULAE/TABEL 2: FORMULES

$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$	$pV = nRT$
$n = \frac{m}{M}$	$n = \frac{N}{N_A}$
$n = \frac{V}{V_m}$	$c = \frac{n}{V}$ OR/OF $c = \frac{m}{MV}$

TABLE 3: THE PERIODIC TABLE OF ELEMENTS/TABEL 3: DIE PERIODIEKE TABEL VAN ELEMENTE

1 (I)	2 (II)	3	4	5	6	7	8	9	10	11	12	13 (III)	14 (IV)	15 (V)	16 (VI)	17 (VII)	18 (VIII)	
1 2,1 H 1	KEY/SLEUTEL Atomic number <i>Atoomgetal</i> Electronegativity <i>Elektronegatiwiteit</i> Symbol <i>Simbool</i> Approximate relative atomic mass <i>Benaderde relatiewe atoommassa</i>											2 He 4						
3 1,0 Li 7	4 1,5 Be 9												5 2,0 B 11	6 2,5 C 12	7 3,0 N 14	8 3,5 O 16	9 4,0 F 19	10 Ne 20
11 0,9 Na 23	12 1,2 Mg 24												13 1,5 Al 27	14 1,8 Si 28	15 2,1 P 31	16 2,5 S 32	17 3,0 Cl 35,5	18 Ar 40
19 0,8 K 39	20 1,0 Ca 40	21 1,3 Sc 45	22 1,5 Ti 48	23 1,6 V 51	24 1,6 Cr 52	25 1,5 Mn 55	26 1,8 Fe 56	27 1,8 Co 59	28 1,8 Ni 59	29 1,9 Cu 63,5	30 1,6 Zn 65	31 1,6 Ga 70	32 1,8 Ge 73	33 2,0 As 75	34 2,4 Se 79	35 2,8 Br 80	36 Kr 84	
37 0,8 Rb 86	38 1,0 Sr 88	39 1,2 Y 89	40 1,4 Zr 91	41 Nb 92	42 1,8 Mo 96	43 1,9 Tc	44 2,2 Ru 101	45 2,2 Rh 103	46 2,2 Pd 106	47 1,9 Ag 108	48 1,7 Cd 112	49 1,7 In 115	50 1,8 Sn 119	51 1,9 Sb 122	52 2,1 Te 128	53 2,5 I 127	54 Xe 131	
55 0,7 Cs 133	56 0,9 Ba 137	57 La 139	72 1,6 Hf 179	73 Ta 181	74 W 184	75 Re 186	76 Os 190	77 Ir 192	78 Pt 195	79 Au 197	80 Hg 201	81 1,8 Tl 204	82 1,8 Pb 207	83 1,9 Bi 209	84 2,0 Po	85 2,5 At	86 Rn	
87 0,7 Fr	88 0,9 Ra 226	89 Ac																
			58 Ce 140	59 Pr 141	60 Nd 144	61 Pm	62 Sm 150	63 Eu 152	64 Gd 157	65 Tb 159	66 Dy 163	67 Ho 165	68 Er 167	69 Tm 169	70 Yb 173	71 Lu 175		
			90 Th 232	91 Pa	92 U 238	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr		

Atomic Combinations	Intramolecular bond: bond which occurs between atoms within molecules Electronegativity: a measure of the tendency of an atom to attract a bonding pair of electrons Covalent bond: a sharing of at least one pair of electrons by two atoms Non - polar covalent (pure covalent): an equal sharing of electrons Polar covalent: unequal sharing of electrons leading to a dipole forming (as a result of electronegativity difference) Ionic bond: a transfer of electrons and subsequent electrostatic attraction Metallic bonding: being between a positive kernel and a sea of delocalized electrons
Intermolecular Forces	Ion-dipole forces: occurs between a polar molecule and an ion Ion-induced dipole forces: occurs between an ion and a non-polar molecule Van der Waals forces: weak electrostatic forces Dipole-dipole forces: occurs between two polar molecules Dipole-induced dipole forces: occurs between a polar and a non-polar molecule Induced-dipole-induced dipole forces (London Dispersion): occurs between two non-polar molecules Explain hydrogen bonds: strong intermolecular forces that occur in molecules containing hydrogen bonded to nitrogen, oxygen or fluorine Intermolecular force: a weak force of attraction between molecules or between atoms of noble gases
Ideal Gases and Thermal properties	Standard conditions: temperature of 0°C (273K) and pressure of 1,01x10⁵ Pa (1atm) Boyle's law: The volume of an enclosed gas is inversely proportional to its pressure, provided the temperature remains constant Charles'law: The volume of an enclosed gas is directly proportional to the absolute temperature provided the pressure remains constant Guy-Lussac's law: The pressure of an enclosed gas is directly proportional to its temperature on the Kelvin scale, at a constant volume
Energy and Chemical Change	Heat of reaction (ΔH): the net change of chemical potential energy of the system Exothermic reactions: reactions which transfer potential energy into thermal energy Endothermic reactions: reactions which transfer thermal energy into potential energy Activation energy: the minimum energy needed for a reaction to take place. Activated complex: the unstable transition state from reactants to products
Acids and Bases	Arrhenius theory: Acid: a substance that produces hydrogen ions (H⁺)/hydronium ions (H₃O⁺) when it dissolves in water Base: a substance that produces hydroxide ions (OH⁻) when it dissolves in water Lowry-Brønsted theory: Acid: a proton (H⁺ ion) donor Base: a proton (H⁺ ion) acceptor Strong acids: ionise completely in water to form a high concentration of H₃O⁺ ions. Eg. hydrochloric acid, sulphuric acid, nitric acid Weak acids: ionise incompletely in water to form a low concentration of H₃O⁺ ions. Eg. ethanoic acid, oxalic acid Strong bases: dissociate completely in water to form a high concentration of OH⁻ ions. Eg. sodium hydroxide, potassium hydroxide Weak bases: dissociate/ionise incompletely in water to form a low concentration of OH⁻ ions. Eg. ammonia, calcium carbonate, potassium carbonate, calcium carbonate, sodium hydrogen carbonate Concentrated acids/bases: contain a large amount (number of moles) of acid/base in proportion to the volume of water Dilute acids/bases: contain a small amount (number of moles) of acid/base in proportion to the volume of water Ampholyte (amphiprotic substance): a substance that can act as either an acid or a base. Eg. Water
Redox Reactions	Oxidation number: a number assigned to each element in a compound in order to keep track of the electrons during a reaction. Oxidation: a loss of electrons, an increase in oxidation number Reduction: a gain of electrons, a decrease in oxidation number Oxidising agent: a substance that is reduced/gains electrons. Reducing agent: a substance that is oxidised/loses electrons. Anode: the electrode where oxidation takes place Cathode: the electrode where reduction takes place Electrolyte: a solution/liquid/dissolved substance that conducts electricity through the movement of ions

MOLECULAR STRUCTURE

MOLECULAR STRUCTURE

Knowing the structure of a molecule enables you to determine its physical and chemical properties. The structure mainly depends on the type of chemical bond (force) that exist between the atoms that the molecule consists of.

CHEMICAL BONDS

Chemical bond: the net electrostatic force that two atoms sharing electrons exert on each other.

Bonding occurs when valence electrons are shared between two atoms or transferred from one atom to another. Valence electrons correspond to the group number of an element on the Periodic table.

Valence electrons: electrons in the outermost energy level of an atom that take part in bonding.

The type of bond that forms is dependent on the difference in electronegativity (ΔEN) between the atoms:

$\Delta EN = 0$: Non-polar (pure) covalent
(an equal sharing of electrons)

$\Delta EN < 1$: Weak polar

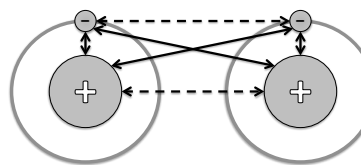
$\Delta EN \leq 2,1$: Polar covalent
(unequal sharing of electrons leading to a dipole forming)

$\Delta EN > 2,1$: Ionic
(transfer of electrons and subsequent electrostatic attraction)

BOND ENERGY

There are various attractive and repulsive forces at play between the two atoms during bonding.

- Attractive forces between the protons of one atom and the electrons of another.
- Attractive forces between the protons and electrons from the same atom.
- A repulsive force between the protons from each atom.
- A repulsive force between the electrons from each atom.



The net electrostatic forces will determine bond strength, which can be quantified as the bond energy. This is the energy required to break the bond, or energy released when bonds are formed.

Bond energy is the amount of energy required to break one mol of a specific covalent bond in gaseous phase.

FACTORS INFLUENCING BOND STRENGTH

Bond strength is determined by:

Bond length

The shorter the length of the bond, the stronger the bond.

Atom size

The smaller the atoms, the stronger the bond.

Bond order

The more bonds (double, triple bonds etc.) between the atoms, the stronger the bond.

BOND LENGTH

Bond length: the average distance between the nuclei of two bonded atoms.

As the atoms get closer, the attractive forces get stronger until the minimum possible potential energy is reached (bond energy). The distance between the nuclei of the atoms at the minimum potential energy is the bond length.

If the two atoms get closer than the bonding length, they will be forced apart by the repulsive forces, increasing the potential energy.

FACTORS INFLUENCING BOND LENGTH

Bond length is determined by:

Atom size

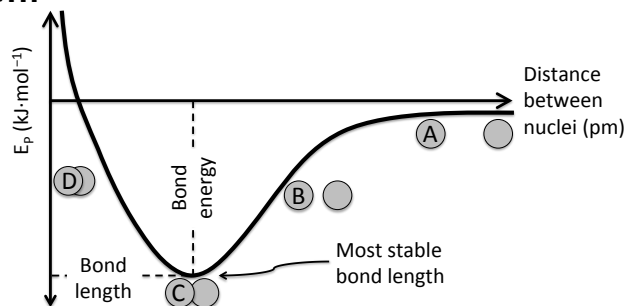
The smaller the atoms, the shorter the bond.

Bond order

The more bonds (double, triple bonds etc.) between the atoms, the shorter the bond.

Difference in electronegativity (ΔEN)

The greater the ΔEN , the shorter the bond.



Process of bond formation

- A:** Atoms are infinitely separated, potential energy is nearly zero.
B: as the atoms move closer, the forces of attraction and repulsion increase until the forces of attraction dominate.
C: the lowest, most stable energy state reached, chemical bond forms.
D: Atoms move too close, forces of repulsion increase, potential energy increases.

25

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A) Covalent Bonding (Between non-metals)

Covalent bonding is the sharing of at least one pair of electrons by two atoms.

Non-polar (pure) covalent

An equal sharing of electrons

Eg. H – P bond: $\Delta EN = EN(P) - EN(H) = 0$

Weak polar covalent

Eg. H – Br bond: $\Delta EN = EN(Br) - EN(H) = 0,7$

Polar covalent

An unequal sharing of electrons leading to a dipole forming

Eg. H – O bond: $\Delta EN = EN(O) - EN(H) = 1,4$

B) Ionic Bonding

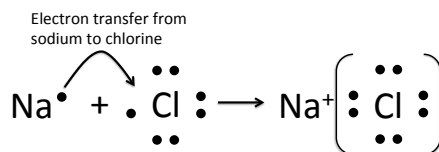
(between metals and non-metals)

Ionic bonding is a transfer of electrons and subsequent electrostatic attraction.

1. Involves a complete transfer of electron(s).
2. Metal atom gives e^- to non-metal.
3. Metal forms a positive cation.
4. Non-metal forms a negative anion.
5. Electrostatic attraction of ions leads to formation of giant crystal lattice.

Ionic Bonding takes place in two steps.

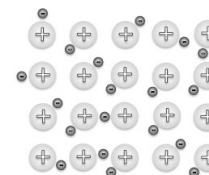
1. Transfer of $e^-(s)$ to form ions
2. Electrostatic attraction



C) Metallic Bonding (between metals)

Metallic bonding is the bond between the positive metal kernels and the sea of delocalized electrons.

The metal atoms release their valence electrons to surround them. There is a strong but flexible bond between the positive metal kernels and a sea of delocalised electrons.



MOLECULAR STRUCTURE

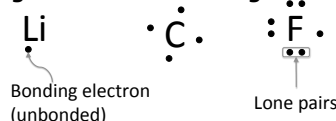
LEWIS DIAGRAMS

Molecules and the atoms that they are made up of are extremely small and cannot be seen with the naked eye. Models are used to visualize the atoms and the chemical bonds between them. One of the ways that we visualize chemical bonds is by means of Lewis diagrams.

Lewis diagrams show the valence electrons around the nucleus, represented by the element symbol.

EXAMPLE:

Give the Lewis diagrams for the following elements: Li, C, F



General steps to draw Lewis diagrams

Lewis diagrams can be drawn for a variety of molecules by using the following general steps:

1. Choose the central atom- the one with the lowest electronegativity (found on the Periodic Table).
2. Determine the total number of valence electrons.
3. Put one shared pair between the central and terminal atoms.
4. Arrange the remaining electrons around the atoms so that 8 electrons are placed around the terminal atoms. (except hydrogen = 2 electrons)
5. If there are not 8 valence electrons around the central atom, move some of the electrons in between the atoms to form multiple bonds.

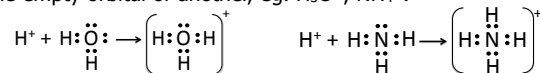
EXAMPLE:

Give the Lewis diagram for the CO₂ molecule.

1. C is the central atom as it has an electronegativity of 2,5.
2. CO₂ has 4 + 6 + 6 = 16 valence electrons = 8 electron pairs.
3. O:C:O
4. 4 electrons have been used: 16-4 = 12 electrons are left.
:O:C:O:
5. Two bonds (a double bond) between each C and O are formed.
:O::C::O:

DATIVE BONDING/ COORDINATE BONDING

A coordinate bond is formed when one atom donates both electrons to form a bonding pair. The filled electron orbital (lone pair) of one atom overlaps with the empty orbital of another, eg. H₃O⁺, NH₄⁺.



VALENCE SHELL ELECTRON PAIR REPULSION (VSEPR)

Valence shell electron pair repulsion theory: a model used to predict the shape of a molecule based on the number of electron pairs that surround the central atom.

There are five ideal shapes, when there are no lone pairs on the central atom:

Shape name	General formula	Terminal atoms	Lone pairs	Example
Linear	*AX ₂	2	0	Cl-Be-Cl
Trigonal planar	*AX ₃	3	0	
Tetrahedral	*AX ₄	4	0	
Trigonal bipyramidal	*AX ₅	5	0	
Octahedral	*AX ₆	6	0	

*A is the central atom and X represents the terminal atoms.

Molecules that have lone pairs will have a slightly different shape, since the lone pairs exert repulsive forces on the other bonding pairs, pushing them down.

Shape name	General formula	Terminal atoms	Lone pairs	Example
Angular/Bent	*AX ₂ L ₂	2	2	
Trigonal pyramidal	*AX ₃ L ₁	3	1	

BOND VS MOLECULAR POLARITY

Bond polarity

Bond polarity is determined by the electronegativity of the 2 atoms that form the bond.

Electronegativity is the tendency of an atom to attract a shared electron pair during bonding.

If one atom has a greater electronegativity than another, the electrons will be pulled more towards one atom than another. As such a shift of electrons creates negative and positive charge distributions inside the molecule.

Polar bond: an unequal distribution of electrons between two atoms during bonding.



EN (Cl) > EN (H):
Electrons shift towards chlorine.

Chlorine slightly negative (δ⁻) and hydrogen slightly positive (δ⁺).

Non-polar bond: an equal distribution of electrons between two atoms during bonding.



EN (H) = EN (H):
Bonding electrons are evenly shared.

Charge is evenly distributed and no dipole formed.

Molecular polarity

A molecule can have polar bonds, but not be polar as a whole. Molecular polarity is determined by the shape of the molecule.

Polar molecule: a molecule over which charge is distributed unevenly.



Lone pairs + EN (O):
O is slightly negative.

Lower EN (H):
H is slightly positive.

∴ uneven charge distribution
∴ polar molecule.

Non-polar molecule: a molecule over which the charge is evenly distributed.



EN (F):
F is slightly negative.

EN (B):
B is slightly positive.

F atoms evenly distributed
∴ non-polar molecule.

INTERMOLECULAR FORCES

STRENGTH OF IMF

Hydrogen bonding > Ion-dipole > dipole-dipole > ion-induced dipole > dipole-induced dipole > London dispersion forces

TYPES OF INTERMOLECULAR FORCES

Hydrogen bonding	IMF's involving ions		Van der Waals Forces		
Hydrogen bonding	Ion-dipole	Ion-induced dipole	Dipole-dipole	Dipole-induced dipole	London dispersion forces
A type of dipole-dipole attraction, but much STRONGER. Between small, highly electronegative atoms. Elements F, N, O bonded to H. Eg. H₂O.	IMF that occur between an ion and a polar molecule (dipole). Eg. NaCl in water.	Ion induces a dipole in an atom or in a non-polar molecule . Eg. Cl-ion and C ₆ H ₁₄ .	IMF that occur between polar molecules (same or not the same molecules). Eg. H ₂ S; CH ₃ Cl.	Polar molecule induces a dipole in an atom or in a non-polar molecule. Eg. O ₂ in water.	IMF between non-polar molecules that form temporary dipoles.

INTERMOLECULAR FORCES (IMF)

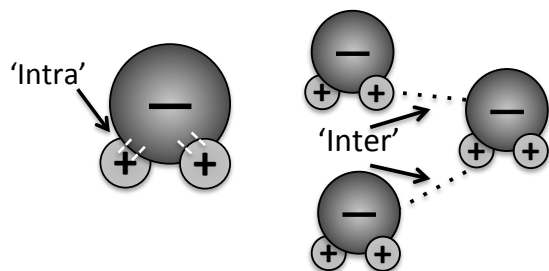
Intermolecular forces are weak forces of attraction between molecules or between atoms of noble gases.

IMF vs Intramolecular bonds

Intermolecular forces are not the same as intramolecular bonds.

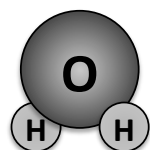
Intramolecular bonds exist between atoms in a molecule.

Intermolecular forces exist between molecules or between atoms of noble gases.



AMAZING WATER MOLECULE

- Non-symmetrical polar molecule.



- Intramolecular covalent bonds.
- Bent/angular molecular shape.
- Contains hydrogen bonding between molecules. These strong IMF need a large amount of energy to overcome.
- Water vapour acts as a greenhouse gas by absorbing the sun's radiation.
- The ocean acts as a heat reservoir and regulates the temperature of earth.

PROPERTIES OF WATER

Specific heat capacity

The amount of energy needed to raise the temperature of 1 kg of water by 1 °C. Water has a high specific heat capacity.

A high heat capacity requires more energy for the temperature to change. This helps with heat regulation on the earth.

Melting and boiling points

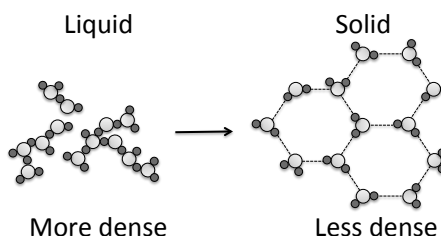
Strong hydrogen bonding IMF's require large amounts of energy to overcome intermolecular forces.

Melting point: 0 °C

Boiling point: 100 °C at atmospheric pressure.

Density

As water freezes the molecules orientate themselves so that the volume expand and the density decreases. Ice forms a crystal lattice.



Decrease in density of ice helps regulate the temperature of the earth and the climate.

Ice floats on water forming an insulating layer between water and the atmosphere keeping the water from freezing and preserving aquatic life.

EXAMPLE:

Complete the table below by identifying the dominant intermolecular force present in each example.

Substance	Intermolecular force
CO ₂	London dispersion
CO	Dipole-dipole
NH ₃	Hydrogen bonding
NaCl in water	Ion-dipole
HF	Hydrogen bonding
NO and CH ₄ gas mix	Dipole-induced dipole
HCl	Dipole-dipole
KMnO ₄ in CHCl ₃	Ion-dipole

Phase of molecules

IMF between molecules causes them to be attracted to one another.

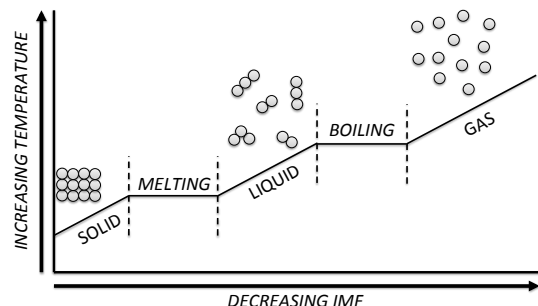
Stronger IMF = Stronger attraction

At the same temperature:

Solid: Strong IMF

Liquid: Intermediate IMF

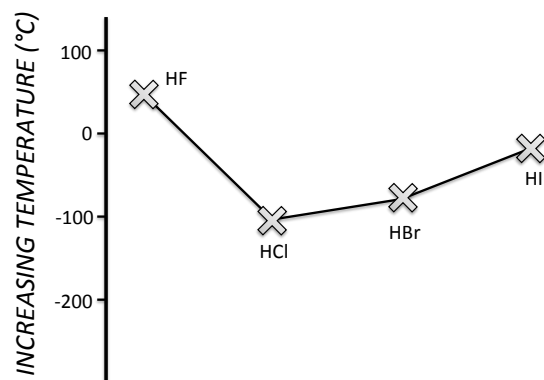
Gas: Weak IMF



Phase change

Melting: Melting points increase with increase in IMF.

Boiling: Boiling points increase with increase in IMF.



HF contains hydrogen bonding → strongest IMF → highest boiling point. HCl, HBr and HI all contain dipole-dipole forces and therefore the boiling point increases with increasing molecular mass.

Evaporation: Evaporation decreases with increase in IMF. Higher vapor pressures correspond to weaker IMF.

Adhesion

Adhesion is the intermolecular attraction of molecules to molecules of a different substance.

The strength of adhesive forces are dependent on the two specific substances interacting with each other.

Cohesion

Cohesion is the intermolecular attraction between molecules of the same substance.

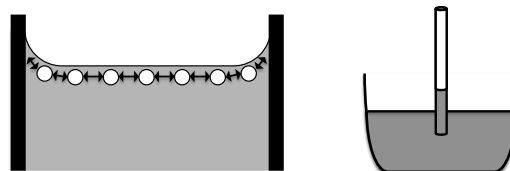
Stronger IMF = Greater cohesive forces

Capillarity

Capillarity is the tendency of liquid to rise in a tube.

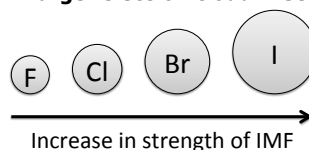
Capillary action occurs when the adhesive forces are stronger than the cohesive forces.

Stronger IMF between liquid and tube = Greater capillary action



Size of molecules

Larger molecule = Larger electron cloud = Stronger IMF



Thermal expansion

Thermal expansion is the expanding of a material when heated.

As the temperature increases, the kinetic energy of the molecules increase. This additional energy can overcome the IMF and molecules move further apart.

Stronger IMF = molecules held together strongly = Lower thermal expansion

Solubility

Solubility is the ability of a solute to dissolve in a solvent.

A solute will dissolve in a solvent with similar IMF's. "like dissolves like".

Polar and ionic solute will dissolve in a polar solvent

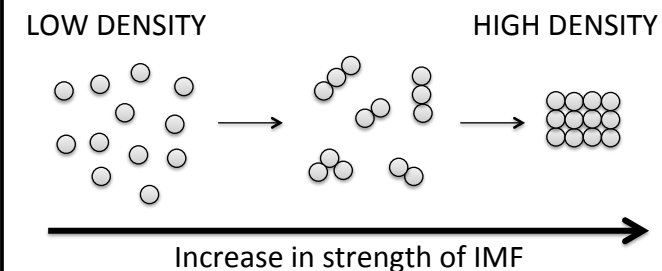
A non-polar solute will dissolve in a non-polar solvent

Density

Density is the number of particles per unit volume.

Increased IMF increases the attractive force between the particles, causing the particles to become more tightly packed. The arrangement of the particles determine the number of particles per volume, thereby determining the density.

Stronger IMF = Particles closer together = Greater density



Viscosity

Viscosity is a liquids resistance to flow.

Stronger IMF will cause the molecules in the liquid to hold together more strongly, causing the viscosity to increase.

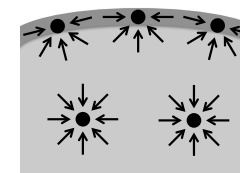
Stronger IMF = Greater viscosity

Surface tension

Surface tension is the cohesive forces between molecules on the surface of a liquid.

Molecules at the surface of a liquid experience only inward intermolecular forces.

Stronger IMF = Greater surface tension



IDEAL GASES

KINETIC MOLECULAR THEORY

Properties of gases according to kinetic molecular theory

- Particles are far apart- large spaces between them.
- Particles move with Brownian motion- Fast, random motion.
- Gases undergo diffusion- Particles spread out to fill the container.
- The forces between particles are negligibly small.
- Particles collide elastically with other particles and the walls of the container.

Three measurable variables:

Temperature (T)- a measure of average kinetic energy.

Volume (V)- the space occupied by the gas in the container.

Pressure (p)- the outward force per unit area applied by gas when the gas particles collide with the container walls.

Standard Temperature and Pressure or STP

Standard Temperature = 0 °C or 273 K

Standard Pressure = 101,3 kPa (1,013 x 10⁵ Pa)

IDEAL GASES

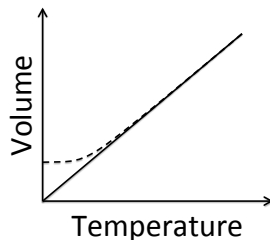
Ideal gases are theoretical gases that obey the gas laws under all conditions of temperature and pressure.

- The particles of a gas are all identical and in constant motion.
- The volume of the gas is due to the motion of the particles as the particles have no volume themselves.
- The intermolecular forces between gas particles are negligible.
- All collisions are perfectly elastic.

DEVIATION FROM IDEAL GAS

At LOW temperatures:

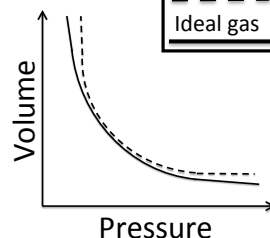
- Gas particles move much slower, decreasing the number of collisions between the particles and the container walls. Pressure of the gas is lower than expected.
- Attractive forces are stronger due to the particles being closer together and moving slower. The gas is more likely to become a liquid and the volume is greater than expected.



Real gas
Ideal gas

At HIGH pressure:

- The volume of the gas particles becomes significant in relation to the container.
- Increases in the intermolecular forces between the particles due to proximity, gas will liquify and the volume is larger than expected.

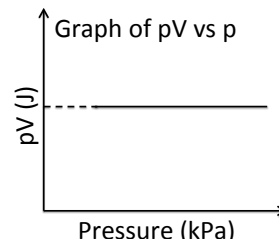
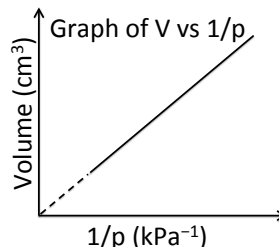
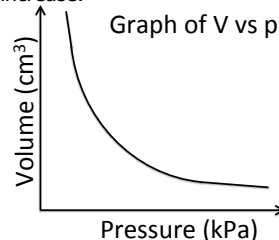


BOYLE'S LAW

$$p_1 V_1 = p_2 V_2 \quad V \propto \frac{1}{p} \quad (\text{constant } T)$$

The volume of an enclosed gas is inversely proportional to the pressure of the gas if the temperature remains constant.

The temperature remains constant, therefore the average E_k of the particles remains the same. If the volume decreases, more collisions would take place and the pressure would increase.



Example:

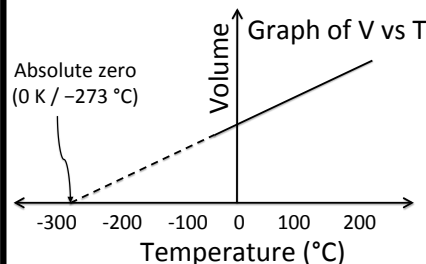
A balloon has a volume of 1000 cm³ at a pressure of 60 kPa. If the pressure on the balloon changes to 100 kPa, calculate the new volume of the balloon.

$$\begin{aligned} p_1 V_1 &= p_2 V_2 \\ (1000)(60) &= (100)V_2 \\ V_2 &= 600 \text{ cm}^3 \end{aligned}$$

CHARLES' LAW

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad V \propto T \quad (\text{constant } P)$$

The volume of an enclosed gas is directly proportional to the temperature (in Kelvin) of the gas provided the pressure remains constant.



By extending the graph, absolute zero (0 Kelvin) can be derived. 0 K is the theoretical minimum temperature, as volume (V) becomes zero at this temperature. Real gases deviate from the ideal gas laws at low temperatures, as the volume of the gas and its particles can never become zero.

$$^{\circ}\text{C} = \text{K} - 273$$

$$\text{K} = ^{\circ}\text{C} + 273$$

NB: Temperature must always be measured in Kelvin!

Example:

A certain sample of gas has a volume of 125 cm³ at standard temperature and pressure. If the pressure of the gas remains constant but the temperature of the gas increases to 25 °C, calculate the new volume of the gas.

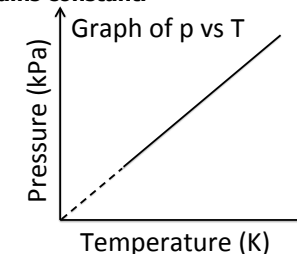
$$T_2 = 25 + 273 = 298 \text{ K}$$

$$\begin{aligned} \frac{V_1}{T_1} &= \frac{V_2}{T_2} \\ \frac{125}{273} &= \frac{V_2}{298} \\ V_2 &= 136,45 \text{ cm}^3 \end{aligned}$$

GAY LUSSAC'S LAW

$$\frac{p_1}{T_1} = \frac{p_2}{T_2} \quad P \propto T \quad (\text{constant } V)$$

The pressure of an enclosed gas is directly proportional to the absolute temperature if the volume of the gas remains constant.



A decrease in temperature indicates a decrease in kinetic energy. As kinetic energy decreases, so does the outward force during collisions between particles and container.

Example:

Calculate the pressure of a gas at 25 °C, if originally the gas had a pressure of 200 Pa at a temperature of 100 °C.

$$\begin{aligned} \frac{p_1}{T_1} &= \frac{p_2}{T_2} \\ \frac{200}{373} &= \frac{p_2}{298} \\ p_2 &= 159,79 \text{ Pa} \end{aligned}$$

GENERAL GAS EQUATION

Variables of fixed amount of gas when system changes occur.

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

p, V can be in any **consistent** units
T in Kelvin

IDEAL GAS EQUATION

Properties under single set of conditions.

$$pV = nRT$$

p = pressure in Pa

V = volume in m³

n = number of mole of gas (mol)

R = universal gas constant (8,31 J·K⁻¹·mol⁻¹)

T = temperature in K

QUANTITATIVE ASPECTS OF CHEMICAL CHANGE

The Mole

Atoms, molecules and ions are too small to count, and there are so many particles in even the smallest sample of a substance.

There are more particles of water in a teaspoon than there are teaspoons of water in all the oceans.

Rather than dealing with the particles individually, we deal with a special number of particles.

The **mole** is a name for a special number. Many numbers have names, such as:

2 = pair

3 = hat-trick

12 = dozen

A **mole** of particles is an amount of $6,02 \times 10^{23}$ particles. **$6,02 \times 10^{23}$ is known as Avogadro's number, N_A .** Avogadro's number (N_A) is too big to imagine.

602 000 000 000 000 000 000 .

This many grains of sand, piled on the surface of the earth would almost reach the moon.

The mole is defined as the number of particles or atoms in 12,0 g of Carbon-12.

Molar Mass

Particles are too small to weigh individually.

Molar mass (M) is defined as the mass of one mole of particles (atoms, molecules or formula units) and is measured in the unit $\text{g} \cdot \text{mol}^{-1}$.

$$\text{number of mole (mol)} \leftarrow n = \frac{m}{M} \rightarrow \begin{array}{l} \text{mass of substance (g)} \\ \text{molar mass (g} \cdot \text{mol}^{-1}) \end{array}$$

Relative atomic mass (A_r) is the average mass of an atom compared to the mass of a Carbon 12 atom. It is measured in atomic mass units (**amu**).

Molar mass (M) of an element is equal to the magnitude of **relative atomic mass (A_r)** in amu. **This is found on the periodic table.** See the table below for other substances:

Type of substance	Particles	Example	Formula	Molar mass $\text{g} \cdot \text{mol}^{-1}$
Element	Atoms	Neon	Ne	20
Covalent compound	Usually Molecules	Carbon dioxide	CO_2	$12+32$ $= 44$
Ionic compound	Ions (formula units)	Salt	NaCl	$23+35,5$ $= 58,5$
Metallic compound	Positive kernels and delocalized electrons	Gold	Au	197

EXAMPLE:

What is the relative formula mass of Calcium sulphate (CaSO_4)?

$$M_R(\text{CaSO}_4) = A_r(\text{Ca}) + A_r(\text{S}) + (4 \times A_r(\text{O}))$$

$$= 40 + 32 + (4 \times 16)$$

$$= 136 \text{ (no unit)}$$

EXAMPLE:

What is the molar mass of Calcium sulphate (CaSO_4)?

$$136 \text{ g} \cdot \text{mol}^{-1}$$

EXAMPLE:

What is the relative molecular mass of sucrose ($\text{C}_{12}\text{H}_{22}\text{O}_{11}$)?

$$M_R(\text{C}_{12}\text{H}_{22}\text{O}_{11}) = 12 \times A_r(\text{C}) + 22 \times A_r(\text{H}) + 11 \times A_r(\text{O})$$

$$= (12 \times 12) + (22 \times 1) + (11 \times 16)$$

$$= 342 \text{ (no unit)}$$

EXAMPLE:

What is the molar mass of sucrose ($\text{C}_{12}\text{H}_{22}\text{O}_{11}$)?

$$342 \text{ g} \cdot \text{mol}^{-1}$$

Percentage Composition

$$\text{Percentage composition of element} = \frac{\text{molar mass of element}}{M_R \text{ of compound}} \times 100$$

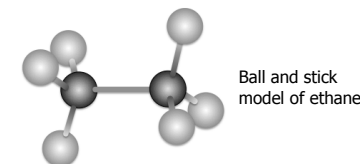
Consider these iron ores: haematite and magnetite – which contains more iron by mass?

Ore	Haematite	Magnetite
Formula	Fe_2O_3	Fe_3O_4
Relative molecular mass	$(2 \times 56) + (3 \times 16)$ $= 160$	$(3 \times 56) + (4 \times 16)$ $= 232$
% iron by mass	$[(2 \times 56) / 160] \times 100$ $= 70\%$	$[(3 \times 56) / 232] \times 100$ $= 72\%$

$\therefore$ magnetite contains more iron

Different types of Chemical Formulae

Consider the substance ethane



It also can be represented using a formula. There are three types of formulas we use:

Molecular formula	Actual number of each atom.	Eg. C_2H_6
Empirical formula	Simplest whole number ratio of the atoms.	Eg. $\text{C}_2\text{H}_6 \rightarrow \text{CH}_3$
Structural formula	Shows how the atoms are joined.	$\begin{array}{cc} \text{H} & \text{H} \\ & \\ \text{H}-\text{C} & -\text{C}-\text{H} \\ & \\ \text{H} & \text{H} \end{array}$

QUANTITATIVE ASPECTS OF CHEMICAL CHANGE

Concentrations of solutions

Solutions are homogeneous (uniform) mixtures of two or more substances. A solution is formed when a solute dissolves in a solvent.

The solvent and solute can be a gas, liquid, or solid. The most common **solvent** is liquid water. This is called an **aqueous solution**.

Solution	Solute	Solvent
salt water	Salt	water
Soda water	Carbon dioxide	water

Concentration

The **concentration** of a solution is the number of mole of solute per unit volume of solution.

$$\text{concentration (mol} \cdot \text{dm}^{-3}) \leftarrow C = \frac{n}{V} \rightarrow \text{volume (dm}^3\text{)}$$

n → number of moles (mol)
 V → volume (dm³)

can also be calculated with

$$c = \frac{m}{MV}$$

i.e. The number moles of solute per 1 dm³ of solution i.e. mol.dm⁻³. If a solution of **potassium permanganate KMnO₄** has a concentration of 2 mol.dm⁻³ it means that for every 1 dm³ of solution, there are 2 moles of KMnO₄ dissolved in the solvent.

Note:
 1000 cm³ = 1 dm³ (= 1 litre)
 1 cm³ = 0,001 dm³
 1 cm³ = 1 ml

EXAMPLE:

A solution contains 10 g of sodium hydroxide, NaOH, in 200 cm³ of solution. Calculate the concentration of the solution.

$$\begin{aligned} n(\text{NaOH}) &= \frac{m}{M} \\ &= \frac{10}{23 + 16 + 1} \\ &= 0,25 \text{ mol} \end{aligned}$$

$$V = 200 \text{ cm}^3 = 0,2 \text{ dm}^3$$

$$\begin{aligned} c(\text{NaOH}) &= \frac{n}{V} \\ &= \frac{0,25}{0,2} \\ &= 1,25 \text{ mol} \cdot \text{dm}^{-3} \end{aligned}$$

EXAMPLE:

Calculate the mass of solute in 600 cm³ of 1,5 mol.dm⁻³ sodium chloride solution.

$$V = 600 \text{ cm}^3 = 0,6 \text{ dm}^3$$

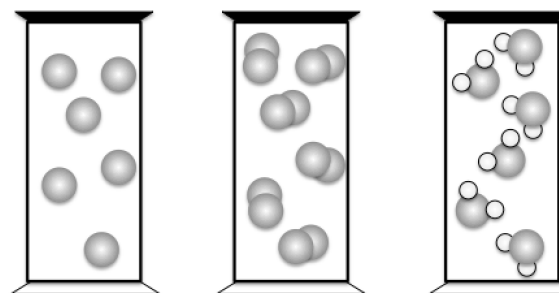
$$\begin{aligned} M(\text{NaCl}) &= 23 + 35,5 \\ &= 58,5 \text{ g} \cdot \text{mol}^{-1} \end{aligned}$$

$$\begin{aligned} n &= cV \\ &= 1,5 \times 0,6 \\ &= 0,9 \text{ mol} \end{aligned}$$

$$\begin{aligned} m &= nM \\ &= 0,9 \times 58,5 \\ &= 52,65 \text{ g} \end{aligned}$$

Molar Volumes of Gases

If different gases have the same volume under the same conditions of temperature and pressure, they will have the same number of molecules.

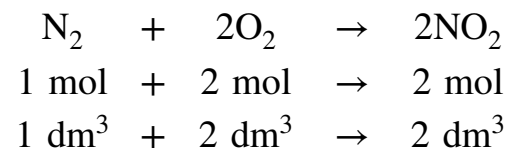


The **molar volume** of a gas, V_M , is the volume occupied by one mole of the gas.

V_M for **all gases** at STP is **22.4 dm³·mol⁻¹**.

Standard Temperature and Pressure (STP) is 273 K (0°C) and 1,01x10⁵ Pa.

This also means that for reactions at constant temperature and pressure, gas volumes will react in the same ratio as the molar ratio.



$$\text{number of moles (mol)} \leftarrow n = \frac{V}{V_M} \rightarrow \text{molar gas volume at STP (22,4 dm}^3 \cdot \text{mol}^{-1}\text{)}$$

V → volume of gaseous substance (dm³)

EXAMPLE:

A gas jar with a volume of 224 cm³ is full of **chlorine gas**, at STP. How many **moles** of chlorine gas are there in the gas jar?

$$\begin{aligned} n &= \frac{V}{V_M} \\ &= \frac{0,224}{22,4} \\ &= 0,01 \text{ mol} \end{aligned}$$

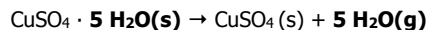
QUANTITATIVE ASPECTS OF CHEMICAL CHANGE

Water of crystallization

Some ionic crystals trap a certain number of water molecules between the ions as they are forming. These water molecules are known as "Water of crystallization".

Eg. Hydrated copper sulphate:

$\text{CuSO}_4 \cdot 5 \text{H}_2\text{O}$ has 5 water molecules per formula unit. When the hydrated salt crystals are heated, the water molecules evaporate off, leaving the anhydrous salt behind.



To calculate the number of moles of water of crystallization:

1. Calculate the mass of water that evaporated off.
2. Calculate the moles of water.
3. Calculate the moles of anhydrous salt.
4. Determine the ratio of water to anhydrous salt.
5. Write the formula for the hydrated salt.

Note:

The dot in the formula ($\cdot$) between the salt and the water means that a light bond is formed. It is **NOT** a multiplication dot.

EXAMPLE:

13,2 g of a sample of zinc sulphate, $\text{ZnSO}_4 \cdot x\text{H}_2\text{O}$, was heated in a crucible. Calculate the number of moles of water of crystallisation if 7,4 g of solid remained.

$$1. m(\text{H}_2\text{O}) = 13,2 \text{ g} - 7,4 \text{ g} \\ = 5,8 \text{ g}$$

$$2. n(\text{H}_2\text{O}) = \frac{m}{M} \\ = \frac{5,8}{18} \\ = 0,32 \text{ mol}$$

$$3. n(\text{ZnSO}_4) = \frac{m}{M} \\ = \frac{7,4}{161} \\ = 0,046 \text{ mol}$$

$$4. \text{ratio} = \frac{\text{mol water}}{\text{mol anhydrous salt}} \\ = \frac{0,32}{0,046} \\ = 1 : 7$$

$$5. \therefore \text{formula} = \text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$$

Calculating the Empirical Formula of a Compound from Mass

Empirical formula is the chemical formula of a compound that shows the smallest whole number ratio of the atoms.

To calculate the empirical formula of a compound from mass:

1. Determine the mass of the elements.
2. Determine mol of each substance.
3. Simplify the atomic ratio.

EXAMPLE:

In a combustion reaction 0,48 g of magnesium ribbon is burnt. The amount of magnesium oxide produced is 0,80 g.

Calculate the **empirical formula** for **magnesium oxide**.

Steps	Magnesium	Oxygen
Step 1: Mass of element	0.48 g	0.80 – 0.48 = 0.32 g
Step 2: Mol (divide by mass of 1 mol)	$n = m / M$ $= 0.48 / 24$ $= 0,02 \text{ mol}$	$n = m / M$ $= 0.32 / 16$ $= 0,02 \text{ mol}$
Step 3: Atom ratio (divide by smallest no in ratio)	1	1

Empirical formula: MgO

EXAMPLE:

A sample of an **oxide of copper** contains 8 g of copper combined with 1 g of oxygen.

Find the **empirical formula** of the compound.

Steps	Copper	Oxygen
Step 1: Mass of element	8 g	1 g
Step 2: Mol (divide by mass of 1 mol)	$n = m / M$ $= 8 / 63,5$ $= 0,126 \text{ mol}$	$n = m / M$ $= 1 / 16$ $= 0,0625 \text{ mol}$
Step 3: Atom ratio (divide by smallest no in ratio)	0,126/0,0625 ≈ 2	0,0625/0,0625 $= 1$

Empirical formula: Cu₂O

Calculating the Empirical Formula from Percentage Composition

The empirical formula of a compound can also be found from its percentage composition. We assume that 100 g of the compound is analysed, then each percentage gives the mass of the element in grams in 100 g of the compound.

An **oxide of sulphur** contains 40% sulphur and 60% oxygen by mass. Determine the **empirical formula** of this oxide of sulphur.

Steps	Sulphur	Oxygen
Step 1: % of element	40	60
Step 2: Mass of element (g)	40	60
Step 3: Mol	$n = m / M$ $= 40 / 32$ $= 1,25 \text{ mol}$	$n = m / M$ $= 60 / 16$ $= 3,75 \text{ mol}$
Step 4: Smallest mol ratio	1,25 / 1,25 $= 1$	3,75 / 1,25 $= 3$

Empirical formula: SO₃

QUANTITATIVE ASPECTS- REACTIONS

Empirical formula to Molecular Formula

The **empirical formula** is the simplest whole number ratio of atoms in a molecule. The **molecular formula** is the actual ratio of the atoms in a molecule.

The molecular formula can be calculated from the empirical formula and the relative molecular mass.

STEPS TO DETERMINE MOLECULAR FORMULA:

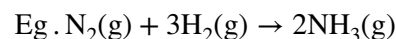
1. Determine the empirical formula (if not given).
2. Determine the molar mass of the empirical formula.
3. Determine the ratio between molecular formula and empirical formula.
4. Multiply the ratio into the empirical formula

EXAMPLE:

Butene has the empirical formula CH_2 . The molecular mass of butene is $56 \text{ g} \cdot \text{mol}^{-1}$. Determine the molecular formula of butene.

1. Empirical formula given: CH_2
2.
$$\begin{aligned} M(\text{CH}_2) &= 12 + 1 + 1 \\ &= 14 \text{ g} \cdot \text{mol}^{-1} \end{aligned}$$
3.
$$\begin{aligned} \text{ratio number} &= \frac{\text{molecular formula mass}}{\text{empirical formula mass}} \\ &= \frac{56}{14} \\ &= 4 \end{aligned}$$
4.
$$\text{CH}_2 \times 4 = \text{C}_4\text{H}_8$$

Balanced chemical equations



The balanced chemical equation is the "recipe". It tells us:

- The reactants used i.e. Nitrogen and Hydrogen
- The products produced. i.e. ammonia
- The states of the reactants and products (all gases here)
- The molar ratio of the reactants to products.

1 molecule of nitrogen reacts with 3 molecules of hydrogen to form 2 molecules of ammonia.

1 mole of nitrogen reacts with 3 moles of hydrogen to form 2 moles of ammonia.

Approach to reaction stoichiometry

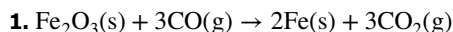
1. Write a balanced chemical equation.
2. Change the 'given' amount into mole (use limiting reactant if applicable).
3. Determine the number of mole of the 'asked' substance using the mole ratio.
4. Determine the 'asked' amount from the number of mole.

EXAMPLE:

To obtain iron, iron (III) oxide reacts with carbon monoxide according to the following word equation:



What mass of iron is produced from 48 g of iron (III) oxide?



2.
$$\begin{aligned} n(\text{Fe}_2\text{O}_3) &= \frac{m}{M} \\ &= \frac{48}{160} \\ &= 0,3 \text{ mol} \end{aligned}$$

3.
$$\begin{array}{ccc} \text{Fe}_2\text{O}_3 & : & \text{Fe} \\ 1 & : & 2 \\ 0,3 \text{ mol} & : & 0,6 \text{ mol} \end{array}$$

4.
$$\begin{aligned} m(\text{Fe}) &= nM \\ &= (0,6)(56) \\ &= 33,6 \text{ g} \end{aligned}$$

GIVEN VALUE

GIVEN MOL

ASKED MOL

ASKED VALUE

STEP TWO:

Solid: $n = \frac{m}{M}$	Solution: $n = cV$	Gas: $n = \frac{V}{22,4}$ (At STP)
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STEP THREE: Use molar ratios

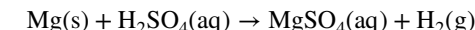
STEP FOUR:

Solid: $m = nM$	Solution: $c = \frac{n}{V}$	Gas: $V = n \times 22,4$ (At STP)
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Limiting Reactants

In a reaction between two substances, one reactant is likely to be used up completely before the other. This limits the amount of product formed.

Consider the reaction between magnesium and dilute sulphuric acid. The balanced chemical equation is



This means that 1 mole of magnesium reacts with 1 mole of sulphuric acid. Both reactants will be completely used up by the time the reaction stops.

What happens if 1 mole of magnesium reacts with 2 mole of sulphuric acid? There is now insufficient magnesium to react with all of the sulphuric acid. 1 mole of sulphuric acid is left after the reaction.

All of the magnesium is used up, We say the magnesium is the **limiting reactant**. Some sulphuric acid is left after the reaction. We say the sulphuric acid is in **excess**.

The amount of limiting reactant will determine:

- The amount of product formed.
- The amount of other (excess) reactants used.

Determining limiting reactants

1. Calculate the number of moles of each reactant.
2. Determine the ratio between reactants.
3. Determine limiting reactant using the ratios.

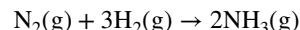
NOTE:

If one reactant is in **excess**, it means **that there is more than enough of it**. If there are only 2 reactants and one is in excess, it means that the other is the limiting reactant.

QUANTITATIVE ASPECTS OF CHEMICAL CHANGE

EXAMPLE:

A 8,4 g sample of nitrogen reacts with 1,5 g hydrogen. The balanced equation is:



Determine (a) which reactant is the limiting reactant, and (b) the mass of ammonia that can be produced.

(a)

$$\begin{aligned} 1. \quad n(\text{N}_2) &= \frac{m}{M} \\ &= \frac{8,4}{28} \\ &= 0,3 \text{ mol} \end{aligned}$$

$$\begin{aligned} n(\text{H}_2) &= \frac{m}{M} \\ &= \frac{1,5}{2} \\ &= 0,75 \text{ mol} \end{aligned}$$

$$\begin{array}{lcl} 2. \quad \text{N}_2 & : & \text{H}_2 \\ 1 & : & 3 \\ 0,3 \text{ mol} & : & 0,9 \text{ mol} \\ 0,25 \text{ mol} & : & 0,75 \text{ mol} \end{array}$$

3.

If all nitrogen is used, 0,9 mol hydrogen is needed. However, only 0,75 mol hydrogen is available. The hydrogen will run out first, therefore hydrogen is the limiting reactant.

(b)

Because the hydrogen is the limiting reactant, it will determine the mass of ammonia produced:

$$\begin{array}{lcl} \text{H}_2 & : & \text{NH}_3 \\ 3 & : & 2 \\ 0,75 \text{ mol} & : & 0,5 \text{ mol} \\ \\ n(\text{NH}_3) & = & nM \\ & = & (0,5)(17) \\ & = & 8,5 \text{ g} \end{array}$$

Percentage Purity

Sometimes chemicals are not pure and one needs to calculate the percentage purity. Only the pure component of the substance will react. For an impure sample of a substance:

$$\text{Percentage purity} = \frac{\text{Mass of pure substance}}{\text{Mass of impure substance}} \times 100$$

STEPS TO DETERMINE THE PERCENTAGE PURITY

1. Determine moles of products.
2. From the balanced formula, determine the ratio between reactants and products.
3. Using the ratio, determine the number of moles of reactants.
4. Determine the mass of pure reactant.
5. Calculate the percentage purity of the sample.

EXAMPLE:

An impure sample of calcium carbonate, CaCO_3 , contains calcium sulphate, CaSO_4 , as an impurity. When excess hydrochloric acid was added to 6g of the sample, 1200 cm^3 of gas was produced (measured at STP). Calculate the percentage purity of the calcium carbonate sample. The equation for the reaction is:



$$1. \quad n(\text{CO}_2) = \frac{V}{V_M} = \frac{1,2}{22,4} = 0,054 \text{ mol}$$

$$\begin{array}{lcl} 2. \quad \text{CaCO}_3 & : & \text{CO}_2 \\ 1 & : & 1 \\ 0,054 & : & 0,054 \end{array} \quad \begin{array}{lcl} 3. \quad \text{CaCO}_3 & : & \text{CO}_2 \\ 1 & : & 1 \\ 0,054 & : & 0,054 \end{array}$$

$$\therefore 0,054 \text{ mol CaCO}_3 \text{ reacted}$$

$$4. \quad m(\text{CaCO}_3) = nM = (0,054)(40 + 12 + 16 + 16 + 16) = 5,4 \text{ g}$$

$$5. \quad \text{Percentage purity} = \frac{\text{Mass of pure substance}}{\text{Mass of impure substance}} \times 100$$

$$\text{Percentage purity} = \frac{5,4}{6,0} \times 100$$

$$\text{Percentage purity} = 90 \%$$

Percentage Yield

When you make a chemical in a laboratory a little of the chemical is always lost, due to evaporation into the surrounding air, or due to a little being left in solution. Some of the reactants may not react. We say that the reaction has not run to completion.

This results in the amount of the chemical produced always being less than the maximum theoretical amount you would expect. We can express this by the percentage yield:

$$\text{Percentage yield} = \frac{\text{Mass of product produced}}{\text{Maximum theoretical mass of product}} \times 100$$

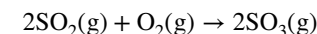
Percentage yield is usually determined using mass, but can also be determined with mol and volume.

STEPS TO DETERMINE THE PERCENTAGE YIELD

1. Determine moles of reactants.
2. From the balanced formula, determine the ratio between reactants and products.
3. Using the ratio, determine the number of moles of products.
4. Determine the theoretical mass of product.
5. Calculate the percentage yield.

EXAMPLE:

128g of sulphur dioxide, SO_2 , was reacted with oxygen to produce sulphur trioxide, SO_3 . The equation for the reaction is:



140g of SO_3 was produced in the reaction. Calculate the percentage yield of the reaction.

$$1. \quad n(\text{SO}_2) = \frac{m}{M} = \frac{128}{64} = 2 \text{ mol}$$

$$\begin{array}{lcl} 2. \quad \text{SO}_2 & : & \text{SO}_3 \\ 2 & : & 2 \\ 1 & : & 1 \\ \therefore 2 \text{ mol SO}_2 \end{array} \quad \begin{array}{lcl} 3. \quad \text{SO}_2 & : & \text{SO}_3 \\ 1 & : & 1 \\ 2 & : & 2 \\ \therefore 2 \text{ mol SO}_3 \end{array}$$

$$4. \quad m(\text{SO}_3) = nM = (2)(32 + 16 + 16 + 16) = 160 \text{ g}$$

$$5. \quad \text{Percentage yield} = \frac{\text{Mass of product produced}}{\text{Maximum theoretical mass of product}} \times 100$$

$$\text{Percentage yield} = \frac{140}{160} \times 100$$

$$\text{Percentage yield} = 87.5 \%$$

ENERGY AND CHEMICAL CHANGE

ENERGY CHANGE

The energy change that takes place occurs because of bonds being broken and new bonds being formed.

When bonds are broken, energy is absorbed from the environment.

When bonds are formed, energy is released into the environment.

The net energy change will determine if the reaction is endothermic or exothermic.

ACTIVATION ENERGY

In order to start a reaction, energy first needs to be absorbed to break the bonds. This energy is known as the **activation energy- the minimum energy required to start a chemical reaction**.

Once the bonds have been broken, the atoms in the chemical system form an **activated complex- a temporary transition state between the reactants and the products**.

ENTHALPY AND ENTHALPY CHANGE

Enthalpy (H) is the total amount of stored chemical energy (potential energy) of the reactants and the products. During chemical reactions, energy can be exchanged between the chemical system and the environment, resulting in a change in enthalpy. This change in enthalpy, ΔH , represents the heat of the reaction measured in $\text{kJ}\cdot\text{mol}^{-1}$.

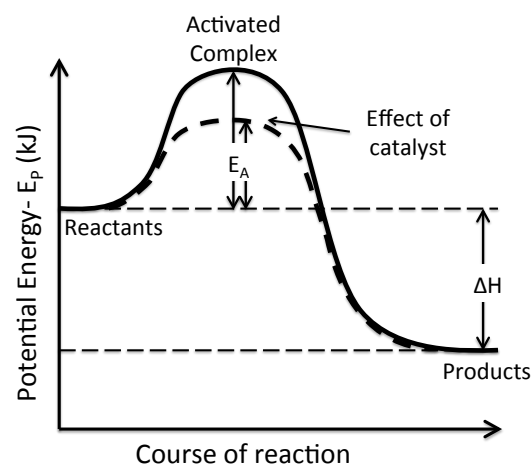
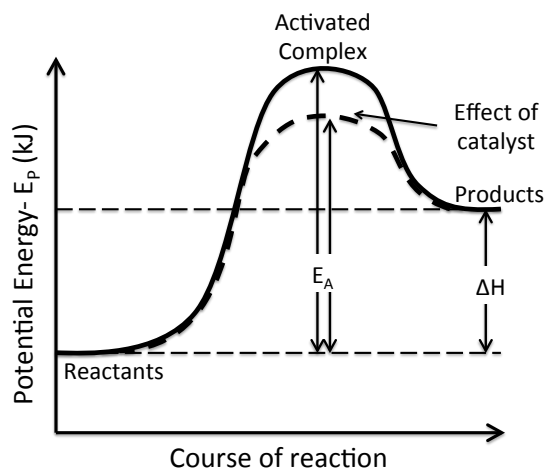
The heat of reaction (ΔH) is the net change of chemical potential energy of the system.

CHEMICAL SYSTEM AND THE ENVIRONMENT

The chemical system is the reactant and product molecules.

The environment is the surroundings of the chemical system, including the container in which the reaction takes place, or the water in which the molecules are dissolved.

ENDOTHERMIC	EXOTHERMIC
Definition: A reaction that absorbs heat energy from the surroundings	Definition: A reaction that releases heat energy into the environment
More energy absorbed than released	More energy released than absorbed
Net energy change is energy absorbed from the environment	Net energy change is energy released into the environment
The chemical system's energy increases ($\Delta H > 0$)	The chemical system's energy decreases ($\Delta H < 0$)
The environment's energy decreases	The environment's energy increases
Temperature of the environment decreases (test tube gets colder)	Temperature of the environment increases (test tube gets hotter)



CATALYST

In order for a reaction to occur, enough energy has to be provided (activation energy) for particles to collide effectively.

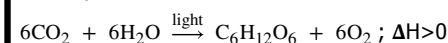
The amount of required energy can be decreased by using a catalyst. A catalyst is a chemical substances that lowers the activation energy required without taking part in the reaction. By lowering the activation energy, the rate of the reaction can also be increased.

A catalyst is a substance that increases the rate of the reaction but remains unchanged at the end of the reaction

IMPORTANT REACTIONS

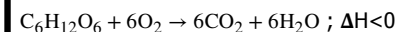
ENDOTHERMIC

Photosynthesis

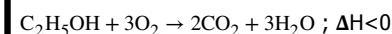


EXOTHERMIC

Cellular respiration



Combustion



ACID/BASE DEFINITIONS**Arrhenius**

An **acid** is a substance that produces hydrogen ions (H^+) / hydronium ions (H_3O^+) when dissolved in water.

A **base** is a substance that produces hydroxide ions (OH^-) when dissolved in water.

Bronsted-Lowry

An **acid** is a proton (H^+ ion) donor.

A **base** is a proton (H^+ ion) acceptor.

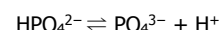
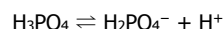
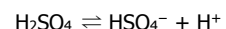
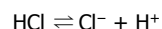
ACID PROTICITY

Some acids are able to donate more than one proton. The number of protons that an acid can donate is referred to as the acid proticity.

1 proton- monoprotic

2 protons- diprotic

3 protons- triprotic

**CONJUGATE ACID-BASE PAIRS**

An acid forms a conjugate base when it donates a proton.

acid $\rightleftharpoons$ conjugate base + H^+

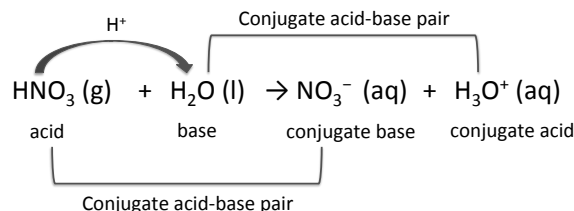
A base forms a conjugate acid when it accepts a proton.

base + H^+ $\rightleftharpoons$ conjugate acid

Conjugate acid-base pairs are compounds that differ by the presence of one proton, or H^+ .

EXAMPLE:

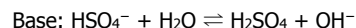
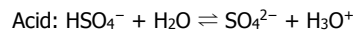
Identify the conjugate acid-base pair in the following example:

**AMPHOLYTE/ AMPHOTERIC SUBSTANCES**

Ampholyte- A substance that can act as both an acid or a base.

Amphoteric/amphiprotic substances can therefore either donate or accept protons. Common ampholytes include H_2O , HCO_3^- and HSO_4^- .

HSO_4^- as an ampholyte:



ACIDS AND BASES

CONCENTRATED VS DILUTE ACIDS AND BASES

Concentration is the number of moles of solute per unit volume of solution.

A concentrated acid is an acid with a large amount of solute (the acid) dissolved in a small volume of solvent (water).

A dilute acid is an acid with a small amount of solute (the acid) dissolved in a large volume of solvent (water).

Concentrated strong acid - 1mol.dm^{-3} of HCl

Concentrated weak acid - 1mol.dm^{-3} of CH_3COOH

Dilute strong acid - $0,01\text{mol.dm}^{-3}$ of HCl

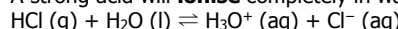
Dilute weak acid - $0,01\text{mol.dm}^{-3}$ of CH_3COOH

STRONG VS WEAK ACIDS AND BASES

The strength of an acid/base refers to the ability of the substance to ionise or dissociate.

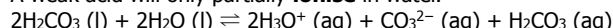
ACIDS

A strong acid will **ionise** completely in water.



(strong acid $\rightarrow$ weak conjugate base)

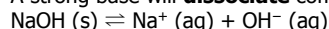
A weak acid will only partially **ionise** in water.



(weak acid $\rightarrow$ strong conjugate base)

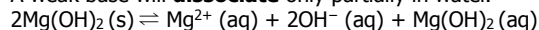
BASES

A strong base will **dissociate** completely in water.



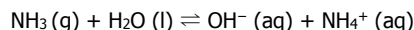
(strong base $\rightarrow$ weak conjugate acid)

A weak base will **dissociate** only partially in water.



(weak base $\rightarrow$ strong conjugate acid)

NH_3 is an exception, it ionises.

**INFLUENCE OF ACID/BASE STRENGTH**Reaction rate

Reaction rates increase as the strength of the acid/base increases.

Stronger acid = higher concentration of ions = greater rate of reaction.

Conductivity

Conductivity increases as the strength of the acid/base increases.

Stronger acid = higher concentration of H^+ = greater conductivity.

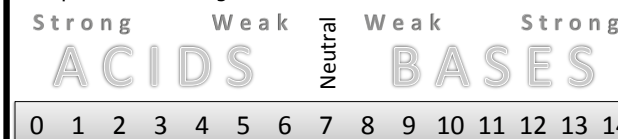
COMMON ACIDS		COMMON BASES	
Hydrochloric acid (HCl)	STRONG	Sodium Hydroxide (NaOH)	STRONG
Nitric acid (HNO_3)		Potassium hydroxide (KOH)	
Sulfuric acid (H_2SO_4)		Sodium hydrogen carbonate (NaHCO_3)	
Hydrofluoric acid (HF)	WEAK	Calcium carbonate (CaCO_3)	WEAK
Sulfurous acid (H_2SO_3)			
Carbonic acid (H_2CO_3)		Sodium carbonate (Na_2CO_3)	
Acetic acid / ethanoic acid (CH_3COOH)		Ammonia (NH_3)	
Phosphoric acid (H_3PO_4)			

THE pH SCALE

The pH of a solution is a number that represents the acidity or alkalinity of a substance.

The greater the concentration of H^+ ions in solution, the more acidic the solution and the lower the pH. The lower the concentration of H^+ in solution, the more alkali the solution and the higher the pH.

The pH scale is a range from 0 to 14.

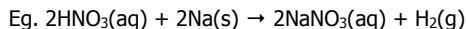
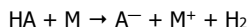


ACIDS AND BASES

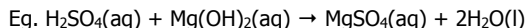
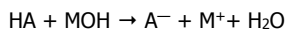
PROTOLYTIC REACTIONS

Protolytic reactions are reactions during which protons (H⁺) are transferred.

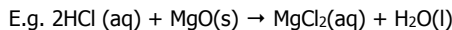
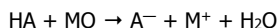
acid + metal → salt + hydrogen



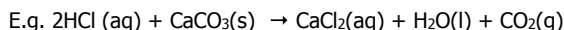
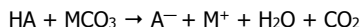
acid + metal hydroxide (base) → salt + water



acid + metal oxide → salt + water



acid + metal carbonate → salt + water + carbon dioxide



The ionic salt is made up of A⁻ (from the acid) and M⁺ (from the base).

HYDROLYSIS OF SALTS

Hydrolysis is the reaction of a salt with water. **Salt is a substance in which the hydrogen of an acid has been replaced by a cation.** During the hydrolysis, the salt will form an acidic, alkali or neutral solution. The acidity of the salt is dependent on the relative strength of the acid and base that is used.

Strong acid, weak base

The weak base will form a strong conjugate acid. The strong acid will form a weak conjugate base. The strong conjugate acid will form an acidic solution.

Weak acid, strong base

The weak acid will form a strong conjugate base. The strong base will form a weak conjugate acid. The strong conjugate base will form an alkali solution.

ACID STRENGTH	BASE STRENGTH	SALT
Strong	Weak	Acidic
Strong	Strong	Neutral
Weak	Strong	Alkali

INDICATORS

An indicator is a compound that changes colour according to the pH of the substance. During titrations, the indicator needs to be selected according to the acidity/alkalinity of the salt that will be produced (see hydrolysis).

INDICATOR	COLOUR IN ACID	COLOUR IN BASE	COLOUR AT EQUIVALENCE POINT	PH RANGE OF EQUIVALENCE
Litmus	Red	Blue		4,5 - 8,3
Methyl orange	Red	Yellow	Orange	3,1 - 4,4
Bromothymol blue	Yellow	Blue	Green	6,0 - 7,6
Phenolphthalein	Colourless	Pink	Pale Pink	8,3 - 10,0

Neutral: pH 7

Neutralisation is when the equivalence point is reached. Equivalence point is NOT when the solution is at pH 7, but when the molar amount of acid and base is the same according to the molar ratio. The pH at neutralisation is dependent on the salt that is formed. (see hydrolysis).

Neutralisation is the point where an acid and base have reacted so neither is in excess.

TITRATIONS

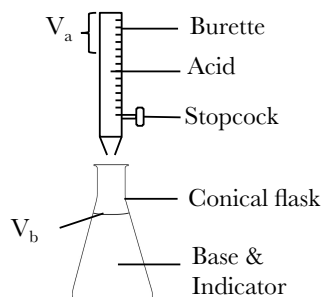
A titration is a practical laboratory method to determine the concentration of an acid or base. The concentration of an acid or base can be determined by accurate neutralisation with a **standard solution- a solution of known concentration**. Neutralisation occurs at the equivalence point, when the molar amount of acid and base is the same according to the molar ratio.

$$\frac{n_a}{n_b} = \frac{c_a V_a}{c_b V_b}$$

n- number of mole of substance (mol)/ mole ratio
c- concentration of acid/base (mol.dm⁻³)
V- volume of solution (dm³)

$$\begin{aligned} 1 \text{ mL} &= 1 \text{ cm}^3 \\ 1 \text{ L} &= 1 \text{ dm}^3 \\ 1000 \text{ mL} &= 1 \text{ L} \\ 1000 \text{ cm}^3 &= 1 \text{ dm}^3 \end{aligned}$$

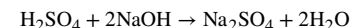
Titration setup



1. Pipette known solution into conical flask (usually base).
2. Add appropriate indicator to flask.
3. Add unknown concentration solution to the burette (usually acid).
4. Add solution from burette to conical flask at a dropwise rate (remember to swirl).
5. Stop burette when indicator shows neutralisation/equivalence point has been reached.

EXAMPLE:

During a titration, 25 cm³ of dilute H₂SO₄ neutralises 40 cm³ of NaOH solution. If the concentration of the H₂SO₄ solution is 0,25 mol.dm⁻³, calculate the concentration of the NaOH.



$$\begin{aligned} n_a &= 1 & n_b &= 2 \\ c_a &= 0,25 \text{ mol} \cdot \text{dm}^{-3} & c_b &= ? \\ V_a &= 25 \text{ cm}^3 = 0,025 \text{ dm}^3 & V_b &= 40 \text{ cm}^3 = 0,04 \text{ dm}^3 \end{aligned}$$

By titration equations

$$\begin{aligned} \frac{n_a}{n_b} &= \frac{c_a V_a}{c_b V_b} \\ \frac{1}{2} &= \frac{(0,25)(0,025)}{c_b(0,04)} \\ c_b &= 0,31 \text{ mol} \cdot \text{dm}^{-3} \end{aligned}$$

By first principles:

$$\begin{aligned} \text{Acid:} & \\ n &= cV \\ &= (0,25)(0,025) \\ &= 6,25 \times 10^{-3} \text{ mol} \\ \text{Base:} & \\ c &= \frac{n}{V} \\ &= \frac{6,25 \times 10^{-3} \times 2}{0,04} \\ &= 0,31 \text{ mol} \cdot \text{dm}^{-3} \end{aligned}$$

REDOX REACTIONS

REDOX REACTION

A redox reaction is a reaction in which there is a transfer of electrons between elements.

Oxidation is the loss of electrons (oxidation number increases).

Reduction is the gain of electrons (oxidation number decreases).

The oxidising agent is the substance which accepts electrons. It is the substance which is reduced and causes the other substance to be oxidised.

The reducing agent is the substance that donates electrons. It is the substance which is oxidised and causes the other substance to be reduced.

OIL: Oxidation is loss
RIG: Reduction is gain

LEO: Loss of electrons is oxidation
GER: Gain of electrons is reduction

OXIDATION NUMBERS

In order to keep track of the electrons during a chemical reaction oxidation numbers are assigned to each element in the reaction. The oxidation number is similar to the valency of the element.

Rules for assigning oxidation numbers.

- Pure elements and diatomic elements (eg. O_2) = 0.
- Hydrogen = +1 (except when bonded to a metal, then -1).
- Oxygen = -2 (except peroxides, eg. H_2O_2 , = -1). (when bonded to fluorine, = +2).
- Metals = group number.
group 1=+1; group 2=+2; group 3=+3
- The oxidation number of monoatomic ions is the same as its charge. Eg. Zn^{2+} : Zn = +2
- Group 17 elements = -1.
- The oxidation number of transition metals is indicated by stock notation. Eg. iron (III) chloride : Fe = +3
- In a neutral compound, the sum of the oxidation numbers is 0.
- In a polyatomic ion the sum of the oxidation numbers is equal to the charge of the ion.

Example:

Give the oxidation number of each of the elements in the following:

a) O_2	b) H_2S	c) $KMnO_4$	d) SO_4^{2-}	e) $FeCl_3$
O = 0	H = +1 S = -2	K = +1 Mn = +7 O = -2	S = +6 O = -2	Fe = +3 Cl = -1

REPRESENTING REDOX REACTIONS

Redox reactions can be shown in two half-reactions showing the transfer of electrons.

Oxidation half-reaction: $X \rightarrow X^{2+} + 2e^-$ (electrons are shown as products)

Reduction half-reaction: $Y + 2e^- \rightarrow Y^{2-}$ (electrons are shown as reactants)

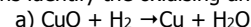
Nett reaction: $X + Y \rightarrow XY$ (no electrons are shown in the reaction)

NOTE:

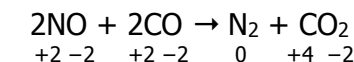
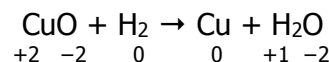
The number of e^- must balance.

EXAMPLE:

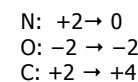
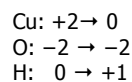
In the following equations identify the oxidising and reducing agents:



Step 1:
write all oxidation numbers



Step 2:
Identify change in oxidation number for each element



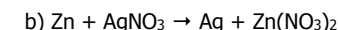
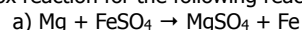
Step 3:
Identify what has oxidised/reduced

$Cu^{2+}(CuO)$: oxidation number decrease $\rightarrow$ gained electrons $\rightarrow$ reduced $\rightarrow$ **oxidising agent**
 H_2 : oxidation number increase $\rightarrow$ lost electrons $\rightarrow$ oxidised $\rightarrow$ **reducing agent**

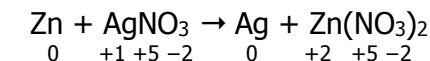
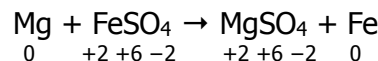
$N^{2+}(NO)$: oxidation number decrease $\rightarrow$ gained electrons $\rightarrow$ reduced $\rightarrow$ **oxidising agent**
 $C^{2+}(CO)$: oxidation number increase $\rightarrow$ lost electrons $\rightarrow$ oxidised $\rightarrow$ **reducing agent**

EXAMPLE:

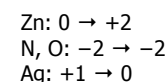
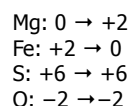
Write the balanced redox reaction for the following reactions:



Step 1:
Write all oxidation numbers



Step 2:
Identify change in oxidation number for each element

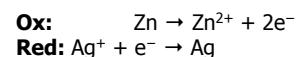
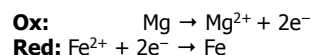


Step 3:
Identify what has oxidised/reduced

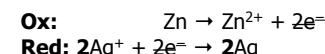
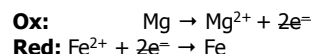
Mg: oxidation number increased $\rightarrow$ lost electrons $\rightarrow$ **oxidised**
 $Fe^{2+}(FeSO_4)$: oxidation number decrease $\rightarrow$ gained electrons $\rightarrow$ **reduced**

$Ag^+(AgNO_3)$: oxidation number decrease $\rightarrow$ gained electrons $\rightarrow$ **reduced**
Zn: oxidation number increase $\rightarrow$ lost electrons $\rightarrow$ **oxidised**

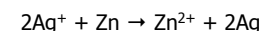
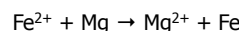
Step 4:
Write the half reactions



Step 5:
Balance electrons

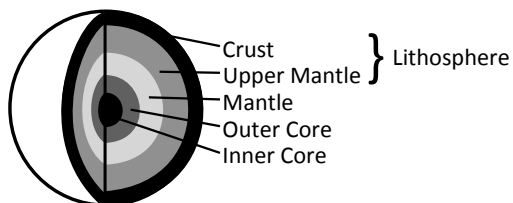


Step 6:
Write overall reaction



LITHOSPHERE

- The lithosphere is made up of the earth's crust and upper mantle.
- The crust contains non-renewable fossil fuels, minerals and soil chemicals (nutrients).



- The elements in the lithosphere are not in element form. The compounds are in the form of ore- mixture of rock, sand and minerals.
- Mining and mineral extraction is required to extract useful materials from the lithosphere.

Mining can occur in open-pit mining or deep-level mining.

Open-pit mining is the removal of soil from the surface of the crust. This results in big holes (Kimberley, Cullinan) and is very destructive to the environment.

Deep-level mining is the digging of shafts and subterranean tunnels deep in the crust. It has less environmental impact, but is more expensive and requires highly skilled workers. It results in large mounds of processed soil (mine dumps).

MINING IN SOUTH AFRICA**History of mining in South Africa**

ERA	PERIOD	MATERIALS AND WEAPONS	EVIDENCE FOUND IN SA
Stone age	Early (2,5 mil - 200 000 years ago)	Hand axe - sharpened stone	Mrs Ples in Sterkfontein caves
	Middle (250 000 - 30 000 years ago)	Stone treated with fire	Blombos caves
	Late (30 000 years ago)	Tools made from stone, wood and bone. Pottery and copper objects	Melkhoutboom caves
Bronze age	30 000 - 1 800 years ago	Bronze tools and objects	
Iron age	1 800 years ago	Iron metal weapons, more advanced	Mellville Koppies and Mapungubwe furnaces

Current mining activity in South Africa

Mining is important to the South African economy. A variety of minerals and precious metals are exported, stimulating the GDP, employment and infrastructure development.

GOLD MINING

Gold is a precious metal that has a high market value.

Mined in the Witwatersrand (Gauteng), Welkom and Virginia (Free State), Klerksdorp (North West) and in Mpumalanga.

STEPS IN GOLD EXTRACTION**1. Gold ore**

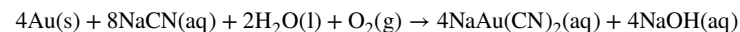
Gold ore is extracted from deep-level mining.

2. Comminution : Crushing and milling

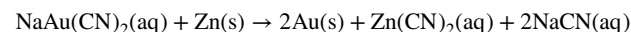
Gold is crushed into a fine powder.

3. Leaching: Cyanidation process

A cyanide solution is used to dissolve the gold from the fine powder.

**4. Extraction**

Gold is removed from solution by precipitation. Zinc is dissolved in gold solution, and zinc replaced the gold. The Gold forms a precipitate which is removed by filtration.

**5. Recovery: Smelting**

The precipitate that has been filtered out is smelted in a furnace to form gold bars of 99% purity.

6. Refining: produces 99,9% pure gold

Calcination: other metals are oxidised in the presence of gold to remove moisture
Fusion: Calcinated material is mixed with flux and melted in a furnace. Gold floats and is removed.

IMPACT OF GOLD MINING ON THE ENVIRONMENT

Gold mining results in holes in the ground. The soil removed creates mine dumps, resulting in a loss of biodiversity.

Water from mines can pollute ground and surface water.

Large amounts of energy is required to smelt the gold.

Cyanidation uses and forms cyanide compounds which are toxic.

IRON MINING

Iron is a strong material used in manufacturing of a wide range of products.

Large iron mines promote job creation and stimulates the economy.

Iron is not mined in its pure form, it is found as magnetite (Fe_3O_2) and haematite (Fe_2O_3).

Mined in Kathu (Northern Cape) and Thabazimbi (Limpopo).

STEPS IN IRON EXTRACTION

1. Mining

Iron ore is mined from open-pit mines.

2. Crushing

Iron ore is crushed to reduce the particle size.

3. Separation and Sorting

Iron ore is separated according to purity. High grade iron ore are sent directly to blast furnace. Lesser grade iron ore undergoes beneficiation.

4. Beneficiation

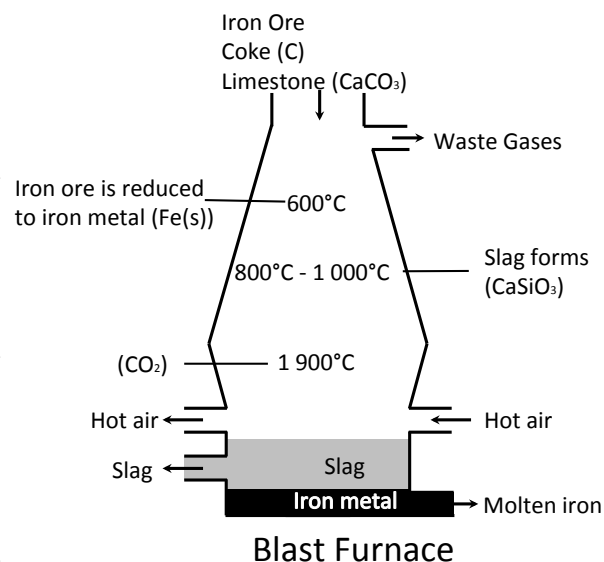
Lesser grade ore is further crushed and washed to form a slurry. The slurry is magnetised and pellets are formed from the slurry. Lastly the pellets undergo sintering, it is heated to set the pellets.

5. Blending

Pellets of various grades are mixed.

6. Furnacing

Iron ore pellets are placed into a blast furnace with coke (Carbon) and Limestone (CaCO_3). Iron ore is then reduced to pure molten iron. Impurities are removed as slag.



IMPACT OF IRON MINING ON THE ENVIRONMENT

Open-pit mining destroys the landscape and vegetation.

Large amounts of water is required, reducing the amount of water in aquifers available to fauna and flora.

Large open-pit mines result in a lot of dust pollution in the atmosphere.

Large amounts of CO₂ are released from the blast furnacing processes.

Large amounts of electricity are required to melt the iron ore.

Iron products (steel etc.) are recyclable, however the recycling process required large amounts of electricity.

PHOSPHATE MINING

Phosphate is a primary nutrient for all plants, stimulating root development and increasing flower growth.

Phosphates are used to produce fertilisers, phosphoric acid and animal food supplements.

The largest phosphate mining site in South Africa is in Phalaborwa (Limpopo).

Phosphates are processed by Foskor (Richard's Bay) to produce phosphoric acid and phosphate-based fertilisers.

STEPS IN PHOSPHATE EXTRACTION

1. Mining

Phosphate is mined from open-pit mines. High-grade phosphate tailings are produced from copper mines.

2. Primary crushing

Phosphate rocks are crushed into a coarse ore.

3. Secondary & Tertiary crushing

Coarse ore is crushed into a fine ore powder.

4. Milling

The ore powder is mixed with water to form a fine slurry.

5. Phosphate floatation

Air is bubbled through the slurry to separate phosphates from the ore.

6. Filtration

Phosphates are filtered from the slurry.

7. Drying

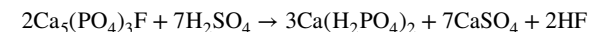
Phosphates are heated and dried to form a dry chemical powder.

8. Transportation

Phosphates are taken to fertiliser companies/ processing plants.

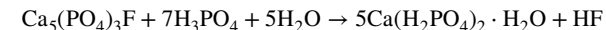
8.a) Fertiliser Company

Sulfuric acid is added to make soluble superphosphates. Superphosphates are used in fertilisers.



8.b) Processing Plant

Phosphoric acid added to make triple-superphosphates. Because it does not contain calcium sulfate, the product is a higher percentage phosphate.



IMPACT OF PHOSPHATE MINING ON THE ENVIRONMENT

Phosphate processing creates fluoride and SO₂ air pollutants.

The products of phosphates (fertilisers) can pollute water systems leading to eutrophication (algae bloom, algae die, decomposing algae removes oxygen out of the water, living organisms die).

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