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SCIENCE CLINIC

DBE ESSENTIALS

GRADE

12



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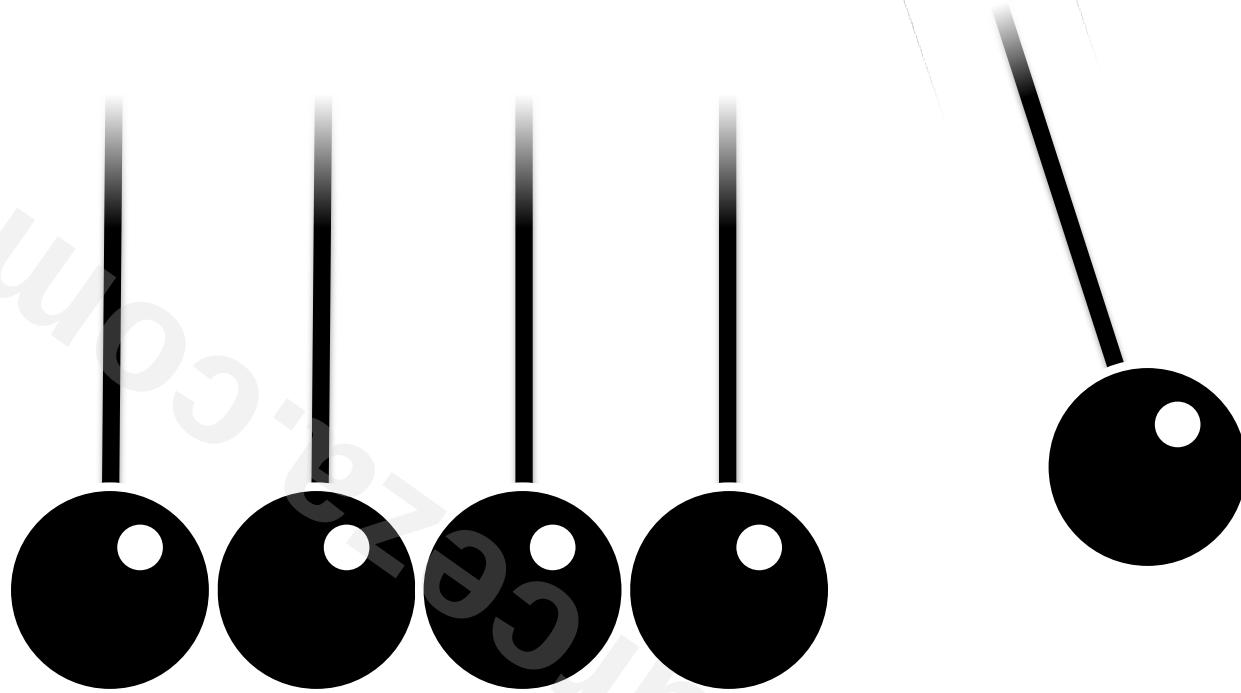
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Physics

**DATA FOR PHYSICAL SCIENCES GRADE 12
PAPER 1 (PHYSICS)**

**GEGEWENS VIR FISIESE WETENSKAPPE GRAAD 12
VRAESTEL 1 (FISIKA)**

TABLE 1: PHYSICAL CONSTANTS/TABEL 1: FISIESE KONSTANTES

NAME/NAAM	SYMBOL/SIMBOOL	VALUE/WAARDE
Acceleration due to gravity <i>Swaartekragversnelling</i>	g	$9,8 \text{ m}\cdot\text{s}^{-2}$
Universal gravitational constant <i>Universele gravitasiekonstant</i>	G	$6,67 \times 10^{-11} \text{ N}\cdot\text{m}^2\cdot\text{kg}^{-2}$
Speed of light in a vacuum <i>Spoed van lig in 'n vakuum</i>	c	$3,0 \times 10^8 \text{ m}\cdot\text{s}^{-1}$
Planck's constant <i>Planck se konstante</i>	h	$6,63 \times 10^{-34} \text{ J}\cdot\text{s}$
Coulomb's constant <i>Coulomb se konstante</i>	k	$9,0 \times 10^9 \text{ N}\cdot\text{m}^2\cdot\text{C}^{-2}$
Charge on electron <i>Lading op elektron</i>	-e	$-1,6 \times 10^{-19} \text{ C}$
Electron mass <i>Elektronmassa</i>	m_e	$9,11 \times 10^{-31} \text{ kg}$
Mass of Earth <i>Massa van Aarde</i>	M	$5,98 \times 10^{24} \text{ kg}$
Radius of Earth <i>Radius van Aarde</i>	R_E	$6,38 \times 10^6 \text{ m}$

TABLE 2: FORMULAE/TABEL 2: FORMULES

MOTION/BEWEGING

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

FORCE/KRAG

$F_{\text{net}} = ma$	$p = mv$
$f_s^{\text{max}} = \mu_s N$	$f_k = \mu_k N$
$F_{\text{net}} \Delta t = \Delta p$ $\Delta p = mv_f - mv_i$	$w = mg$
$F = G \frac{m_1 m_2}{d^2}$ or/of $F = G \frac{m_1 m_2}{r^2}$	$g = G \frac{M}{d^2}$ or/of $g = G \frac{M}{r^2}$

WORK, ENERGY AND POWER/ARBEID, ENERGIE EN DRYWING

$W = F \Delta x \cos \theta$	$U = mgh$ or/of $E_p = mgh$
$K = \frac{1}{2} mv^2$ or/of $E_k = \frac{1}{2} mv^2$	$W_{\text{net}} = \Delta K$ or/of $W_{\text{net}} = \Delta E_k$ $\Delta K = K_f - K_i$ or/of $\Delta E_k = E_{kf} - E_{ki}$
$W_{\text{nc}} = \Delta K + \Delta U$ or/of $W_{\text{nc}} = \Delta E_k + \Delta E_p$	$P = \frac{W}{\Delta t}$
$P_{\text{av}} = Fv_{\text{av}}$ / $P_{\text{gemid}} = Fv_{\text{gemid}}$	

WAVES, SOUND AND LIGHT/GOLWE, KLANK EN LIG

$v = f \lambda$	$T = \frac{1}{f}$
$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$ $f_L = \frac{v \pm v_L}{v \pm v_b} f_b$	$E = hf$ or /of $E = h \frac{c}{\lambda}$
$E = W_o + E_{k(\text{max})}$ or/of $E = W_o + K_{\text{max}}$ where/waar	
$E = hf$ and/en $W_o = hf_o$ and/en $E_{k(\text{max})} = \frac{1}{2} mv_{\text{max}}^2$ or/of $K_{\text{max}} = \frac{1}{2} mv_{\text{max}}^2$	

ELECTROSTATICS/ELEKTROSTATIKA

$F = \frac{kQ_1Q_2}{r^2}$	$E = \frac{kQ}{r^2}$
$V = \frac{W}{q}$	$E = \frac{F}{q}$
$n = \frac{Q}{e} \quad \text{or/of} \quad n = \frac{Q}{q_e}$	

ELECTRIC CIRCUITS/ELEKTRIESE STROOMBANE

$R = \frac{V}{I}$	emf ($\mathcal{E}$) = $I(R + r)$ emk ($\mathcal{E}$) = $I(R + r)$
$R_s = R_1 + R_2 + \dots$ $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$	$q = I \Delta t$
$W = Vq$ $W = VI \Delta t$ $W = I^2 R \Delta t$ $W = \frac{V^2 \Delta t}{R}$	$P = \frac{W}{\Delta t}$ $P = VI$ $P = I^2 R$ $P = \frac{V^2}{R}$

ALTERNATING CURRENT/WISSELSTROOM

$I_{\text{rms}} = \frac{I_{\text{max}}}{\sqrt{2}} \quad / \quad I_{\text{wgk}} = \frac{I_{\text{maks}}}{\sqrt{2}}$ $V_{\text{rms}} = \frac{V_{\text{max}}}{\sqrt{2}} \quad / \quad V_{\text{wgk}} = \frac{V_{\text{maks}}}{\sqrt{2}}$	$P_{\text{ave}} = V_{\text{rms}} I_{\text{rms}} \quad / \quad P_{\text{gemiddeld}} = V_{\text{wgk}} I_{\text{wgk}}$ $P_{\text{ave}} = I_{\text{rms}}^2 R \quad / \quad P_{\text{gemiddeld}} = I_{\text{wgk}}^2 R$ $P_{\text{ave}} = \frac{V_{\text{rms}}^2}{R} \quad / \quad P_{\text{gemiddeld}} = \frac{V_{\text{wgk}}^2}{R}$
--	---

Grade 12 Physics Definitions	
Newton's Laws Revision	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 Newton's first law of motion: an object 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 object exerts a force on a second object, the second object exerts a force of equal magnitude in the opposite direction on the first object 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
Momentum and Impulse	Momentum: the product of an object's mass and its velocity Newton's second law in terms of momentum: the net force acting on an object is equal to the rate of change of momentum of the object in the direction of the resultant/net force Impulse: the product of the resultant/net force acting on an object and the time the resultant/net force acts on the object. It is a vector quantity Closed/an isolated system (in Physics): a system on which the resultant/net external force is zero. A closed/an isolated system excludes external forces that originate outside the colliding bodies, e.g. friction. Only internal forces, e.g. contact forces between the colliding objects, are considered Principle of conservation of linear momentum: the total linear momentum of a closed system remains constant (is conserved)
Vertical Projectile Motion	Projectile: an object upon which the only force acting is the force of gravity
Work, Energy and Power	Work done on an object by a constant force F: is $F\Delta x \cos\theta$, where F is the magnitude of the force, Δx the magnitude of the displacement and θ the angle between the force and the displacement Work-energy theorem: The net/total work done on an object is equal to the change in the object's kinetic energy OR the work done on an object by a resultant/net force is equal to the change in the object's kinetic energy. ($W_{net} = \Delta E_k$) Conservative force: is a force for which the work done in moving an object between two points is independent of the path taken Non-conservative force: is a force for which the work done in moving an object between two points depends on the path taken Principle of conservation of mechanical energy: the total mechanical energy (sum of gravitational potential energy and kinetic energy) in an isolated system remains constant Power: is the rate at which work is done or energy is expended
Doppler Effect	Doppler Effect: the change in frequency (or pitch) of the sound detected by a listener because the sound source and the listener have different velocities relative to the medium of sound propagation
Electrostatics	Coulomb's law: the magnitude of the electrostatic force exerted by one point charge (Q_1) on another point charge (Q_2) 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
Electric Circuits	Ohm's law: the potential difference across a conductor is directly proportional to the current in the conductor at constant temperature Power: the rate at which work is done
Electrodynamics	Rms value: the DC potential difference/current which dissipates the same amount of energy as AC
Optical Phenomena and Properties of Materials	Photoelectric effect: the process whereby electrons are ejected from a metal surface when light of suitable frequency is incident on that surface Threshold frequency (f_0): the minimum frequency of light needed to emit electrons from a certain metal surface Work function (W_0): the minimum energy that an electron in the metal needs to be emitted from the metal surface

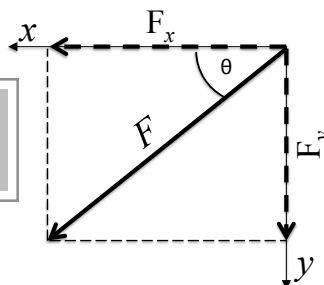
VECTORS IN 2D

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. We can use sin or cos, provided that the angle is between the force F and the horizontal.

$$F_x = F \cos \theta$$

$$F_y = F \sin \theta$$

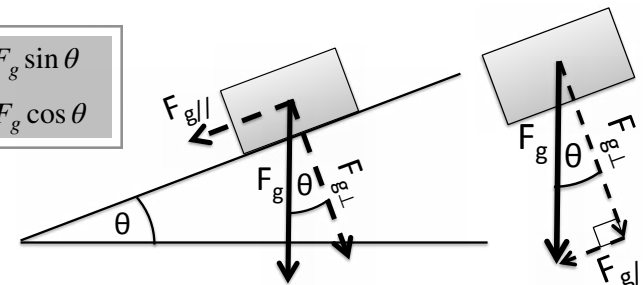


COMPONENTS ON A SLOPE

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

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

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

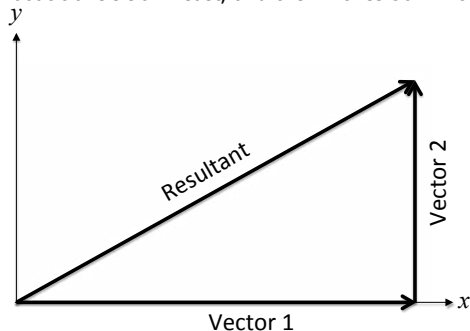


CONSTRUCTING FORCE TRIANGLE

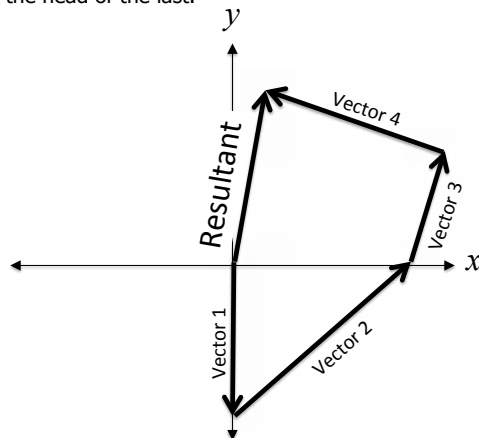
When forces are not co-linear, force triangles can be used to determine resultant forces or the equilibrant. When force triangles are formed, basic geometric rules can be used to determine vectors or resultants.

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.

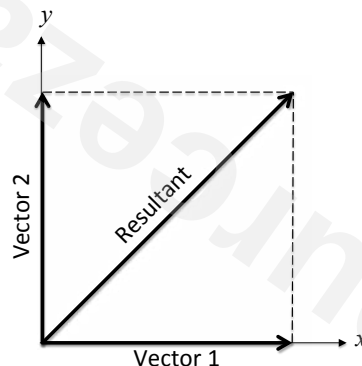


This principle can also be applied to more than 2 vectors taken in order. The resultant is from the tail of the first vector to the head of the last.

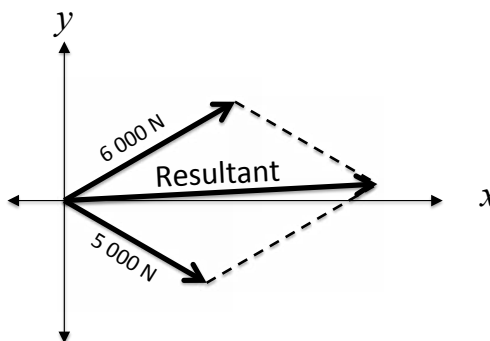


Parallelogram

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 (common origin).



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

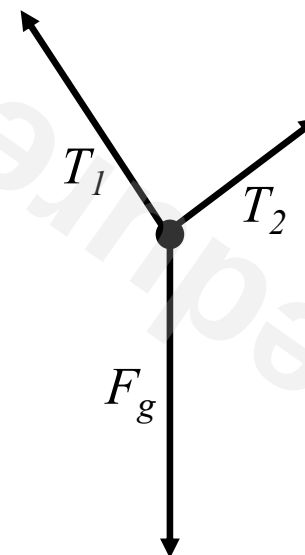
The vector arrows can be manipulated to form a force triangle to determine the resultant forces or an equilibrant. The vectors/arrows may only be moved if the magnitude and direction are both kept constant.

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

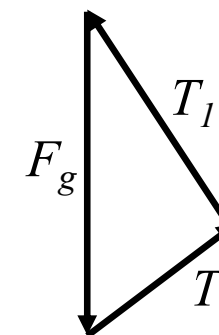
- Length of arrow (magnitude)
- Angle of the arrow (direction)
- The direction of the arrow head

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

RESULTANT: The single vector which has the same effect as the original vectors acting simultaneously on an object.

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:

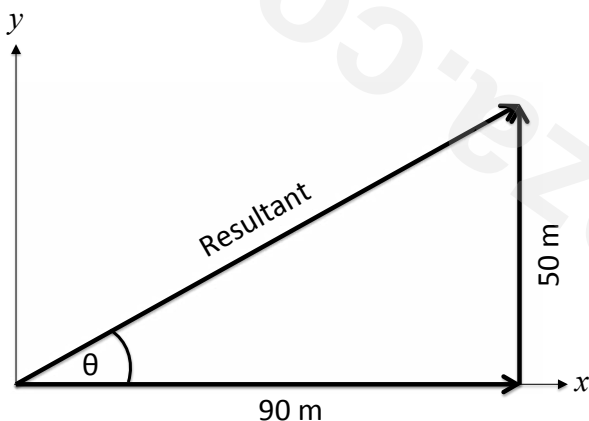
$$R^2 = x^2 + y^2$$

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 $60,95^\circ$

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.

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:

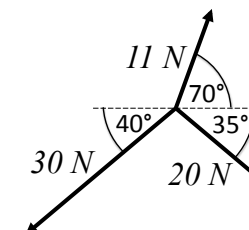
$$\begin{aligned} F_x &= F \cos \theta & F_y &= F \sin \theta \\ &= 11 \cos 70 & &= 11 \sin 70 \\ &= 3,76 \text{ N right } (90^\circ) & &= 10,34 \text{ N up } (0^\circ) \end{aligned}$$

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

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

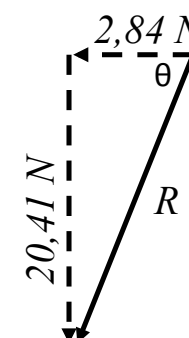
3. Find resultant-Pythagoras.

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

4. Find angle- trigonometry

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

$\therefore$ Resultant = 20,61 N at a bearing of $187,92^\circ$



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 (F_E)	Applied force (F_A)
Gravitational force (w/F_g)	Tension (T or F_T)
Magnetic force	Friction (F_f or f_s/f_k)
	Normal force (N/F_N)

A force is a push or a pull action exerted on an object by another 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 $1 \text{ N} = 1 \text{ kg}\cdot\text{m}\cdot\text{s}^{-2}$.

NOTE:

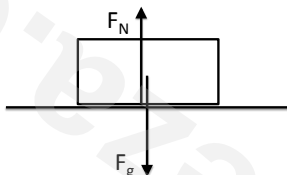
Free-Body Diagram: forces drawn away from a dot which represents the object

Normal force (F_N)

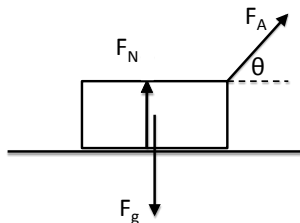
The perpendicular force exerted by a surface on an object in contact with it.

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

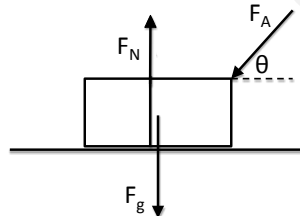
$$F_N = F_g$$



If alternative forces act on the object, the normal force will change depending on the direction and magnitude of the applied force. All vertical forces must be balanced if there is no acceleration in the vertical plane.



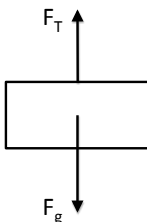
$$\begin{aligned} F_N + F_{Ay} - F_g &= 0 \\ F_N + F_A \sin \theta &= F_g \end{aligned}$$



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

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** **OR** the **full magnitude of F_g** for **vertically suspended objects that are stationary/moving at constant velocity**.

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

**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, parallel to the surface.

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 is determined by the properties of both the contact surfaces of the object and 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 from 0 N 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)

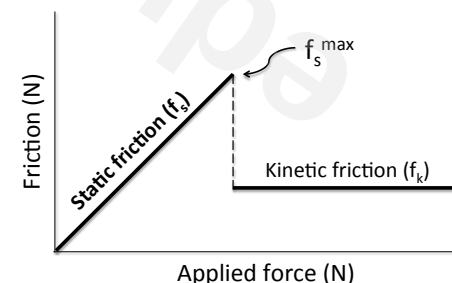
Kinetic friction is the **frictional force on a moving object that opposes the motion of the object**. The magnitude of the kinetic friction is constant for the specific system at all velocities greater than zero, and irrespective of the applied force.

$$f_k = \mu_k F_N$$

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

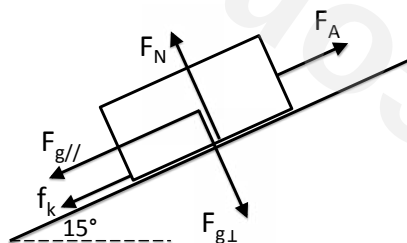
An object continues in a state of rest or uniform (moving with constant) velocity unless it is acted upon by an unbalanced (net or resultant) force.

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

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

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

A 3kg 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 upwards as positive:

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

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

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** (new F_{net}), preventing the forward motion of the person.

Newton's Second Law of Motion

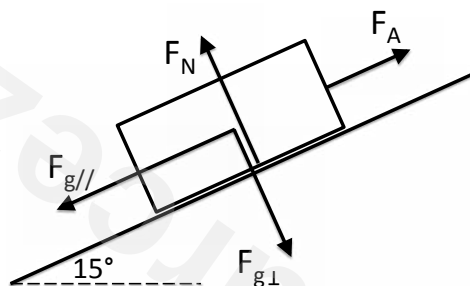
When a net force is applied to an object of mass, it accelerates in the direction of the net force. The acceleration is directly proportional to the net force and inversely proportional to the mass.

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:

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

Effect of Newton's Second Law on overloading:

According to Newton's Second Law, the acceleration of an object is directly proportional to the net 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.

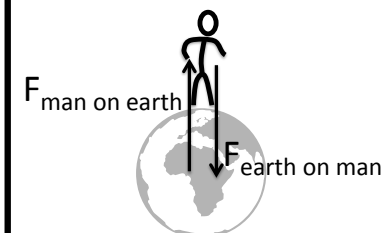
NB!

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:

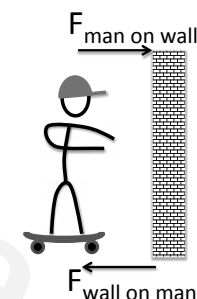
- Equal in magnitude
- Opposite in direction
- Acts on different objects (and therefore **DO NOT CANCEL** each other out)



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.

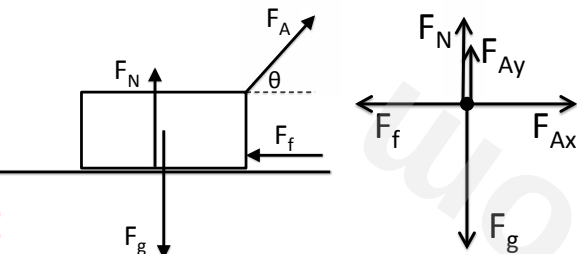
NEWTON'S LAWS OF MOTION

ALL EXAMPLES:
DIRECTION OF MOTION POSITIVE

Horizontal

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

Pulled at an angle



Horizontal:

$$F_{net} = ma$$

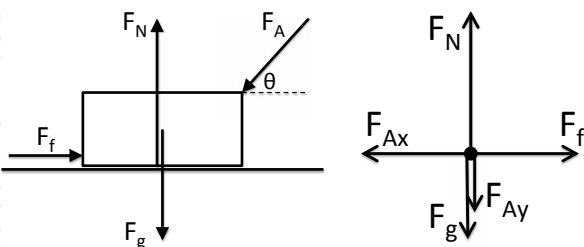
$$F_{Ax} + (-F_f) = ma$$

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:

$$F_{net} = 0$$

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

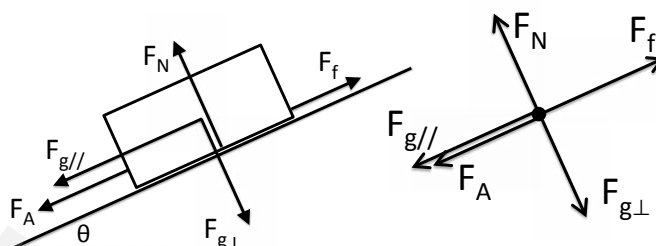
Slopes

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

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

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

Force applied down the slope



Parallel:

$$F_{net} = ma$$

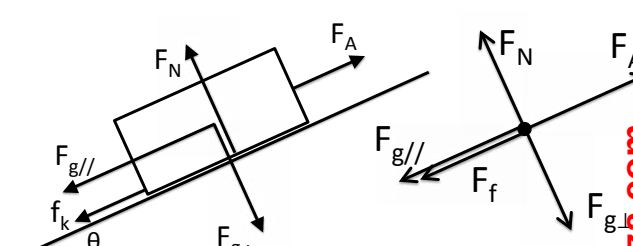
$$F_{g//} + F_A + (-F_f) = ma$$

Perpendicular:

$$F_{net} = 0$$

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

Force applied up the slope



Parallel:

$$F_{net} = ma$$

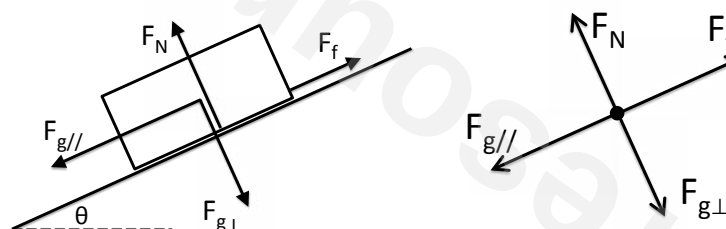
$$(-F_{g//}) + (-F_f) + F_A = ma$$

Perpendicular:

$$F_{net} = 0$$

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

No force applied



Parallel:

$$F_{net} = ma$$

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

Perpendicular:

$$F_{net} = 0$$

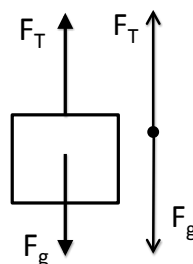
$$F_{g\perp} + (-F_N) = 0$$

Lift stationary/constant velocity

Vertical:

$$F_{net} = 0$$

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



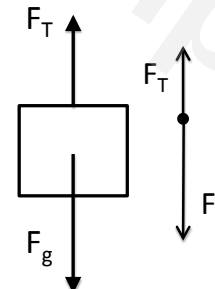
Lift accelerating

Vertical:

$$F_{net} = ma$$

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

Acceleration will be in the direction of the greatest force.

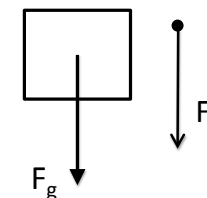


Lift in freefall (cable snap)

Vertical:

$$F_{net} = ma$$

$$F_g = ma$$



Suspended

Horizontal resultant = 0 N.

Vertical resultant determines acceleration.

REMEMBER: No normal or friction forces.

NEWTON'S LAWS OF MOTION

ALL EXAMPLES:
DIRECTION OF MOTION POSITIVE

Connected objects (e.g Pulley Systems)

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).

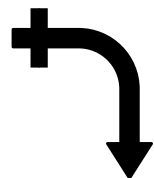
The velocity and acceleration of all objects are equal in magnitude and direction.

Multiple axes

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

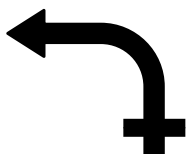
The velocity and acceleration of all objects are equal in magnitude NOT DIRECTION.

Vector direction on multiple axes



Clockwise:
Right and Down positive
Left and Up negative

OR



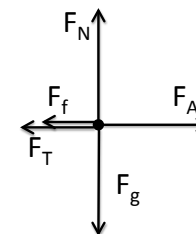
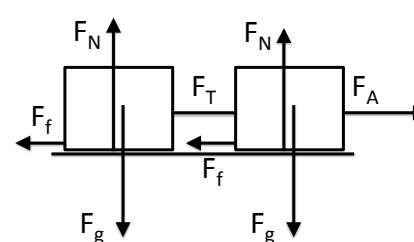
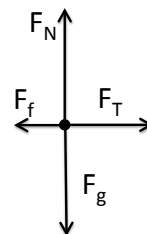
Anti-clockwise:
Left and Up positive
Right and Down negative

Objects attached by rope/cable

Horizontal:

$$F_{net} = ma$$

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



Horizontal:

$$F_{net} = ma$$

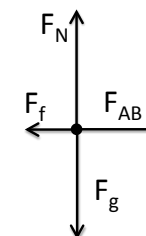
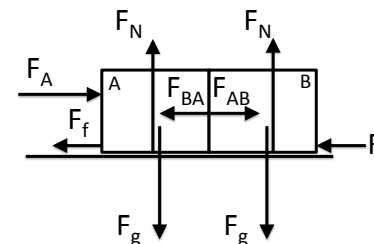
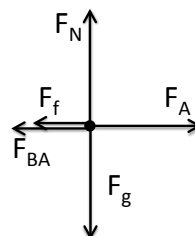
$$F_A + (-F_T) + (-F_f) = ma$$

Objects in contact

Horizontal:

$$F_{net} = ma$$

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



Horizontal:

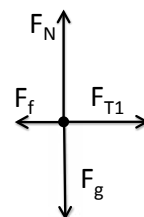
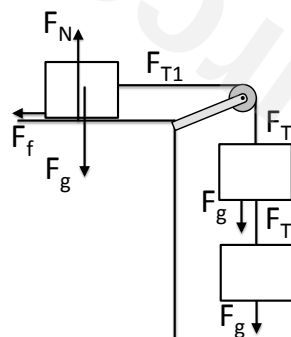
$$F_{net} = ma$$

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

Multiple axes

In these examples,
clockwise is positive:

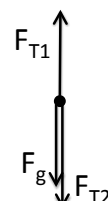
Right positive
Down positive



Horizontal:

$$F_{net} = ma$$

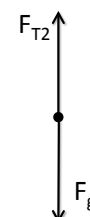
$$F_{T1} + (-F_f) = ma$$



Vertical:

$$F_{net} = ma$$

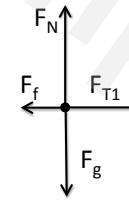
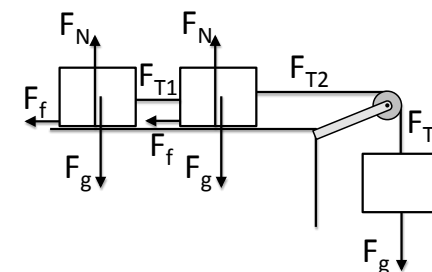
$$F_g + (-F_{T1}) + F_{T2} = ma$$



Vertical:

$$F_{net} = ma$$

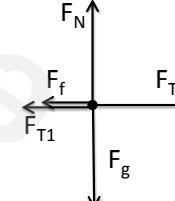
$$F_g + (-F_{T2}) = ma$$



Horizontal:

$$F_{net} = ma$$

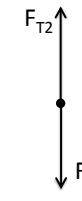
$$F_{T1} + (-F_f) = ma$$



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

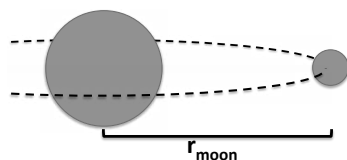
m = object mass (kg)

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.

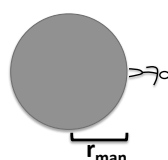


Thus, the distance is determined between the centers of the two bodies.



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) [gravitation force]

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)

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

$$m_o g = \frac{Gm_o m_p}{r_p^2}$$

$$g = \frac{Gm_p}{r_p^2}$$

$$\therefore g = \frac{Gm_p}{r_p^2}$$

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

CALCULATIONS

The gravitational 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 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.

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

$$\begin{aligned} F &= \frac{Gm_1m_2}{r^2} \\ &= \frac{6,67 \times 10^{-11} (5,97 \times 10^{24}) (1,99 \times 10^{30})}{(1,5 \times 10^{11})^2} \\ &= 3,52 \times 10^{22} \text{ N attraction} \end{aligned}$$

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:

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

$$\therefore \left(\frac{Gm_{\text{m}}m_{\text{s}}}{r_{\text{ms}}^2} \right) = \left(\frac{Gm_{\text{e}}m_{\text{s}}}{r_{\text{es}}^2} \right)$$

MOMENTUM AND IMPULSE

MOMENTUM

Momentum: the product of the mass of an object and its velocity.

Momentum can be thought of as quantifying the motion of an object. The following equation is used to calculate momentum:

$$p = mv$$

p = momentum ($\text{kg} \cdot \text{m} \cdot \text{s}^{-1}$)
 m = mass (kg)
 v = velocity ($\text{m} \cdot \text{s}^{-1}$)

VECTOR NATURE OF MOMENTUM

Momentum is a vector quantity and has both magnitude and direction. It is therefore important to **always include direction** in all momentum calculations.

EXAMPLE:

A golf ball of mass 0,05 kg leaves a golf club at a velocity of $90 \text{ m} \cdot \text{s}^{-1}$ in an easterly direction. Calculate the momentum of the golf ball.

Choosing east as positive:

$$\begin{aligned} p &= mv \\ &= (0,05)(90) \\ &= 4,5 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1} \text{ east} \end{aligned}$$

CHANGE IN MOMENTUM

When a net force acts on an object, it results in a change in velocity for the object and therefore a change in momentum (p) for the object. The change in momentum can be calculated by using:

$$\Delta p = p_f - p_i$$

Δp = change in momentum ($\text{kg} \cdot \text{m} \cdot \text{s}^{-1}$)

p_f = final momentum ($\text{kg} \cdot \text{m} \cdot \text{s}^{-1}$)

p_i = initial momentum ($\text{kg} \cdot \text{m} \cdot \text{s}^{-1}$)

Due to the vector nature of momentum, it is very important to choose a positive direction.

EXAMPLE:

A 1000 kg car initially moving at a constant velocity of $16 \text{ m} \cdot \text{s}^{-1}$ in an easterly direction approaches a stop street, starts breaking and comes to a complete standstill. Calculate the change in the car's momentum.

Choosing east as positive:

$$\begin{aligned} \Delta p &= p_f - p_i \\ \Delta p &= mv_f - mv_i \\ \Delta p &= (1\,000)(0) - (1\,000)(16) \\ \Delta p &= -16\,000 \\ \therefore \Delta p &= 16\,000 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1} \text{ west} \end{aligned}$$

EXAMPLE:

A cricket ball with a mass of 0,2 kg approaches a cricket bat at a velocity of $40 \text{ m} \cdot \text{s}^{-1}$ east and leaves the cricket bat at a velocity of $50 \text{ m} \cdot \text{s}^{-1}$ west. Calculate the change in the ball's momentum during its contact with the cricket bat.

Choosing east as positive:

$$\begin{aligned} \Delta p &= p_f - p_i \\ \Delta p &= mv_f - mv_i \\ \Delta p &= (0,2)(-50) - (0,2)(40) \\ \Delta p &= -18 \\ \therefore \Delta p &= 18 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1} \text{ west} \end{aligned}$$

NEWTON'S SECOND LAW OF MOTION

Newton's second law in terms of momentum: The resultant/net force acting on an object is equal to the rate of change of momentum of the object in the direction of the resultant/net force.

According to Newton's Second Law, a resultant force applied to an object will cause the object to accelerate. When the net force on an object changes, so does its velocity and hence the momentum.

$$F_{\text{net}} \Delta t = \Delta p$$

F_{net} = resultant force (N)

Δp = change in momentum ($\text{kg} \cdot \text{m} \cdot \text{s}^{-1}$)

Δt = time (s)

Derivation from Newton's Second Law

$$F_{\text{net}} = ma$$

$$F_{\text{net}} = m \frac{\Delta v}{\Delta t}$$

$$F_{\text{net}} = \frac{mv_f - mv_i}{\Delta t}$$

$$F_{\text{net}} = \frac{\Delta p}{\Delta t}$$

$$F_{\text{net}} \Delta t = \Delta p$$

IMPULSE

Impulse: the product of the net force acting on an object and the time the over which the net force acts on the object.

By rearranging Newton's second law in terms of momentum, we find that impulse is equal to the change in momentum of an object according to the impulse-momentum theorem:

$$\text{Impulse} = F \Delta t$$

$$\text{Impulse} = \Delta p$$

$$m \Delta v = \Delta p$$

Impulse, $F \Delta t$, is measured in N·s.

Δp is measured in $\text{kg} \cdot \text{m} \cdot \text{s}^{-1}$

The change in momentum is directly dependent on the magnitude of the resultant force and the duration for which the force is applied. Impulse is a vector, $\therefore$ direction specific.

EXAMPLE:

A golf ball with a mass of 0,1 kg is driven from the tee. The golf ball experiences a force of 1000 N while in contact with the golf club and moves away from the golf club at $30 \text{ m} \cdot \text{s}^{-1}$. For how long was the golf club in contact with the ball?

$$\begin{aligned} F_{\text{net}} \Delta t &= m \Delta v \\ 1000t &= (0,1)(30 - 0) \\ t &= 3 \times 10^{-3} \text{ s} \end{aligned}$$

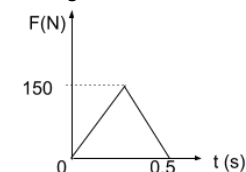
EXAMPLE:

Why can airbags be useful during a collision? State your answer by using the relevant scientific principle.

The change in momentum remains constant, but the use of an airbag prolongs the time (**t**) of impact during the accident. The resultant force experienced is inversely proportional to the contact time (**F** $\propto$ **1/t**), therefore resulting in a smaller resultant force (**F_{net}**) (Δp is constant).

EXAMPLE:

The following graph shows the force exerted on a hockey ball over time. The hockey ball is initially stationary and has a mass of 150 g.



Calculate the magnitude of the impulse (change in momentum) of the hockey ball.

$$F_{\text{net}} \Delta t = \text{area under graph}$$

$$\text{impulse} = \frac{1}{2} b \perp h$$

$$\text{impulse} = \frac{1}{2} (0,5)(150)$$

$$\text{impulse} = 37,5 \text{ N} \cdot \text{s}$$

CONSERVATION OF MOMENTUM

CONSERVATION OF MOMENTUM

Conservation of linear momentum: The total linear momentum of an isolated system remains constant.

$$\begin{aligned}\Sigma p_{\text{before}} &= \Sigma p_{\text{after}} \\ p_{A(\text{before})} + p_{B(\text{before})} &= p_{A(\text{after})} + p_{B(\text{after})} \\ m_A v_{iA} + m_B v_{iB} + \dots &= m_A v_{fA} + m_B v_{fB} + \dots\end{aligned}$$

System: A set number of objects and their interactions with each other.

External forces: Forces outside of the system.

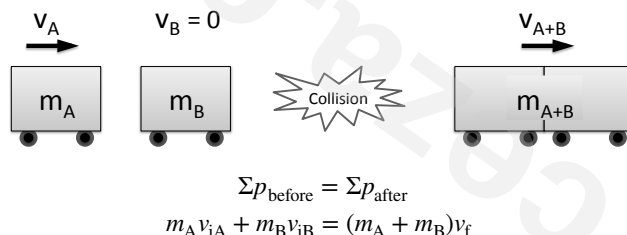
Isolated system: A system on which the net external force is zero.

Collisions

Move off together

When objects collide and move off together, their masses can be added as one object

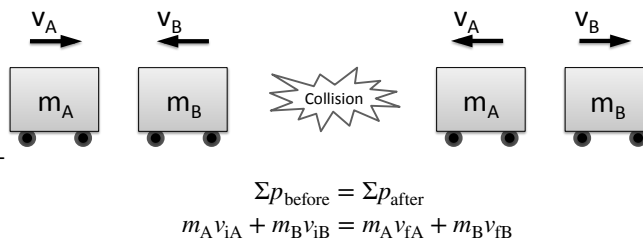
Objects that are stationary (B) have an initial velocity of zero.



Collide and rebounds

Objects can collide and move off separately

REMEMBER: The velocity and momentum are vectors (i.e. direction specific). Velocity substitution must take direction into account.



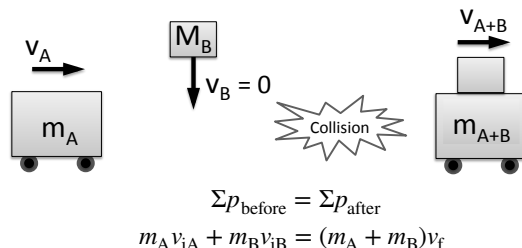
Object dropped vertically on a moving object

Example: A stuntman jumps off a bridge and lands on a truck.

Linear momentum = momentum along one axis.

A dropped object has a horizontal velocity of zero,

$$\therefore v_{iB} = 0 \text{ m} \cdot \text{s}^{-1}$$



NEWTON'S THIRD LAW AND MOMENTUM

During a collision, the objects involved will exert forces on each other. Therefore, according to Newton's third law, if object A exerts a force on object B, object B will exert a force on object A where the two forces are equal in magnitude, but opposite in direction.

The magnitude of the force, the contact time and therefore the impulse on both objects are equal in magnitude.

Forces are applied between objects during:

Collisions: Move off together, collide and deflect, object dropped vertically on moving object.

Explosions: Explosions, springs, firearms

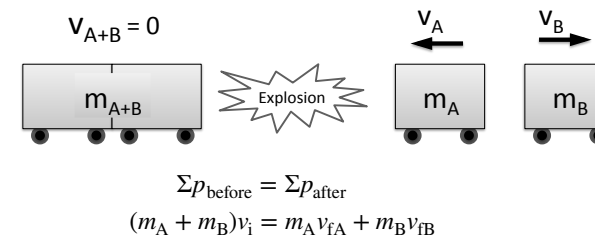
Explosions

Explosions

Objects that experience the same explosion will experience the same force.

The acceleration, velocity and momentum of the object is dependent on the mass.

Objects that are stationary (A+B) have an initial velocity of zero.

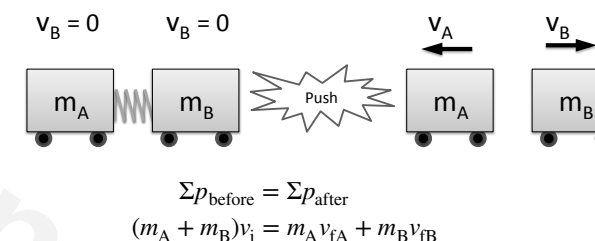


Springs

The spring will exert the same force on both objects (Newton's Third Law).

The acceleration, velocity and momentum of the object is dependent on the mass.

Objects that are stationary (A+B) have a velocity of zero.

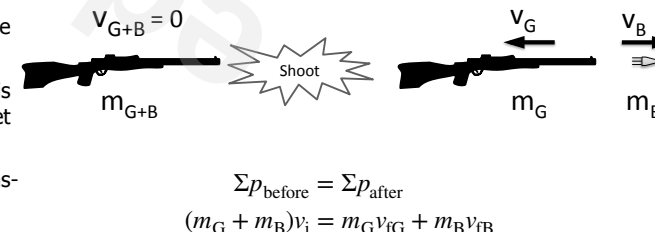


Firearms/ cannons

The gun and bullet will experience the same force.

The acceleration of the weapon is significantly less than the bullet due to mass difference

Recoil can be reduced by increasing the mass of the weapon.



ELASTIC VS INELASTIC COLLISIONS

Elastic collision: a collision in which both momentum and kinetic energy are conserved.

Inelastic collision: a collision in which only momentum is conserved.

In an isolated system, momentum will always be conserved. To prove that a collision is elastic, we only have to prove that kinetic energy is conserved.

Kinetic energy can be calculated using the mass and velocity of an object:

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

E_K = kinetic energy (J)

m = mass (kg)

v = velocity ($\text{m} \cdot \text{s}^{-1}$)

Elastic collision: $\Sigma E_{k(\text{before})} = \Sigma E_{k(\text{after})}$

Inelastic collision: $\Sigma E_{k(\text{before})} \neq \Sigma E_{k(\text{after})}$

(some energy is lost as sound or heat)

EXAMPLE:

The velocity of a moving trolley of mass 1 kg is $3 \text{ m} \cdot \text{s}^{-1}$. A block of mass 0,5 kg is dropped vertically on to the trolley. Immediately after the collision the speed of the trolley and block is $2 \text{ m} \cdot \text{s}^{-1}$ in the original direction. Is the collision elastic or inelastic? Prove your answer with a suitable calculation.

$$\begin{aligned}\Sigma E_{k(\text{before})} &= \frac{1}{2}m_t v_t^2 + \frac{1}{2}m_b v_b^2 \\ &= \frac{1}{2}(1)(3)^2 + \frac{1}{2}(0,5)(0)^2 \\ &= 4,5 \text{ J}\end{aligned}$$

$$\begin{aligned}\Sigma E_{k(\text{after})} &= \frac{1}{2}m_{t+b} v_{t+b}^2 \\ &= \frac{1}{2}(1 + 0,5)(2)^2 \\ &= 3 \text{ J}\end{aligned}$$

$$\Sigma E_{k(\text{before})} \neq \Sigma E_{k(\text{after})}$$

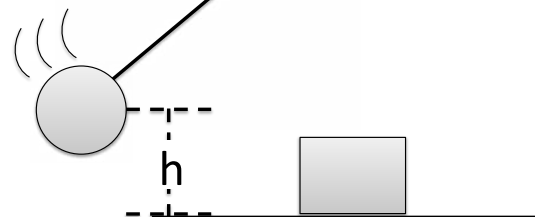
$\therefore$ Kinetic energy is not conserved and the collision is inelastic

PENDULUMS

DOWNWARD SWING:

Conservation of mechanical energy (E_M) to determine velocity at the bottom of the swing:

$$\begin{aligned}E_{M(\text{top})} &= E_{M(\text{bottom})} \\ mgh + \frac{1}{2}mv^2 &= mgh + \frac{1}{2}mv^2\end{aligned}$$



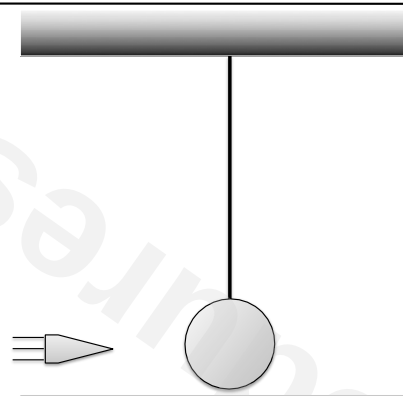
COLLISION:

Conservation of linear momentum to determine the velocity of the block after impact.

$$\Sigma p_{\text{before}} = \Sigma p_{\text{after}}$$

$$p_{A(\text{before})} + p_{B(\text{before})} = p_{A(\text{after})} + p_{B(\text{after})}$$

$$m_A v_{iA} + m_B v_{iB} + \dots = m_A v_{fA} + m_B v_{fB} + \dots$$



COLLISION:

Conservation of linear momentum to determine the velocity of the pendulum after impact.

$$\Sigma p_{\text{before}} = \Sigma p_{\text{after}}$$

$$p_{A(\text{before})} + p_{B(\text{before})} = p_{A(\text{after})} + p_{B(\text{after})}$$

$$m_A v_{iA} + m_B v_{iB} + \dots = m_A v_{fA} + m_B v_{fB} + \dots$$

UPWARD SWING:

Conservation of mechanical energy (E_M) to determine height that the pendulum will reach:

$$\begin{aligned}E_{M(\text{bottom})} &= E_{M(\text{top})} \\ mgh + \frac{1}{2}mv^2 &= mgh + \frac{1}{2}mv^2\end{aligned}$$

ENERGY

ENERGY

The ability to do work

Unit: joules (J)

Scalar quantity

Gravitational Potential Energy (E_P)

The energy an object possesses due to its position relative to a reference point.

Amount of energy transferred when an object changes position relative to the earth's surface.

$$E_P = mgh$$

$g = 9,8 \text{ m}\cdot\text{s}^{-2}$, m is mass in kg,
 h is height in m above the ground

Example:

Determine the gravitational potential energy of a 500 g ball when it is placed on a table with a height of 3 m.

$$\begin{aligned} E_P &= mgh \\ &= (0,5)(9,8)(3) \\ &= 14,7 \text{ J} \end{aligned}$$

Kinetic Energy (E_K)

The energy an object has as a result of the object's motion

Amount of energy transferred to an object as it changes speed.

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

m is mass in kg,
 v is velocity in $\text{m}\cdot\text{s}^{-1}$

Example:

Determine the kinetic energy of a 500 g ball when it travels with a velocity of 3 $\text{m}\cdot\text{s}^{-1}$.

$$\begin{aligned} E_K &= \frac{1}{2}mv^2 \\ &= \frac{1}{2}(0,5)(3^2) \\ &= 2,25 \text{ J} \end{aligned}$$

Mechanical Energy (E_M)

The sum of gravitational potential and kinetic energy of an object at a point

$$\begin{aligned} E_M &= E_P + E_K \\ E_M &= mgh + \frac{1}{2}mv^2 \end{aligned}$$

EXAMPLE:

A ball, mass 500 g, is thrown horizontally through the air. The ball travels at a velocity of $1,8 \text{ m}\cdot\text{s}^{-1}$ and is 2,5 m from the ground. Determine the mechanical energy of the ball.

$$\begin{aligned} E_M &= E_P + E_K \\ E_M &= mgh + \frac{1}{2}mv^2 \\ E_M &= (0,5)(9,8)(2,5) + \frac{1}{2}(0,5)(1,8^2) \\ E_M &= 13,06 \text{ J} \end{aligned}$$

PRINCIPLE OF CONSERVATION OF MECHANICAL ENERGY

Principle of conservation of mechanical energy: The total mechanical energy in an isolated system remains constant.

The law of conservation of mechanical energy applies when there is no friction or air resistance acting on the object. In the absence of air resistance, or other forces, the mechanical energy of an object moving in the earth's gravitational field in free fall, is conserved.

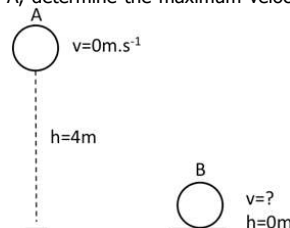
$$\begin{aligned} E_{MECH_A} &= E_{MECH_B} \\ (E_P + E_K)_A &= (E_P + E_K)_B \\ (mgh + \frac{1}{2}mv^2)_A &= (mgh + \frac{1}{2}mv^2)_B \end{aligned}$$

General law of conservation of energy: Energy cannot be created or destroyed, merely transferred.

In the following instances the gravitational potential energy of an object is converted to kinetic energy (and vice versa), while the mechanical energy remains constant.

EXAMPLE 1: Object moving vertically

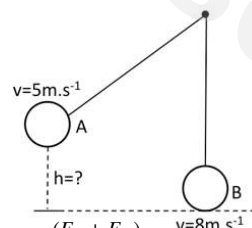
A 2 kg ball is dropped from rest at A, determine the maximum velocity of the ball at B just before impact.



$$\begin{aligned} (E_P + E_K)_A &= (E_P + E_K)_B \\ (mgh + \frac{1}{2}mv^2)_A &= (mgh + \frac{1}{2}mv^2)_B \\ (2)(9,8)(4) + \frac{1}{2}(2)(0^2) &= (2)(9,8)(0) + \frac{1}{2}(2)v_B^2 \\ 78,4 + 0 &= 0 + 1v_B^2 \\ v_B &= \sqrt{78,4} \\ v_B &= 8,85 \text{ m}\cdot\text{s}^{-1} \text{ downwards} \end{aligned}$$

EXAMPLE 3: Pendulum

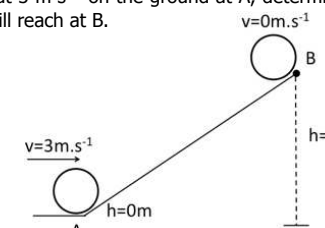
The 2 kg pendulum swings from A at $5 \text{ m}\cdot\text{s}^{-1}$ to B, on the ground, where its velocity is $8 \text{ m}\cdot\text{s}^{-1}$. Determine the height at A.



$$\begin{aligned} (E_P + E_K)_A &= (E_P + E_K)_B \\ (mgh + \frac{1}{2}mv^2)_A &= (mgh + \frac{1}{2}mv^2)_B \\ (2)(9,8)(h_A) + \frac{1}{2}(2)(5^2) &= (2)(9,8)(0) + \frac{1}{2}(2)(8^2) \\ 19,6h_A + 25 &= 0 + 64 \\ \frac{64 - 25}{19,6} &= h_A \\ h_A &= 1,99 \text{ m} \end{aligned}$$

EXAMPLE 2: Object moving on an inclined plane

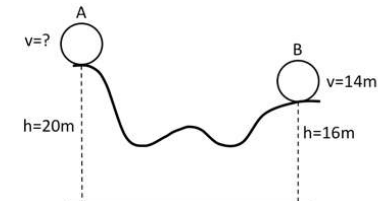
A 2 kg ball rolls at $3 \text{ m}\cdot\text{s}^{-1}$ on the ground at A, determine the maximum height the ball will reach at B.



$$\begin{aligned} (E_P + E_K)_A &= (E_P + E_K)_B \\ (mgh + \frac{1}{2}mv^2)_A &= (mgh + \frac{1}{2}mv^2)_B \\ (2)(9,8)(0) + \frac{1}{2}(2)(3^2) &= (2)(9,8)(h_B) + \frac{1}{2}(2)(0^2) \\ 0 + 9 &= 19,6h_B + 0 \\ \frac{9}{19,6} &= h_B \\ h_B &= 0,46 \text{ m} \end{aligned}$$

EXAMPLE 4: Rollercoaster

The 2 kg ball rolls on a toy rollercoaster from A, at 20 m above the ground, to B where its height is 8 m and velocity is $14 \text{ m}\cdot\text{s}^{-1}$. Calculate its starting velocity at A.



$$\begin{aligned} (E_P + E_K)_A &= (E_P + E_K)_B \\ (mgh + \frac{1}{2}mv^2)_A &= (mgh + \frac{1}{2}mv^2)_B \\ (2)(9,8)(20) + \frac{1}{2}(2)(v_A^2) &= (2)(9,8)(16) + \frac{1}{2}(2)(14^2) \\ 392 + v_A^2 &= 313,6 + 196 \\ v_A &= \sqrt{313,6 + 196 - 392} \\ v_A &= 10,84 \text{ m}\cdot\text{s}^{-1} \text{ to the right} \end{aligned}$$

WORK, ENERGY AND POWER

WORK

Work done is the transfer of energy. **Work done on an object by a force is the product of the displacement and the component of the force parallel to the displacement.**

$$W = F\Delta x \cos \theta$$

W = work (J)
F = force applied (N)
 Δx = displacement (m)
 θ = Angle between F and Δx

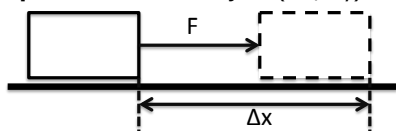
NOTE:

Work is a scalar quantity, i.e. NO DIRECTION for F or x!

The joule is the amount of work done when a force of one newton moves its point of application one meter in the direction of the force.

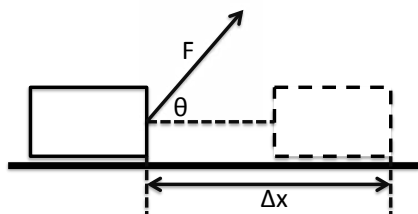
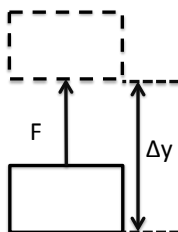
Work always involves two things:

1. A **force** which acts on a certain object. (F)
2. The **displacement** of that object. (Δx / Δy)



When a resultant force is applied to an object, the resultant force **accelerates** the block across distance Δx . Work has been done to increase the **kinetic energy** of the block.

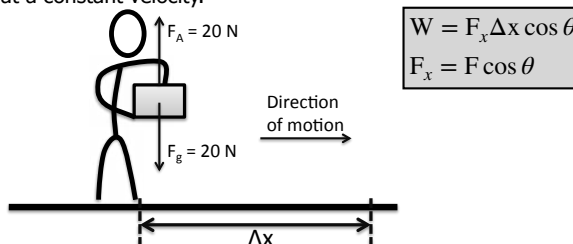
If a resultant force is applied to an object vertically, the resultant force **lifts** the block through distance Δy . Work has been done to increase the **potential energy** of the block. "Lifting" usually implies at a constant velocity.



Work is only done in the direction of the displacement. Work is done by the component of the force that is parallel to the displacement. The angle between the force and the displacement is θ . If no displacement takes place due to the applied force, no work is done.

No Work done on an object (moving at a constant velocity) if the force and displacement are perpendicular to each other.

Consider a man carrying a suitcase with a weight of 20 N on a 'travelator' moving at a constant velocity.

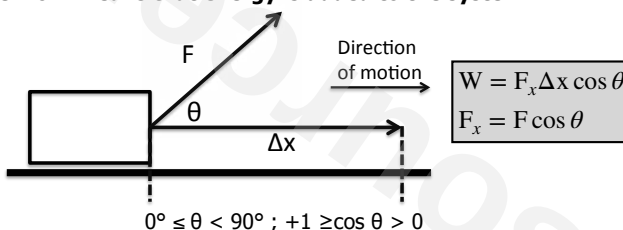


F_A is perpendicular to the displacement: $\theta = 90^\circ$; $\cos 90^\circ = 0$.

No force in the plane of the displacement, hence, NO WORK IS DONE by F_A and F_g and no energy is transferred. We can also say that F_A / F_g does not change the potential energy (height) or kinetic energy (vertical velocity) of the object.

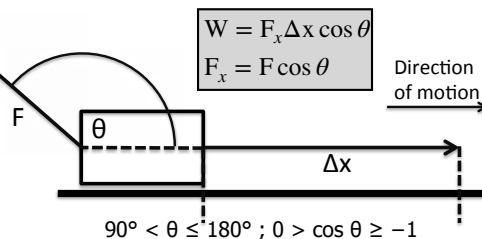
A force/force component in the direction of the displacement does positive work on the object. **The force increases the energy of the object.**

Positive work means that energy is added to the system.



A force/force component in the opposite direction of the displacement does negative work on the object. **The force decreases the energy of the object.**

Negative work means that energy is being removed from the system.



NB: Never use a – for F in the opposite direction. The $\cos \theta$ makes provision for that.

NET WORK ON AN OBJECT

A number of forces can act on an object at the same time. Each force can do work on the object to change the energy of the object. The net work done on the object is the sum of the work done by each force acting on the object.

If W_{net} is **positive**, energy is **added** to the system.

If W_{net} is **negative**, energy is **removed** from the system.

Work and Energy are SCALARS, and NOT direction specific.

EXAMPLE:

Calculate the net work done on a trolley where a force of 30 N is applied to the trolley. The trolley moves 3 m to the left. The force of friction is 5 N to the right.

Work done by applied force:

$$\begin{aligned} W_A &= F_A \Delta x \cos \theta \\ &= (30)(3) \cos 0 \\ &= 90 \text{ J gained} \end{aligned}$$

Work done by frictional force:

$$\begin{aligned} W_f &= F_f \Delta x \cos \theta \\ &= (5)(3) \cos 180 \\ &= -15 \text{ J "lost"} \end{aligned}$$

Work done by gravity

$$\begin{aligned} W_g &= F_g \Delta x \cos \theta \\ &= (F_g)(3) \cos 90 \\ &= 0 \text{ J} \end{aligned}$$

Work done by normal force

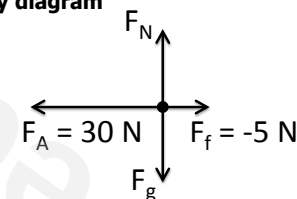
$$\begin{aligned} W_N &= F_N \Delta x \cos \theta \\ &= (F_N)(3) \cos 90 \\ &= 0 \text{ J} \end{aligned}$$

$$\begin{aligned} W_{\text{net}} &= W_A + W_f + W_N + W_g \\ &= 90 - 15 + 0 + 0 \\ &= 75 \text{ J nett energy gained} \end{aligned}$$

Alternative method for determining net work:

1. Draw a free body showing only the forces acting on the object.
2. Calculate the resultant (net) force acting on the object.
3. Calculate the net work using $W_{\text{net}} = F_{\text{net}} \Delta x \cos \theta$

Step 1: Freebody diagram



Take left as positive:

Step 2: Calculate F_{net}

$$\begin{aligned} F_{\text{net}} &= F_A + F_f \\ &= 30 - 5 \\ &= 25 \text{ N left} \end{aligned}$$

Step 3: Net work

$$\begin{aligned} W_{\text{net}} &= F_{\text{net}} \Delta x \cos \theta \\ &= (25)(3) \cos 0 \\ &= 75 \text{ J gained} \end{aligned}$$

WORK, ENERGY AND POWER

WORK ENERGY THEOREM

According to Newton's Second Law of Motion, when a resultant force acts on an object, the object accelerates. This means there is a change in velocity of the object, and therefore a change in kinetic energy of the object, since $E_k = \frac{1}{2}mv^2$

WORK-ENERGY THEOREM: The work done by a net force on an object is equal to the change in the kinetic energy of the object

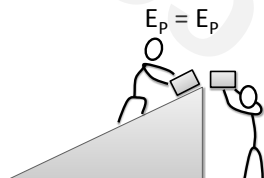
$$W_{\text{net}} = \Delta E_K$$

$$F_{\text{net}} \Delta x = \frac{1}{2}m(v_f^2 - v_i^2)$$

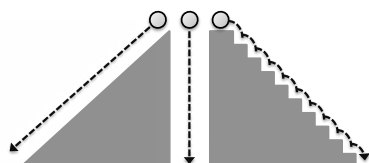
CONSERVATIVE FORCES

A force is a conservative force if:

1. The work done by the force in moving an object from point A to point B is independent of the path taken.
2. The net work done in moving an object in a closed path which starts and ends at the same point is zero.



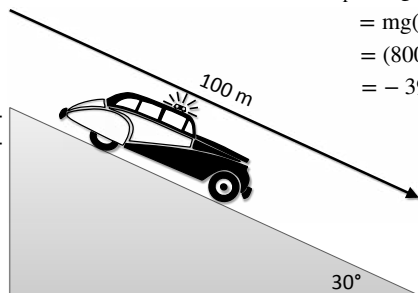
Conservative force conserve mechanical energy. Example of conservative forces are gravitational force and spring force.



The work done by gravity on each ball is independent of the path taken. Only the h_i is considered.

EXAMPLE:

An 800 kg car traveling at $15 \text{ m}\cdot\text{s}^{-1}$ down a 30° hill needs to stop within 100 m to avoid an accident. Using energy calculations only, determine the magnitude of the average force that must be applied to the brakes over the 100 m. Assume that the surface is frictionless.



$$\begin{aligned}\Delta E_p &= mg\Delta h \\ &= mg(h_f - h_i) \\ &= (800)(9,8)(0 - 100 \sin 30^\circ) \\ &= -392\,000 \text{ J}\end{aligned}$$

$$\begin{aligned}\Delta E_K &= E_{Kf} - E_{Ki} \\ &= \frac{1}{2}m(v_f^2 - v_i^2) \\ &= \frac{1}{2}(800)(0^2 - 15^2) \\ &= -90\,000 \text{ J}\end{aligned}$$

$$\begin{aligned}W_{\text{nc}} &= \Delta E_K + \Delta E_p \\ F_A \Delta x \cos \theta &= \Delta E_K + \Delta E_p \\ F_A (100) \cos 180 &= -90\,000 - 392\,000 \\ F_A &= \frac{-482\,000}{-100} \\ F_A &= 4\,820 \text{ N}\end{aligned}$$

NON-CONSERVATIVE FORCES

(F_T , F_A , F_f , $F_{\text{air resistance}}$)

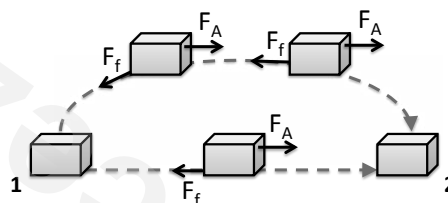
A force is a non-conservative force if:

1. The work done by the force in moving an object from point A to point B is dependent of the path taken.
2. The net work done in moving an object in a closed path which starts and ends at the same point is not zero.

A non-conservative force does not conserve mechanical energy.

A certain amount of energy is converted into other forms such as internal energy of the particles which the objects is made of. An example of a non-conservative force is the frictional force.

Consider the crate on a rough surface being pushed with a constant force F_A from position 1 to position 2 along two different paths.



The work done by F_A is more when the longer path is taken. The work done to overcome the friction will result in the surface of the crate becoming hotter. This energy is dissipated (as sound and/or heat) and is very difficult to retrieve, i.e. not conserved.

Note: the total energy of the system is conserved in all cases, whether the forces are conservative or non-conservative.

$$\begin{aligned}W_{\text{nc}} &= \Delta E_K + \Delta E_p \\ &= \frac{1}{2}m(v_f^2 - v_i^2) + mg\Delta h\end{aligned}$$

POWER

Power is the rate at which work is done OR the rate at which energy is transferred.

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

P = power (watt)

W = work (J)

Δt = time (s)

EXAMPLE:

Calculate the power expended by an engine when an object of mass 100 kg is lifted to a height of 2,2 m in a time of 3 s, at a constant velocity.

$$\begin{aligned}P &= \frac{W}{\Delta t} \\ &= \frac{F \Delta x \cos \theta}{\Delta t} \\ &= \frac{(100)(9,8)(2,2) \cos 0}{3} \\ &= 718,67 \text{ W}\end{aligned}$$

NOTE:

$$\begin{aligned}F_{\text{net}} &= 0 \text{ N} \\ W_{\text{net}} &= 0 \text{ J} \\ P_{\text{net}} &= 0 \text{ W}\end{aligned}$$

AVERAGE POWER (CONSTANT VELOCITY)

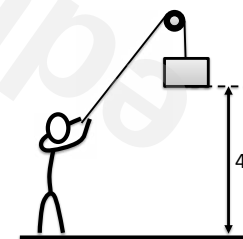
We can calculate the average power needed to keep an object moving at constant speed using the equation:

$$P_{\text{average}} = F v_{\text{average}}$$

$$P_{\text{average}} = F \frac{\Delta x}{\Delta t}$$

EXAMPLE:

A man lifts a 50 kg bag of cement from ground level up to a height of 4 m above ground level in such a way that the bag of cement moves at constant velocity (i.e. no work is done to change kinetic energy). Determine his average power if he does this in 10 s.



$$\begin{aligned}P_{\text{average}} &= F v_{\text{average}} \\ &= F \frac{\Delta y}{\Delta t} \\ &= (50)(9,8) \left(\frac{4}{10} \right) \\ &= 196 \text{ W}\end{aligned}$$

This cannot be used for object in freefall, unless the object has reached terminal velocity.

WORK, ENERGY AND POWER

WHEN TO USE WHICH FORMULAE

CONSERVATION OF MECHANICAL ENERGY

$$E_{M_A} = E_{M_B}$$

$$(E_P + E_K)_A = (E_P + E_K)_B$$

- When there are no external force (F_A/F_f) present.
- Any track/pendulum with a curve that is not a straight line.

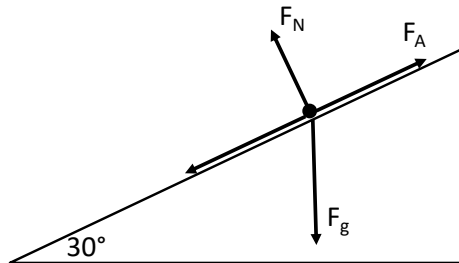
WORK-ENERGY PRINCIPLE

$$W_{\text{net}} = \Delta E_K$$

$$= \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

- If an object is accelerating on a horizontal/incline plane.

Any of the following methods may be used:



A. $F_{\text{net}} \rightarrow W_{\text{net}}$

- Determine F_{net} separately

$$F_{\text{net}} = F_A - F_f - F_{g\parallel}$$

$$F_{\text{net}} = F_A - F_f - F_g \sin \theta$$

$$F_{\text{net}} = F_A - F_f - (100 \sin 30^\circ)$$

- Apply F_{net} to W_{net}

$$W_{\text{net}} = F_{\text{net}} \Delta x \cos \theta = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

A. $W_{\text{net}} = \Sigma W$

- Determine W of each force separately

$$W_A = F_A \Delta x \cos \theta$$

$$W_N = F_N \Delta x \cos \theta$$

$$W_g = F_g \Delta x \cos \theta$$

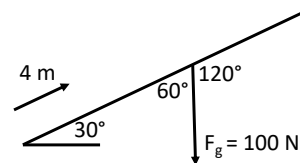
$$W_f = F_f \Delta x \cos \theta$$

- Apply ΣW to W_{net}

$$W_A + W_f + W_g + W_N = W_{\text{net}} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

ALTERNATIVE METHODS TO DETERMINE WORK DONE BY F_g ON A SLOPE WITHOUT RESOLVING F_g INTO $F_{g\perp}$ AND $F_{g\parallel}$

- When an object moves up a slope with a known angle

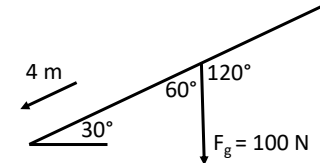


$$W_g = F_g \Delta x \cos \theta$$

$$= (100)(4) \cos 120^\circ$$

$$= -200 \text{ J}$$

- When an object moves down a slope with a known angle

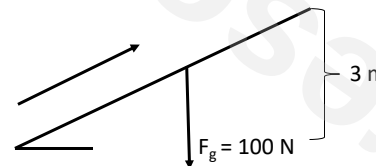


$$W_g = F_g \Delta x \cos \theta$$

$$= (100)(4) \cos 60^\circ$$

$$= 200 \text{ J}$$

- When an object moves up a slope without a given angle, but with specified height

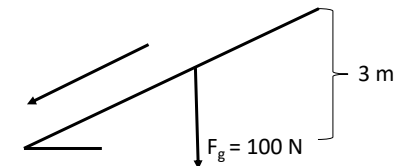


$$W_g = F_g \Delta x \cos \theta$$

$$= (100)(3) \cos 180^\circ$$

$$= -300 \text{ J}$$

- When an object moves down a slope without a given angle, but with specified height



$$W_g = F_g \Delta x \cos \theta$$

$$= (100)(3) \cos 0^\circ$$

$$= 300 \text{ J}$$

MOTION IN 1D

VARIABLES

v_i	initial velocity
v_f	final velocity
a	acceleration
$\Delta x / \Delta y$	displacement
Δt	change in time

EQUATIONS OF MOTION

$$v_f = v_i + a \Delta t$$

$$\Delta x = v_i \Delta t + \frac{1}{2} a \Delta t^2$$

$$v_f^2 = v_i^2 + 2a \Delta x$$

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

Steps to using the equations:

- Draw a diagram of the motion of the object.
- Identify each stage of the motion (**where the acceleration has changed**).
- Choose a positive direction and use the same convention throughout.
- Record the information given and value required by writing next to each variable. Check the unit and direction.
- Select correct equation and solve for unknown.
- Include units and direction in your answer.

Remember:

'starting from rest' means: u or $v_i = 0$
 'comes to a stop' means: v or $v_f = 0$
 Slowing down means: acceleration is negative ($a < 0$), while still moving in a positive direction.
 Constant velocity means: $a = 0$, $u = v$ or $v_i = v_f$
 Use a new set of variables for each stage of the motion.
 Conversion of units: $1 \text{ m} \cdot \text{s}^{-1} = 3,6 \text{ km} \cdot \text{h}^{-1}$.

Calculations:

A racing car starting from rest on the grid, travels straight along the track and reaches the 400 m mark after 8,6 s.
 a) What was its average acceleration?

v_i	0
v_f	/
a	?
Δx	400 m
Δt	8,6 s

Let forward be positive.

$$\Delta x = v_i \Delta t + \frac{1}{2} a \Delta t^2$$

$$400 = (0)(8,6) + \frac{1}{2} a 8,6^2$$

$$a = 10,82 \text{ m} \cdot \text{s}^{-2} \text{ forward}$$

- b) What was its velocity at the 400 m mark?

$$v_f = v_i + a \Delta t$$

$$v_f = 0 + (10,82)(8,6)$$

$$v_f = 93,05 \text{ m} \cdot \text{s}^{-1} \text{ forward}$$

- c) At the 400 m mark, the brakes are applied and the car slowed down at $2 \text{ m} \cdot \text{s}^{-2}$ to come to rest. Calculate the time it took for the car to stop.

NB! New stage of motion.
Find the new value of each variable.

v_i	$93,05 \text{ m} \cdot \text{s}^{-1}$
v_f	0
a	$-2 \text{ m} \cdot \text{s}^{-2}$
Δx	/
Δt	?

Let forward be positive.

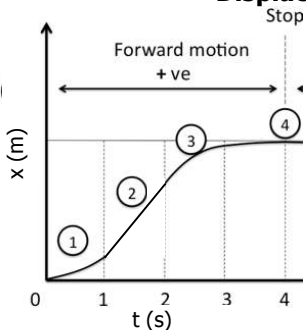
$$v_f = v_i + a \Delta t$$

$$0 = 93,05 - 2t$$

$$t = 46,53 \text{ s}$$

Position vs Time	Velocity vs Time	Acceleration vs Time
Stationary (velocity = $0 \text{ m} \cdot \text{s}^{-1}$)		
Constant velocity (acceleration = $0 \text{ m} \cdot \text{s}^{-2}$)		
Increasing velocity (constant positive acceleration)		
Decreasing velocity (constant negative acceleration)		

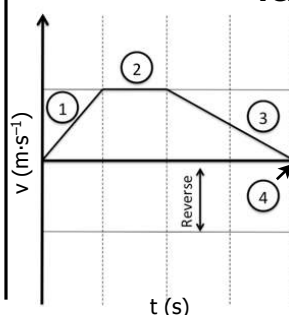
Displacement-Time



- 1 is positive acceleration
- 2 is constant velocity
- 3 is negative acceleration
- 4 is at rest

GRADIENT:
Velocity
AREA BELOW GRAPH:
n/a

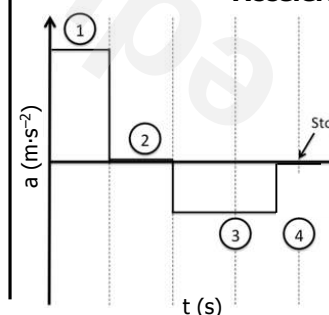
Velocity-Time



- 1 is positive acceleration
- 2 is constant velocity
- 3 is negative acceleration
- 4 is at rest, $v = 0 \text{ m} \cdot \text{s}^{-1}$

GRADIENT:
Acceleration
AREA BELOW GRAPH:
 Δ Displacement

Acceleration-Time



- 1 is positive acceleration
- 2 is constant velocity ($a = 0$)
- 3 is negative acceleration
- 4 is at rest or constant v

GRADIENT:
n/a
AREA BELOW GRAPH:
 Δ Velocity

PROJECTILE MOTION

A projectile is an object that moves freely under the influence of gravity only. It is not controlled by any mechanism (pulley or motor). The object is in free fall, but may move upwards (thrown up) or downwards.

Forces on a projectile

In the absence of friction, the gravitational force of the earth is the **only** force acting on a free falling body. This force always acts downwards.

Because the gravitational force is always downward, a projectile that is moving upward, must slow down. When a projectile is moving downward, it moves in the direction of the gravitational force, therefore it will speed up.

Acceleration due to gravity

All free falling bodies near the surface of the earth have the same acceleration due to gravity. This acceleration is $9,8 \text{ m}\cdot\text{s}^{-2}$ downward.

Ignoring air resistance/friction; If a marble and a rock are released from the same height at the same time, they will strike the ground simultaneously, and their final velocity will be the same.

Their momentum (mv) and kinetic energy ($\frac{1}{2}mv^2$) are not the same, due to a difference in mass.

If two objects are released from different heights, they have the same acceleration, but they strike the ground at different times and have different velocities.

$$v_f = v_i + a\Delta t$$

$$v_f^2 = v_i^2 + 2a\Delta y$$

$$\Delta y = v_i\Delta t + \frac{1}{2}a\Delta t^2$$

$$\Delta y = \left(\frac{v_i + v_f}{2}\right)\Delta t$$

Δy = displacement (m)

Δt = time (s)

v_i = initial velocity ($\text{m}\cdot\text{s}^{-1}$)

v_f = final velocity ($\text{m}\cdot\text{s}^{-1}$)

a = acceleration ($\text{m}\cdot\text{s}^{-2}$)
($9,8 \text{ m}\cdot\text{s}^{-2}$ downwards)

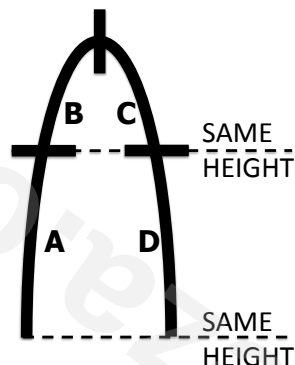
REMEMBER:

1. Draw a sketch diagram
2. Write down given variables
3. Choose positive direction
4. Solve

VERTICAL PROJECTILE MOTION

PARTS OF PROJECTILE PATH

Only vertical movement (up and down) is considered, no horizontal movement is taken into account. The path of projectile motion can be analysed using the 4 sections as shown below. The combination of these 4 parts will depend on the actual path travelled by the projectile. Example: Dropped projectile is sections C and D only. Object thrown upwards and falls on roof is sections A to C.



Time:

$$t_A = t_D$$

$$t_B = t_C$$

Displacement:

$$\Delta y_A = \Delta y_D$$

$$\Delta y_B = \Delta y_C$$

Velocity:

$$v_{iA} = v_{fD}$$

$$v_{fA} = v_{iD}$$

$$v_{iB} = v_{fC}$$

$$v_{fB} = v_{iC} = 0 \text{ m}\cdot\text{s}^{-1}$$

EXAMPLE:

An object is projected vertically upwards. 4 seconds later, it is caught at the same height (point of release) on its way downwards. Determine how long it took the ball to pass a height of 8 m in the upward direction. Choose downward as positive direction.

total time = 4 s

$$\therefore t_{\text{up}} = 2 \text{ s}$$

$$v_f = v_i + a\Delta t$$

$$0 = v_i + (9,8)(2)$$

$$v_i = -19,6$$

$$\therefore v_i = 19,6 \text{ m}\cdot\text{s}^{-1} \text{ up}$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\Delta y = v_i\Delta t + \frac{1}{2}a\Delta t^2$$

$$-8 = -19,6t + \frac{1}{2}(9,8)t^2$$

$$0 = 4,9t^2 - 19,6t + 8$$

$$t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$t = \frac{-(-19,6) \pm \sqrt{(-19,6)^2 - 4(4,9)(8)}}{2(4,9)}$$

$$t = 0,46 \text{ s}$$

$$\therefore t = 0,46 \text{ s}$$

*time for downward direction

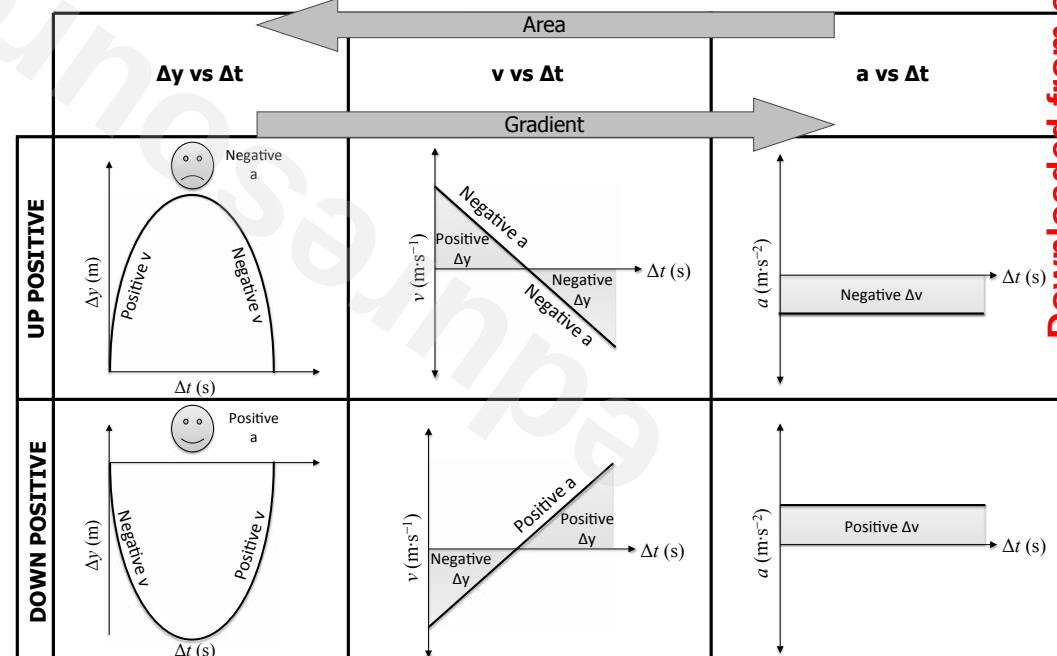
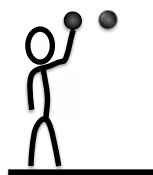
GRAPHS OF PROJECTILE MOTION

(Eg. A ball is thrown into the air and is caught at the same height.)

Graph manipulation:

Change in positive direction:
Flip graph along x-axis

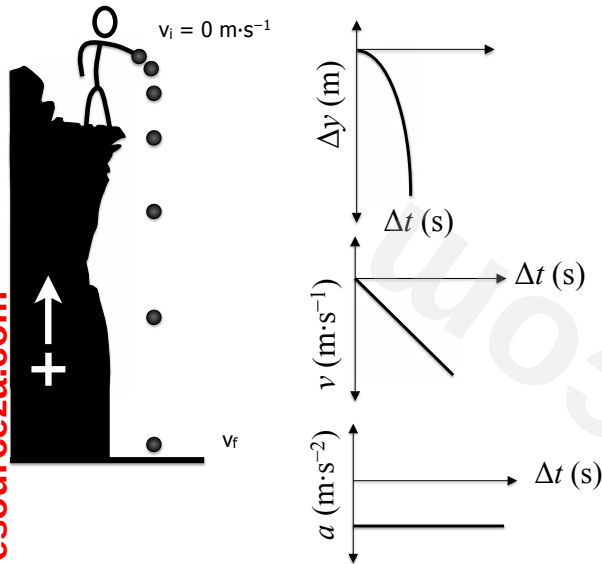
Change in reference position:
Shift x-axis (Δy - Δt only)



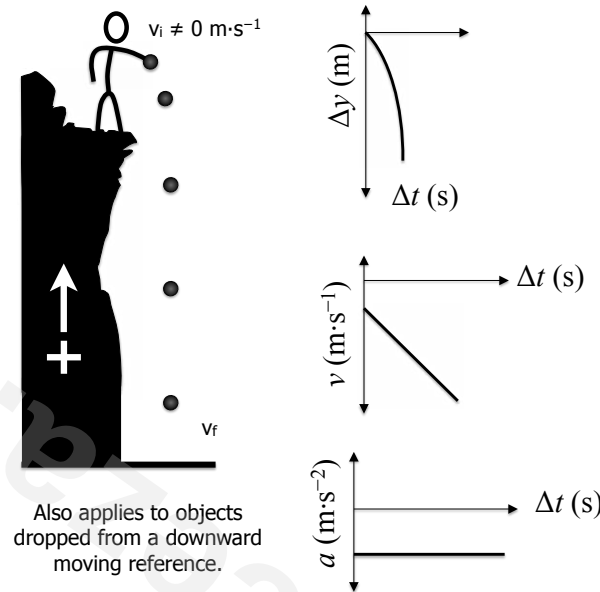
PATH OF A PROJECTILE

ALL EXAMPLES:
UP POSITIVE, POINT OF RELEASE IS REFERENCE

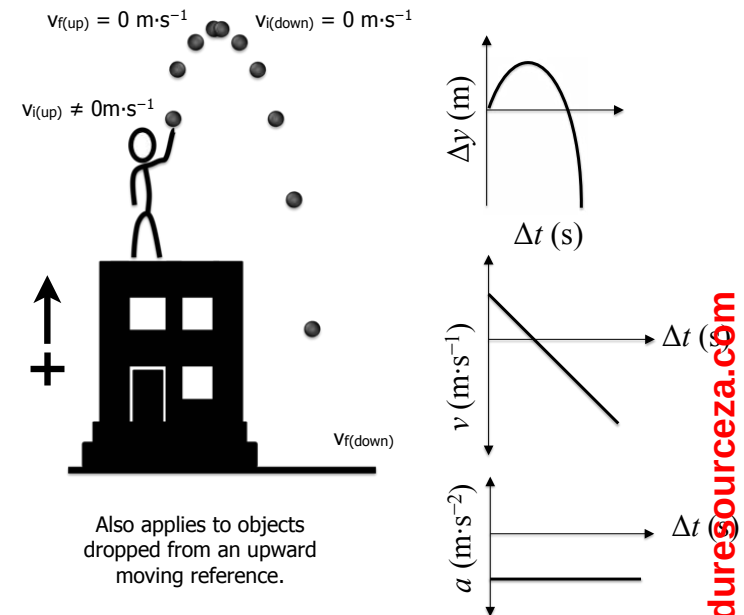
OBJECT DROPPED FROM HEIGHT (C+D)



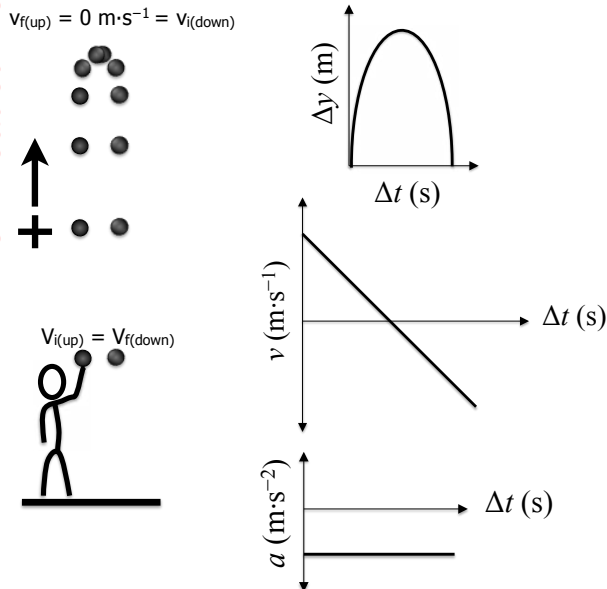
OBJECT THROWN DOWN FROM HEIGHT (D)



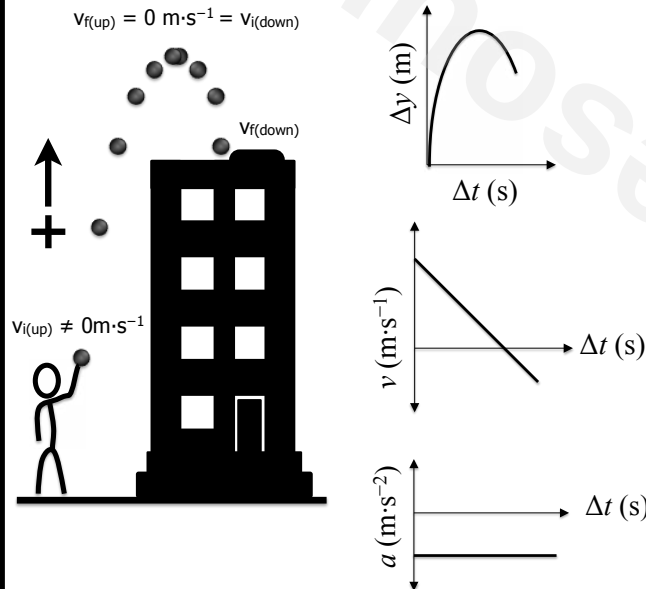
OBJECT THROWN UP FROM HEIGHT (B+C+D)



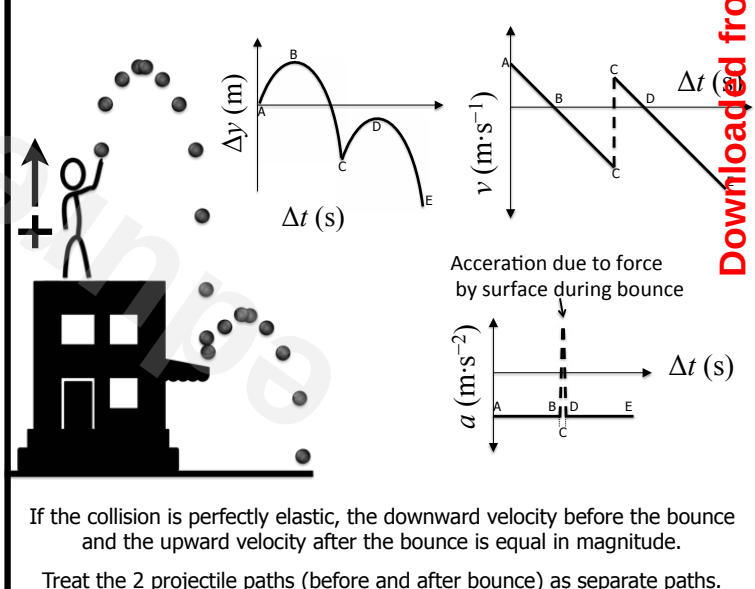
OBJECT THROWN UP AND CAUGHT (A+B+C+D)



OBJECT THROWN UP, LANDS AT HEIGHT (A+B+C)



OBJECT THROWN UP FROM HEIGHT, BOUNCES (B+C+D)



SPECIAL PROJECTILE PATHS

HOT AIR BALLOON



When an object is dropped from a moving reference (hot air balloon), the initial velocity will be equal to that of the reference. The acceleration of the object will be downwards at $9,8 \text{ m}\cdot\text{s}^{-2}$, regardless of the acceleration of the reference.

EXAMPLE:

A hot air balloon ascends with a constant velocity of $5 \text{ m}\cdot\text{s}^{-1}$. A ball is dropped from the hot air balloon at a height of 50 m and falls vertically towards the ground. Determine (a) the distance between the hot air balloon and ball after 2 seconds and (b) the velocity of the ball when it reaches the ground.

- (a) Take downwards as positive:
Distance travelled by balloon :

$$\Delta y = v_i \Delta t + \frac{1}{2} a \Delta t^2$$

$$= (-5)(2) + \frac{1}{2}(0)(2^2)$$

$$= -10$$

$$\therefore \Delta y = 10 \text{ m up}$$

Distance travelled by ball :

$$\Delta y = v_i \Delta t + \frac{1}{2} a \Delta t^2$$

$$= (-5)(2) + \frac{1}{2}(9,8)(2^2)$$

$$= -10 + 19,6$$

$$\therefore \Delta y = 9,6 \text{ m down}$$

$$\therefore \text{total distance} = 10 + 9,6$$

$$= 19,6 \text{ m apart}$$

- (b) Take downwards as positive:

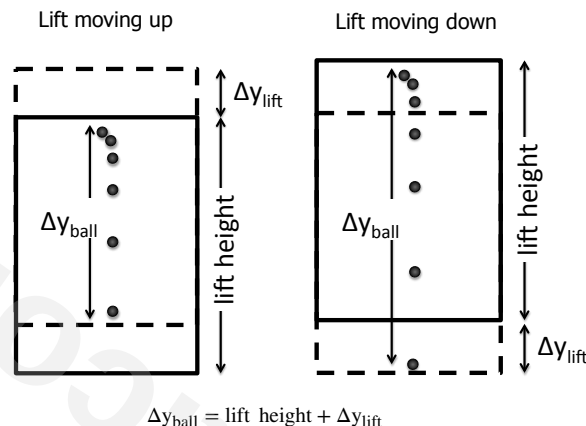
$$v_f^2 = v_i^2 + 2a\Delta y$$

$$v_f^2 = (-5)^2 + 2(9,8)(50)$$

$$v_f = \sqrt{25 + 980}$$

$$v_f = 31,70 \text{ m}\cdot\text{s}^{-1} \text{ downwards}$$

LIFT



EXAMPLE:

A lift accelerates upwards at a rate of $1,4 \text{ m}\cdot\text{s}^{-2}$. As the lift starts to move, a lightbulb falls from the ceiling of the lift. Determine how long it takes the lightbulb to reach the lift's floor. The height from the ceiling of the lift to its floor is 3m.

Take downwards as positive:

movement of lift :

$$\Delta y_{\text{lift}} = v_i \Delta t + \frac{1}{2} a \Delta t^2$$

$$y_{\text{lift}} = (0)t + \frac{1}{2}(-1,4)t^2$$

$$\therefore y_{\text{lift}} = -0,7t^2$$

movement of bulb :

$$\Delta y_{\text{bulb}} = v_i \Delta t + \frac{1}{2} a \Delta t^2$$

$$3 + y_{\text{lift}} = (0)t + \frac{1}{2}(9,8)t^2$$

$$3 - 0,7t^2 = 4,9t^2$$

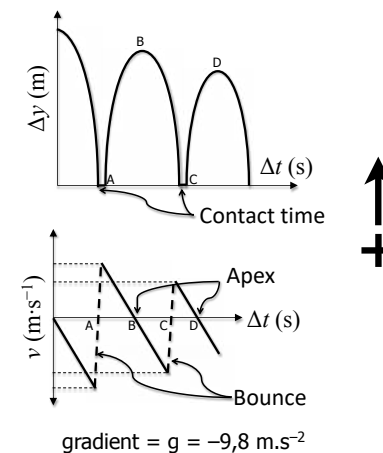
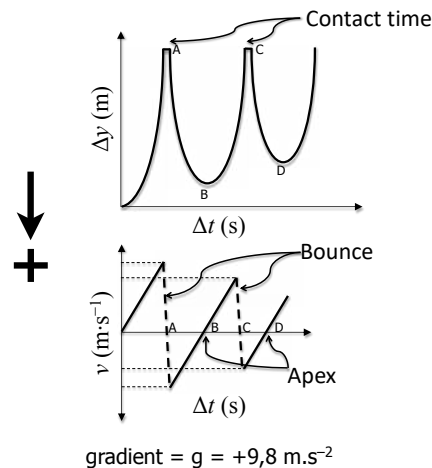
$$3 = 5,6t^2$$

$$\therefore t = 0,73 \text{ s}$$

Simultaneous equation is needed because there are 2 unknown variables:

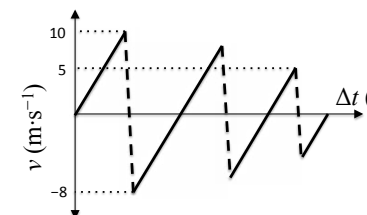
- Distance that lift moved
- Time to reach floor

BOUNCING BALL – Ball falls from rest and bounces



EXAMPLE:

The velocity-time graph below represents the bouncing movement of a 0,1 kg ball. Use the graph to answer the questions that follow:



- a) Which direction of movement is positive?

Downwards

- b) How many times did the ball bounce?

3 times

- c) What does the gradient of the graph represent?

Acceleration of the ball

- d) Are the collisions between the ball and ground elastic or inelastic?

After each bounce there is a decrease in magnitude of the velocity of the ball, and therefore a change in kinetic energy. The collisions are inelastic as kinetic energy is not conserved.

- e) If the ball is in contact with the ground for a duration of 0,08 s, determine the impulse on the ball

$$\text{Impulse} = \Delta p$$

$$= m(v_f - v_i)$$

$$= (0,1)(-8 - 10)$$

$$= -1,8$$

$$\therefore \text{Impulse} = 1,8 \text{ N}\cdot\text{s upwards}$$

- f) Predict why the ball stopped moving.
it was most likely caught

SERIES

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

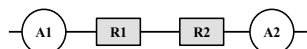
PARALLEL

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

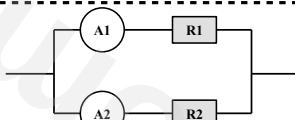
CURRENT is the rate of flow of charge.

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

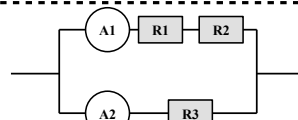
I is the current strength, **Q** the charge in coulombs and **t** the time in seconds. SI unit is ampere (A).



$$I_T = I_1 = I_2$$



$$I_T = I_1 + I_2$$



$$I_T = I_1 + I_2$$

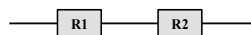
$$I_1 = I_{R1} = I_{R2}$$

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

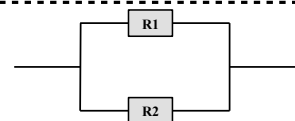
$$V = IR$$

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

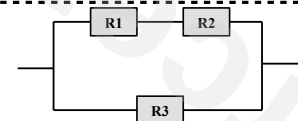
Resistance (R) is the quotient of the **potential difference (V)** across a conductor and the **current (I)** in it. The unit of resistance is called the **ohm (Ω)**.



$$R_s = R_1 + R_2$$



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



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

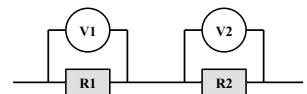
POTENTIAL DIFFERENCE (p.d.) is the work done per unit positive charge to move the charge from one point to another. It is often referred to as voltage.

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

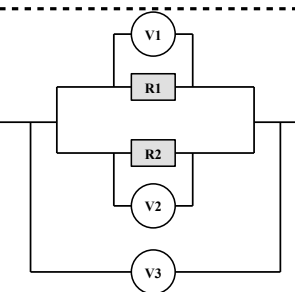
V is Potential difference in V (volts), **W** is Work done or energy transferred in J (joules) and **Q** is Charge in C (coulombs).

NOTE:

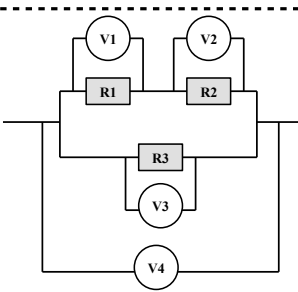
1. Emf ($\mathcal{E}$): voltage across cells when no current is flowing (open circuit).
2. V_{term} or V_T : voltage across cells when current is flowing.



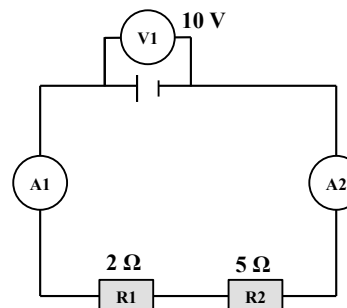
$$V_s = V_1 + V_2$$



$$V_p = V_1 = V_2 = V_3$$



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

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

a) Determine the total resistance.

$$R_{tot} = R_1 + R_2$$

$$= 2 + 5$$

$$= 7 \Omega$$

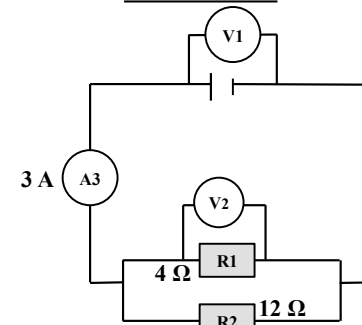
b) Determine the reading on A1 and A2.

$$V = IR$$

$$10 = I(7)$$

$$I = 1,43 \text{ A}$$

$$\therefore A1 = A2 = 1,43 \text{ A}$$

Parallel circuit

a) Determine the total resistance.

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

$$= \frac{1}{4} + \frac{1}{12}$$

$$= \frac{1}{3}$$

$$\therefore R_p = 3 \Omega$$

b) Determine the reading on V1 and V2.

$$V_1 = IR$$

$$= (3)(3)$$

$$= 9 \text{ V}$$

$$\therefore V1 = V2 = 9 \text{ V}$$

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.

$$a) \frac{1}{R_p} = \frac{1}{R_2} + \frac{1}{R_3}$$

$$= \frac{1}{2} + \frac{1}{4}$$

$$= \frac{3}{4}$$

$$\therefore R_p = \frac{4}{3} = 1,33 \Omega$$

$$R_{tot} = R_3 \Omega + R_p$$

$$= 3 + 1,33$$

$$= 4,33 \Omega$$

$$b) R_{tot} = \frac{V_{tot}}{I_1}$$

$$4,33 = \frac{15}{I_1}$$

$$I_1 = 3,46 \text{ A}$$

$$c) R_p = \frac{V_1}{I_1}$$

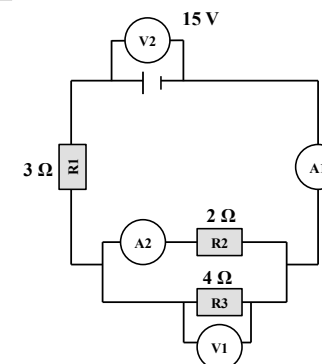
$$1,33 = \frac{V_1}{3,46}$$

$$V_1 = 4,60 \text{ V}$$

$$d) R_{2\Omega} = \frac{V_1}{I_2}$$

$$2 = \frac{4,60}{I_2}$$

$$I_2 = 2,30 \text{ A}$$



ELECTRICITY

INTERNAL RESISTANCE

OHM'S LAW

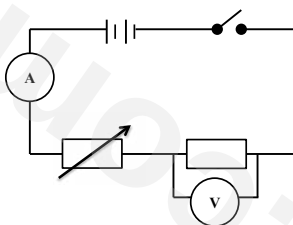
The potential difference across the conductor is directly proportional to the current through the conductor provided that the temperature remains constant.

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

Proof of Ohm's law:

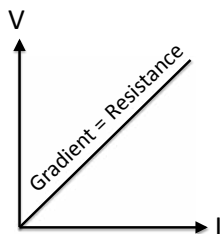
The current in the circuit is changed using the rheostat, thus current is the independent variable and potential difference is the dependent variable. It is important that the temperature of the resistor is kept constant.

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



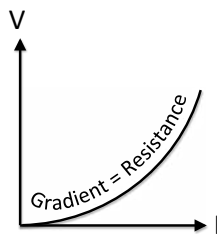
Ohmic conductor

- 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.

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

$$P = VI$$

$$P = I^2 R$$

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

P = power (W)

W = work (J)

Δt = time (s)

I = current (A)

V = potential difference (V)

R = resistance (Ω)

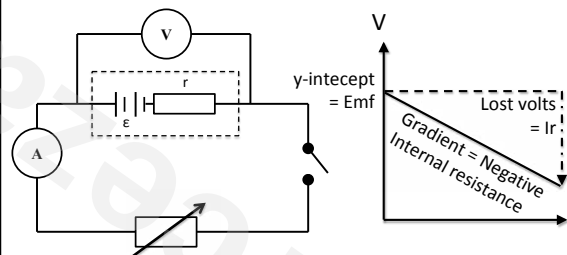
The potential difference across a battery not connected in a circuit is the emf of the battery.

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

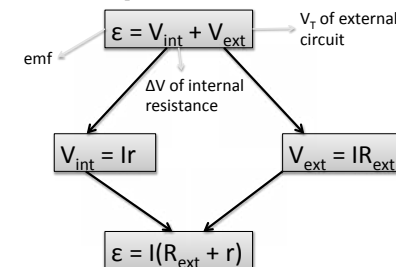
Note:
P in kW
t in hours

Example

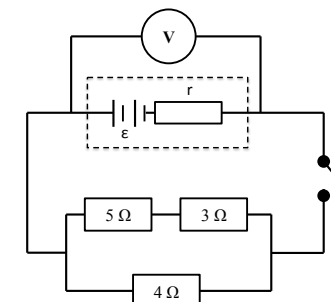
A geyser produces 1200 W of power. Calculate the cost of having the geyser switched on for 24 hours, if the price of electricity is R1,55 per unit.

$$\begin{aligned} \text{Cost} &= \text{power} \times \text{time} \times \text{cost per unit} \\ &= (1,2)(24)(1,55) \\ &= \text{R}44,64 \end{aligned}$$

CALCULATIONS (WITH INTERNAL RESISTANCE)



EXAMPLE:



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.
- How will the voltmeter reading change when the 4 Ω resistor is removed?

$$\begin{aligned} a) \quad R_{top} &= R_{5\Omega} + R_{3\Omega} \\ &= 5 + 3 \\ &= 8 \, \Omega \end{aligned}$$

$$R_{top} : R_{4\Omega}$$

$$8 : 4$$

$$2 : 1$$

$$\therefore I_{top} : I_{4\Omega}$$

$$1 : 2$$

$$I_{4\Omega} = 2I_{top}$$

$$= 2(1)$$

$$= 2 \, \text{A}$$

$$I_{tot} = I_{top} + I_{4\Omega}$$

$$= 1 + 2$$

$$= 3 \, \text{A}$$

$$\begin{aligned} b) \quad \frac{1}{R_p} &= \frac{1}{R_{top}} + \frac{1}{R_{4\Omega}} \\ &= \frac{1}{8} + \frac{1}{4} \\ &= \frac{3}{8} \end{aligned}$$

$$R_p = \frac{8}{3} = 2,67 \, \Omega$$

$$\varepsilon = I(R + r)$$

$$12 = 3(2,67 + r)$$

$$r = 1,33 \, \Omega$$

- When the 4 Ω resistor is removed, the external resistance increases and the current decreases. ($I \propto 1/R$). Emf and internal resistance are constant, therefore a decrease in current will result in an increase in external V_T (Voltmeter reading)

$$V = \varepsilon - Ir$$

ELECTROSTATICS

FLASHBACK!!

Principle of conservation of charge.

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

Principle of charge quantization.

$$N_{e^-} = \frac{Q}{q_e}$$

Unit of charges:

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 magnitude of the electrostatic force exerted by one point charge (Q_1) on another point charge (Q_2) is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance (r) between them.

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

F = force of attraction between charges Q_1 and Q_2 (N)

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

Q = magnitudes of charge (C)

r = distance between charges (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

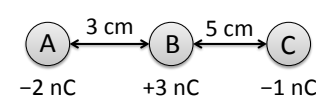
The force can be calculated using

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

- Substitute charge magnitude only.
- Direction determined by nature of 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 .



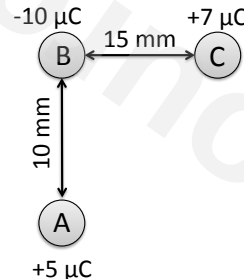
$$\begin{aligned} \textcircled{1} F_{AB} &= \frac{kQ_AQ_B}{r^2} \\ &= \frac{9 \times 10^9 (2 \times 10^{-9})(3 \times 10^{-9})}{(3 \times 10^{-2})^2} \\ &= 6 \times 10^{-5} \text{ N left (A attracts B)} \end{aligned}$$

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

$$\begin{aligned} \textcircled{3} F_{\text{net}} &= F_{AB} + F_{CB} \\ &= (-6 \times 10^{-5}) + (1,08 \times 10^{-5}) \\ &= -4,92 \times 10^{-5} \\ \therefore F_{\text{net}} &= 4,92 \times 10^{-5} \text{ N left} \end{aligned}$$

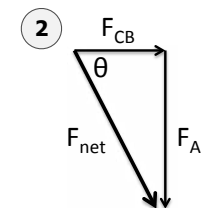
2 Dimensional

Determine the resultant electrostatic force on Q_B .



$$\begin{aligned} \textcircled{1} F_{AB} &= \frac{kQ_AQ_B}{r^2} \\ &= \frac{9 \times 10^9 (5 \times 10^{-6})(10 \times 10^{-6})}{(10 \times 10^{-3})^2} \\ &= 4\,500 \text{ N down (A attracts B)} \end{aligned}$$

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



$$\begin{aligned} \textcircled{3} \text{PYTHAGORAS :} \\ F_{\text{net}}^2 &= F_{AB}^2 + F_{CB}^2 \\ F_{\text{net}} &= \sqrt{4\,500^2 + 2\,800^2} \\ F_{\text{net}} &= 5\,300 \text{ N} \end{aligned}$$

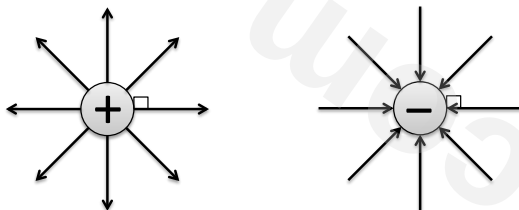
$$\begin{aligned} \textcircled{4} \tan \theta &= \frac{o}{a} \\ \theta &= \tan^{-1} \frac{F_{AB}}{F_{CB}} \\ \theta &= \tan^{-1} \frac{4\,500}{2\,800} \\ \theta &= 58,11^\circ \\ \therefore F_{\text{net}} &= 5\,300 \text{ N at } 58,11^\circ \text{ clockwise from the positive x-axis} \end{aligned}$$

ELECTRIC FIELDS

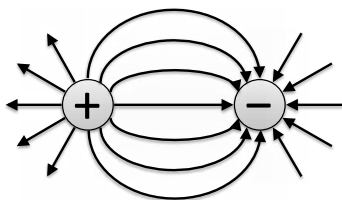
An electric field is the region around an electric charge where another charge (or charged object) will experience an electrostatic force. The direction of the electric field at a point is the direction that a positive test charge (+1C) would move if placed at that point.

REMEMBER: Field lines leave a conducting surface at 90 °

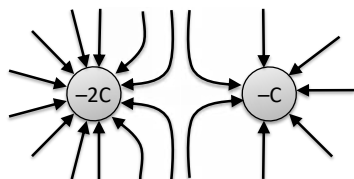
Single point charges



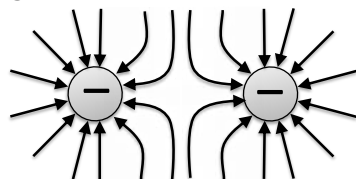
Unlike charges (of equal magnitude)



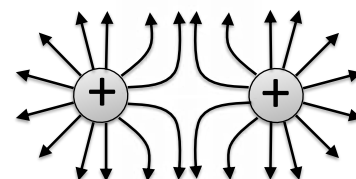
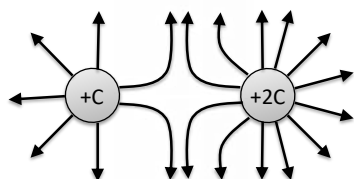
Like charges



Different magnitude charges



Equal magnitude 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 (N·C⁻¹)

F = force on charge q (N)

q = charge (C)

q is the charge that experiences the force.

Force due to charge Q



Charge experiencing the electric field due to charge Q

EXAMPLE:

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



+2μC



-5μC

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

DIRECTION OF E:

Direction that charge q would move IF it was positive.

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

E = electric field strength (N·C⁻¹)

k = Coulomb's constant (9×10⁹ N·m²·C⁻²)

Q = charge (C)

r = distance from charge Q (m)

Q is the charge that creates the electric field.



Certain point in space

Distance between charge Q and point X

EXAMPLE:

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



+3μC



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

DIRECTION OF E:

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

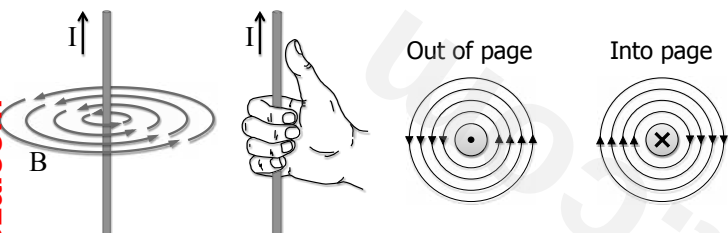
NOTE:

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

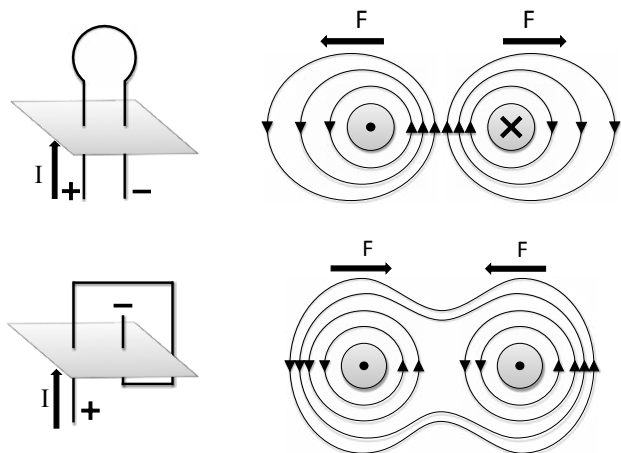
INDUCTION OF A MAGNETIC FIELD

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

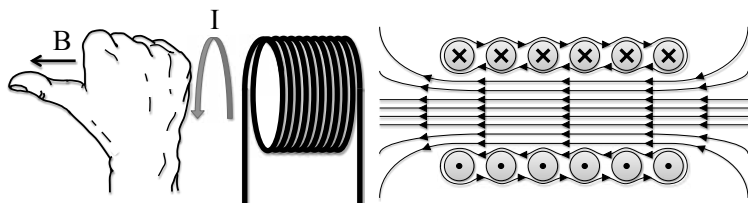
The direction of the magnetic field can be determined by the **right hand thumb rule**. For a straight, single wire, point the thumb of your right hand in the direction of the conventional current and your curled fingers will point in the direction of the magnetic field around the wire.



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, and relative motion occurs between the conductor and magnet, it causes movement of charge in the wire. As a result, an EMF is induced in the wire, which causes an induced current. 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.

NOTE THAT NO CALCULATIONS ARE REQUIRED, ONLY RELATIONSHIP BETWEEN VARIABLES

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

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 (ϕ) is the result of the product of the perpendicular component of the magnetic field (B) and cross-sectional area (A) the field lines pass through.

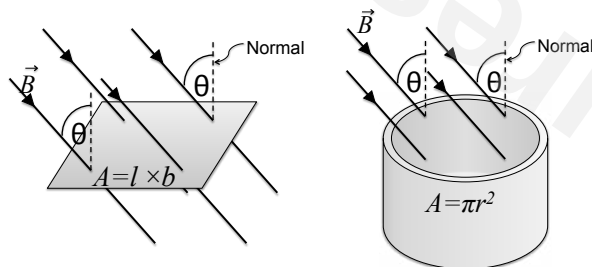
$$\phi = BA \cos \theta$$

ϕ = magnetic flux (Wb)

B = magnetic flux density (T)

A = area (m^2)

θ = angle between magnetic field line and normal



INCREASING THE INDUCED EMF

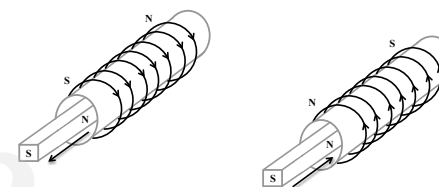
- Increase the rate of change of magnetic flux, ie. decrease the time it takes to change the flux, ie. increase speed of movement.
- Increase the number of loops in the coil.
- Increase the strength of the magnet.
- Increase the surface area of the loops in the coil.
- Increase the change of flux by 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.

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**.



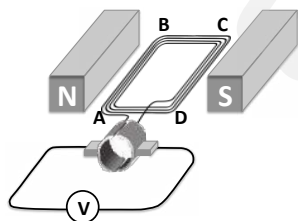
Lenz's Law states that the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnetic flux.

GENERATORS

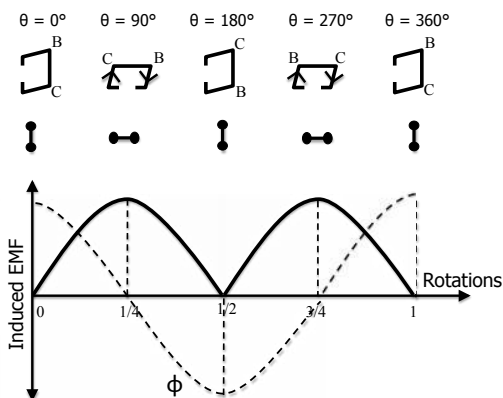
Generators convert mechanical energy into electrical energy. A generator works on the principal of mechanically rotating a conductor in a magnetic field. This creates a changing flux which induces an emf in the conductor.

Direct

A direct current generator uses a split ring commutator to connect the conductor to the external circuit instead of a slip ring.

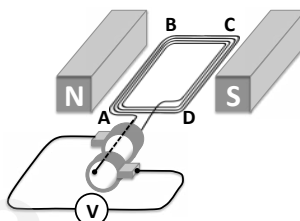


The current in the external circuit does not change direction and is known as direct current (DC).

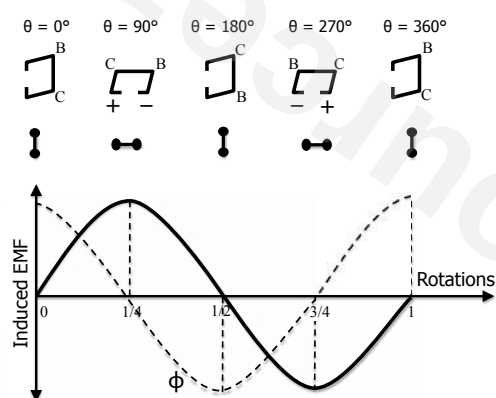


Alternating

The alternating current generator is connected to the external circuit by 2 slip rings which is connected to the conductor. The slip rings make contact with brushes which are connected to the external circuit.



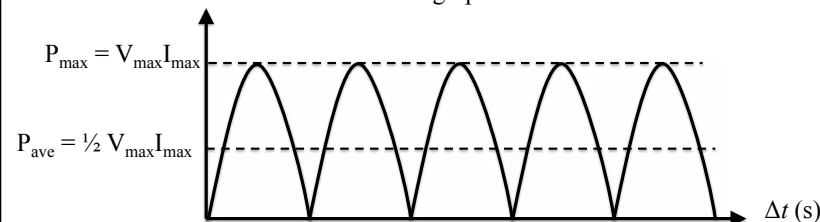
The direction of the current changes with every half turn of the coil. The current that is produced is known as alternating current (AC).



ALTERNATING CURRENT

The potential difference and current for an alternating current fluctuates between a positive and negative maxima. The average potential difference and current is zero and so the average power is used to define the potential difference and current for an alternating current.

Power versus time graph for a AC circuit.



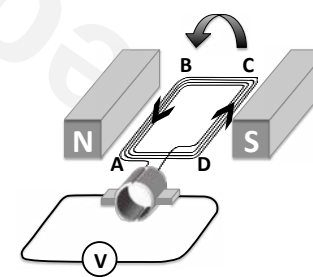
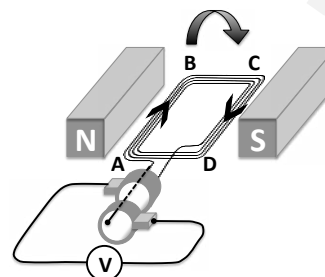
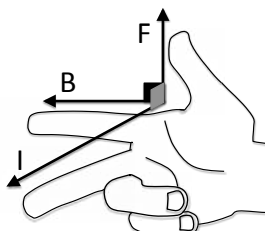
$$\begin{aligned} P_{\text{ave}} &= \frac{1}{2} P_{\text{max}} \\ &= \frac{1}{2} (V_{\text{max}} \cdot I_{\text{max}}) \\ &= \frac{1}{\sqrt{2}} V_{\text{max}} \cdot \frac{1}{\sqrt{2}} I_{\text{max}} \\ &= V_{\text{rms}} \cdot I_{\text{rms}} \end{aligned}$$

The potential difference for an alternating current is therefore defined by the root mean square of the maximum potential difference (V_{rms}) and the current for an alternating current is defined as the root mean square of the maximum current (I_{rms}). These values can be calculated from the maximum potential difference and maximum current as follows:

$$\begin{aligned} V_{\text{rms}} &= \frac{V_{\text{max}}}{\sqrt{2}} \\ I_{\text{rms}} &= \frac{I_{\text{max}}}{\sqrt{2}} \end{aligned}$$

FLEMING'S RIGHT HAND-DYNAMO RULE

The right hand rule is used to predict the direction of the induced emf in the coil. Using your right hand, hold your first finger, second finger and thumb at right angles to each other. Point your first finger in the direction of the magnetic field (N to S), your thumb in the direction of the motion (or force) of the conductor. The middle finger will point in the direction of the induced current (from + to -).

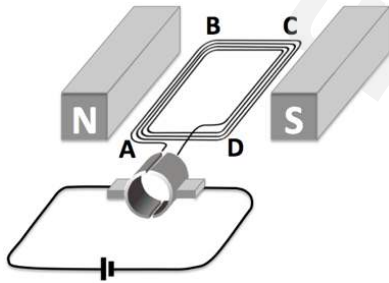


MOTORS

Electric motors convert electrical energy to mechanical energy. It consists of a current carrying armature, connected to a source by a commutator and brushes and placed in a magnetic field.

Direct

A direct current motor uses a split ring commutator to connect the conductor to the external circuit instead of a slip ring.

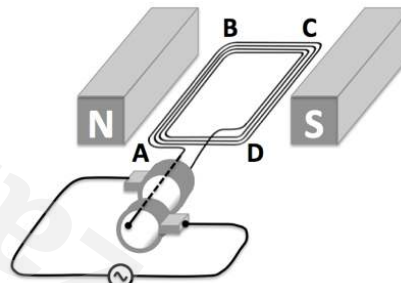


The split ring commutator allows the current in the coil to alternate with every half turn, which allows the coil to continue to rotate in the same direction.

When a charge moves in a magnetic field it experiences a force. The force experienced on both sides of the armature creates torque which makes it turn. The direction of the force can be explained using the left hand rule.

Alternating

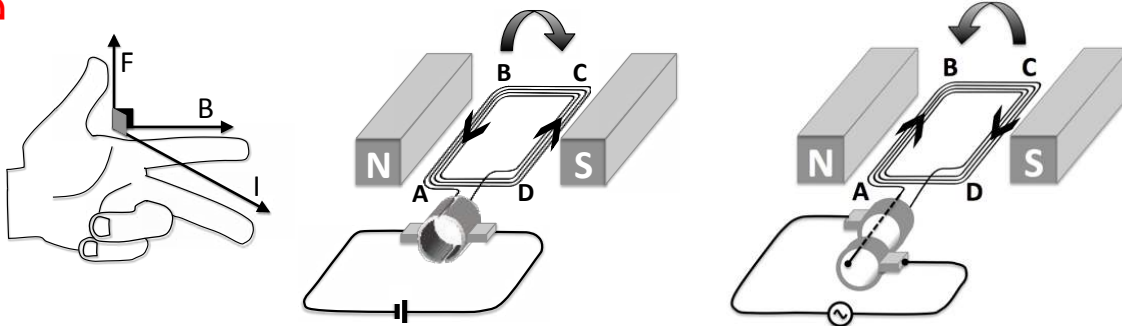
The alternating current motor is connected to the external circuit by a slip ring. The slip ring makes contact with brushes which are connected to the external circuit attached to an alternating current source.



The direction of the current in the coil is constantly changing, which allows the coil to continue to rotate in the same direction.

FLEMING'S LEFT HAND MOTOR RULE

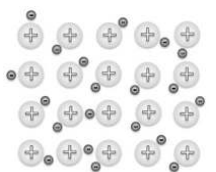
The Left hand Rule is used to predict the direction of the movement of the coil in the motor. Using your left hand, hold your first finger, second finger and thumb right angles to each other. Point your first finger in the direction of the magnetic field, your second finger in the direction of the conventional current and your thumb will then point in the direction of the force.



PHOTOELECTRIC EFFECT

PARTICLE NATURE OF LIGHT

The photoelectric effect occurs when light is shone on a metal's surface and this causes the metal to emit electrons.



Metals are bonded in such a way that they share their valence electrons in a sea of delocalized electrons. In order to get an electron to be removed from the surface of a metal, you would have to provide it with enough energy in order to escape the bond.

The energy that light provides enables the electron to escape and this phenomenon is called photoelectric effect.

PHOTON ENERGY

Photons are "little packets" of energy called quanta, which act as particles. The energy of the photon(light) can be calculated in one of two ways:

$$E = hf$$

$$E = \frac{hc}{\lambda}$$

E = energy of the photon measured in joules (J)

h = Planck's constant, $6,63 \times 10^{-34}$ (J·s)

f = frequency measured in hertz (Hz)

λ = wavelength measured in meters (m)

c = speed of light, 3×10^8 (m·s⁻¹)

THRESHOLD FREQUENCY (f_0), WORK FUNCTION (W_0) AND ELECTRON ENERGY

The frequency required to produce enough energy to emit an electron is called the threshold frequency (f_0). **The threshold frequency (f_0) is the minimum frequency of incident radiation at which electrons will be emitted from a particular metal. The minimum amount of energy needed to emit an electron from the surface of a metal is known as the work function (W_0).** The work function is material specific.

If the energy of the photons exceed the work function (i.e. the frequency of light exceeds the threshold frequency), the excess energy is transferred to the liberated electron in the form of kinetic energy.

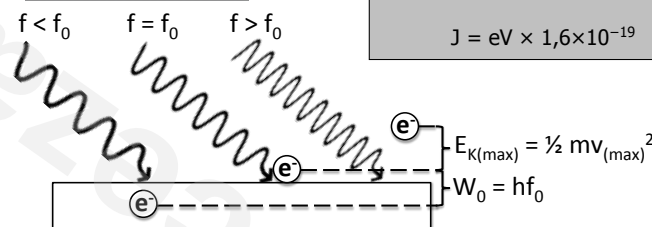
The kinetic energy of the electron can be determined by:

$$E = W_0 + E_{K(\max)}$$

NOTE:

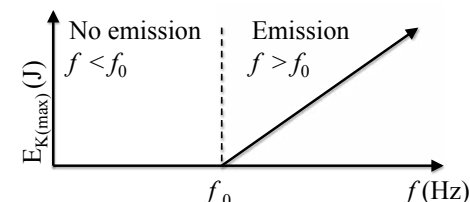
Sometimes work function is given in eV. Convert from eV to J:

$$J = \text{eV} \times 1,6 \times 10^{-19}$$

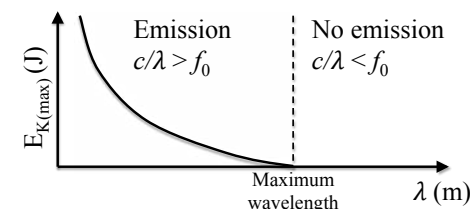


FREQUENCY AND WAVELENGTH

An increase in frequency will increase the kinetic energy of the electrons. On a graph of $E_{K(\max)}$ vs frequency, the x-intercept indicates the threshold frequency.

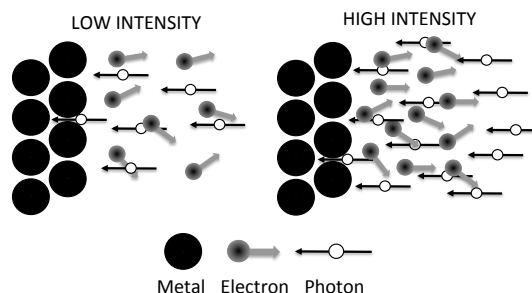
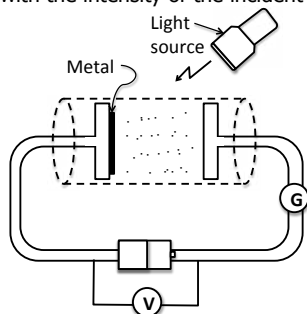


Similarly, on the graph of $E_{K(\max)}$ vs wavelength, the x-intercept indicates the maximum wavelength of light that can emit an electron (wavelength is inversely proportional to frequency).



INTENSITY AND FREQUENCY

Increasing the intensity (brightness) of the light (radiation) means that there are more photons with the same frequency. This will result in more electrons with the same amount of energy being emitted. Thus the number of electrons emitted per second increases with the intensity of the incident radiation



Note that the energy of the electrons remain the same. If the frequency of the incident radiation is below the cut-off frequency, then increasing the intensity of the radiation has no effect i.e. it does not cause electrons to be ejected. To increase the energy, the frequency of the radiant light needs to be increased.

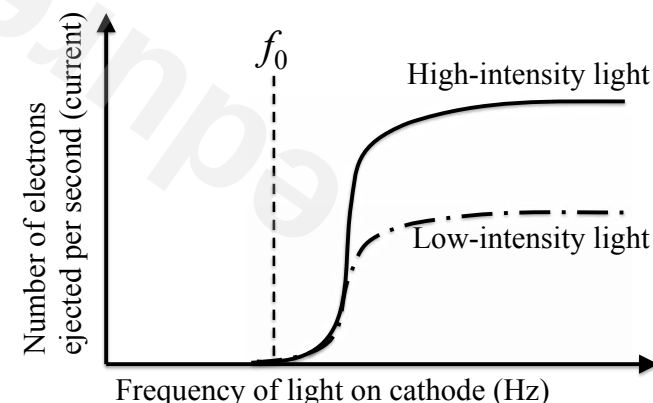
INCREASE **INTENSITY** AT CONSTANT FREQUENCY = INCREASE **AMOUNT** OF EMITTED ELECTRONS

INCREASE **FREQUENCY** AT CONSTANT INTENSITY = INCREASE **KINETIC ENERGY** OF EMITTED ELECTRONS

INTENSITY, FREQUENCY AND CURRENT

The higher the intensity of the radiation, the more electrons are emitted per second. Therefore an increased intensity will increase the current produced.

The higher the frequency, the more kinetic energy is provided to the same number of electrons. The rate of electron flow REMAINS THE SAME.



EMISSION AND ABSORPTION SPECTRA

CONTINUOUS SPECTRUM

When white light shines through a prism, the light is dispersed into a spectrum of light. It is called the continuous spectrum. White light is made up of all the colours of the spectrum, and when dispersed we are able to see the components of white light. This is the same range as the visible spectrum.

R O Y G B I V
red orange yellow green blue indigo violet

The white light is emitted from a bulb, therefore the continuous spectrum is an emission spectrum. Red has the lowest frequency, and violet the highest.

ATOMIC EMISSION SPECTRA

When an element in the gaseous phase is heated, it emits light. If the light produced is passed through a prism, a spectrum is produced. However, this spectrum is not continuous, but consists of only some lines of colour. This is known as **line emission spectrum**.

Each element has their own light signature as no two elements have the same spectrum.

589 nm



(a) sodium



(b) helium



(c) iron



(d) neon

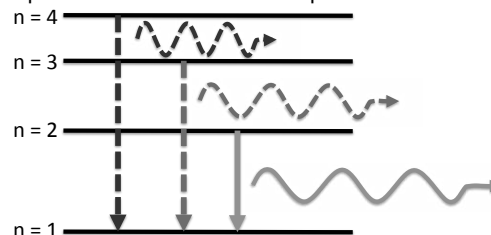


(e) hydrogen

blue ————— wavelength —————> red

ENERGY LEVELS

The lines on the atomic spectrum (line emission spectrum) are as a result of electron transitions between energy levels. As electrons gain energy (heat) they transition to a higher state of energy, hence a higher energy level. As the element cools, the electrons drop back down to the lower energy state. As they do this they emit the absorbed energy in the form of light (photons). Therefore, each electron gives off a frequency of light which corresponds with the line emission spectrum.



Electrons in the $n = 1$ energy level are closest to the nucleus and have the lowest potential energy. Electrons in the energy level furthest from the nucleus (eg. $n = 4$) has the highest potential energy. If an electron is free from the atom then it has zero potential energy. The potential energy is given as a negative value due to a decrease in potential as the electrons get close to the nucleus.

As the electrons transition from their energized state back to their normal state they give off energy that is equal to the difference in potential energy between the energy levels.

$$\Delta E = E_2 - E_1$$

ΔE = difference in potential energy between two energy levels

E_2 = the highest energy state

E_1 = the lowest energy state

The amount of energy that is released relates directly to a specific frequency or wavelength (thus colour) of light.

$$E = hf \quad E = \frac{hc}{\lambda}$$

EXAMPLE:

A sample of hydrogen gas is placed in a discharge tube. The electron from the hydrogen atom emits energy as it transitions from energy level E_6 ($-0,61 \times 10^{-19}$ J) to E_2 ($-5,46 \times 10^{-19}$ J). Determine the wavelength of light emitted.

$$\begin{aligned} \Delta E &= E_6 - E_2 \\ &= -0,61 \times 10^{-19} - (-5,46 \times 10^{-19}) \quad 4,85 \times 10^{-19} = \frac{(6,63 \times 10^{-34})(3 \times 10^8)}{\lambda} \\ &= 4,85 \times 10^{-19} \text{ J} \quad \lambda = 4,1 \times 10^{-7} = 410 \text{ nm} \end{aligned}$$

ATOMIC ABSORPTION SPECTRA

As white light is passed through a cold gaseous element, the electrons inside the atoms of the element absorb the energy of the light (photons). The energy is absorbed in specific bands which corresponds to the energy required by electrons to transition between energy levels.

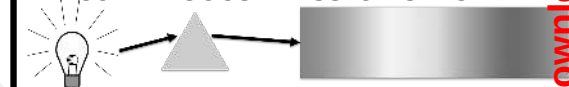
The absorbed energy furthermore corresponds to a specific frequency of light. As the electrons absorb energy, the specific frequency of light disappears, resulting in an absorption spectrum. The black lines below represent the energy absorbed by the element.



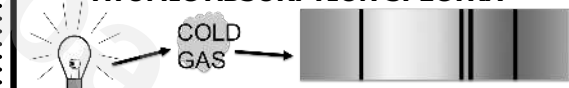
The absorption spectra for a specific element will be the inverse of its emission spectrum.



CONTINUOUS EMISSION SPECTRA



ATOMIC ABSORPTION SPECTRA



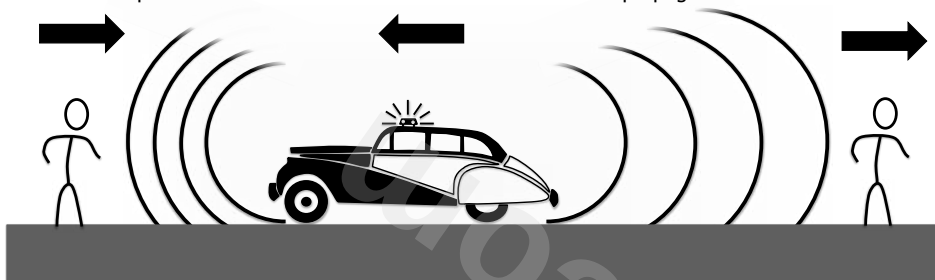
ATOMIC EMISSION SPECTRA



DOPPLER EFFECT

As a sound source moves through space, it moves relative to the waves that it has already produced. This causes an apparent change in wavelength, and therefore also a change in the perceived frequency.

Doppler effect: The change in the frequency of the sound observed by a listener, because the sound source and the listener have different speeds relative to the medium in which the sound is propagated.



When a source moves **towards** an observer OR an observer moves **towards** a source, the distance between the wavefronts (wavelength) is decreased and the perceived **frequency** increases.

When a source moves **away** from an observer OR an observer moves **away** from a source, the distance between the wavefronts (wavelength) is increased and the perceived **frequency** decreases.

A change in wavelength/frequency can be observed as:

- **Sound-** A change in pitch (higher frequency, higher pitch)
- **Light-** A change in light colour (red-shift OR blue shift)

EQUATIONS

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

REMEMBER:
ALWAYS start with the **FULL** original formula (on data sheet)!

f_L	=	frequency of listener (Hz)
v	=	speed of sound ($\text{m}\cdot\text{s}^{-1}$)
	=	OR
	=	speed of light ($3 \times 10^8 \text{ m}\cdot\text{s}^{-1}$)
v_L	=	velocity of listener ($\text{m}\cdot\text{s}^{-1}$)
v_s	=	velocity of source ($\text{m}\cdot\text{s}^{-1}$)
f_s	=	frequency of source (Hz)

To convert between frequency and wavelength:

Material waves (i.e. sound)

$$v = f\lambda$$

v	=	speed of wave ($\text{m}\cdot\text{s}^{-1}$)
f	=	frequency of sound (Hz)
λ	=	wavelength (m)

Electromagnetic radiation

$$c = f\lambda$$

c	=	speed of light ($3 \times 10^8 \text{ m}\cdot\text{s}^{-1}$)
f	=	frequency of sound (Hz)
λ	=	wavelength (m)

Listener away from source (-)

Decrease in observed frequency.

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

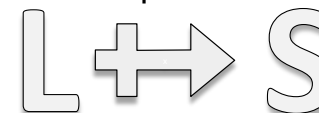
$$f_L = \frac{v - v_L}{v} f_s$$

Source away from listener (+)

Decrease in observed frequency.

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

$$f_L = \frac{v}{v + v_s} f_s$$



Listener to source (+)

Increase in observed frequency.

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

$$f_L = \frac{v + v_L}{v} f_s$$

Source to listener (-)

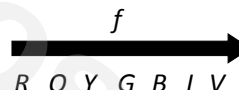
Increase in observed frequency.

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

$$f_L = \frac{v}{v - v_s} f_s$$

DOPPLER EFFECT AS PROOF OF EXPANDING UNIVERSE

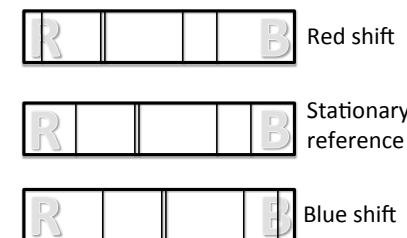
The visible range of the electromagnetic spectrum is as follow:



Red light has a longer wavelength than blue light, thus a shift towards the red spectrum (longer wavelength, lower frequency) indicates that the source of the light is moving away from the observer.

Red shift: object moving away from observer.
Blue shift: object moving towards observer.

The shift can be observed by comparing the absorption spectra of moving stars with a stationary reference sample.



Because most stars exhibit a red shift, we can conclude that they are moving away from the earth and thus that the universe is expanding.

APPLICATIONS OF DOPPLER EFFECT

Medicine

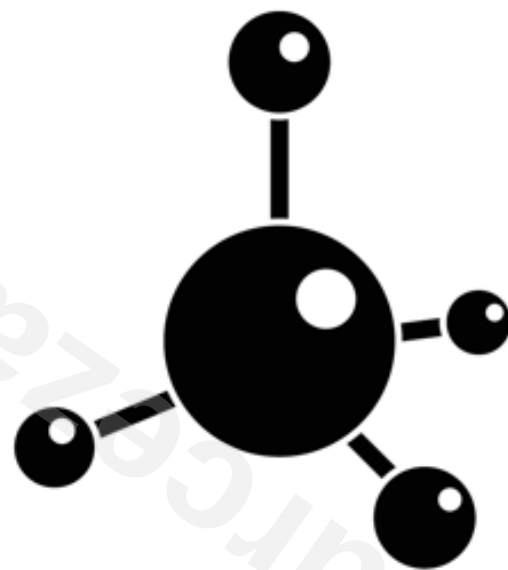
- Measures blood flow rate
- Observation of foetus heart rate

Maritime

- SONAR positioning underwater

Law enforcement

- Radar monitoring of speeding cars



Chemistry

**DATA FOR PHYSICAL SCIENCES GRADE 12
PAPER 2 (CHEMISTRY)**

**GEGEWENS VIR FISIESTE WETENSKAPPE GRAAD 12
VRAESTEL 2 (CHEMIE)**

TABLE 1: PHYSICAL CONSTANTS/TABEL 1: FISIESTE KONSTANTES

NAME/NAAM	SYMBOL/SIMBOOL	VALUE/WAARDE
Standard pressure <i>Standaarddruk</i>	p^θ	$1,013 \times 10^5 \text{ Pa}$
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^θ	273 K
Charge on electron <i>Lading op elektron</i>	e	$-1,6 \times 10^{-19} \text{ C}$
Avogadro's constant <i>Avogadro-konstante</i>	N_A	$6,02 \times 10^{23} \text{ mol}^{-1}$

TABLE 2: FORMULAE/TABEL 2: FORMULES

$n = \frac{m}{M}$	$n = \frac{N}{N_A}$
$c = \frac{n}{V}$ or/of $c = \frac{m}{MV}$	$n = \frac{V}{V_m}$
$\frac{c_a v_a}{c_b v_b} = \frac{n_a}{n_b}$	$\text{pH} = -\log[\text{H}_3\text{O}^+]$
$K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 1 \times 10^{-14} \text{ at/by } 298 \text{ K}$	
$E_{\text{cell}}^\theta = E_{\text{cathode}}^\theta - E_{\text{anode}}^\theta / E_{\text{sel}}^\theta = E_{\text{katode}}^\theta - E_{\text{anode}}^\theta$ or/of $E_{\text{cell}}^\theta = E_{\text{reduction}}^\theta - E_{\text{oxidation}}^\theta / E_{\text{sel}}^\theta = E_{\text{reduksie}}^\theta - E_{\text{oksidasie}}^\theta$ or/of $E_{\text{cell}}^\theta = E_{\text{oxidisingagent}}^\theta - E_{\text{reducingagent}}^\theta / E_{\text{sel}}^\theta = E_{\text{oksideermiddel}}^\theta - E_{\text{reduseermiddel}}^\theta$	

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 H 1																	2 He 4
3 Li 7	4 Be 9											5 B 11	6 C 12	7 N 14	8 O 16	9 F 19	10 Ne 20
11 Na 23	12 Mg 24											13 Al 27	14 Si 28	15 P 31	16 S 32	17 Cl 35,5	18 Ar 40
19 K 39	20 Ca 40	21 Sc 45	22 Ti 48	23 V 51	24 Cr 52	25 Mn 55	26 Fe 56	27 Co 59	28 Ni 59	29 Cu 63,5	30 Zn 65	31 Ga 70	32 Ge 73	33 As 75	34 Se 79	35 Br 80	36 Kr 84
37 Rb 86	38 Sr 88	39 Y 89	40 Zr 91	41 Nb 92	42 Mo 96	43 Tc 98	44 Ru 101	45 Rh 103	46 Pd 106	47 Ag 108	48 Cd 112	49 In 115	50 Sn 119	51 Sb 122	52 Te 128	53 I 127	54 Xe 131
55 Cs 133	56 Ba 137	57 La 139	72 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 Tl 204	82 Pb 207	83 Bi 209	84 Po 209	85 At 210	86 Rn 222
87 Fr 223	88 Ra 226	89 Ac 227															
			58 Ce 140	59 Pr 141	60 Nd 144	61 Pm 147	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 231	92 U 238	93 Np 237	94 Pu 244	95 Am 243	96 Cm 247	97 Bk 247	98 Cf 251	99 Es 252	100 Fm 257	101 Md 258	102 No 259	103 Lr 262	

KEY/SLEUTEL

Atomic number
Atoomgetal

Electronegativity
Elektronegatiwiteit

Symbol
Simbool

Approximate relative atomic mass
Benaderde relatiewe atoommassa

29 Cu 63,5

TABLE 4A: STANDARD REDUCTION POTENTIALS
TABEL 4A: STANDAARDREDUKSIEPOTENSIALE

Half-reactions/Halfreaksies	E^{θ} (V)
$F_2(g) + 2e^- \rightleftharpoons 2F^-$	+ 2,87
$Co^{3+} + e^- \rightleftharpoons Co^{2+}$	+ 1,81
$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O$	+1,77
$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O$	+ 1,51
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-$	+ 1,36
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O$	+ 1,33
$O_2(g) + 4H^+ + 4e^- \rightleftharpoons 2H_2O$	+ 1,23
$MnO_2 + 4H^+ + 2e^- \rightleftharpoons Mn^{2+} + 2H_2O$	+ 1,23
$Pt^{2+} + 2e^- \rightleftharpoons Pt$	+ 1,20
$Br_2(l) + 2e^- \rightleftharpoons 2Br^-$	+ 1,07
$NO_3^- + 4H^+ + 3e^- \rightleftharpoons NO(g) + 2H_2O$	+ 0,96
$Hg^{2+} + 2e^- \rightleftharpoons Hg(l)$	+ 0,85
$Ag^+ + e^- \rightleftharpoons Ag$	+ 0,80
$NO_3^- + 2H^+ + e^- \rightleftharpoons NO_2(g) + H_2O$	+ 0,80
$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	+ 0,77
$O_2(g) + 2H^+ + 2e^- \rightleftharpoons H_2O_2$	+ 0,68
$I_2 + 2e^- \rightleftharpoons 2I^-$	+ 0,54
$Cu^+ + e^- \rightleftharpoons Cu$	+ 0,52
$SO_2 + 4H^+ + 4e^- \rightleftharpoons S + 2H_2O$	+ 0,45
$2H_2O + O_2 + 4e^- \rightleftharpoons 4OH^-$	+ 0,40
$Cu^{2+} + 2e^- \rightleftharpoons Cu$	+ 0,34
$SO_4^{2-} + 4H^+ + 2e^- \rightleftharpoons SO_2(g) + 2H_2O$	+ 0,17
$Cu^{2+} + e^- \rightleftharpoons Cu^+$	+ 0,16
$Sn^{4+} + 2e^- \rightleftharpoons Sn^{2+}$	+ 0,15
$S + 2H^+ + 2e^- \rightleftharpoons H_2S(g)$	+ 0,14
$2H^+ + 2e^- \rightleftharpoons H_2(g)$	0,00
$Fe^{3+} + 3e^- \rightleftharpoons Fe$	- 0,06
$Pb^{2+} + 2e^- \rightleftharpoons Pb$	- 0,13
$Sn^{2+} + 2e^- \rightleftharpoons Sn$	- 0,14
$Ni^{2+} + 2e^- \rightleftharpoons Ni$	- 0,27
$Co^{2+} + 2e^- \rightleftharpoons Co$	- 0,28
$Cd^{2+} + 2e^- \rightleftharpoons Cd$	- 0,40
$Cr^{3+} + e^- \rightleftharpoons Cr^{2+}$	- 0,41
$Fe^{2+} + 2e^- \rightleftharpoons Fe$	- 0,44
$Cr^{3+} + 3e^- \rightleftharpoons Cr$	- 0,74
$Zn^{2+} + 2e^- \rightleftharpoons Zn$	- 0,76
$2H_2O + 2e^- \rightleftharpoons H_2(g) + 2OH^-$	- 0,83
$Cr^{2+} + 2e^- \rightleftharpoons Cr$	- 0,91
$Mn^{2+} + 2e^- \rightleftharpoons Mn$	- 1,18
$Al^{3+} + 3e^- \rightleftharpoons Al$	- 1,66
$Mg^{2+} + 2e^- \rightleftharpoons Mg$	- 2,36
$Na^+ + e^- \rightleftharpoons Na$	- 2,71
$Ca^{2+} + 2e^- \rightleftharpoons Ca$	- 2,87
$Sr^{2+} + 2e^- \rightleftharpoons Sr$	- 2,89
$Ba^{2+} + 2e^- \rightleftharpoons Ba$	- 2,90
$Cs^+ + e^- \rightleftharpoons Cs$	- 2,92
$K^+ + e^- \rightleftharpoons K$	- 2,93
$Li^+ + e^- \rightleftharpoons Li$	- 3,05

Increasing oxidising ability/Toenemende oksiderende vermoë

Increasing reducing ability/Toenemende reducerende vermoë

TABLE 4B: STANDARD REDUCTION POTENTIALS
TABEL 4B: STANDAARDREDUKSIEPOTENSIALE

Half-reactions/Halfreaksies	E^{θ} (V)
$\text{Li}^{+} + \text{e}^{-} \rightleftharpoons \text{Li}$	-3,05
$\text{K}^{+} + \text{e}^{-} \rightleftharpoons \text{K}$	-2,93
$\text{Cs}^{+} + \text{e}^{-} \rightleftharpoons \text{Cs}$	-2,92
$\text{Ba}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Ba}$	-2,90
$\text{Sr}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Sr}$	-2,89
$\text{Ca}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Ca}$	-2,87
$\text{Na}^{+} + \text{e}^{-} \rightleftharpoons \text{Na}$	-2,71
$\text{Mg}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Mg}$	-2,36
$\text{Al}^{3+} + 3\text{e}^{-} \rightleftharpoons \text{Al}$	-1,66
$\text{Mn}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Mn}$	-1,18
$\text{Cr}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Cr}$	-0,91
$2\text{H}_2\text{O} + 2\text{e}^{-} \rightleftharpoons \text{H}_2(\text{g}) + 2\text{OH}^{-}$	-0,83
$\text{Zn}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Zn}$	-0,76
$\text{Cr}^{3+} + 3\text{e}^{-} \rightleftharpoons \text{Cr}$	-0,74
$\text{Fe}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Fe}$	-0,44
$\text{Cr}^{3+} + \text{e}^{-} \rightleftharpoons \text{Cr}^{2+}$	-0,41
$\text{Cd}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Cd}$	-0,40
$\text{Co}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Co}$	-0,28
$\text{Ni}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Ni}$	-0,27
$\text{Sn}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Sn}$	-0,14
$\text{Pb}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Pb}$	-0,13
$\text{Fe}^{3+} + 3\text{e}^{-} \rightleftharpoons \text{Fe}$	-0,06
$2\text{H}^{+} + 2\text{e}^{-} \rightleftharpoons \text{H}_2(\text{g})$	0,00
$\text{S} + 2\text{H}^{+} + 2\text{e}^{-} \rightleftharpoons \text{H}_2\text{S}(\text{g})$	+0,14
$\text{Sn}^{4+} + 2\text{e}^{-} \rightleftharpoons \text{Sn}^{2+}$	+0,15
$\text{Cu}^{2+} + \text{e}^{-} \rightleftharpoons \text{Cu}^{+}$	+0,16
$\text{SO}_4^{2-} + 4\text{H}^{+} + 2\text{e}^{-} \rightleftharpoons \text{SO}_2(\text{g}) + 2\text{H}_2\text{O}$	+0,17
$\text{Cu}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Cu}$	+0,34
$2\text{H}_2\text{O} + \text{O}_2 + 4\text{e}^{-} \rightleftharpoons 4\text{OH}^{-}$	+0,40
$\text{SO}_2 + 4\text{H}^{+} + 4\text{e}^{-} \rightleftharpoons \text{S} + 2\text{H}_2\text{O}$	+0,45
$\text{Cu}^{+} + \text{e}^{-} \rightleftharpoons \text{Cu}$	+0,52
$\text{I}_2 + 2\text{e}^{-} \rightleftharpoons 2\text{I}^{-}$	+0,54
$\text{O}_2(\text{g}) + 2\text{H}^{+} + 2\text{e}^{-} \rightleftharpoons \text{H}_2\text{O}_2$	+0,68
$\text{Fe}^{3+} + \text{e}^{-} \rightleftharpoons \text{Fe}^{2+}$	+0,77
$\text{NO}_3^{-} + 2\text{H}^{+} + \text{e}^{-} \rightleftharpoons \text{NO}_2(\text{g}) + \text{H}_2\text{O}$	+0,80
$\text{Ag}^{+} + \text{e}^{-} \rightleftharpoons \text{Ag}$	+0,80
$\text{Hg}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Hg}(\ell)$	+0,85
$\text{NO}_3^{-} + 4\text{H}^{+} + 3\text{e}^{-} \rightleftharpoons \text{NO}(\text{g}) + 2\text{H}_2\text{O}$	+0,96
$\text{Br}_2(\ell) + 2\text{e}^{-} \rightleftharpoons 2\text{Br}^{-}$	+1,07
$\text{Pt}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Pt}$	+1,20
$\text{MnO}_2 + 4\text{H}^{+} + 2\text{e}^{-} \rightleftharpoons \text{Mn}^{2+} + 2\text{H}_2\text{O}$	+1,23
$\text{O}_2(\text{g}) + 4\text{H}^{+} + 4\text{e}^{-} \rightleftharpoons 2\text{H}_2\text{O}$	+1,23
$\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^{+} + 6\text{e}^{-} \rightleftharpoons 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$	+1,33
$\text{Cl}_2(\text{g}) + 2\text{e}^{-} \rightleftharpoons 2\text{Cl}^{-}$	+1,36
$\text{MnO}_4^{-} + 8\text{H}^{+} + 5\text{e}^{-} \rightleftharpoons \text{Mn}^{2+} + 4\text{H}_2\text{O}$	+1,51
$\text{H}_2\text{O}_2 + 2\text{H}^{+} + 2\text{e}^{-} \rightleftharpoons 2\text{H}_2\text{O}$	+1,77
$\text{Co}^{3+} + \text{e}^{-} \rightleftharpoons \text{Co}^{2+}$	+1,81
$\text{F}_2(\text{g}) + 2\text{e}^{-} \rightleftharpoons 2\text{F}^{-}$	+2,87

Increasing oxidising ability/Toenemende oksiderende vermoë

Increasing reducing ability/Toenemende reduserende vermoë

Grade 12 Chemistry Definitions	
Intermolecular Forces Revision	Boiling point: The temperature at which the vapour pressure equals atmospheric pressure Melting point: The temperature at which the solid and liquid phases of a substance are at equilibrium Vapour pressure: The pressure exerted by a vapour at equilibrium with its liquid in a closed system
Organic chemistry	Organic molecules: molecules containing carbon atoms Functional group: a bond or an atom or a group of atoms that determine(s) the physical and chemical properties of a group of organic compounds Hydrocarbon: organic compounds that consist of hydrogen and carbon only Homologous series: a series of organic compounds that can be described by the same general formula OR in which one member differs from the next with a CH₂ group Saturated compounds: compounds in which there are no multiple bonds between C atoms in their hydrocarbon chains Unsaturated compounds: compounds with one or more multiple bonds between C atoms in their hydrocarbon chains Functional group: A bond or an atom or a group of atoms that determine(s) the physical and chemical properties of a group of organic compounds Molecular formula: a chemical formula that indicates the type of atoms and the correct number of each in a molecule Structural formula: a structural formula of a compound shows which atoms are attached to which within the molecule. Atoms are represented by their chemical symbols and lines are used to represent ALL the bonds that hold the atoms together Condensed structural formula: this notation shows the way in which atoms are bonded together in the molecule, but DOES NOT SHOW ALL bond lines Structural isomer: Organic molecules with the same molecular formula, but different structural formulae
Polymers	Macromolecule: A molecule that consists of a large number of atoms Polymer: A large molecule composed of smaller monomer units covalently bonded to each other in a repeating pattern Monomer: Small organic molecules that can be covalently bonded to each other in a repeating pattern Polymerisation: A chemical reaction in which monomer molecules join to form a polymer Addition polymerisation: A reaction in which small molecules join to form very large molecules by adding on double bonds Addition polymer: A polymer formed when monomers (usually containing a double bond) combine through an addition reaction. Condensation polymerisation: Molecules of two monomers with different functional groups undergo condensation reactions with the loss of small molecules, usually water Condensation polymer: A polymer formed by two monomers with different functional groups that are linked together in a condensation reaction in which a small molecule, usually water, is lost
Energy change Revision	Heat of reaction (ΔH): the energy absorbed or released in a chemical reaction Exothermic reactions: reactions that release energy Endothermic reactions: reactions that absorb energy Activation energy: the minimum energy needed for a reaction to take place Activated complex: the unstable transition state from reactants to products
Rate and Extent of reaction	Reaction rate: as the change in concentration of reactants or products per unit time Positive catalyst: a substance that increases the rate of a chemical reaction without itself undergoing a permanent change.
Chemical Equilibrium	Open system: one which continuously interacts with its environment Closed system: one which is isolated from its surroundings Chemical equilibrium: it is a dynamic equilibrium when the rate of the forward reaction equals the rate of the reverse reaction Le Chatelier's principle: when the equilibrium in a closed system is disturbed, the system will re-instate a new equilibrium by favouring the reaction that will oppose the disturbance

Grade 12 Chemistry Definitions

Acids and Bases	Arrhenius theory Acid: a substance that produces hydrogen ions (H^+) 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 H_3O^+ ions. Weak acids: Ionise incompletely in water to form a low concentration of H_3O^+ ions. Strong bases: dissociate completely in water to form a high concentration of OH^- ions. Weak bases: dissociate/ionise incompletely in water to form a low concentration of OH^- ions. 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 Auto-ionisation of water: the reaction of water with itself to form H_3O^+ ions and OH^- ions K_w: the equilibrium constant for the ionisation of water or the ionic product of water or the ionisation constant of water, i.e. $K_w = [H_3O^+][OH^-] = 1 \times 10^{-14}$ by 298 K
Electrochemical Reactions	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 Electrolysis: the chemical process in which electrical energy is converted to chemical energy OR the use of electrical energy to produce a chemical change Galvanic cell: self-sustaining reaction, conversion of chemical energy to electrical energy Electrolytic cell: electrode reaction sustained by a supply of electrical energy, conversion of electrical energy into chemical energy
Fertilizers	Eutrophication: the process by which an ecosystem, e.g. a river or dam, becomes enriched with inorganic plant nutrients, especially phosphorus and nitrogen, resulting in excessive plant growth. As plant growth becomes excessive, the amount of dead and decaying plant material increases rapidly.

Organic compounds contain carbon and hydrogen atoms. These compounds can be in the gaseous, liquid, or solid phase. All living matter contains organic compounds.

UNIQUENESS OF CARBON

Carbon is very unique and is the basic building block of all organic compounds. It's atoms have a valency of four in a tetrahedral arrangement. This means it is able to **make four bonds**.

Carbon atoms can form single, double or triple bonds



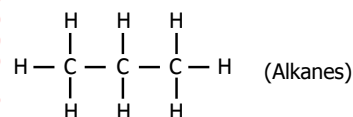
HYDROCARBONS

A hydrocarbon is a compound that contains only carbon and hydrogen atoms. These compounds can be saturated (single bonds) and unsaturated (double or triple bonds).

Hydrocarbon: A compound containing only carbon and hydrogen atoms.

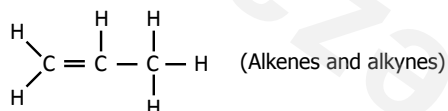
Saturated compound:

A compound in which all of the bonds between carbon atoms are single bonds.

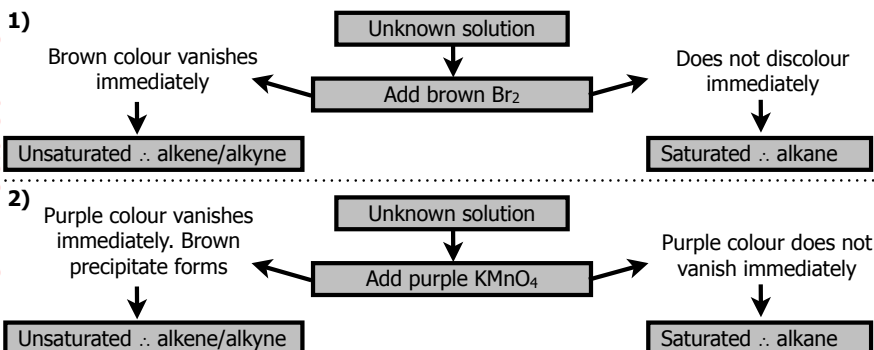


Unsaturated compound:

A compound in which there is at least one double and/or triple bond between carbon atoms.



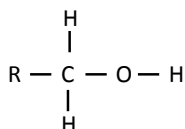
Test to differentiate between saturated and unsaturated solutions



CLASSIFICATION OF ALCOHOL

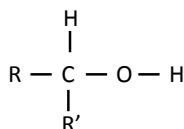
Primary

One C bonded to the C bonded to the OH



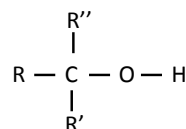
Secondary

Two C's bonded to the C bonded to the OH



Tertiary

Three C's bonded to the C bonded to the OH



REPRESENTING ORGANIC COMPOUNDS

We use a variety of ways to draw or write organic compounds. We either make use of the molecular formula, condensed formula or we use full structural formulae.

Molecular formula	A chemical formula that indicates the type of atoms and the correct number of each in the molecule.	C_3H_8
Condensed formula	The notation shows the way in which atoms are bonded to each other in a molecule, but does not show all bond lines.	$\text{CH}_3\text{CH}_2\text{CH}_3$
Structural formula	This formula shows all the bonds and atoms in the molecule.	$\begin{array}{c} \text{H} & \text{H} & \text{H} \\ & & \\ \text{H}-\text{C}- & \text{C}- & \text{C}-\text{H} \\ & & \\ \text{H} & \text{H} & \text{H} \end{array}$
General formula	Describes the homologous series formula for similar compounds.	Alkanes: $\text{C}_n\text{H}_{2n+2}$

ISOMERS

Isomers: Compounds having the same molecular formula but different structural formulae.

Chain isomers	Chain isomers have the same molecular formula but different arrangements of chains in the molecule.	butane $\begin{array}{c} \text{H} & \text{H} & \text{H} & \text{H} \\ & & & \\ \text{H}-\text{C}- & \text{C}- & \text{C}- & \text{C}-\text{H} \\ & & & \\ \text{H} & \text{H} & \text{H} & \text{H} \end{array}$	2-methylpropane $\begin{array}{c} \text{H} & \text{H} & \text{H} \\ & & \\ \text{H}-\text{C}- & \text{C}- & \text{C}-\text{H} \\ & & \\ \text{H} & \text{H} & \text{H} \\ \\ \text{H} \end{array}$
Positional isomers	These have the same molecular formula but the functional group is in a different position	propan-1-ol $\begin{array}{c} & & \text{H} \\ & & \\ & & \text{O} \\ & & \\ \text{H}-\text{C}- & \text{C}- & \text{C}-\text{H} \\ & & \\ \text{H} & \text{H} & \text{H} \end{array}$	propan-2-ol $\begin{array}{c} & \text{H} & \\ & & \\ & \text{O} & \\ & & \\ \text{H}-\text{C}- & \text{C}- & \text{C}-\text{H} \\ & & \\ \text{H} & \text{H} & \text{H} \end{array}$
Functional isomers	These have the same molecular formula but a different functional group. Aldehydes and ketone are functional isomers as well as carboxylic acids and esters	propanoic acid $\begin{array}{c} \text{H} & \text{H} & \text{O} \\ & & \\ \text{H}-\text{C}- & \text{C}- & \text{C}-\text{O}-\text{H} \\ & & \\ \text{H} & \text{H} & \end{array}$	methyl ethanoate $\begin{array}{c} \text{H} & \text{O} & \text{H} \\ & & \\ \text{H}-\text{C}- & \text{C}-\text{O}- & \text{C}-\text{H} \\ & & \\ \text{H} & & \text{H} \end{array}$

ORGANIC MOLECULES- NAMING

All organic compounds belong to a specific group which allows us to identify or name the compound. The group that compounds belong to, known as the **homologous series**, depends on the the **functional group** of the compound.

Homologous series: A series of organic compounds that can be described by the same general formula OR in which one member differs from the next with a CH₂ group

Functional group: A bond or an atom or a group of atoms that determine(s) the physical and chemical properties of a group of organic compounds

NAMING ORGANIC COMPOUNDS

Every distinct compound has a unique name, and there is only one possible structure for any IUPAC (International Union of Pure and Applied Chemistry) name. The IUPAC method for naming is a set pattern. It indicates the **longest chain** (the longest continuous chain), the **functional group** and names of **substituent groups** (side chains) or atoms attached to the longest chain.

Three parts of an IUPAC name:



The **root name** indicates the number of carbon atoms in the longest chain. This chain **must contain the functional group**. The **prefix** indicates the **number and location** of atoms or groups (substituents) attached to the longest chain. The **suffix** identifies the **functional group**.

Steps to naming organic compounds:

1. Identify the longest continuous carbon chain which must contain the functional group.
2. Number the longest carbon chain beginning at the carbon (carbon 1) nearest to the functional group with the alkyl substituents on the lowest numbered carbon atoms of the longest chain.
3. Name the longest chain according to the number of carbons in the chain. (**the root name**)
4. The **suffix** of the compound name is dependent on the functional group.
5. Identify and name substituents (alkyl and halogen substituents), indicating the position of the substituent
6. For several identical side chains use the prefix di-, tri-, tetra-
7. Arrange substituents in alphabetical order in the name of the compound, ignore the prefix di-, tri-, tetra- (**substituent prefix**)
8. Indicate position using numbers.

Number of carbon atoms in main chain	Root name
1	meth-
2	eth-
3	prop-
4	but-
5	pent-
6	hex-
7	hept-
8	oct-
9	non-
10	dec-

Number of substituents	Substituent prefix
2	di eg. dimethyl
3	tri eg. triethyl
4	tetra eg. tetramethyl

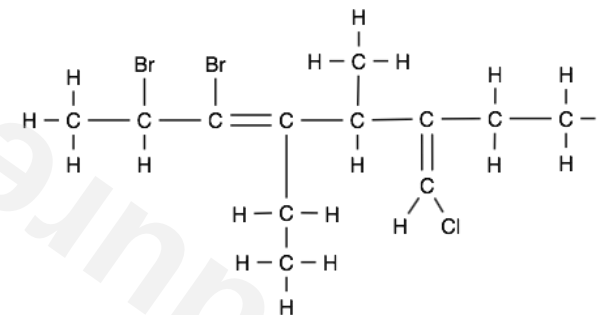
NOTE:
A maximum of THREE substituent chains (alkyl substituents) are allowed on the main chain

NOTE:
comma between numbers
number , number
dash between letter and number
letter - number - letter

Substituent	Formula	Structural formula	Name
Alkyl	CH ₃ -		methyl-
	CH ₃ CH ₂ -		ethyl-
	CH ₃ CH ₂ CH ₂ -		propyl-
Halogen	X-		X represents a halogen: Fluorine: fluoro- Chlorine: chloro- Bromine: bromo- Iodine: iodo-

EXAMPLE:

Write down the name of the molecule below:



Substituents

1-chloro
2,4-diethyl
3-methyl
5,6-dibromo

Main chain

7 = hept

Functional group

1,4-diene

5,6-dibromo-1-chloro-2,4-diethyl-3-methylhept-1,4-diene

ORGANIC FUNCTIONAL GROUPS

Homologous series and General formula	Functional group	Suffix	Examples			Properties
			Structural formula	Condensed formula	Name	
Alkanes C_nH_{2n+2}	Single bonds $R - C - C - R'$	-ane		$CH_3CH_2CH_3$	propane	Polarity: Non-Polar IMF: Weak London Reactions: Substitution, Elimination, Combustion
Alkenes C_nH_{2n}	Double bonds $R - C = C - R'$	-ene		$CH_3CH=CH_2$	propene	Polarity: Non-polar IMF: London Reactions: Addition, combustion
Alkynes C_nH_{2n-2}	Triple bonds $R - C \equiv C - R'$	-yne		$CH \equiv CCH_3$	propyne	Polarity: Non-polar IMF: London Reactions: Addition
Haloalkane/ Haloalkene (Alkyl halide)	Halogens (Group 17) $R - C - R'$	fluoro- chloro- bromo- iodo-		$CH_2BrCHClCH_3$	1-bromo-2-chloropropane	Polarity: Polar IMF: Dipole-Dipole Reactions: Elimination, Substitution
Alcohols $C_nH_{2n+2}O$	Hydroxyl $R - O - H$	-ol		$CH_3CH_2CH_2OH$	propan-1-ol	Polarity: Polar IMF: Strong Hydrogen bonds Reactions: Substitution, Elimination, Esterification, Combustion
Carboxylic acids $C_nH_{2n}O_2$	Carboxyl $R - C - O - H$	-oic acid		CH_3CH_2COOH	propanoic acid	Polarity: Polar IMF: Strong Hydrogen bonds Reactions: Esterification
Esters $R-COO-R'$	Carbonyl $R - C - O - R'$	-yl (alch.) -oate (carbox.)		$CH_3CH_2COOCH_2CH_3$ (carbox.) (alch.)	ethyl propanoate	Polarity: Polar IMF: Dipole-Dipole Reactions: Formed by esterification
Aldehydes $C_nH_{2n+1}CHO$	Formyl $R - C - H$	-al		CH_3CH_2CHO	propanal	Polarity: Polar IMF: Dipole-Dipole
Ketone $R-COC-R'$	Carbonyl $R - C - R'$	-one		CH_3COCH_3	propan-2-one	Polarity: Polar IMF: Dipole-Dipole

ORGANIC INTERMOLECULAR FORCES

Intermolecular forces are forces that exist between molecules in the solid, liquid and gaseous phases. They are electrostatic attractive forces. The strength of the IMF will determine the freedom of the particles, determining the phase of the substance (solid, liquid, gas).

Intermolecular force are a weak force of attraction between molecules or between atoms of noble gases

The types of intermolecular forces that exists between different types of organic molecules and the strength of the intermolecular forces will affect the physical properties of a molecule.

TYPES OF IMF	Hydrogen Bonds	- Strongest of all the intermolecular forces - Act over shorter distances. - Between molecules that are strongly polar that contain hydrogen bonded to a small highly electronegative atom such as N, O or F.	Alcohols (1 bonding site) Carboxylic Acids (2 bonding sites)
	Dipole-Dipole Forces	- Stronger than Dispersion forces/Induced Dipole forces. - Between slightly polar molecules. - Force of attraction between the δ^+ end of the one molecule and the δ^- end of another.	Aldehydes Ketones Esters Alkyl Halides
	Induced Dipole Forces (London)	- Very weak Van der Waals forces. - Between non-polar molecules that form induced (temporary) dipoles and these temporary dipoles attract each other	Alkanes Alkenes Alkynes

RELATIONSHIP BETWEEN PHYSICAL PROPERTIES AND IMF

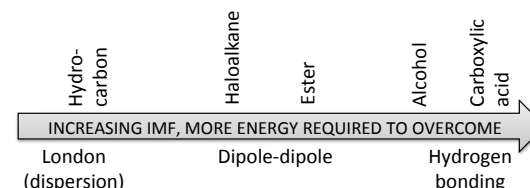
PHYSICAL PROPERTY	RELATIONSHIP TO IMF
Melting Point: The temperature at which the solid and liquid phases of a substance are at equilibrium. It is the temperature where solid particles will undergo a phase change (melt) and become a liquid.	Directly proportional
Boiling Point: The temperature at which vapour pressure of the substance equals atmospheric pressure. It is the temperature where liquid boils and turns into a vapour (gas).	Directly proportional
OPTIONAL	
Vapour Pressure: This is the pressure that an enclosed vapour at equilibrium exerts on the surface of its liquid.	Inversely proportional
Viscosity: this is the measure of a liquid's resistance to flow. A liquid with high viscosity resists motion e.g. syrup. A liquid with low viscosity is runny e.g. water.	Directly proportional
Solubility: Substances will only dissolve in substances that are like bonded. A non-polar substance will dissolve in a non-polar substance. A polar substance will dissolve only in polar substances.	Inversely proportional
Density: Density is a measure of the mass per unit volume. The solid phase of the substance is generally more dense than the gaseous and liquid phase.	Directly proportional
Flammability: The ability to burn in air or ignite causing combustion. Most organic compounds are flammable and burn in oxygen to form carbon dioxide and water.	Inversely proportional
Odour: Different functional groups attach differently to different receptors in our nose. Different organic substances give off odour quicker based on their intermolecular forces and distinct odours.	Inversely proportional

COMPARING IMF

1. Identify the type of intermolecular force.
2. Discuss the difference between the two compounds (① → ④).
3. Discuss how this difference either ↑ or ↓ the strength of the intermolecular force.
4. Discuss how the physical property is affected (↑ or ↓).
5. Discuss energy required to overcome forces.

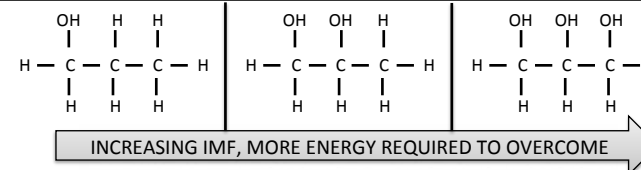
① TYPE OF FUNCTIONAL GROUP

The more polar the molecule, the stronger the IMF



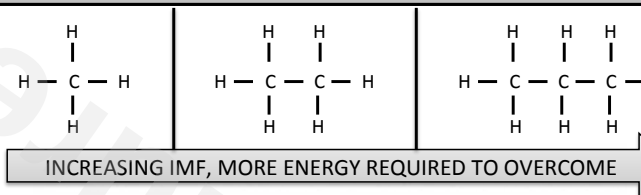
② NUMBER OF FUNCTIONAL GROUPS

An increase in functional groups increase the IMF



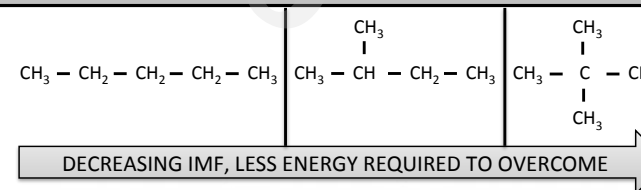
③ CHAIN LENGTH: MOLECULAR MASS

The greater the number of carbon atoms in the chain, the greater the molecular mass. An increase in molecular mass increases the IMF



④ CHAIN LENGTH: BRANCHES

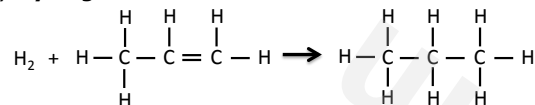
More branching results in a smaller contact surface area and lower the strength of the IMF



ADDITION REACTIONS (UNSATURATED → SATURATED)

Addition reactions are reactions where atoms are added to an organic molecule. The double or triple bonds break open and the new atoms are added to the carbon atoms on either side of the double or triple bond.

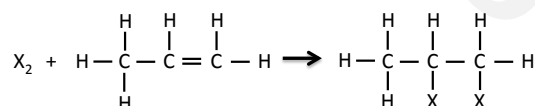
We can add hydrogen (H₂), a halogen (Group 7 – e.g. Cl₂), a Hydrogen halide or water H₂O. In addition reactions alkenes or alkynes form an alkane chain as a product.

1) Hydrogenation – add H₂

hydrogen + alkene/alkyne → alkane

Reaction conditions:

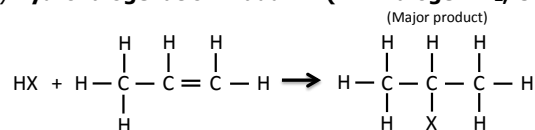
The alkene needs to be dissolved in a non-polar solvent and needs to have a catalyst present eg. Pt, Ni or Pd.

2) Halogenation – add X (X = Halogen: F₂, Cl₂, Br₂, I₂)

halogen + alkene/alkyne → haloalkane

Reaction conditions:

No water to be present if it is to take place

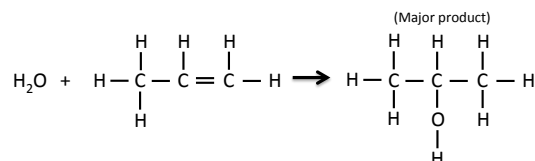
3) Hydrohalogenation – add HX (X = Halogen: F₂, Cl₂, Br₂, I₂)

hydrogen halide + alkene/alkyne → haloalkane

Reaction conditions:

No water to be present if it is to take place.

Markovnikov's rule: The H atom will bond to the carbon atom which has the greater number of H atoms bonded to it. (Form biggest H groups)

4) Hydration – add of H₂O

water (H₂O) + alkene/alkyne → alcohol

Reaction conditions:

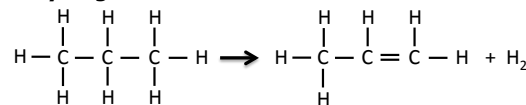
Strong but dilute acid catalyst e.g. H₂SO₄ or H₃PO₄
Heat in the form of steam (H₂O) reactant

Markovnikov's rule: The H atom will bond to the carbon atom which has the greater number of H atoms bonded to it. (Form biggest H groups)

ELIMINATION REACTIONS (SATURATED → UNSATURATED)

An elimination reaction is a reaction where atoms or groups of atoms are removed from an organic molecule to form either a double or triple bonded compound.

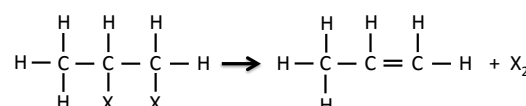
This reaction is the opposite reaction to the addition reactions and is the removal of hydrogen (H₂), a halogen (Group 7 – e.g. Cl₂), a hydrogen halide or water H₂O. In elimination reactions, alkanes form either an alkene or alkyne chain as a product.

1) Dehydrogenation – remove H₂

alkane → alkene + hydrogen

Reaction conditions:

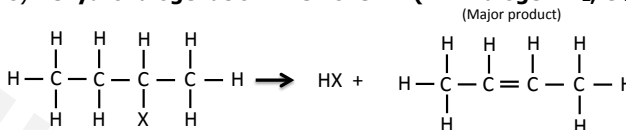
The alkane needs to be in the presence of a catalyst eg. Pt, Ni or Pd.

2) Dehalogenation – remove X (X = Halogen: F₂, Cl₂, Br₂, I₂)

haloalkane → alkene + halogen

Reaction conditions:

Takes place in an unreactive solvent

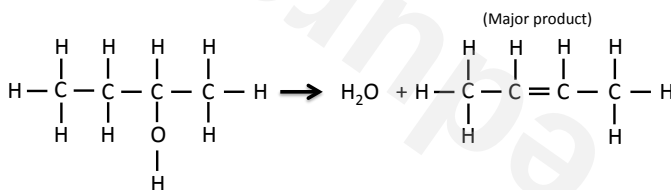
3) Dehydrohalogenation – remove HX (X = Halogen: F₂, Cl₂, Br₂, I₂)

haloalkane → hydrogen halide + alkene

Reaction conditions:

Takes place in the presence of concentrated NaOH/KOH in ethanol as the solvent. Strong heating under reflux.

Zaitzev's rule: H atom is removed from the carbon atom with the least number of H atoms. (Keeps biggest H groups)

4) Dehydration – remove H₂O

alcohol → water (H₂O) + alkene

Reaction conditions:

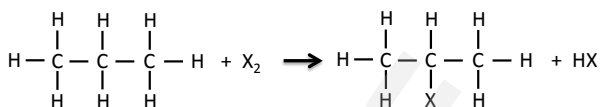
Requires the heating of an alcohol with concentrated acid catalyst eg. H₂SO₄ or H₃PO₄. The acid should be in excess

Sulfuric acid is known as a dehydrating agent.

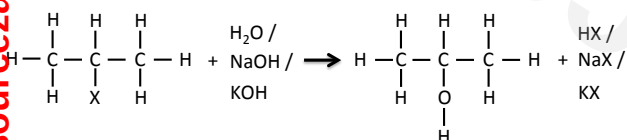
Zaitzev's rule: H atom is removed from the carbon atom with the least number of H atoms. (Keeps biggest H groups)

SUBSTITUTION REACTIONS (SATURATED → SATURATED)

Substitution reactions is when an atom or group of atoms in an organic molecule are replaced or swapped/exchanged for another atom or group of atoms. Substitution reactions take place between compounds that are saturated alkanes, haloalkanes and alcohols.

1) Alkanes: Halogenation- Substitute X₂ (X = Halogen: F₂, Cl₂, Br₂, I₂)**Reaction conditions:**

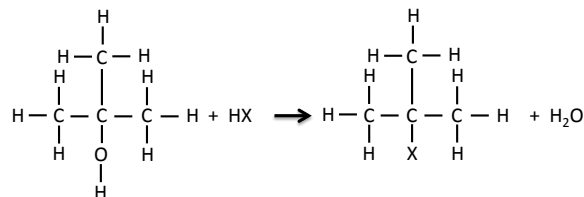
Reaction takes place in the presence of sunlight/heat

**2) Haloalkanes: Hydrolysis - Substitute H₂O****Reaction conditions:**

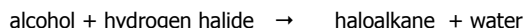
The haloalkane is dissolved in an ethanol solution and treated with hot aqueous NaOH/KOH solution

**3) Alcohols: Hydrohalogenation- Substitute HX (X = Halogen: F₂, Cl₂, Br₂, I₂)**

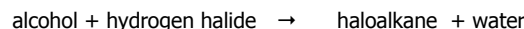
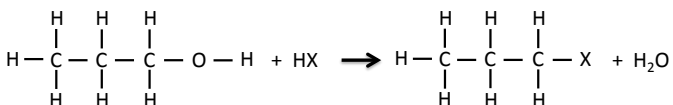
Tertiary alcohols

**Reaction conditions:**

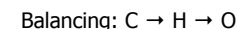
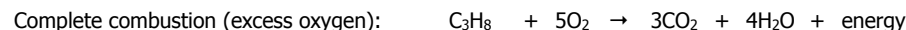
Require HX present at room temperature.



Primary and secondary alcohols

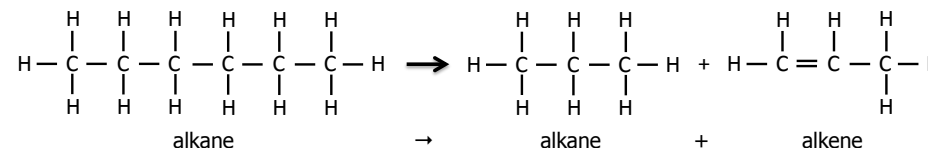
**COMBUSTION/OXIDATION REACTIONS**

Hydrocarbons are the main source of fuel in the world at the moment. They are used in the production of electrical energy and as fuel for various engines. When hydrocarbons and alcohols react with oxygen they form water and carbon dioxide. These reactions are exothermic and produce large quantities of heat.

**CRACKING**

Hydrocarbons can be made up of very long chains of hundreds of carbons. Crude oil is a mixture of many large hydrocarbons and each source of crude oil is different resulting in different types and amounts of hydrocarbons.

Shorter chain hydrocarbons are more useful to use as fuels as they burn more readily and are more flammable. Cracking is the breaking up of long hydrocarbon chains into smaller more useful hydrocarbons. An alkene and alkane will be the products as a result of cracking. Cracking is a type of elimination reaction.

**Thermal cracking**

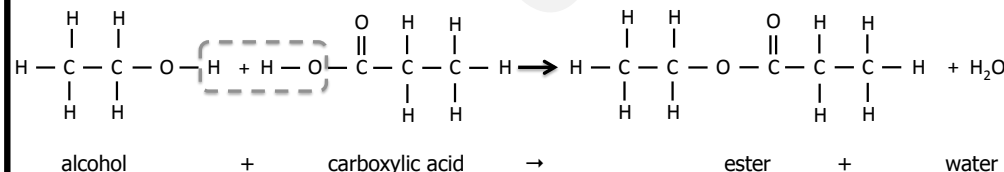
This method makes use of high pressures (up to 70 atmospheres) and high temperatures to crack the long hydrocarbon chains with no catalyst. **Products: alkanes and alkenes.**

Catalytic cracking

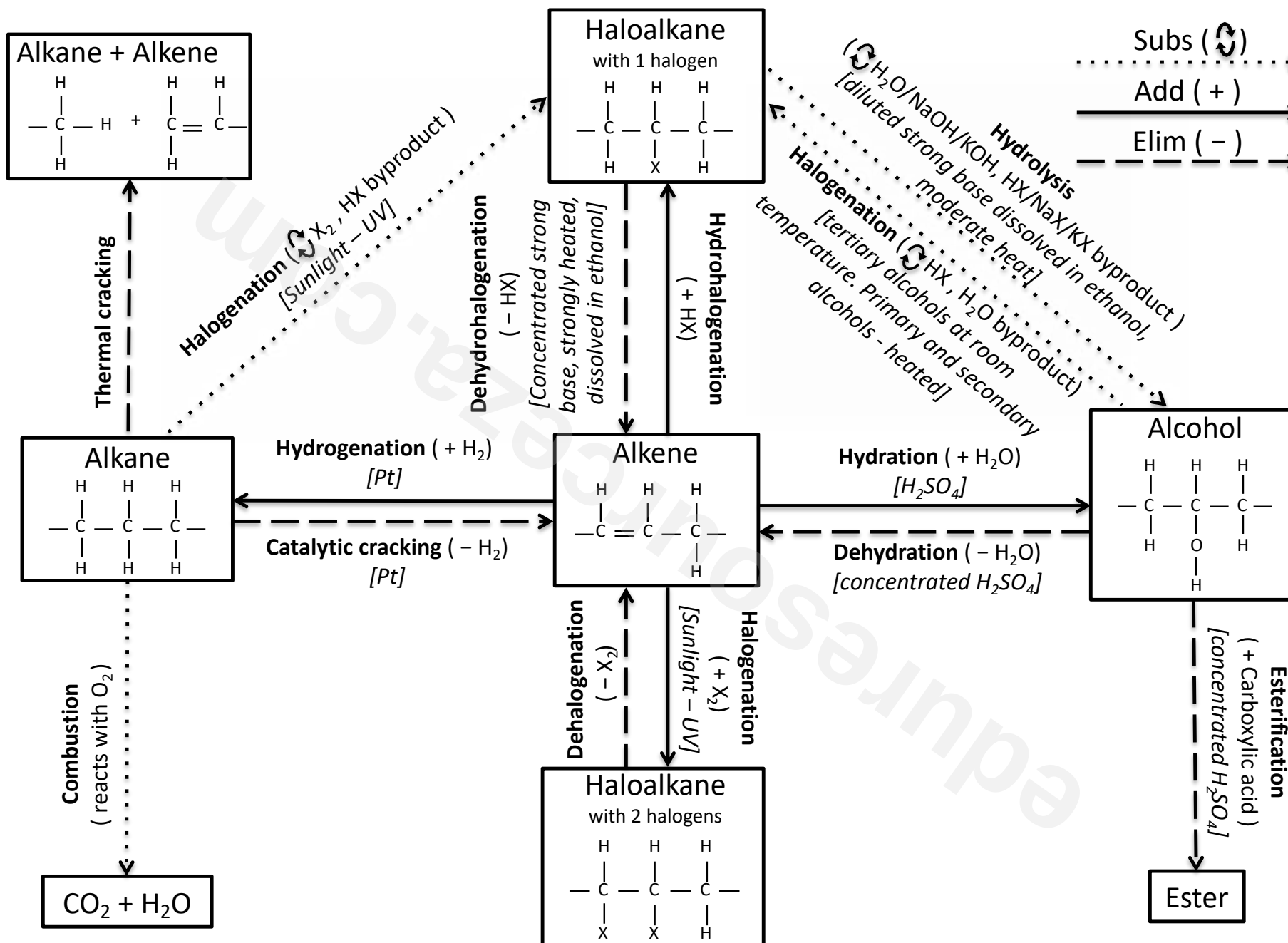
This method uses a catalyst to crack long carbon chains at low pressure (up to 1 atmosphere) and low temperature. The heated crude oil is passed into a fractional distillation column and passed over a catalyst. The column is hottest at the bottom and coolest at the top. The crude oil separates according to boiling points and condenses as the gas rises up the column. The substances/chains with the longest chains will have higher boiling points and condense at the bottom and vice versa. **Products: alkanes and alkenes OR alkenes and H₂.**

ESTERIFICATION

This is a reaction between an alcohol and a carboxylic acid in the **presence of a concentrated acid catalyst, H₂SO₄**. This reaction is a type of an elimination reaction and is also known as a condensation reaction as two organic molecules form one organic molecule and water is removed from the reactants and forms as a product in the reaction. Esters are responsible for the various smells which occur in nature and they are generally pleasant smells like banana and apple etc.



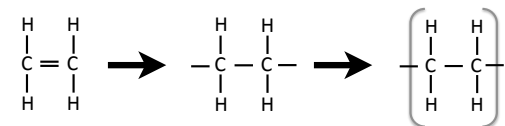
SUMMARY OF ORGANIC REACTIONS



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Addition polymers are made by joining two or more monomers which have double bonds- unsaturated molecules. (These are alkene's and alkyne's) and form long single bonded chains.

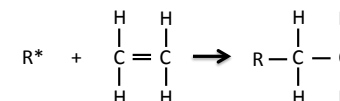
The double bond breaks open and the electrons join the two monomers together to create the long chain. No atoms are added or lost. Monomers may have different groups that are attached to the carbon atoms.



ethene polymer (polyethene)

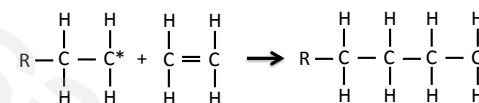
Polyethene is used to make squeeze bottles, plastic bags, films, toys and molded objects, and electric insulation. Polythene has the recycling number 4.

The presence of a free radical initiates the double bond of the monomer to break open. A free radical is a molecule that has an unpaired electron. When the monomer reacts with the free radical it creates another free radical.



*** : Free radical
(unpaired electron)**

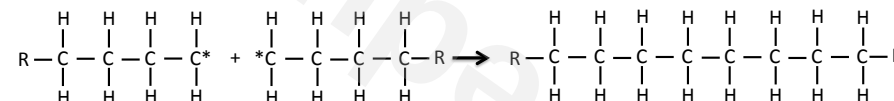
This new free radical will add to the double bond of another monomer and create another free radical. The chain will continue to grow and get longer and longer. These additions give rise to a macromolecule. This reaction takes place very quickly.



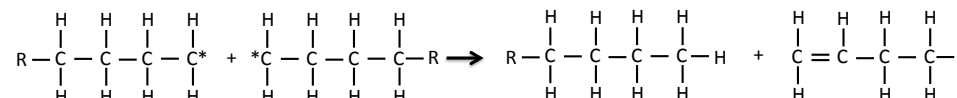
*** : Free radical
(unpaired electron)**

There are two ways in which the polymerization can terminate.

- Two radicals join together and terminate.

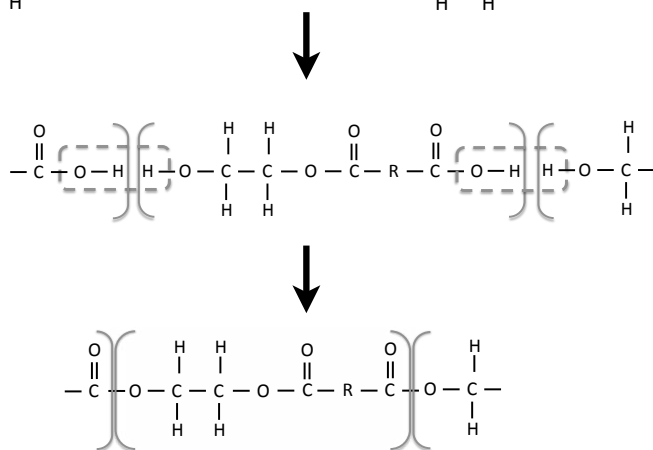


- One radical removes a hydrogen from another radical and forms a saturated molecule (alkane) and forces the other radical to form an unsaturated molecule(alkene).



Condensation polymerization occurs when two different monomers which have functional groups (alcohols and carboxylic acids) on both ends of their molecules react. In this reaction a water molecule is eliminated.

A polyester forms in a similar way as to a normal ester i.e. an alcohol and carboxylic acid reacting. The only difference is that the alcohol and carboxylic acids have a functional group on both their ends and are diols and dicarboxylic acids.

$$\begin{array}{c} \text{H} \quad \text{H} \\ | \quad | \\ \text{H}-\text{O}-\text{C}-\text{C}-\text{O}-\text{H} + \text{H}-\text{O}-\text{C}(=\text{O})-\text{R}-\text{C}(=\text{O})-\text{O}-\text{H} \\ | \quad | \\ \text{H} \quad \text{H} \end{array} \xrightarrow{\text{Esterification}} \begin{array}{c} \text{H} \quad \text{H} \\ | \quad | \\ \text{H}-\text{O}-\text{C}-\text{C}-\text{O}-\text{C}(=\text{O})-\text{R}-\text{C}(=\text{O})-\text{O}-\text{H} \\ | \quad | \\ \text{H} \quad \text{H} \end{array} + \text{H}_2\text{O}$$
$$\begin{array}{ccccccc} \text{H} & \text{H} & & \text{O} & \text{O} & \text{Esterification} & \text{H} & \text{H} & & \text{O} & & \text{O} \\ | & | & & || & || & \text{---} & | & | & & || & & || \\ \text{H}-\text{O}-\text{C}-\text{C}-\text{O}-\text{C}-\text{R}-\text{C}-\text{O}-\text{H} & + & \text{H}-\text{O}-\text{C}-\text{C}-\text{O}-\text{C}-\text{R}-\text{C}-\text{O}-\text{H} \\ | & | & & & & & | & | & & & & \\ \text{H} & \text{H} & & & & & \text{H} & \text{H} & & & & \end{array}$$


POLYMERS

MONOMER NAME	MONOMER STRUCTURE	FREE RADICAL BUILDING BLOCK	POLYMER STRUCTURE	POLYMER NAME
Addition polymerization				
Propene	$\begin{array}{c} \text{H} & \text{H} \\ & \\ \text{C} & = & \text{C} \\ & \\ \text{H} & \text{CH}_3 \end{array}$	$\begin{array}{c} \text{H} & \text{H} \\ & \\ -\text{C} & - & \text{C}- \\ & \\ \text{H} & \text{CH}_3 \end{array}$	$\begin{array}{ccccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \\ & & & & & & \\ -\text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C}- \\ & & & & & & & & & & & & \\ \text{H} & \text{CH}_3 & \text{H} & \text{CH}_3 & \text{H} & \text{CH}_3 & \text{H} & \text{CH}_3 & \text{H} & \text{CH}_3 & \text{H} & \text{CH}_3 & \end{array}$	Polypropylene
Styrene	$\begin{array}{c} \text{H} & & \text{H} \\ & \diagdown & / \\ & \text{C} = & \text{C} \\ & / & \diagdown \\ \text{H} & & \text{C}_6\text{H}_5 \end{array}$	$\begin{array}{c} \text{H} & \text{H} \\ & \\ -\text{C} & - & \text{C}- \\ & \\ \text{H} & \text{C}_6\text{H}_5 \end{array}$	$\begin{array}{ccccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \\ & & & & & & \\ -\text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C}- \\ & & & & & & & & & & & & \\ \text{H} & \text{C}_6\text{H}_5 & \text{H} & \text{C}_6\text{H}_5 & \text{H} & \text{C}_6\text{H}_5 & \text{H} & \text{C}_6\text{H}_5 & \text{H} & \text{C}_6\text{H}_5 & \text{H} & \text{C}_6\text{H}_5 & \end{array}$	Polystyrene
Vinyl acetate	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{O}=\text{C} \\ \\ \text{H}-\text{O} \\ \\ \text{H}-\text{C}=\text{C}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array}$	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{O}=\text{C} \\ \\ \text{H}-\text{O} \\ \\ -\text{C}-\text{C}- \\ \quad \\ \text{H} \quad \text{H} \end{array}$	$\begin{array}{ccccccc} \text{H} & & \text{H} & & \text{H} & & \text{H} \\ & & & & & & \\ \text{H}-\text{C}-\text{H} & \text{H}-\text{C}-\text{H} & \text{H}-\text{C}-\text{H} & \text{H}-\text{C}-\text{H} & \text{H}-\text{C}-\text{H} & \text{H}-\text{C}-\text{H} & \text{H}-\text{C}-\text{H} \\ & & & & & & \\ \text{O}=\text{C} & \text{O}=\text{C} & \text{O}=\text{C} & \text{O}=\text{C} & \text{O}=\text{C} & \text{O}=\text{C} & \text{O}=\text{C} \\ & & & & & & \\ \text{H}-\text{O} & \text{H}-\text{O} & \text{H}-\text{O} & \text{H}-\text{O} & \text{H}-\text{O} & \text{H}-\text{O} & \text{H}-\text{O} \\ & & & & & & \\ -\text{C}-\text{C}- & -\text{C}-\text{C}- & -\text{C}-\text{C}- & -\text{C}-\text{C}- & -\text{C}-\text{C}- & -\text{C}-\text{C}- & -\text{C}-\text{C}- \\ & & & & & & \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$	PVA (polyvinyl acetate)
Chloroethene	$\begin{array}{c} \text{Cl} & \text{H} \\ & \\ \text{C} & = & \text{C} \\ & \\ \text{H} & \text{H} \end{array}$	$\begin{array}{c} \text{Cl} & \text{H} \\ & \\ -\text{C} & - & \text{C}- \\ & \\ \text{H} & \text{H} \end{array}$	$\begin{array}{ccccccc} \text{Cl} & \text{H} & \text{Cl} & \text{H} & \text{Cl} & \text{H} & \\ & & & & & & \\ -\text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C}- \\ & & & & & & & & & & & & \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \end{array}$	PVC (polyvinyl chloride)
Condensation polymerization				
Lactic acid	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H}-\text{O}-\text{C}-\text{C}-\text{O}-\text{H} \\ \quad \\ \text{H} \quad \text{O} \end{array}$	Polymer formed by esterification. REMEMBER: Water is formed as byproduct.	$\begin{array}{ccccccc} \text{H} & & \text{H} & & \text{H} & & \text{H} \\ & & & & & & \\ \text{H}-\text{C}-\text{H} & \text{H}-\text{C}-\text{H} & \text{H}-\text{C}-\text{H} & \text{H}-\text{C}-\text{H} & \text{H}-\text{C}-\text{H} & \text{H}-\text{C}-\text{H} & \text{H}-\text{C}-\text{H} \\ & & & & & & \\ \text{O} & \text{O} & \text{O} & \text{O} & \text{O} & \text{O} & \text{O} \\ & & & & & & \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$	PLA (polylactic acid) PLA monomer formed from biological fermentation of plant materials is biodegradable. Used for packaging material, has the potential to alleviate land-fill disposal problems.

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.

The mole is the SI unit for the amount of substance. 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 .**

$$n = \frac{N}{N_A}$$

number of mole (mol) ← n → number of particles
 ← N_A → Avogadro's number ($6,02 \times 10^{23}$)

EXAMPLE:

Determine the amount of H^+ ions in 3 mol of H_2SO_4 .
 $N(H_2SO_4) = nN_A$ $H_2SO_4 : H^+$
 $= 3(6,02 \times 10^{23})$ $1 : 2$
 $= 1,81 \times 10^{24} H_2SO_4 \text{ molecules}$ $1,81 \times 10^{24} : 3,62 \times 10^{24}$
 $\therefore N(H^+) = 3,62 \times 10^{24} \text{ ions}$

Molar Mass

Particles are too small to weigh individually.

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

$$n = \frac{m}{M}$$

number of mole (mol) ← n → mass of substance (g)
 ← M → molar mass ($g \cdot mol^{-1}$)

EXAMPLE:

Determine the number of moles in 13 g of $CuSO_4$.
 $M(CuSO_4) = 63,5 + 32 + 4(16)$ $n = \frac{m}{M}$
 $= 159,5 g \cdot mol^{-1}$ $= \frac{13}{159,5}$
 $= 0,082 \text{ mol}$

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

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 moles of solute per unit volume of solution.

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

concentration ($mol \cdot dm^{-3}$) ← c → number of moles (mol) of solute
 → V → volume (dm^3) of solution

can also be calculated with

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

Concentration is the number moles of solute per $1 dm^3$ of solution i.e. $mol \cdot dm^{-3}$. If a solution of **potassium permanganate $KMnO_4$** has a concentration of $2 mol \cdot dm^{-3}$ it means that for every $1 dm^3$ of solution, there are 2 moles of $KMnO_4$ dissolved in the solvent.

EXAMPLE:

A solution contains 10 g of sodium hydroxide, $NaOH$, in $200 cm^3$ of solution. Calculate the concentration of the solution.

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

$$V = 200 cm^3 = 0,2 dm^3$$

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

EXAMPLE:

Calculate the mass of solute in $600 cm^3$ of $1,5 mol \cdot dm^{-3}$ sodium chloride solution.

$$\begin{aligned} V &= 600 cm^3 = 0,6 dm^3 \\ M(NaCl) &= 23 + 35,5 \\ &= 58,5 g \cdot mol^{-1} \end{aligned}$$

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

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

Molar Volumes of Gases

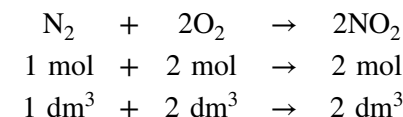
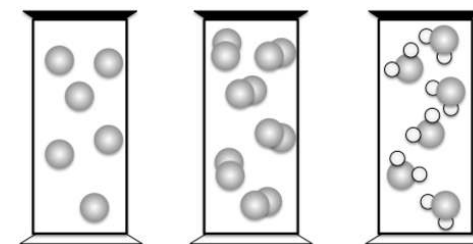
If different gases have the same volume under the same conditions of temperature and pressure, they will have the same number of molecules.

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 $22,4 dm^3 \cdot mol^{-1}$.

Standard Temperature and Pressure (STP) is $273 K (0^\circ C)$ and $1,01 \times 10^5 Pa (1 atm)$.

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



$$n = \frac{V}{V_M}$$

number of moles (mol) ← n → volume of gaseous substance (dm^3)
 → V_M → molar gas volume at STP ($22,4 dm^3 \cdot mol^{-1}$)

EXAMPLE:

A gas jar with a volume of $224 cm^3$ is full of **chlorine gas**, at STP. How many **moles** of chlorine gas are there in the gas jar?

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

Calculating Empirical Formula from Mass

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

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

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)	$0,125 / 0,0625$ ≈ 2	$0,0625 / 0,0625$ $= 1$

Empirical formula: Cu₂O

Calculating 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: Divide by smallest mol ratio	$1,25 / 1,25$ $= 1$	$3,75 / 1,25$ $= 3$

Empirical formula: SO₃

Empirical formula to Molecular Formula

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

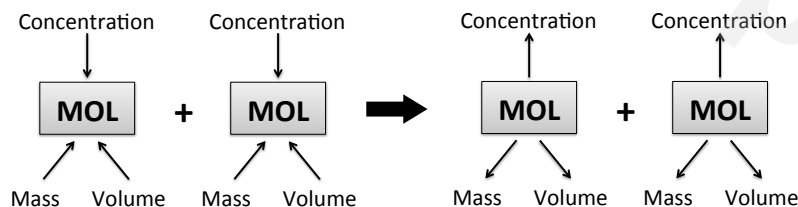
EXAMPLE:

An unknown organic compound has the empirical formula CH₂. The molecular mass of butene is 56g · mol⁻¹. Determine the molecular formula of the compound.

1. **Empirical formula given:** CH₂
2. **Determine the molar mass of the empirical formula.**
 $M(\text{CH}_2) = 12 + 1 + 1$
 $= 14 \text{ g} \cdot \text{mol}^{-1}$
3. **Determine the ratio between molecular and empirical.**
 $\text{ratio number} = \frac{\text{molecular formula mass}}{\text{empirical formula mass}}$
 $= \frac{56}{14}$
 $= 4$
4. **Multiply the ratio into the empirical formula**
 $\text{CH}_2 \times 4 = \text{C}_4\text{H}_8$

Approach to reaction stoichiometry

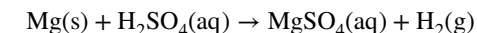
1. Write a balanced chemical equation.
2. Convert the 'given' amount into mole (use limiting reactant if applicable).
3. Determine the number of mole of the 'asked' substance using the mole ratio.
4. Determine the 'asked' amount from the number of mole.



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 and 2 moles of sulphuric acid are available to react? 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.

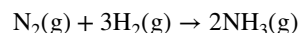
NOTE:

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)

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

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

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

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:

$$\begin{array}{lcl} \text{H}_2 & : & \text{NH}_3 \\ 3 & : & 2 \\ 0,75 \text{ mol} & : & 0,5 \text{ mol} \end{array}$$

$$\begin{aligned} m(\text{NH}_3) &= nM \\ &= (0,5)(17) \\ &= 8,5 \text{ g} \end{aligned}$$

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 cm³ of gas was produced (measured at STP). Calculate the percentage purity of the calcium carbonate sample. The equation for the reaction is:



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

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

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

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

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

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

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

Percentage Yield

Yield is the measure of the extent of a reaction, generally measured by comparing the amount of product against the amount of product that is possible.

Some of the product may be 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 product produced being less than the maximum theoretical amount you would expect. We can express this by the percentage yield:

$$\text{Percentage yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100$$

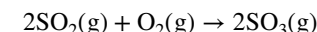
Percentage yield is usually determined using mass, but can also be determined with mol and volume.

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.

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

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

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

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

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

$$\text{Percentage yield} = 87,5 \%$$

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. (endothermic)

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

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 OR the energy required to form the activated complex.**

Once the bonds have been broken, the atoms in the chemical system form an **activated complex – a high energy, unstable 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.

CATALYST

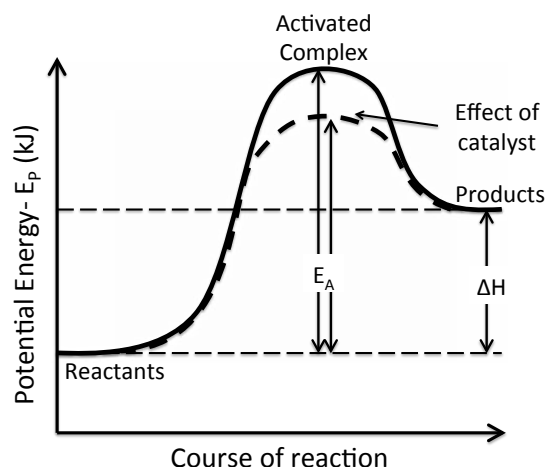
In order for a reaction to occur, enough energy has to be provided (activation energy) for particles to collide effectively.

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

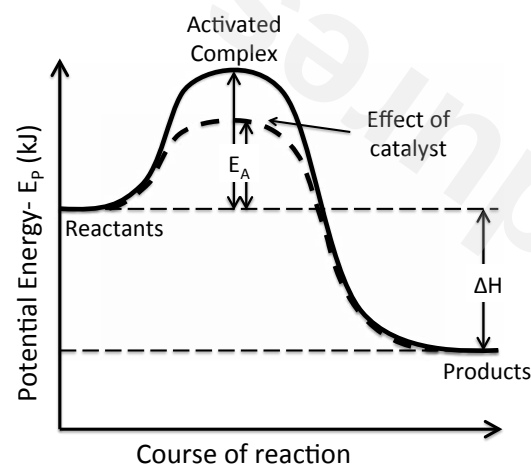
A catalyst is a substance that increases the rate of the reaction but remains unchanged at the end of the reaction.

ENDOTHERMIC	EXOTHERMIC
A reaction that absorbs heat energy	A reaction that releases heat energy
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)

POTENTIAL ENERGY PROFILE GRAPH OF AN ENDOTHERMIC REACTION



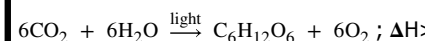
POTENTIAL ENERGY PROFILE GRAPH OF AN EXOTHERMIC REACTION



IMPORTANT REACTIONS

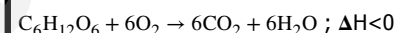
ENDOTHERMIC

Photosynthesis

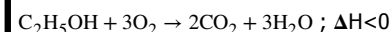


EXOTHERMIC

Cellular respiration



Combustion



RATES OF REACTIONS

The change in concentration per unit time of either a reactant or product.

$$\text{Rate} = \frac{\Delta \text{ amount of product}}{\Delta t}$$

$$\text{Rate} = \frac{\Delta \text{ amount of reactant}}{\Delta t}$$

May be given terms of change in mass per unit time ($\text{g}\cdot\text{s}^{-1}$) OR of change in volume per unit time ($\text{dm}^3\cdot\text{s}^{-1}$) OR change in number of mole per unit time ($\text{mol}\cdot\text{s}^{-1}$)

The gradient of a concentration/mass/volume versus time graph gives the rate of a reaction, thus a steeper gradient means a higher rate of reaction.

COLLISION THEORY

The conditions for successful collisions are:

1. Particles must collide with correct orientation

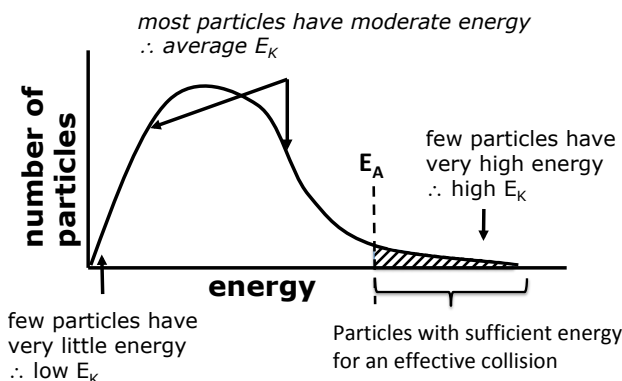
The structure of the molecules and their relative orientations to each other is important for effective collisions. Some catalysts function by improving molecular orientation.

2. Particles must collide with sufficient energy (kinetic energy $\geq$ activation energy)

The molecules have to collide with sufficient amount of energy for bonds to break and the reaction to occur (activation energy).

MAXWELL-BOLTZMAN DISTRIBUTION CURVE

The Maxwell-Boltzman distribution curve shows the distribution of the kinetic energy of molecules. The area under the graph to the right of the E_A line represents the particles with sufficient kinetic energy

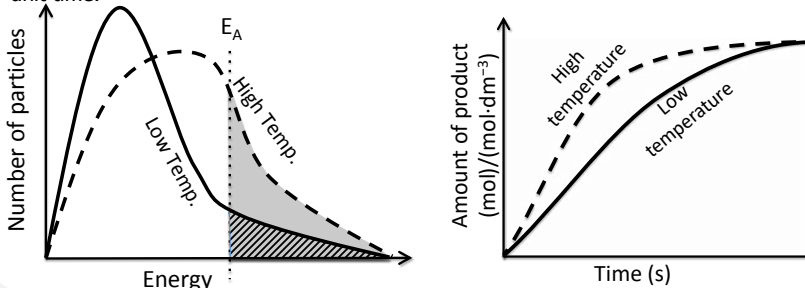


RATES OF REACTIONS

FACTORS INFLUENCING REACTION RATE

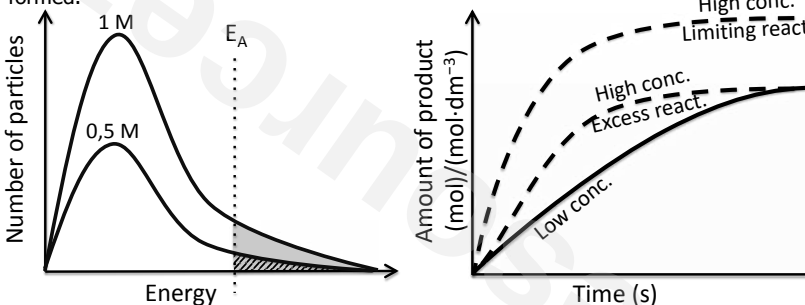
Temperature

Increasing temperature increases rate of reaction. When the temperature increases, the kinetic energy of the particles increases. More particles have sufficient energy to overcome the activation energy, and **more effective collisions** can take place per unit time.



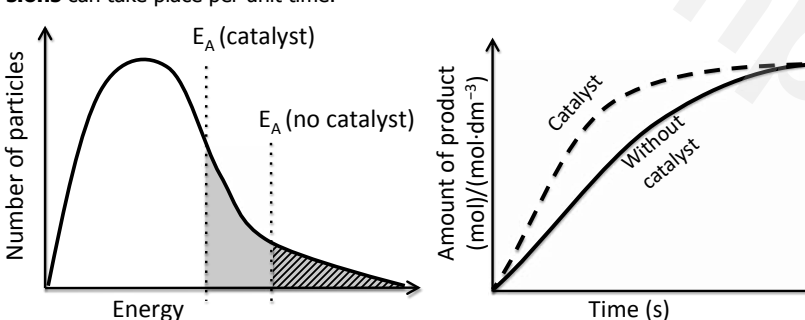
Concentration (gases and solutions only)

Increasing concentration increases rate of reaction. The greater the concentration, the more particles occur per unit volume. More particles have sufficient energy to overcome the activation energy, and **more effective collisions** can take place per unit time. If the concentration of a limiting reactant is increased, more product can be formed.



Catalyst

The presence of a catalyst decreases the activation energy (E_A). More particles have sufficient energy to overcome the lowered activation energy, and **more effective collisions** can take place per unit time.



Nature of reactants

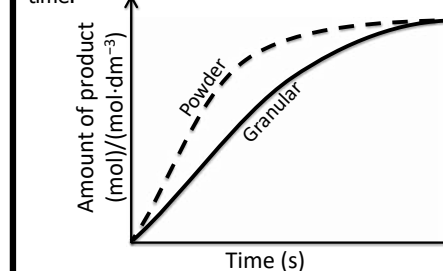
The physical and chemical properties of certain molecules make them more likely to react.

For example:

- O_2 has many effective orientations
- F's electronegativity makes it more reactive
- Tertiary alcohols have limited effective collision orientations due to molecule structure
- Simple (Ca^{2+}) and complex ($\text{C}_2\text{O}_4^{2-}$) ions.

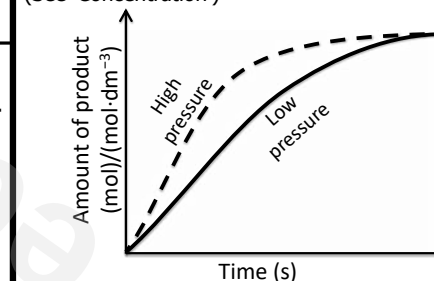
State of division / surface area (solids only)

Increased state of division (powder instead of chunks) increases rate of reaction. Increasing the surface area exposed to collisions increases that number of particles that will undergo collisions, and **more effective collisions** can take place per unit time.



Pressure (gases only)

Increased pressure (by decreasing volume) increases the concentration of the gas thus increasing the rate of reaction. (See 'Concentration')



WAYS TO MEASURE RATE

1. Change in mass
2. Volume of gas produced
3. Change in colour
4. Turbidity (precipitation)
5. Change in pH

All calculated per unit time

CHEMICAL EQUILIBRIUM

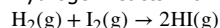
An **open system** is one in which both energy and matter can be exchanged between the system and its surroundings - it interacts continuously with its environment.

A **closed system** is one in which energy can enter or leave the system freely, but no reactant or products can leave or enter the system.

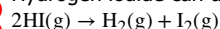
A reaction is a **reversible reaction** when products can be converted back to reactants. Reversible reactions are represented with double arrows.

For example:

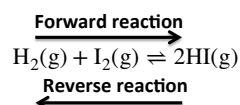
Hydrogen reacts with iodine to form hydrogen iodide:



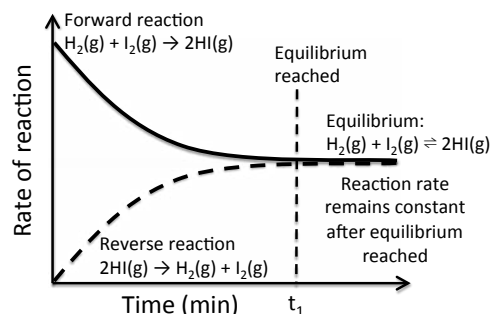
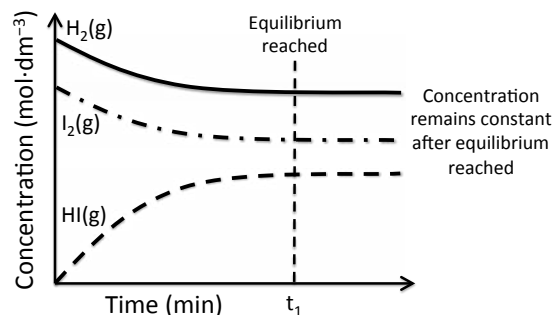
Hydrogen iodide can decompose to form hydrogen and iodine:



Therefore the reversible reaction can be written as:



Dynamic chemical equilibrium refers to a reversible reaction in which the forward reaction and the reverse reaction are taking place at the same rate. The concentrations of the reactants and products are constant. Chemical equilibrium can only be achieved in a closed system.



Equilibrium will shift to decrease any increase in concentration of either reactants or products.

- Adding reactant: forward reaction favoured
- Adding product: reverse reaction favoured

Equilibrium will shift to increase any decrease in concentration of either reactants or products.

- Removing reactant: reverse reaction favoured
- Removing product: forward reaction favoured

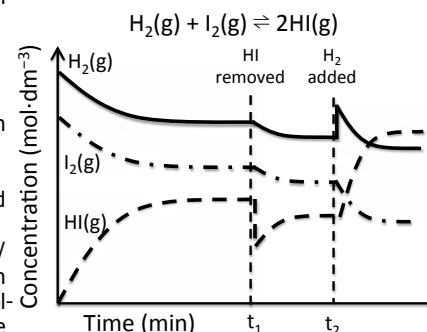
The concentration can be changed by adding/removing reactants/products that are in solution (aq) or a gas (g). Changing the mass of pure solids (s) or volume of liquids (l) will not disrupt the equilibrium or change the rate of the reactions.

LE CHATELIER'S PRINCIPLE

When the equilibrium in a closed system is disturbed, the system will re-instate a new equilibrium by favouring the reaction that will oppose the disturbance.

Factors which affect equilibrium position

1. Concentration



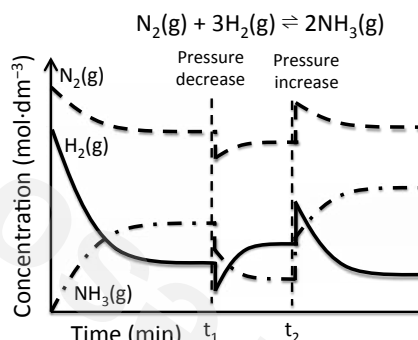
Removing HI (t₁):

When HI is removed, the system re-establishes equilibrium by favouring the reaction that will produce more HI. Because the forward reaction is favoured, some of the reactants are used.

Adding H₂ (t₂):

When adding H₂, the system re-establishes equilibrium by favouring the reaction that uses H₂. Because the forward reaction is favoured, the reactants are used and more product form.

2. Pressure (gases only)



Pressure decrease (t₁):

When the pressure is decreased, the system re-establishes equilibrium by favouring the reaction that will produce more moles of gas. The reverse reaction is favoured, reacting 2 mol gas and forming 4 mol gas.

Pressure increase (t₂):

When the pressure is increased, the system re-establishes equilibrium by favouring the reaction that will produce less moles of gas. The forward reaction is favoured, reacting 4 mol of gas and forming 2 moles of gas.

3. Temperature

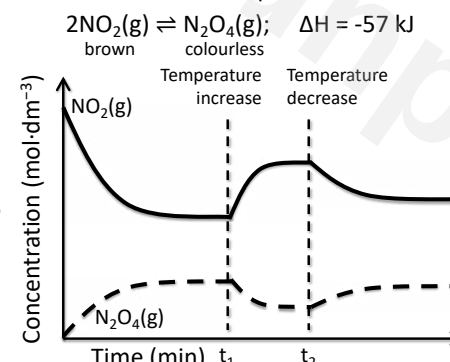
If the temperature is increased, the endothermic reaction will be favoured.

If the temperature decreases, the exothermic reaction is favoured.

The heat of the reaction, ΔH , is always used to indicate the forward reaction.

NOTE: An increase in temperature increases the rate of both the forward and the reverse reaction, but shifts the equilibrium position.

NOTE: Temperature change is the only change that affects K_c .



Temperature increase (t₁):

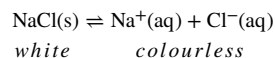
When the temperature is increased, the system re-establishes equilibrium by favouring the reaction that will decrease the temperature (i.e. the endothermic reaction). The reverse reaction will be favoured because the forward reaction is exothermic. The gas mixture becomes darker brown.

Temperature decrease (t₂):

When the temperature is decreased, the system re-establishes equilibrium by favouring the reaction that will increase the temperature (i.e. the exothermic reaction). The forward reaction will be favoured. The gas mixture becomes lighter brown.

COMMON ION EFFECT

When ionic substances are in solution, they form ions:

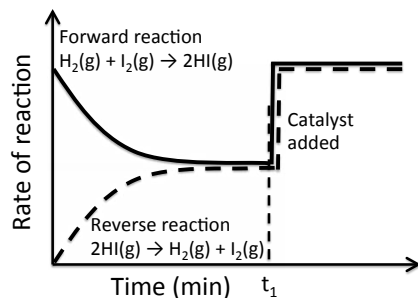


If HCl is added to this solution, the concentration of Cl^- ions will increase because Cl^- is a **common ion**. The system will attempt to re-establish equilibrium by favouring the reverse reaction, forming a white sodium chloride precipitate.

The disturbance of a system at equilibrium that occurs when the concentration of a common ion is increased, is known as the **common ion effect**.

CATALYST AND EQUILIBRIUM

When a catalyst is added, the rate of the forward, as well as the reverse reaction, is increased. The use of a catalyst does not affect the equilibrium position or the K_c value at all.



DESCRIBING EQUILIBRIUM SHIFT ACCORDING TO LE CHATELIER

1. **Identify the disturbance**
Adding/removing reactants or products, pressure change, temperature change.
2. **State Le Chatelier's principle**
3. **System response**
Use up/create more products or reactants, make more/less gas molecules, increase/decrease temperature.
4. **State favoured reaction**
5. **Discuss results**
Equilibrium shift, change in colour/concentration/pressure/temperature.

CHEMICAL EQUILIBRIUM

EQUILIBRIUM CONSTANT (K_c)

General equation: $aA + bB \rightleftharpoons cC$

Where A,B,C are chemical substances (**ONLY aq and g, NOT s or l!**)

and a,b,c are molar ratio numbers

$$K_c = \frac{[C]^c}{[A]^a[B]^b}$$

K_c value is a ratio and therefore has no units.

If $K_c > 1$ then equilibrium lies to the right – there are more products than reactants.

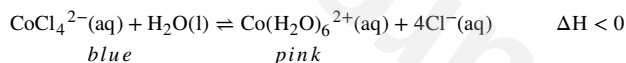
If $K_c < 1$ then equilibrium lies to the left – there are more reactants than products.

K_c values are constant at specific temperatures. If the temperature of the system changes then the K_c value will change.

Temperature	K_c of Exothermic	K_c of Endothermic
Increase	Decrease	Increase
Decrease	Increase	Decrease

EXAMPLE:

Consider the following equilibrium system:



For each change made to the system state and explain the colour change seen.

a) Water added

Adding water decreases the concentration of all the ions. According to Le Chatelier's principle, the equilibrium will shift in such a way so as to produce more ions. Thus the forward reaction will be favoured, forming more product and the solution turns pink.

b) AgNO_3 added

Adding AgNO_3 creates an insoluble precipitate of AgCl . This decreases the Cl^- ion concentration. According to Le Chatelier's principle the equilibrium will shift in such a way so as to produce more Cl^- ions. The forward reaction will be favoured, more product is made and the solution turns pink.

c) Temperature is increased

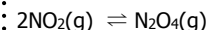
The temperature of the system is increased. According to Le Chatelier's principle, the equilibrium will shift in such a way to reduce the temperature. The reverse endothermic reaction is favoured. This decreases the temperature and produces more reactant and the solution turns blue.

EQUILIBRIUM CONSTANT TABLE

The equilibrium constant table assists in calculating the concentration of reactants and products when the reaction has reached equilibrium.

EXAMPLE:

3 moles of NO_2 are placed in a $1,5 \text{ dm}^3$ container and the following equilibrium is established:



If no volume is given, assume volume = 1 dm^3

At equilibrium it was found that $0,3 \text{ mol}$ of NO_2 was present in the container. Calculate the value of the equilibrium constant for this reaction.

	NO_2	N_2O_4
Ratio	2	1
Initial (mol)	3	0
Change (mol)	-2,7	+1,35
Equilibrium (mol)	0,3	1,35
Eq. concentration in ($\text{mol} \cdot \text{dm}^{-3}$)	$0,3/1,5 = 0,2$	$1,35/1,5 = 0,9$

$$K_c = \frac{[\text{N}_2\text{O}_4]}{[\text{NO}_2]^2} = \frac{(0,9)}{(0,2)^2} = 22,5$$

EXAMPLES OF APPLICATIONS OF CHEMICAL EQUILIBRIUM

The Haber Process: $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g}) \quad \Delta H < 0$

Temperature: The forward reaction is exothermic, thus a decrease in temperature will favour the forward exothermic reaction. However, a decrease in temperature will also decrease the rate of the reaction. Therefore, a compromise between rate and yield is found at a temperature of around 450°C to 550°C .

Pressure: As there are fewer reactant gas particles than product gas particles, an increase in pressure will therefore favour the production of products. Thus the reaction is done under a high pressure of 200 atm .

Catalyst: Iron or Iron Oxide

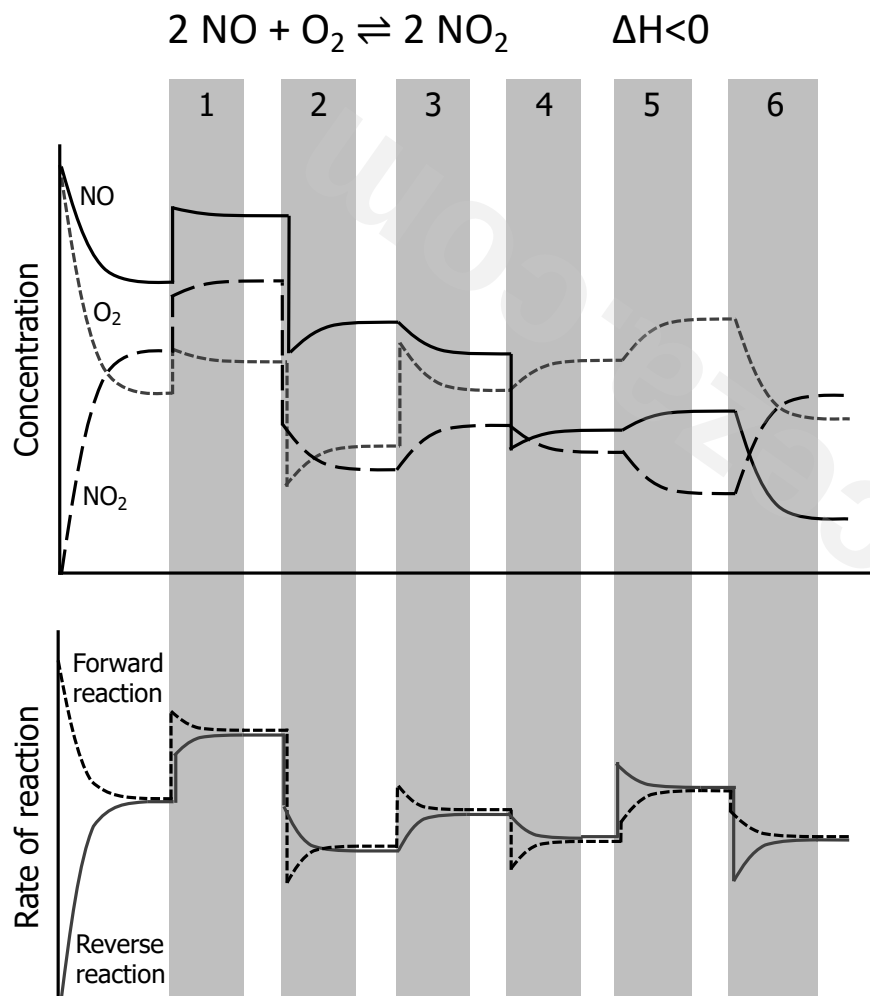
The Contact Process: $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g}) \quad \Delta H < 0$

Temperature: The forward reaction is exothermic, thus a decrease in temperature will favour the forward exothermic reaction. However, a decrease in temperature will also decrease the rate of the reaction. Therefore, a compromise between rate and yield is found at a temperature of around 450°C .

Pressure: There are more reactant gas particles than product gas particles, therefore an increase in pressure will favour the production of product. However, in practice a very high yield is obtained at atmospheric pressure.

Catalyst: Vanadium pentoxide (V_2O_5)

CHEMICAL EQUILIBRIUM – RATE AND CONCENTRATION



1: Increase in pressure

Le Chatelier: The forward reaction is favoured, less gas particles are formed and the pressure decreases.

Concentration:

- ① Concentration of all gasses increases sharply.
- ② The forward reaction is favoured.
- ③ [NO₂] gradually increases, [NO], [O₂] gradually decreases.

Rate: Concentration of all gasses increases, therefore the rate of both the forward and the reverse reaction increases. According to Le Chatelier the forward reaction will be favoured, therefore the forward reaction experiences a greater increase in rate.

2: Decrease in pressure

Le Chatelier: The reverse reaction is favoured, more gas particles are formed and the pressure increases.

Concentration:

- ① Concentration of all gasses decreases sharply.
- ② The reverse reaction is favoured.
- ③ [NO₂] gradually decreases, [NO], [O₂] gradually increases.

Rate: Concentration of all gasses decreases, therefore the rate of both the forward and the reverse reaction decreases. According to Le Chatelier the reverse reaction is favoured, therefore the reverse reaction experiences a smaller decrease in rate.

3: O₂ is added

Le Chatelier: The forward reaction is favoured to decrease the [O₂].

Concentration:

- ① Concentration of O₂ decreases sharply.
- ② The forward reaction is favoured.
- ③ [NO₂] increases gradually, [NO], [O₂] decreases gradually.

Rate: An increase in concentration of a reactant leads to an increase in the rate of the forward reaction.

4: NO is removed

Le Chatelier: The reverse reaction is favoured to increase the [NO].

Concentration:

- ① Concentration of NO decreases sharply.
- ② The reverse reaction is favoured.
- ③ [NO₂] decreases gradually, [NO], [O₂] increases gradually.

Rate: A decrease in concentration of a reactant leads to a decrease in the rate of the forward and reverse reaction.

5: Increase in temperature

Le Chatelier: The reverse (endothermic) reaction is favoured to decrease the temperature.

Concentration:

- ① The reverse reaction is favoured.
- ② [NO₂] decreases gradually, [NO], [O₂] increases gradually.

Rate: An increase in temperature increases the rate of both the forward and the reverse reactions.

6: Decrease in temperature

Le Chatelier: The forward (exothermic) reaction is favoured to increase the temperature.

Concentration:

- ① The forward reaction is favoured.
- ② [NO₂] increases gradually, [NO], [O₂] decreases gradually.

Rate: A decrease in temperature decreases the rate of both the forward and the reverse reactions.

ACID/BASE DEFINITIONS**Arrhenius**

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

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

Lowry-Brønsted

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

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

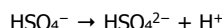
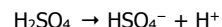
ACID PROTICITY

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.

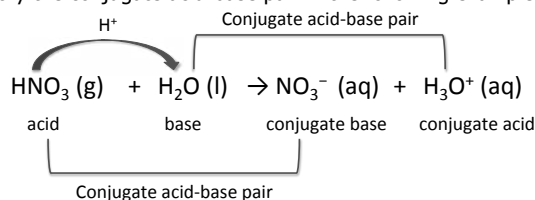
base + H^+ $\rightleftharpoons$ **conjugate acid**



Conjugate acids and bases differ only by a proton (H^+).

EXAMPLE:

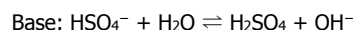
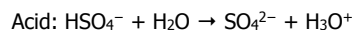
Identify the conjugate acid-base pair in the following example:

**AMPHOLYTE/ AMPHIPROTIC SUBSTANCES**

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

Ampholytes/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. ($c = \frac{n}{V}$ of $c = \frac{m}{MV}$)

A concentrated acid/base contains a large amount (mol) of acid/base in relationship to the volume of water.

A dilute acid/base contains a small amount (mol) of acid/base in relationship to the volume of water.

Concentrated strong acid - $1\text{mol}\cdot\text{dm}^{-3}$ of HCl

Concentrated weak acid - $1\text{mol}\cdot\text{dm}^{-3}$ of CH_3COOH

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

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

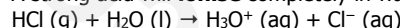
(Similar for bases)

STRONG VS WEAK ACIDS AND BASES

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

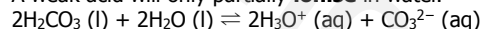
ACIDS

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



(strong acid $\rightarrow$ weak conjugate base)

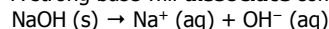
A weak acid will only partially **ionise** in water.



(weak acid $\rightarrow$ strong conjugate base)

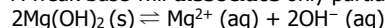
BASES

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



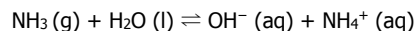
(strong base $\rightarrow$ weak conjugate acid)

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)	
Oxalic acid ($(\text{COOH})_2$)		Calcium carbonate (CaCO_3)	
Hydrofluoric acid (HF)	WEAK	Sodium carbonate (Na_2CO_3)	WEAK
Sulfurous acid (H_2SO_3)		Ammonia (NH_3)	
Carbonic acid (H_2CO_3)			
Acetic acid / ethanoic acid (CH_3COOH)			
Phosphoric acid (H_3PO_4)			

THE pH SCALE

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

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, and is a measure of the $[\text{H}_3\text{O}^+]$ at 25°C (in water).

$$\text{pH} = -\log[\text{H}_3\text{O}^+]$$

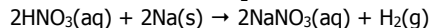
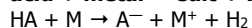


ACIDS AND BASES

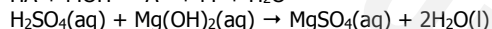
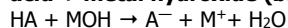
ACID REACTIONS

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

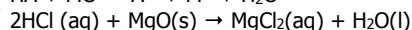
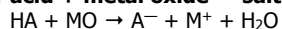
acid + metal → salt + H₂



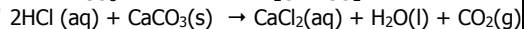
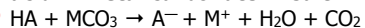
acid + metal hydroxide (base) → salt + H₂O



acid + metal oxide → salt + H₂O



acid + metal carbonate → salt + H₂O + CO₂



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

HYDROLYSIS OF SALTS

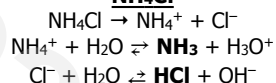
Hydrolysis is the reaction of an ion with water. During hydrolysis, the salt will form an acidic, alkali or neutral solution. The pH of the salt solution is determined by the relative strength of the acid and base that is used to form the salt.

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

A weak acid and a weak base do not form ions readily.

How to determine the pH of a salt

NH₄Cl

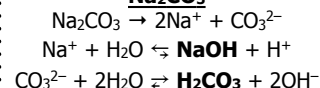


- NH₃ is a weak base
- Equilibrium lies to the right
- High concentration H₃O⁺

- HCl is a strong acid
- Equilibrium lies to the left
- Low concentration OH⁻

High [H₃O⁺], low [OH⁻],
∴ NH₄Cl(aq) is acidic (pH < 7)

Na₂CO₃



- NaOH is a strong base
- Equilibrium lies to the left
- Low concentration H⁺/H₃O⁺

- H₂CO₃ is a weak acid
- Equilibrium lies to the right
- High concentration OH⁻

Low [H₃O⁺], high [OH⁻],
∴ Na₂CO₃(aq) is alkali (pH > 7)

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 pH of the salt solution 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 acid/base has completely reacted with the base/acid according to the molar ratio. The pH at neutralisation is dependent on the salt that is formed. (see hydrolysis).

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 using a **standard solution- a solution of known concentration**. Neutralisation occurs at the equivalence point, when the acid/base has completely reacted with the base/acid according to the molar ratio.

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

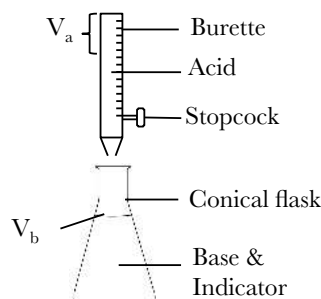
n- number of mole of substance (mol) / mol ratio from the balanced equation

c- concentration of acid/base (mol.dm⁻³)

V- volume of solution (dm³)

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

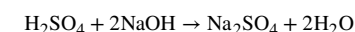
Titration setup



1. Pipette a specific amount of the standard solution into conical flask (usually base).
2. Add appropriate indicator to flask (according to pH of final solution).
3. Fill the buret with the solution of unknown concentration (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.



$$n_a = 1$$

$$c_a = 0,25 \text{ mol} \cdot \text{dm}^{-3}$$

$$V_a = 25 \text{ cm}^3 = 0,025 \text{ dm}^3$$

$$n_b = 2$$

$$c_b = ?$$

$$V_b = 40 \text{ cm}^3 = 0,04 \text{ dm}^3$$

By titration equations

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

$$\frac{1}{2} = \frac{(0,25)(0,025)}{c_b(0,04)}$$

$$c_b = 0,31 \text{ mol} \cdot \text{dm}^{-3}$$

By first principles:

Acid:

$$\begin{aligned} n &= cV \\ &= (0,25)(0,025) \\ &= 6,25 \times 10^{-3} \text{ mol} \end{aligned}$$

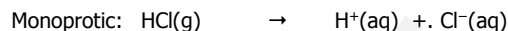
Base:

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

CALCULATING PH VALUE OF A STRONG ACID/BASE

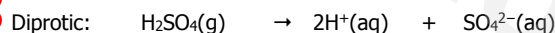
$$\text{pH} = -\log[\text{H}_3\text{O}^+]$$

Strong acids ionise completely in water, meaning that all acids donate their protons (H^+). The concentration of the H^+ ions can be determined from the initial concentration of the acids, taking the proticity of the acid into account.



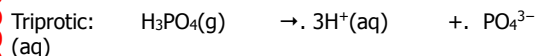
$$1 \text{ mol} : 1 \text{ mol} : 1 \text{ mol}$$

$$0,3 \text{ mol} \cdot \text{dm}^{-3} : 0,3 \text{ mol} \cdot \text{dm}^{-3} : 0,3 \text{ mol} \cdot \text{dm}^{-3}$$



$$1 \text{ mol} : 2 \text{ mol} : 1 \text{ mol}$$

$$0,3 \text{ mol} \cdot \text{dm}^{-3} : 0,6 \text{ mol} \cdot \text{dm}^{-3} : 0,3 \text{ mol} \cdot \text{dm}^{-3}$$



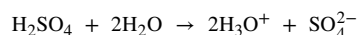
$$1 \text{ mol} : 3 \text{ mol} : 1 \text{ mol}$$

$$0,3 \text{ mol} \cdot \text{dm}^{-3} : 0,9 \text{ mol} \cdot \text{dm}^{-3} : 0,3 \text{ mol} \cdot \text{dm}^{-3}$$

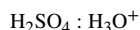
EXAMPLE:

Calculate the pH of a H_2SO_4 solution with a concentration of $0,25 \text{ mol} \cdot \text{dm}^{-3}$

Step 1: Write down the ionisation reaction:



Step 2: determine the ratio of acid to H_3O^+ ions



$$1 : 2$$

Step 3: determine the $[\text{H}_3\text{O}^+]$

$$[\text{H}_3\text{O}^+] = 2[\text{H}_2\text{SO}_4]$$

$$= 2(0,25)$$

$$= 0,5 \text{ mol} \cdot \text{dm}^{-3}$$

Step 4: Calculate the pH

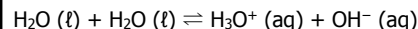
$$\text{pH} = -\log[\text{H}_3\text{O}^+]$$

$$= -\log(0,5)$$

$$= 0,3$$

AUTO-IONISATION OF WATER AND K_w

Water reacts with water to form hydronium and hydroxide ions in the following reaction:



The concentration of $\text{H}_3\text{O}^+(\text{aq})$ and $\text{OH}^-(\text{aq})$ are equal, and the equilibrium constant for the ionisation of water (K_w) is $1,00 \times 10^{-14}$ (at a temperature of 25°C or 298 K), therefore:

$$[\text{H}_3\text{O}^+][\text{OH}^-] = 1,00 \times 10^{-14} \text{ mol} \cdot \text{dm}^{-3}$$

$$[\text{H}_3\text{O}^+] = 1,00 \times 10^{-7} \text{ mol} \cdot \text{dm}^{-3}$$

$$[\text{OH}^-] = 1,00 \times 10^{-7} \text{ mol} \cdot \text{dm}^{-3}$$

When the concentration of $\text{H}_3\text{O}^+(\text{aq})$ and $\text{OH}^-(\text{aq})$ are equal, the solution is neutral and has a pH of 7. $-\log[1 \times 10^{-7}] = 7$

The pH of a base can be determined by first determining the $[\text{OH}^-]$, then the $[\text{H}_3\text{O}^+]$

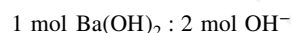
EXAMPLE:

Calculate the pH of a $\text{Ba}(\text{OH})_2$ solution with a concentration of $0,35 \text{ mol} \cdot \text{dm}^{-3}$.

Step 1: Write down the dissociation reaction



Step 2: Determine the mole ratio of base to OH^- ions



Step 3: Determine the $[\text{OH}^-]$

$$[\text{OH}^-] = 2[\text{Ba}(\text{OH})_2]$$

$$= 2(0,35)$$

$$= 0,7 \text{ mol} \cdot \text{dm}^{-3}$$

Step 4: Determine the $[\text{H}_3\text{O}^+]$

$$[\text{H}_3\text{O}^+][\text{OH}^-] = 1,00 \times 10^{-14}$$

$$[\text{H}_3\text{O}^+](0,7) = 1,00 \times 10^{-14}$$

$$[\text{H}_3\text{O}^+] = 1,43 \times 10^{-14} \text{ mol} \cdot \text{dm}^{-3}$$

Step 5: Calculate the pH

$$\text{pH} = -\log[\text{H}_3\text{O}^+]$$

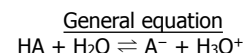
$$= -\log(1,43 \times 10^{-14})$$

$$= 13,84$$

K_a AND K_b VALUES

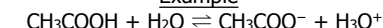
When weak acids or bases are dissolved in water, only partial ionisation/dissociation occurs. There is a mixture of the original reactant as well as the ionic products that were formed. The extent of ionisation can be treated in the same way as the extent to which an equilibrium reaction takes place. The acid dissociation constant (K_a) and base dissociation constant (K_b) values are like the equilibrium constant (K_c), but specifically described the extent of ionisation/dissociation, and therefore the strength of the acid/base.

Calculating K_a



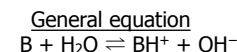
$$K_a = \frac{[\text{A}^-][\text{H}_3\text{O}^+]}{[\text{HA}]}$$

Example



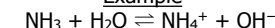
$$K_a = \frac{[\text{CH}_3\text{COO}^-][\text{H}_3\text{O}^+]}{[\text{CH}_3\text{COOH}]}$$

Calculating K_b



$$K_b = \frac{[\text{BH}^+][\text{OH}^-]}{[\text{B}]}$$

Example



$$K_b = \frac{[\text{NH}_4^+][\text{OH}^-]}{[\text{NH}_3]}$$

DETERMINING CONCENTRATION FROM PH

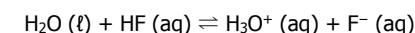
To determine the $[\text{H}_3\text{O}^+]$ when the pH is known:

$$\text{pH} = -\log[\text{H}_3\text{O}^+]$$

$$\therefore [\text{H}_3\text{O}^+] = 10^{-\text{pH}}$$

EXAMPLE:

$0,1 \text{ mol}$ HF is dissolved in 1 dm^3 water. Determine the K_a of HF if the pH is found to be 2,1. HF dissociates according to the following chemical equation:



$$\text{pH} = -\log[\text{H}_3\text{O}^+]$$

$$[\text{H}_3\text{O}^+] = 10^{-2,1}$$

$$[\text{H}_3\text{O}^+] = 7,94 \times 10^{-3} \text{ mol} \cdot \text{dm}^{-3}$$

	HF	H_3O^+	F^-
Ratio	1	1	1
Initial (mol)	0,1	0	0
Change (mol)	$-7,94 \times 10^{-3}$	$+7,94 \times 10^{-3}$	$+7,94 \times 10^{-3}$
Equilibrium (mol)	0,092	$7,94 \times 10^{-3}$	$7,94 \times 10^{-3}$
Eq. concentration in ($\text{mol} \cdot \text{dm}^{-3}$)	0,092	$7,94 \times 10^{-3}$	$7,94 \times 10^{-3}$

$$K_a = \frac{[\text{H}_3\text{O}^+][\text{F}^-]}{[\text{HF}]}$$

$$= \frac{(7,94 \times 10^{-3})(7,94 \times 10^{-3})}{0,092}$$

$$= 6,85 \times 10^{-4}$$

$K_a/K_b > 1$; Strong acid/base
 $K_a/K_b < 1$; Weak acid/base

ELECTROCHEMISTRY-REDOX

REDOX REACTION

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

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 oxidation.)

The reducing agent is the substance that donates electrons.
(It is the substance which is oxidised and causes reduction.)

The anode is the electrode where oxidation takes place.

The cathode is the electrode where reduction takes place.

OIL: Oxidation is loss
RIG: Reduction is gain

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

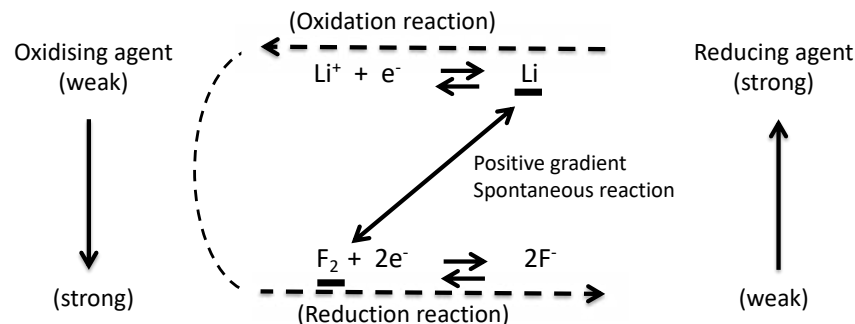
REDCAT: Reduction at cathode
ANOX: Oxidation at anode

TABLE OF STANDARD REDUCTION POTENTIALS (REDOX TABLE)

The oxidation and reduction half reactions can also be found using the Table of Standard Reduction Potentials. (We will use Table 4B).

The reactions shown on the table are all written as reduction half reactions, with the reversible reaction arrow ($\rightleftharpoons$) shown. This means that each reaction is reversible. When a reaction is written from the table the arrow must only be one way (i.e. $\rightarrow$).

The reduction half reaction is written from the table from left to right and the oxidation half reaction is written from right to left.



Once the half-reactions are identified it is possible to write a balanced reaction, without the spectator ions. A spectator ion is an ion in a redox reaction that does not take part in electron transfer. Remember that the number of electrons lost or gained by each substance must be the same.

If the line drawn between the two reactants has a positive gradient, the reaction is spontaneous.

If the line between the reactants are negative, the reaction is non-spontaneous.

STEPS TO WRITING BALANCED REDOX REACTIONS USING REDOX TABLE

1. IDENTIFY THE REACTANTS
2. UNDERLINE REACTANTS ON THE REDOX TABLE
3. DRAW ARROWS IN DIRECTION OF REACTION
4. WRITE THE OXIDATION AND REDUCTION HALF-REACTIONS
5. BALANCE ELECTRONS IF NECESSARY
6. WRITE OVERALL REACTION (LEAVE OUT SPECTATORS)

EXAMPLE:

Zinc metal reacts with an acid, $\text{H}^+(\text{aq})$ to produce hydrogen gas. Using the oxidation and reduction half reactions write a balanced equation for this reaction.

STEP 1: IDENTIFY THE REACTANTS

$\text{Zn}(\text{s})$ and $\text{H}^+(\text{aq})$

STEP 2: UNDERLINE REACTANTS ON THE REDOX TABLE

STEP 3: DRAW ARROWS IN DIRECTION OF REACTION

STEP 4: WRITE THE OXIDATION AND REDUCTION HALF-REACTIONS

Ox half-reaction: $\text{Zn} \rightarrow \text{Zn}^{2+} + 2\text{e}^-$

Red half-reaction: $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$

STEP 5: BALANCE ELECTRONS IF NECESSARY

STEP 6: WRITE OVERALL REACTION (LEAVE OUT SPECTATORS)

Overall: $\text{Zn} + 2\text{H}^+ \rightarrow \text{Zn}^{2+} + \text{H}_2$

EXAMPLE:

Magnesium ribbon is burnt in a gas jar containing chlorine gas. Using half reactions write a balanced chemical equation for this reaction.

Ox half-reaction: $\text{Mg} \rightarrow \text{Mg}^{2+} + 2\text{e}^-$

Red half-reaction: $\text{Cl}_2 + 2\text{e}^- \rightarrow 2\text{Cl}^-$

Overall reaction: $\text{Mg} + \text{Cl}_2 \rightarrow \text{Mg}^{2+} + 2\text{Cl}^-$

EXAMPLE:

Using half reactions, complete and balance the following reaction: $\text{Pb} + \text{Ag}^+$

Ox half reaction: $\text{Pb} \rightarrow \text{Pb}^{2+} + 2\text{e}^-$

Red half reaction: $\text{Ag}^+ + \text{e}^- \rightarrow \text{Ag}$

Ox half reaction: $\text{Pb} \rightarrow \text{Pb}^{2+} + 2\text{e}^-$

(x2 red half reaction): $2\text{Ag}^+ + 2\text{e}^- \rightarrow 2\text{Ag}$

Overall reaction: $\text{Pb} + 2\text{Ag}^+ \rightarrow \text{Pb}^{2+} + 2\text{Ag}$

ELECTROCHEMISTRY- GALVANIC/VOLTAIC CELL

A galvanic cell reaction is always a spontaneous, exothermic reaction during which **chemical energy is converted to electrical energy**. A electric cell/ battery is an example of a galvanic cell.

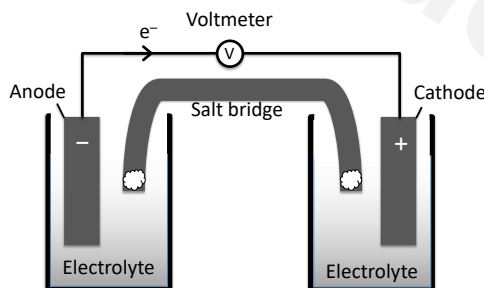
STRUCTURE

Two half-cells (usually in separate containers):

Anode – where oxidation takes place – negative electrode

Cathode – where reduction takes place – positive electrode

The anode and cathode connected together through an external circuit, which allows for current to flow from the anode to the cathode



SALT BRIDGE

The salt bridge connects the two half-cells. It is filled with a saturated ionic solution of either KCl, NaCl, KNO₃ or Na₂SO₄. A concentrated solution is used to reduce the internal resistance. The ends of the tubes are closed with a porous material such as cotton wool or glass wool.

Functions of the salt bridge:

Completes the circuit (which allows current to flow)
Maintains the electrical neutrality of the electrolyte solutions.

EQUILIBRIUM IN A CELL

When the circuit is complete the current will begin to flow. The current and potential difference of the cell is related to the rate of the reaction and extent to which the reaction in the cell has reached equilibrium. As the chemical reaction proceeds, the rate of the forward reaction will decrease, so the rate of transfer of electrons will also decrease which results in the E^θ_{cell} value decreasing.

The cell potential will continue to decrease gradually until equilibrium is reached at which point the cell potential will be zero and the battery is "flat".

Le Chatelier's principle can be applied to increase the EMF, with conditions that favour the forward reaction.

EMF OF THE CELL

The emf of the cell is calculated using one of the following equations:

$$E^\theta_{\text{cell}} = E^\theta_{\text{cathode}} - E^\theta_{\text{anode}}$$

$$E^\theta_{\text{cell}} = E^\theta_{\text{reduction}} - E^\theta_{\text{oxidation}}$$

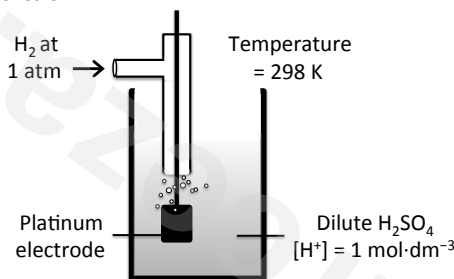
$$E^\theta_{\text{cell}} = E^\theta_{\text{oxidising agent}} - E^\theta_{\text{reducing agent}}$$

A positive E^θ value indicates a spontaneous reaction

The emf of the half-cells are determined using the standard hydrogen half-cell

Standard hydrogen half-cell

The hydrogen half-cell is allocated a reference potential of 0,00 V. All other half-cells will have a potential which is either higher or lower than this reference. This difference is the reading on the voltmeter placed in the circuit.



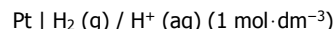
H₂ is bubbled through the electrolyte over the inert platinum electrode.
Reduction potentials are measured under standard conditions:

temperature 25 °C; 298 K

concentration of the solutions 1 mol·dm⁻³

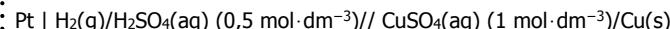
pressure 1 atm; 101,3 kPa (only relevant for gases)

The cell-notation for the hydrogen half-cell is:



EXAMPLE

Consider the cell notation of the following electrochemical cell:



The experimentally determined cell potential is 0,34 V at 25 °C.

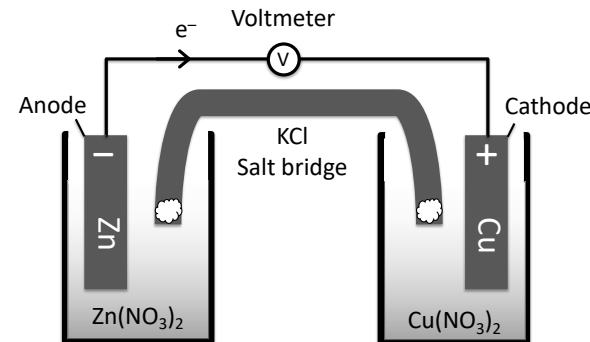
If a value of 0,00 V is given to the hydrogen half-cell, it means that the value of the copper half-cell must be 0,34 V.

$$E^\theta_{\text{cell}} = E^\theta_{\text{cathode}} - E^\theta_{\text{anode}}$$

$$0,34 = E^\theta(\text{Cu}) - 0,00$$

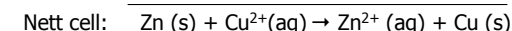
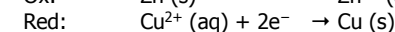
$$E^\theta(\text{Cu}) = + 0,34 \text{ V}$$

ZINC-COPPER CELL

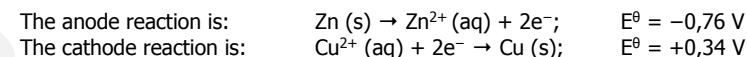


The zinc half-cell (-):

- Zinc electrode
- Zinc salt solution (e.g. zinc (II) nitrate)
- Zn is a stronger RA than Cu, ∴ Zn oxidises
- Oxidation reaction occurs: $\text{Zn} \rightarrow \text{Zn}^{2+} + 2\text{e}^-$
- Anode
- Electrode decreases in mass



For the zinc-copper cell:

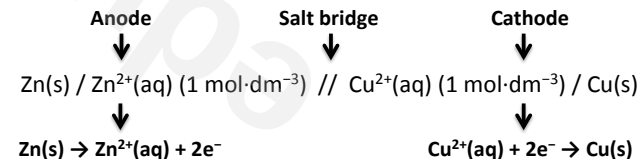


$$E^\theta_{\text{cell}} = E^\theta_{\text{cathode}} - E^\theta_{\text{anode}}$$

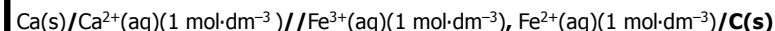
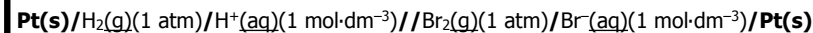
$$= 0,34 - (-0,76)$$

$$= + 1,1 \text{ V (spontaneous)}$$

CELL NOTATION



When the half-reactions do not include conductors (metals), unreactive electrodes are used, e.g. carbon or platinum.



ELECTROLYSIS OF SOLUTIONS

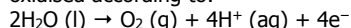
In the electrolysis of NaCl, the Na⁺ ions are not reduced as might be expected. To identify which ions are oxidised/reduced apply the following rules (based on relative strength of OA/RA):

OXIDATION (ANODE):

Either the anion or H₂O will be oxidised.

If a HALOGEN ION (Cl⁻, Br⁻, I⁻, not F⁻) is present, the HALOGEN ION is oxidised.

If no halogen ion is present, or the concentration is very low, water is oxidised according to:



REDUCTION (CATHODE):

Either the cation or H₂O will be reduced.

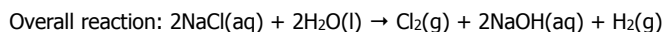
If a GROUP I OR GROUP II METAL CATION is present, WATER will be reduced according to:



Water is reduced because it is a stronger oxidising agent than other group I and II elements. If any other cation is present, the cation will

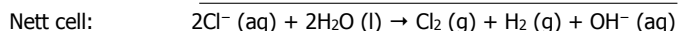
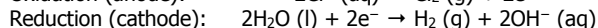
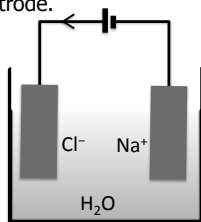
ELECTROLYSIS OF NaCl (CHLOR-ALKALI INDUSTRY)

Brine (concentrated NaCl solution) is placed in an electrolytic cell to produce chlorine gas, hydrogen gas and sodium hydroxide solution.

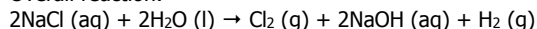


At the anode, Cl⁻ ions are oxidised to form Cl₂ (g). Cl₂ gas bubbles form on the electrode.

At the cathode, water is reduced to form H₂ (g) and OH⁻ (aq). H₂ (g) bubbles form on the electrode.



Overall reaction:



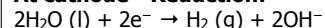
The electrolysis is conducted in specialised electrolytic cells to control the reaction process and allow reactions to occur under controlled conditions.

MEMBRANE CELL

An ion-exchange membrane is used to separate the sodium and chloride ions of the sodium chloride. The selectively permeable ion-exchange membrane is a fluoro-polymer which allows only Na⁺ ions to pass through it. The cell consists of two half cells separated by the membrane. The electrolytic cell has the lowest environmental impact. It is also the most cost effective to run, as the internal resistance is far lower than that of the diaphragm and mercury cells.

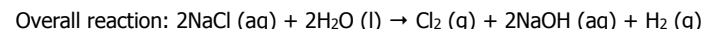
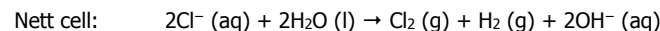
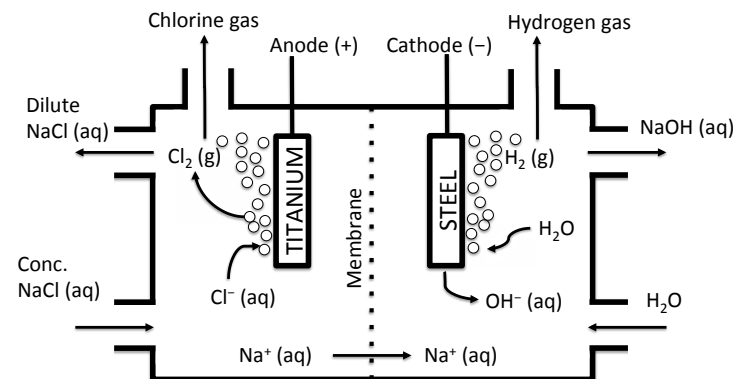
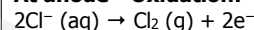
The cathode is filled with pure water

At cathode - Reduction:



The anode is filled with the brine solution

At anode - Oxidation:



FERTILISERS

PLANT NUTRIENTS

Non-mineral nutrients

Some non-mineral nutrients are not derived from soil:

Carbon (C): From CO₂ in the atmosphere

Oxygen (O): From CO₂ and O₂ in the atmosphere

Hydrogen (H): From rainwater in the soil

These non-mineral nutrients are needed in great quantities for the synthesis of glucose through photosynthesis.

Mineral nutrients

Mineral nutrients are dissolved in water in the soil and are absorbed by the roots of the plants. These nutrients can be supplemented by means of fertilisers to ensure healthy plant development.

Nitrogen (N):

Nitrogen is absorbed from nitrate- and ammonium salts in the soil.

- Assists protein formation
- Promotes **leaf growth**
- Improves the rate of above-ground growth

Nitrogen can be found naturally in guano, or synthetically in nitrate- and ammonium salts.

Phosphorus (P):

Phosphorus is absorbed from bonemeal, superphosphate and dissolved fertilisers.

- Stimulates early **root growth**
- Assists in photosynthesis
- Early formation of flowers and maturation of fruits and seeds

Phosphorus can be found naturally in bonemeal, or synthetically in superphosphate fertilisers.

Potassium (K):

Potassium is found in small quantities in organic plant and animal material (compost and manure).

- Promotes protein and carbohydrate synthesis
- Assists photosynthesis
- Improves quality of **flowers and fruit**.
- Makes plants more heat, drought and disease resistance.

Potassium can be found naturally in compost and manure, but is primarily imported from Germany in the form of potash.

NPK FERTILISERS

Fertilisers are classified according to their NPK content ratio. The ratio is given as:

N:P:K (%)

N- Ratio of nitrogen (N)

P- Ratio of phosphorus (P)

K- Ratio of potassium (K)

EXAMPLE 1

3:2:1 (25)
3 of 6 parts are N
2 of 6 parts are P
1 of 6 parts are K
25% of the total mass is pure fertiliser.

EXAMPLE 2

2:6:3 (40)
2 of 11 parts are N
6 of 11 parts are P
3 of 11 parts are K
40% of the total mass is pure fertiliser.

The percentages of each nutrient can be determined as follows:

(FROM EXAMPLE 2)

$$\% \text{ N: } \frac{2}{11} \times 40 = 7,27\%$$

$$\% \text{ P: } \frac{6}{11} \times 40 = 21,82\%$$

$$\% \text{ K: } \frac{3}{11} \times 40 = 10,91\%$$

EUTROFIKASIE

Due to over-irrigation dissolved minerals and phosphates are 'leached' from the soil and ends up in rivers and dams making them nutrient rich.

The nutrient rich water allows algae to grow rapidly. When algae die, it depletes the dissolved O₂ in the water. Fish and other water-life die.

Excess nitrates in drinking water is also harmful to humans.

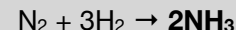
Fractional Distillation of Liquid Air



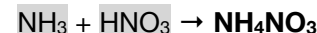
SASOL



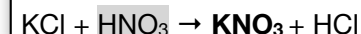
HARBER PROCESS (NH₃)



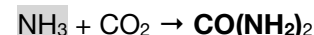
Ammonium nitrate



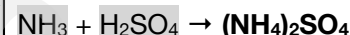
Potassium nitrate



UREA (CO(NH₂)₂)



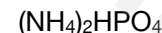
Ammonium sulphate



Monoammonium phosphates



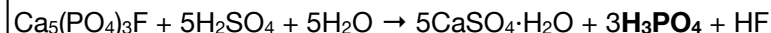
Diammonium phosphates



Triple super phosphates (Ca(H₂PO₄)₂·H₂O)

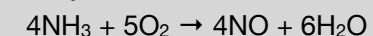
No CaSO₄ byproduct, ∴ Higher P concentration

PHOSPHORIC ACID (H₃PO₄)

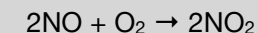


OSTWALD PROCESS (HNO₃)

Catalytic oxidation of ammonia



Oxidation of nitrogen monoxide



Absorption of NO₂ in water



CONTACT PROCESS (H₂SO₄)

Combustion of sulfur



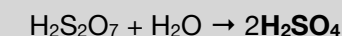
Catalytic oxidation of SO₂



Formation of oleum (H₂S₂O₇)



Conversion of oleum to H₂SO₄



Superphosphates

