SCIENCE CLINIC

DBE ESSENTIALS

GRADE 12

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WHY YOU SHOULD STUDY SCIENCE

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

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

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

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

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

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

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

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

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

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

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

6. **Be a modern-day hero (#2):** South Africa has a growing deficit of expert Science teachers. If you are passionate about Science, and passionate about making a difference, teaching is a massively rewarding career path that is becoming increasingly lucrative. Remember, supply and demand dictate going rates - if there are fewer expert Science teachers around, the demand for expertise leads to increased fees. Become a Science teacher, a thought leader and a role model!

7. **Wealth:** More than a fifth of the planet's wealthiest people on the Forbes 2015 list studied an engineering degree, according to a recent survey by the Approved Index platform. A quarter of the Forbes top-hundred have Science as a foundation for their work.

8. **Discovery:** Science research is a field that allows you to discover the unknown. The deep oceans are unexplored, nanotechnology and photonic crystals have so many secrets, and we're still not sure whether there is any form of life outside near-Earth space. Imagine being the person that publishes a peer-reviewed article to tell the world about a brand new discovery, or a new revelation in our understanding, or a life-altering breakthrough in technology.

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

James Hayes
Founder – Science Clinic

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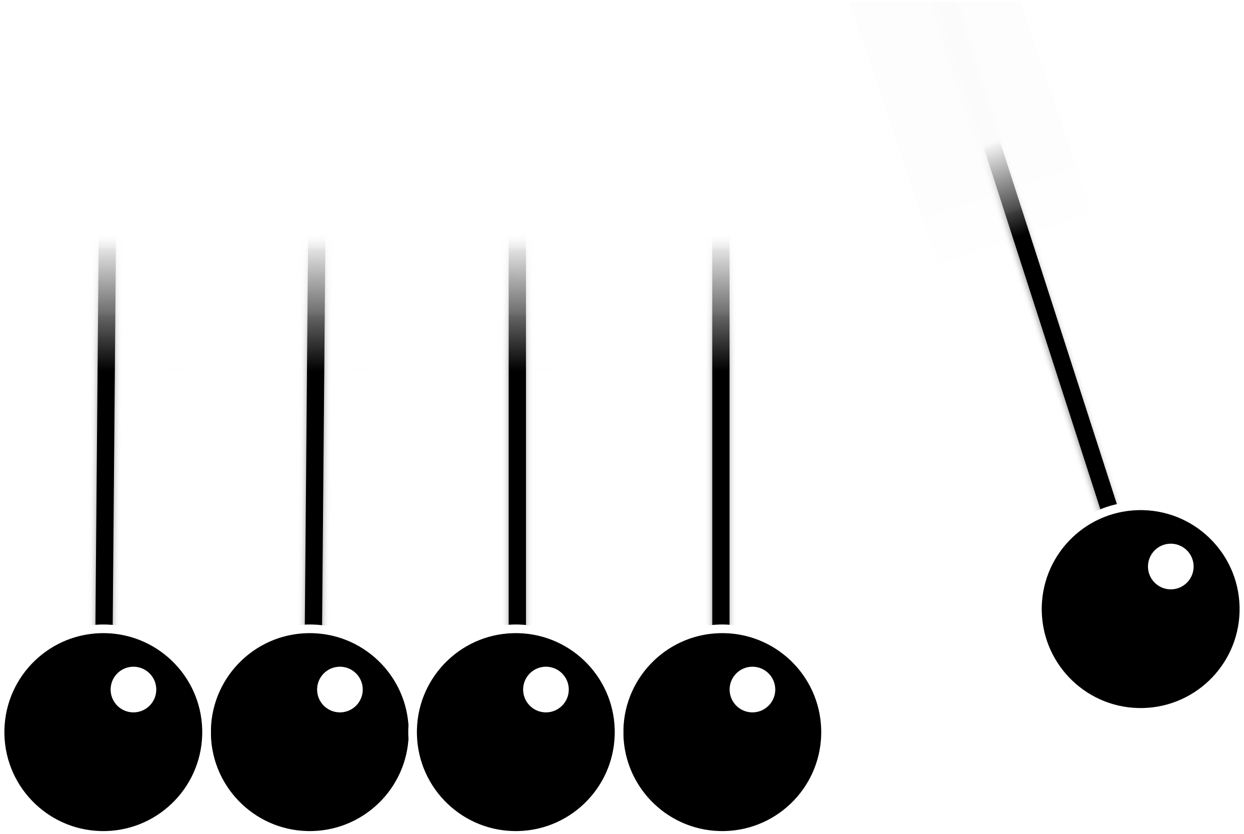

Grade 12 Physics

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

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

Information sheets – Paper 1 (Physics)

TABLE 1: PHYSICAL CONSTANTS

NAME	SYMBOL	VALUE
Acceleration due to gravity	g	$9{,}8\ \mathrm{m\cdot s^{-2}}$
Universal gravitational constant	G	$6{,}67 \times 10^{-11}\ \mathrm{N\cdot m^2\cdot kg^{-2}}$
Speed of light in a vacuum	c	$3{,}0 \times 10^{8}\ \mathrm{m\cdot s^{-1}}$
Planck's constant	h	$6{,}63 \times 10^{-34}\ \mathrm{J\cdot s}$
Coulomb's constant	k	$9{,}0 \times 10^{9}\ \mathrm{N\cdot m^2\cdot C^{-2}}$
Charge on electron	e	$-1{,}6 \times 10^{-19}\ \mathrm{C}$
Electron mass	m_e	$9{,}11 \times 10^{-31}\ \mathrm{kg}$

TABLE 2: FORMULAE

MOTION

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

FORCE

$F_{net} = ma$	$p = mv$
$F_{net}\Delta t = \Delta p$ $\Delta p = mv_f - mv_i$	$w = mg$
$F = \frac{Gm_1m_2}{r^2}$	$g = \frac{Gm}{r^2}$

WORK, ENERGY AND POWER

$W = F\Delta x\cos\theta$	$U = mgh$ OR $E_P = mgh$
$K = \frac{1}{2}mv^2$ OR $E_k = \frac{1}{2}mv^2$	$W_{net} = \Delta K$ OR $W_{net} = \Delta E_k$ $\Delta K = K_f - K_i$ OR $\Delta E_k = E_{kf} - E_{ki}$
$W_{nc} = \Delta K + \Delta U$ OR $W_{nc} = \Delta E_k + \Delta E_p$	$P = \frac{W}{\Delta t}$
$P_{ave} = Fv_{ave}$	

WAVES, SOUND AND LIGHT

$v = f\lambda$	$T = \frac{1}{f}$
$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$	$E = hf$ OR $E = h\frac{c}{\lambda}$
$E = W_o + K_{max}$ OR $E = W_o + E_{k(max)}$ where $E = hf$ and $W_o = hf_o$ and $K_{max} = \frac{1}{2}mv^2_{max}$ OR $E_{k(max)} = \frac{1}{2}mv^2_{max}$	

ELECTROSTATICS

$F = \frac{kQ_1Q_2}{r^2}$	$E = \frac{kQ}{r^2}$
$E = \frac{F}{q}$	$V = \frac{W}{q}$
$n = \frac{Q}{e}$ OR $n = \frac{Q}{q_e}$	

ELECTRIC CIRCUITS

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

ALTERNATING CURRENT

$I_{rms} = \frac{I_{max}}{\sqrt{2}}$ $V_{rms} = \frac{V_{max}}{\sqrt{2}}$	$P_{average} = V_{rms}I_{rms}$ $P_{average} = I^2_{rms}R$ $P_{average} = \frac{V^2_{rms}}{R}$

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. (Know that a frictional force is proportional to the normal force, is independent of the area of contact, is independent of the velocity of motion). **Static frictional force (f_s):** the force that opposes the tendency of motion of a stationary object relative to a surface. **Kinetic frictional force (f_k):** the force that opposes the motion of a moving object relative to a surface. **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.
Momentum and Impulse	**Momentum**: the product of an object's mass and its velocity. **Linear momentum**: of an object is a vector quantity with the same direction as the velocity of the object. **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). **Elastic collision:** a collision where energy is conserved. **Inelastic collision:** a collision where energy is not conserved.
Vertical Projectile Motion	**Projectile:** an object upon which the only force acting is the force of gravity. Projectiles fall freely with gravitational acceleration 'g' accelerate downwards with a constant acceleration irrespective of whether the projectile is moving upward or downward or is at maximum height.
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 is done by a force on an object – the use of 'work is done against a force', e.g. work done against friction, should be avoided.) Work is a scalar quantity and is measured in joules (J). **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. Eg. gravitational force, the elastic force in a spring, electrostatic forces (coulomb forces). **Non-conservative force**: is a force for which the work done in moving an object between two points depends on the path taken. Eg. frictional force, air resistance, tension in a chord. Energy: **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. **Ohmic conductor:** a conductor that obey's Ohm's law. **Non-Ohmic conductor:** a conductor which does not obey Ohm's law. **Internal resistance:** the resistance the cells provide against the flow of charge. **Emf:** the total amount of energy supplied per coulomb of charge in a cell.
Electrodynamics	**Principle of magnetic induction:** a changing magnetic field induces an emf in conductor. **Motor effect**: when a current carrying conductor is placed in a magnetic field it will experience a force. **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_o):** the minimum frequency of light needed to emit electrons from a certain metal surface **Work function (W_o):** the minimum energy that an electron in the metal needs to be emitted from the metal surface

VERTICAL PROJECTILE MOTION

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 freefall, 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 have the same acceleration due to gravity. This acceleration is 9,8 m·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 (½mv^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 a different velocity.

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

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

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

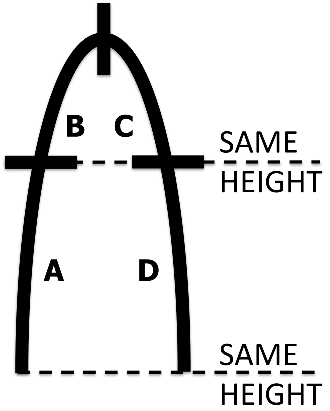
$$\Delta y = \left(\frac{v_i + v_f}{2}\right)\Delta t$$

Δy = displacement (m)
Δt = time (s)
v$_i$ = initial velocity (m·s^{-1})
v$_f$ = final velocity (m·s^{-1})
a = acceleration (m·s^{-2})
(9,8 m·s^{-2} downwards)

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

PARTS OF PROJECTILE PATH

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:
$v_{iA} = v_{fD}$
$v_{fA} = v_{iD}$
$v_{iB} = v_{fC}$
$v_{fB} = v_{iC} = 0$ m·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.

$$\text{total time} = 4\ \text{s}$$
$$\therefore \text{t}_{\text{up}} = 2\ \text{s}$$

$$v_f = v_i + a\Delta t$$
$$0 = v_i + (9{,}8)(2)$$
$$v_i = -19{,}6$$
$$\therefore v_i = 19{,}6\ m\cdot s^{-1}\ up$$

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

$$\Delta y = v_i\Delta t + \tfrac{1}{2}at^2$$
$$-8 = -19{,}6t + \tfrac{1}{2}(9{,}8)t^2$$
$$0 = 4{,}9t^2 - 19{,}6t + 8$$

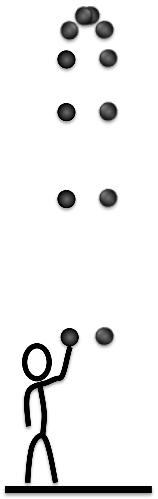
$$t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$
$$t = \frac{-(-19{,}6) \pm \sqrt{(-19{,}6)^2 - 4(4{,}9)(8)}}{2(4{,}9)}$$
$$t = 0{,}46\ s \qquad OR \qquad 3{,}54$$
$$\therefore t = 0{,}46\ s$$

GRAPHS OF PROJECTILE MOTION

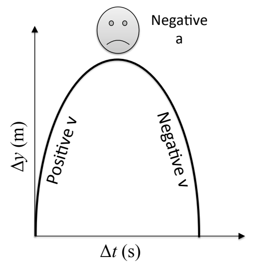
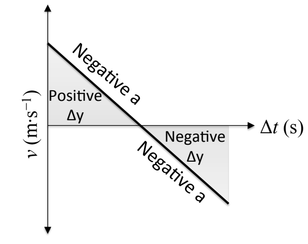
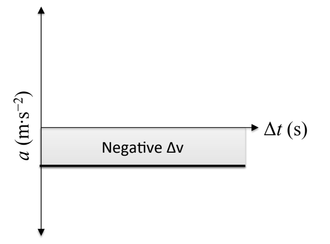
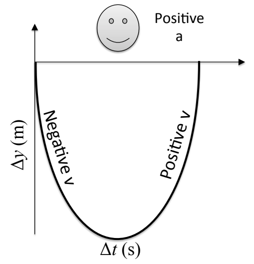
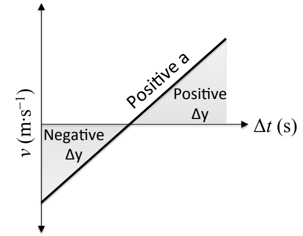
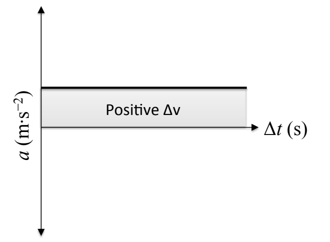
Graph manipulation:

Change in positive direction:
Flip graph along x-axis

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



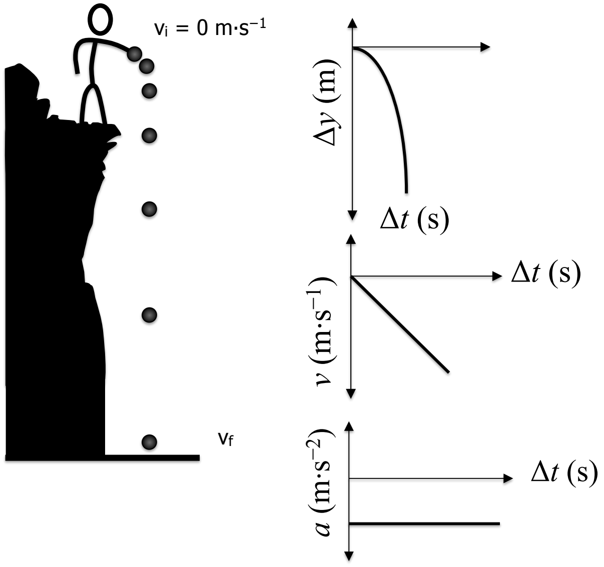
← Area
Gradient →

	Δy vs Δt	**v vs Δt**	**a vs Δt**
UP POSITIVE			
DOWN POSITIVE			

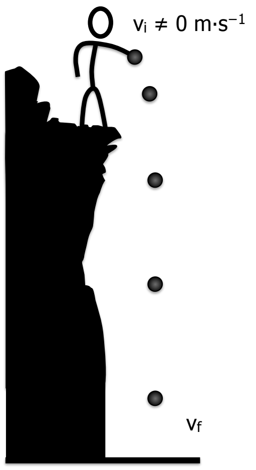
PATH OF A PROJECTILE

ALL EXAMPLES:
UP POSITIVE

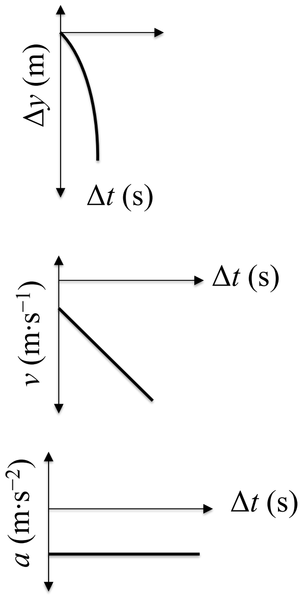
OBJECT DROPPED FROM HEIGHT (C+D)



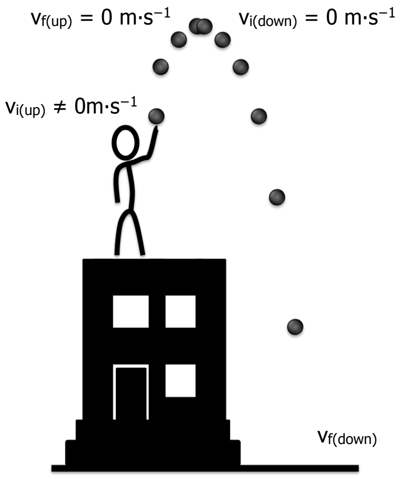
OBJECT THROWN DOWN FROM HEIGHT (D)



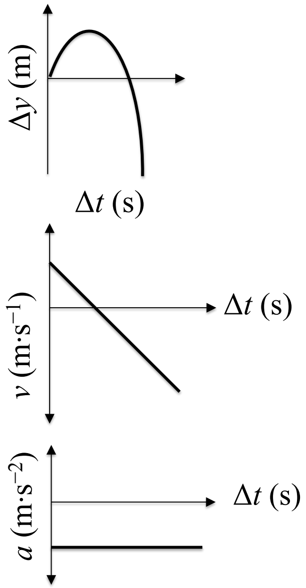
Also applies to objects dropped from a downward moving reference.



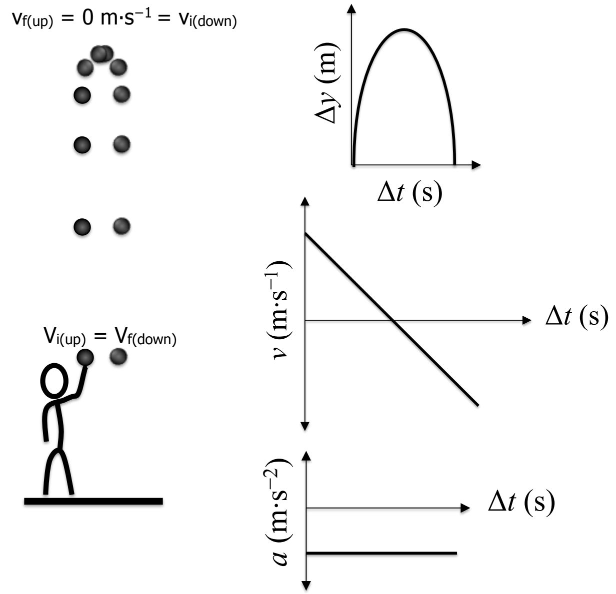
OBJECT THROWN UP FROM HEIGHT (B+C+D)



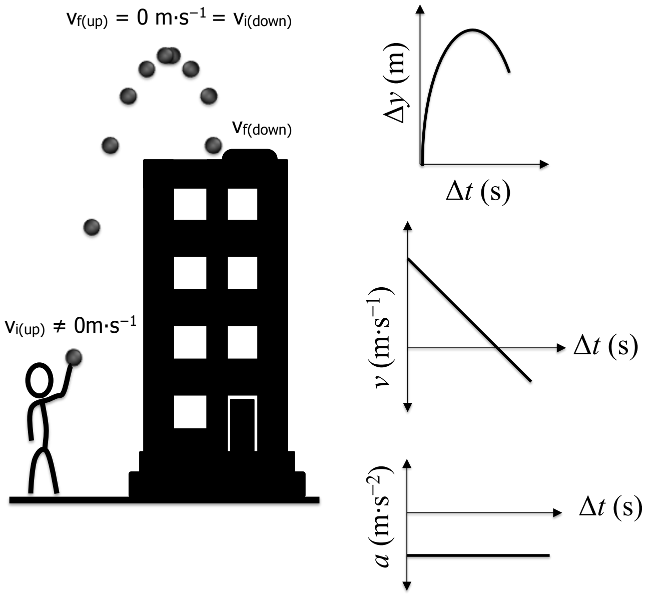
Also applies to objects dropped from an upward moving reference.



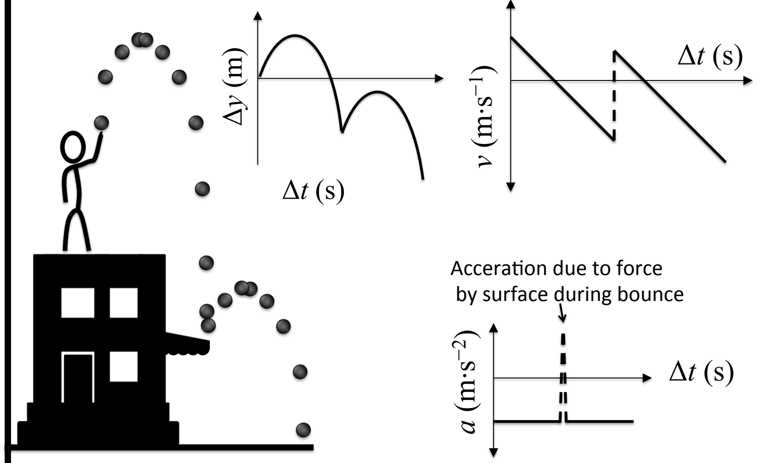
OBJECT THROWN UP AND CAUGHT (A+B+C+D)



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



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

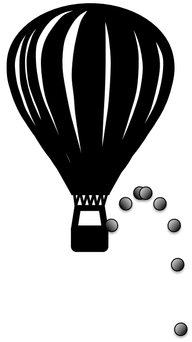


If the collision is perfectly elastic, the downward velocity before the bounce and the upward velocity after the bounce is equal in magnitude.

Treat the 2 projectile paths (before and after bounce) as separate paths.

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 m·s^{-2}, regardless of the acceleration of the reference.

EXAMPLE:

A hot air balloon ascends with a constant velocity of 5 m·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 :

$$\begin{aligned}\Delta y &= v_i\Delta t + \tfrac{1}{2}a\Delta t^2\\ &= (-5)(2) + \tfrac{1}{2}(0)(2^2)\\ &= -10\\ \therefore \Delta y &= 10 \text{ m up}\end{aligned}$$

Distance travelled by ball :

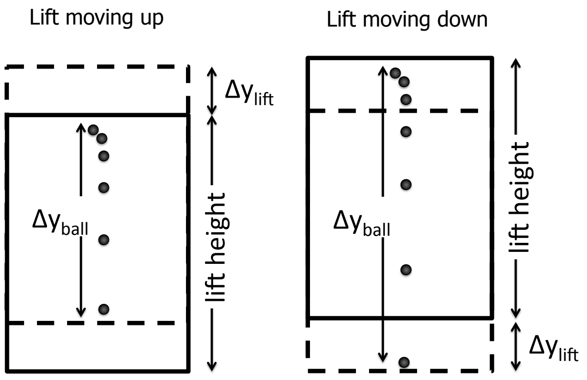
$$\begin{aligned}\Delta y &= v_i\Delta t + \tfrac{1}{2}a\Delta t^2\\ &= (-5)(2) + \tfrac{1}{2}(9{,}8)(2^2)\\ &= -10 + 19{,}6\\ \therefore \Delta y &= 9{,}6 \text{ m down}\end{aligned}$$

$$\begin{aligned}\therefore \text{ total distance} &= 10 + 9{,}6\\ &= 19{,}6 \text{ m apart}\end{aligned}$$

(b) Take downwards as positive:

$$\begin{aligned}v_f^2 &= v_i^2 + 2a\Delta y\\ v_f^2 &= (-5^2) + 2(9{,}8)(50)\\ v_f &= \sqrt{25 + 980}\\ v_f &= 31{,}70 \text{ m}\cdot\text{s}^{-1} \text{ downwards}\end{aligned}$$

LIFT



$$\Delta y_{ball} = \text{lift height} + \Delta y_{lift}$$

EXAMPLE:

A lift accelerates upwards at a rate of 1,4 m·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 elevator :

$$\begin{aligned}\Delta y_{lift} &= v_i\Delta t + \tfrac{1}{2}a\Delta t^2\\ y_{lift} &= (0)t + \tfrac{1}{2}(-1{,}4)t^2\\ \therefore y_{lift} &= -0{,}7t^2\end{aligned}$$

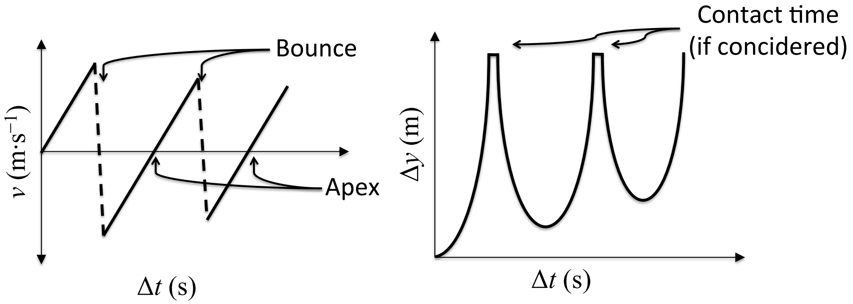
movement of bulb :

$$\begin{aligned}\Delta y_{bulb} &= v_i\Delta t + \tfrac{1}{2}a\Delta t^2\\ 3 + y_{lift} &= (0)t + \tfrac{1}{2}(9{,}8)t^2\\ 3 + y_{lift} &= 4{,}9t^2\\ \therefore y_{lift} &= 4{,}9t^2 - 3\end{aligned}$$

$$\begin{aligned}-0{,}7t^2 &= 4{,}9t^2 - 3\\ -5{,}6t^2 &= -3\\ t^2 &= 0{,}54\\ \therefore t &= 0{,}73 \text{ s}\end{aligned}$$

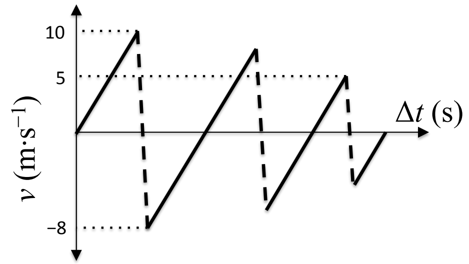
Simultaneous equation is needed because there are 2 unknown variables:
- Distance that lift moved
- Time to reach floor

BOUNCING BALL



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 change is 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

$$\begin{aligned}\text{Impulse} &= \Delta p\\ &= m(v_f - v_i)\\ &= (0{,}1)(-8 - 10)\\ &= -1{,}8\\ \therefore \text{Impulse} &= 1{,}8 \text{ N}\cdot\text{s upwards}\end{aligned}$$

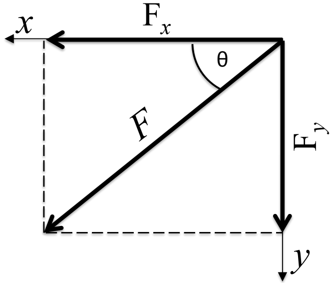
f) Predict why the ball stopped moving.
It stops on the apex, ∴it was most likely caught

VECTORS IN 2D

RESOLVING INTO COMPONENTS

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

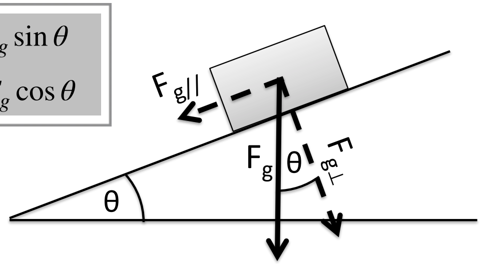
$$F_x = F\cos\theta$$
$$F_y = F\sin\theta$$



COMPONENTS ON A SLOPE

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

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



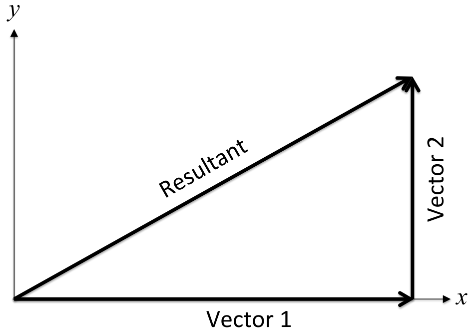
CONSTRUCTING FORCE TRIANGLE

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.

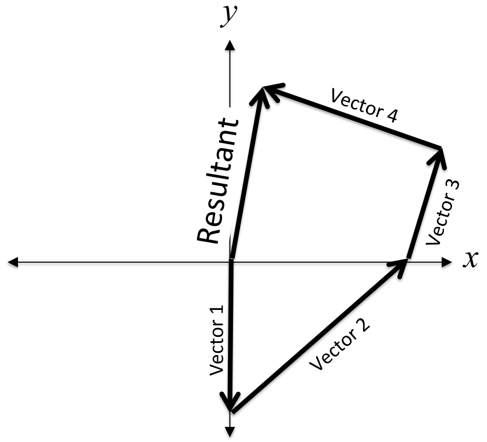
Tail-to-head

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

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

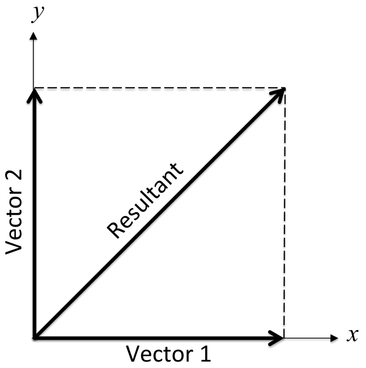


This principle can also be applied to more than 2 vectors taken in order. The resultant is from the tail of the first vector to the head of the last.

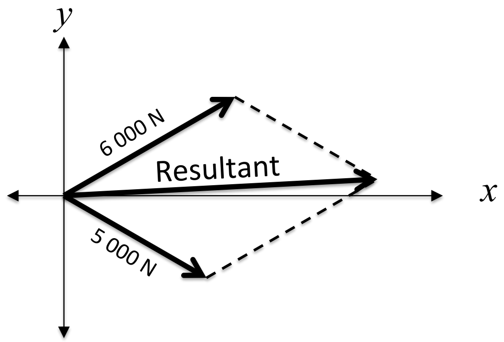


Parallelogram

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.



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



Manipulation

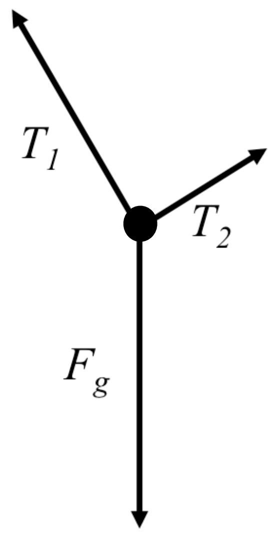
The vector arrows can be manipulated to form a force triangle to determine the resultant forces or an equilibrant.

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

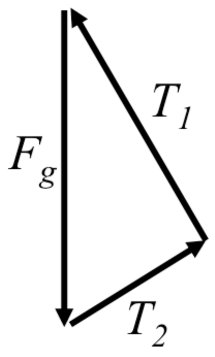
- Length of arrow (magnitude)
- Angle of the arrow (direction)
- The direction of the arrow head

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

Free body diagram



Force triangle



2D VECTORS- RESULTANT AND EQUILIBRANT

RESULTANT: The single vector which has the same effect as the original vectors acting together.

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:

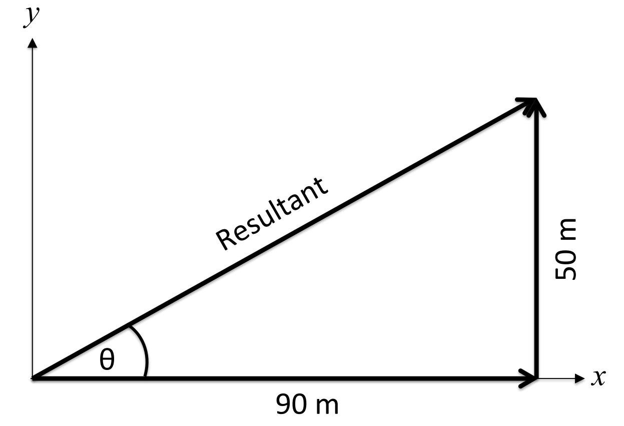
$$R^2 = x^2 + y^2$$

FOR FINDING ANGLES:

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

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 $= 90^\circ - 29{,}05^\circ = \mathbf{60{,}95^\circ}$

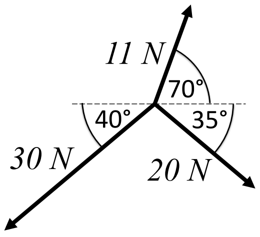
$\therefore$ Displacement = 102,96 m at a bearing of 60,95°

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:

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

30N force:

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

20N force:

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

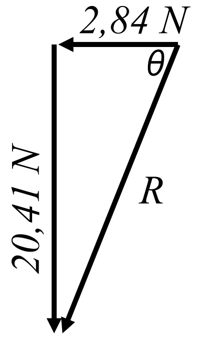
2. Determine the x- and y-resultants of components.

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°

NEWTON'S LAWS OF MOTION

FORCES

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

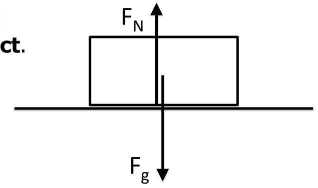
A force is a push or a pull action exerted on an object. This action can be exerted while objects are in contact (contact force) or over a distance (non-contact force).

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 $m\cdot s^{-2}$ in the direction of the force. We can therefore say that 1 N = 1 $kg\cdot m\cdot s^{-2}$.

Normal force (F_N)

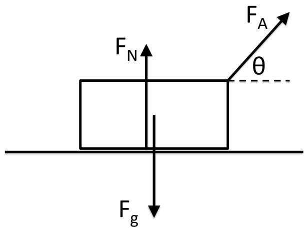
The perpendicular force exerted on by a surface on an object in contact with it.

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

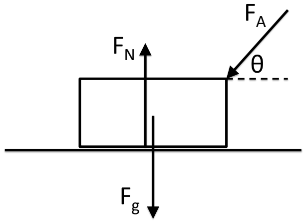


$$F_N = -F_g$$

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

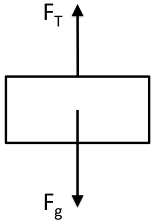


$$F_N + F_{Ay} + F_g = 0$$
$$F_N + F_A \sin\theta = -F_g$$



$$F_N + F_g + F_{Ay} = 0$$
$$F_N = -F_g - F_A \sin\theta$$

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



$$F_T + F_g = 0$$

Friction (F_f or f_s/f_k)

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

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

Static friction (f_s)

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

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

f_s^{max} = maximum static friction (N)
μ_s = coefficient of friction (no unit)
F_N = normal force (N)

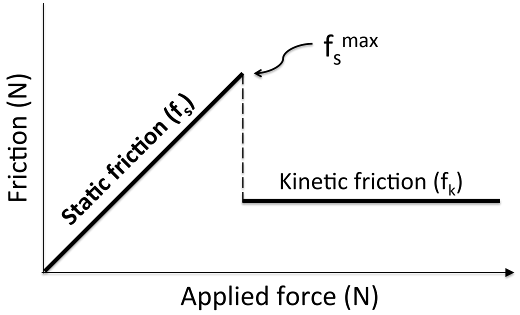
Kinetic friction (f_k)

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)

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



NEWTON'S LAWS OF MOTION

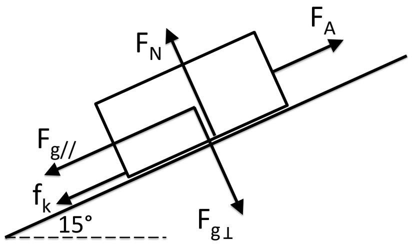
Newton's First Law of Motion

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

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

$$\boxed{F_{net} = 0 \text{ N}} \qquad \boxed{a = 0\ m \cdot s^{-2}}$$

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 downwards as positive:

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

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

Importance of wearing safety belts:

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

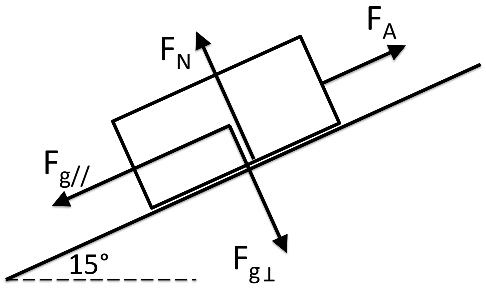
Newton's Second Law of Motion

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

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

$$\boxed{F_{net} = ma} \qquad \boxed{a \neq 0\ m \cdot s^{-2}}$$

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:

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

Effect of Newton's Second Law on overloading:

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

Newton's Third Law of Motion

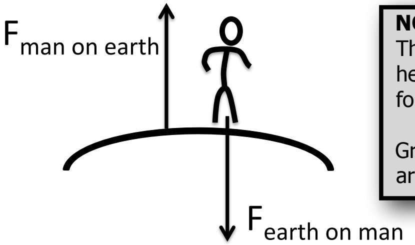
When object A exerts a force on object B, object B simultaneously exerts an oppositely directed force of equal magnitude on object A.

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

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

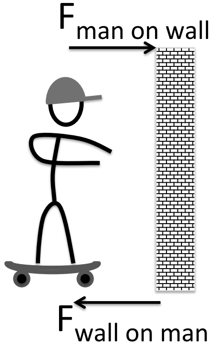
Force pairs properties:

- 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

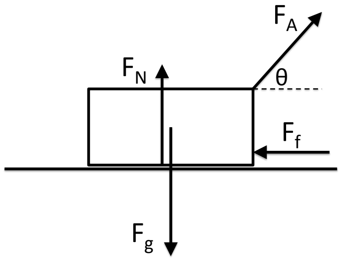
ALL EXAMPLES: DIRECTION OF MOTION POSITIVE

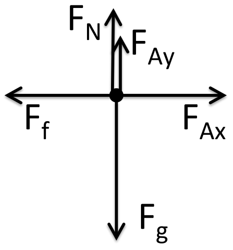
Horizontal

The vertical resultant = 0 N.

The horizontal resultant determines acceleration.

Pulled at an angle





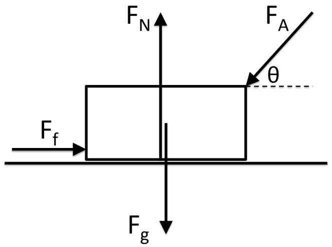
Horizontal:

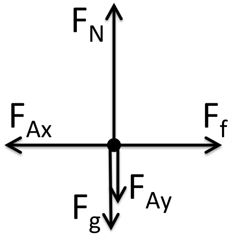
$$F_{net} = ma$$
$$F_{A_x} + (-F_f) = ma$$

Vertical:

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

Pushed at an angle





Horizontal:

$$F_{net} = ma$$
$$F_{A_x} + (-F_f) = ma$$

Vertical:

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

Slopes

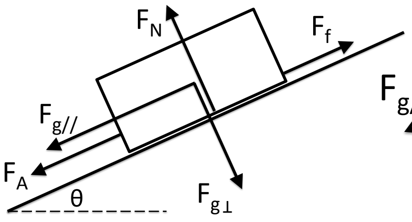
The perpendicular (⊥) resultant = 0 N.

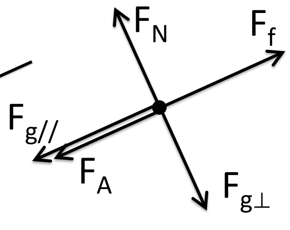
The parallel (//) resultant determines acceleration.

REMEMBER: Use components of weight.

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

Force applied down the slope





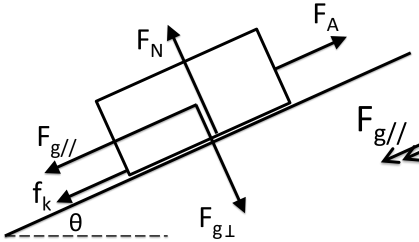
Parallel:

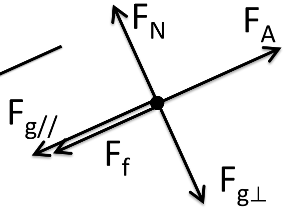
$$F_{net} = ma$$
$$F_{g\parallel} + F_A + (-F_f) = ma$$

Perpendicular:

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

Force applied up the slope





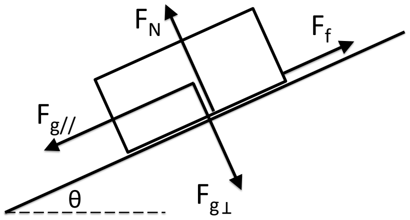
Parallel:

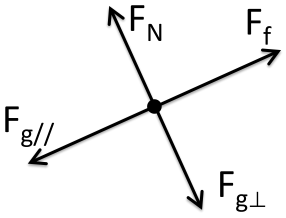
$$F_{net} = ma$$
$$(-F_{g\parallel}) + (-F_f) + F_A = ma$$

Perpendicular:

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

No force applied





Parallel:

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

Perpendicular:

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

Suspended

Horizontal resultant = 0 N.

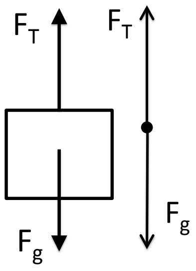
Vertical resultant determines acceleration.

REMEMBER: No normal or friction forces.

Lift stationary/constant velocity

Vertical:

$$F_{net} = 0$$
$$F_g + (-F_T) = 0$$

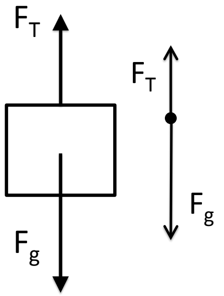


Lift accelerating

Vertical:

$$F_{net} = ma$$
$$F_g + (-F_T) = ma$$

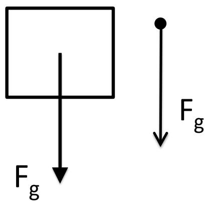
Acceleration will be in the direction of the greatest force.



Lift in freefall (cable snap)

Vertical:

$$F_{net} = ma$$
$$F_g = ma$$



NEWTON'S LAWS OF MOTION

ALL EXAMPLES:
DIRECTION OF MOTION POSITIVE

Connected objects

Do separate free body diagrams for each object.

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

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

Simultaneous equations for acceleration and tension are sometimes needed.

REMEMBER:

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

Touching objects- Newton's Third Law

Same axis

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

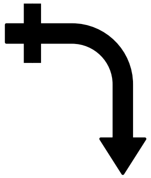
The velocity and acceleration of all objects are equal in magnitude and direction.

Multiple axes

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

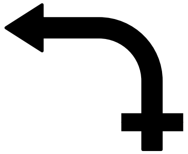
The velocity and acceleration of all objects are equal in magnitude NOT DIRECTION.

Vector direction on multiple axes



Clockwise:
Right and Down positive
Left and Up negative

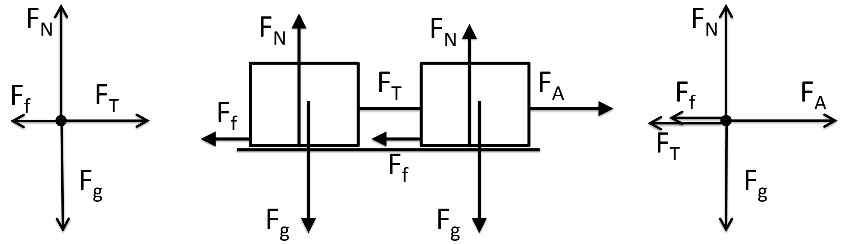
OR



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

Objects attached by rope/cable

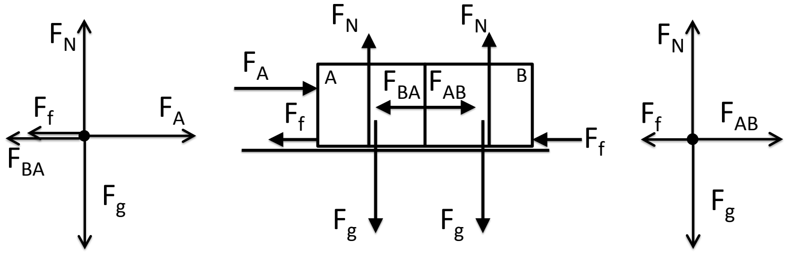
Horizontal:
$$F_{net} = ma$$
$$(-F_f) + F_T = ma$$



Horizontal:
$$F_{net} = ma$$
$$F_A + (-F_T) + (-F_f) = ma$$

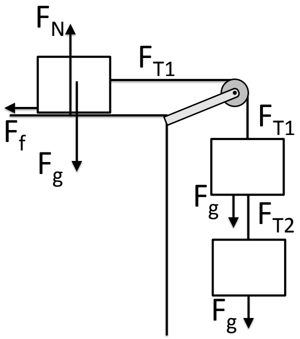
Objects in contact

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



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

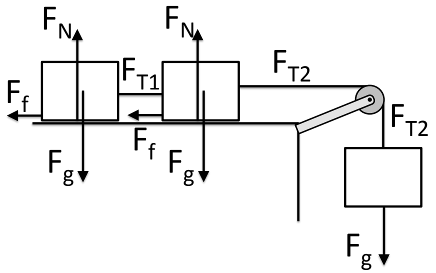
Multiple axes

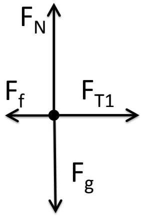


In these examples, clockwise is positive:

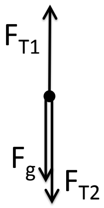
Right positive

Down positive

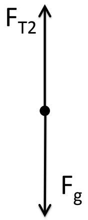




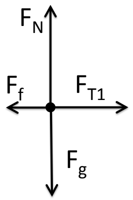
Horizontal:
$$F_{net} = ma$$
$$F_{T1} + (-F_f) = ma$$



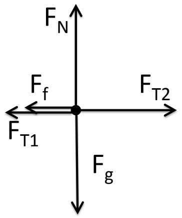
Vertical:
$$F_{net} = ma$$
$$F_g + (-F_{T1}) + F_{T2} = ma$$



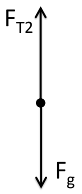
Vertical:
$$F_{net} = ma$$
$$F_g + (-F_{T2}) = ma$$



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



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



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

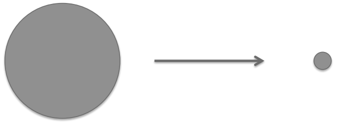
NEWTON'S LAW OF UNIVERSAL GRAVITATION

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.

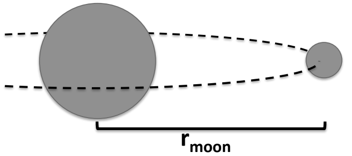
$$\boxed{F = \frac{Gm_1m_2}{r^2}}$$

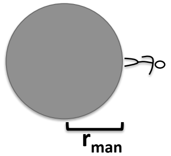
F = force of attraction between objects (N)
G = universal gravitational constant ($6,67 \times 10^{-11}$ N·m²·kg⁻²)
m = object mass (kg)
r = distance between object centers (m)

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 m·s⁻² on earth)
g is the acceleration due to gravity on a specific planet.

G: Universal gravitational constant ($6,67 \times 10^{-11}$ N·m²·kg⁻²)
Proportionality constant which applies everywhere in the universe.

Mass vs Weight

Mass (kg)
A scalar quantity of matter which remains constant everywhere in the universe.

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

RATIOS

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

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

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

$F = \frac{Gm_1m_2}{r^2}$ Write out the formula

$= \frac{G(2m_1)m_2}{(\frac{1}{2}r)^2}$ Substitute changes into formula

$= \frac{2}{\frac{1}{4}}\frac{Gm_1m_2}{r^2}$ Simplify ratio number

$= 8\left(\frac{Gm_1m_2}{r^2}\right)$

$\therefore F_{new} = 8\ F$ Replace original formula

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

$F = \frac{Gm_1m_2}{r^2}$ Write out the formula

$= \frac{G(2m_1)(2m_2)}{(2r)^2}$ Substitute changes into formula

$= \frac{4}{4}\frac{Gm_1m_2}{r^2}$ Simplify ratio number

$= 1\left(\frac{Gm_1m_2}{r^2}\right)$

$\therefore F_{new} = 1\ F$ Replace original formula

DETERMINING GRAVITATIONAL ACCELERATION (g)

$F = m_{object}g$ and $F = \frac{Gm_{object}m_{Planet}}{r^2_{Planet}}$

$$m_og = \frac{Gm_om_P}{r_P^2}$$

$$g = \frac{G\cancel{m_o}m_P}{\cancel{m_o}r_P^2}$$

$$\therefore g = \frac{Gm_P}{r_P^2}$$

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

CALCULATIONS

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

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

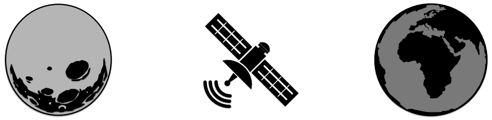
$$F = \frac{Gm_1m_2}{r^2}$$

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

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

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

- Direction specific
- Can be added or subtracted



Take right as positive:

$$\begin{aligned} F_{net\ on\ satallite} &= F_{m\ on\ s} + F_{e\ on\ s} \\ &= -\left(\frac{Gm_mm_s}{r_{ms}{}^2}\right) + \left(\frac{Gm_em_s}{r_{es}{}^2}\right) \end{aligned}$$

MOMENTUM AND IMPULSE

MOMENTUM

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

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

$$\boxed{p = mv}$$

p = momentum $(\mathrm{kg \cdot m \cdot s^{-1}})$

m = mass (kg)

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

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 m·s⁻¹ in an easterly direction. Calculate the momentum of the golf ball.

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

CHANGE IN MOMENTUM

When a moving object comes into contact with another object (moving or stationary) it results in a change in velocity for both objects and therefore a change in momentum (p) for each one. The change in momentum can be calculated by using:

$$\boxed{\Delta p = p_f - p_i}$$

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

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

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

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 m·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:

$$\begin{aligned} \Delta p &= p_f - p_i \\ \Delta p &= mv_f - mv_i \\ \Delta p &= (1000)(0) - (1000)(16) \\ \Delta p &= -1600 \\ \therefore \Delta p &= 1\ 600\ \mathrm{kg \cdot m \cdot s^{-1}}\ \text{west} \end{aligned}$$

EXAMPLE:

A cricket ball with a mass of 0,2 kg approaches a cricket bat at a velocity of 40 m·s⁻¹ east and leaves the cricket bat at a velocity of 50 m·s⁻¹ west. Calculate the change in the ball's momentum during its contact with the cricket bat.

Choosing east as positive:

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

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.

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

F_{net} = resultant force (N)

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

Δt = time (s)

Derivation from Newton's Second Law

$$F_{net} = ma$$

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

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

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

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

IMPULSE

Impulse: the product of the net force and the contact time.

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:

$$\boxed{\begin{aligned} \text{Impulse} &= \mathrm{F}\Delta \mathrm{t} \\ \text{Impulse} &= \Delta \mathrm{p} \\ \mathrm{m}\Delta \mathrm{v} &= \Delta \mathrm{p} \end{aligned}}$$

Impulse, FΔt , is measured in N·s.

Δp is measured in kg·m·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, ∴ 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 m·s⁻¹. For how long was the golf club in contact with the ball?

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

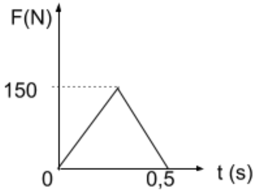
EXAMPLE:

Why can airbags be useful during a collision? State your answer by using the impulse-momentum theorem.

From the impulse-momentum theorem **($F_{net}\Delta t = mv$)**: an airbag prolongs the time **(t)** of impact during the accident, thereby causing a smaller force **(F_{net})** to be exerted on the passenger, because the resultant force experienced is inversely proportional to the contact time **($F_{net} \propto 1/t$)**.

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.

$$\begin{aligned} F_{net}\Delta t &= \text{area under graph} \\ \text{impulse} &= \tfrac{1}{2}b \perp h \\ \text{impulse} &= \tfrac{1}{2}(0{,}5)(150) \\ \text{impulse} &= 37{,}5\ \mathrm{N \cdot s} \end{aligned}$$

CONSERVATION OF MOMENTUM

CONSERVATION OF MOMENTUM

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

$$\Sigma p_{\text{before}} = \Sigma p_{\text{after}}$$
$$p_{\text{A(before)}} + p_{\text{B(before)}} = p_{\text{A(after)}} + p_{\text{B(after)}}$$
$$m_A v_{iA} + m_B v_{iB} + \ldots = m_A v_{fA} + m_B v_{fB} + \ldots$$

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.

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.

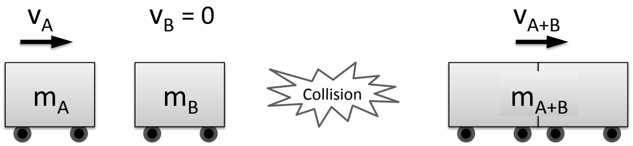
Explosions: Explosions, springs, firearms

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.

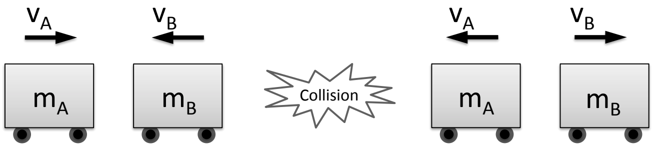


$$\Sigma p_{\text{before}} = \Sigma p_{\text{after}}$$
$$m_A v_{iA} + m_B v_{iB} = (m_A + m_B) v_f$$

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.



$$\Sigma p_{\text{before}} = \Sigma p_{\text{after}}$$
$$m_A v_{iA} + m_B v_{iB} = m_A v_{fA} + m_B v_{fB}$$

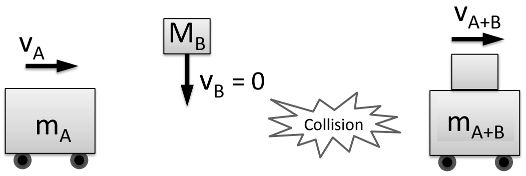
Object dropped vertically on a moving object

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,

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



$$\Sigma p_{\text{before}} = \Sigma p_{\text{after}}$$
$$m_A v_{iA} + m_B v_{iB} = (m_A + m_B) v_f$$

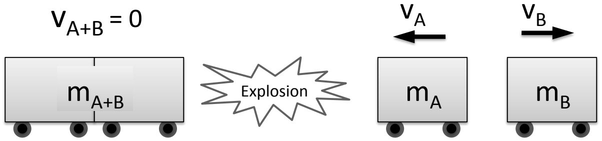
Explosions

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.



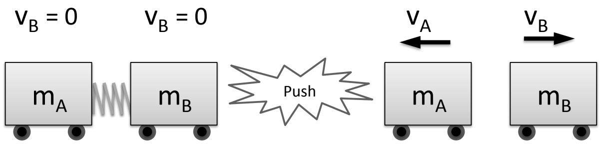
$$\Sigma p_{\text{before}} = \Sigma p_{\text{after}}$$
$$(m_A + m_B) v_i = m_A v_{fA} + m_B v_{fB}$$

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.



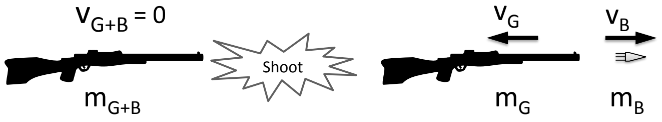
$$\Sigma p_{\text{before}} = \Sigma p_{\text{after}}$$
$$(m_A + m_B) v_i = m_A v_{fA} + m_B v_{fB}$$

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.



$$\Sigma p_{\text{before}} = \Sigma p_{\text{after}}$$
$$(m_G + m_B) v_i = m_G v_{fG} + m_B v_{fB}$$

MOMENTUM AND ENERGY

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:

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

E_K = kinetic energy (J)
m = mass (kg)
v = velocity ($\text{m}\cdot\text{s}^{-1}$)

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

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

(some energy is lost as sound or heat)

EXAMPLE:

The velocity of a moving trolley of mass 1 kg is 3 m·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 m·s^{-1} in the original direction. Is the collision elastic or inelastic? Prove your answer with a suitable calculation.

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

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

$E_{K(before)} \neq E_{K(after)}$

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

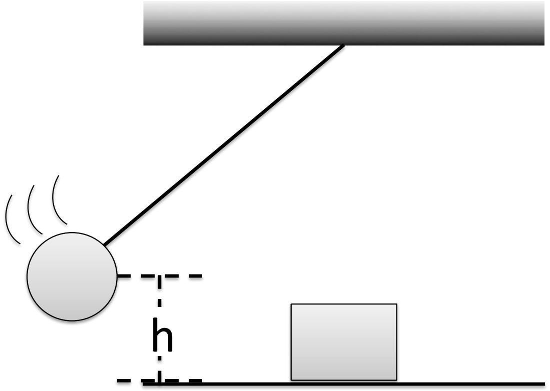
PENDULUMS

DOWNWARD SWING:

Conservation of mechanical energy (E$_M$) to determine velocity at the bottom of the swing:

$$E_{M(top)} = E_{M(bottom)}$$

$$mgh + \tfrac{1}{2}mv^2 = mgh + \tfrac{1}{2}mv^2$$



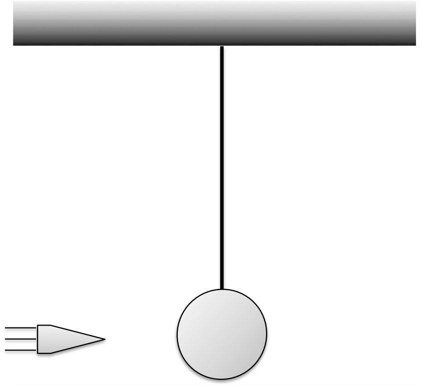
COLLISION:

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

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

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

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



COLLISION:

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

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

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

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

UPWARD SWING:

Conservation of mechanical energy (E$_M$) to determine height that the pendulum will reach:

$$E_{M(bottom)} = E_{M(top)}$$

$$mgh + \tfrac{1}{2}mv^2 = mgh + \tfrac{1}{2}mv^2$$

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 = 9,8m.s^{-2}, m is mass in kg, h is height in m

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

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

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 m.s^{-1}

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

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

Mechanical Energy (E_M)

the sum of gravitational potential and kinetic energy 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 500g, is thrown horizontally through the air. The ball travels at a velocity of 1,8m·s^{-1} and is 2,5m from the ground. Determine the mechanical energy of the ball.

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

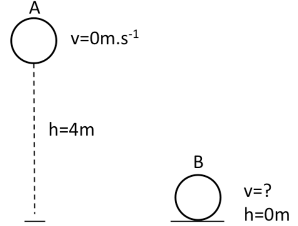
PRINCIPLE OF CONSERVATION OF MECHANICAL ENERGY

Principle of conservation of mechanical energy: In the absence of air resistance or any external forces, the mechanical energy of a system is 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.

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

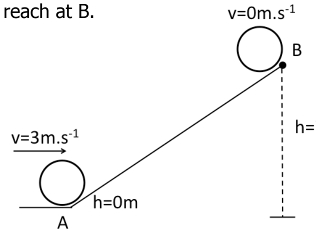
Law of conservation of energy: Energy cannot be created or destroyed, merely transferred.
In the following instances the gravitational potential energy of an object is converted to kinetic energy (and vice versa), while the mechanical energy remains constant

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.



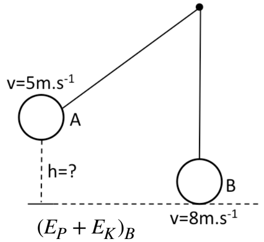
$$\begin{aligned} (E_P + E_K)_A &= (E_P + E_K)_B \\ (mgh + \tfrac{1}{2}mv^2)_A &= (mgh + \tfrac{1}{2}mv^2)_B \\ (2)(9,8)(4) + \tfrac{1}{2}(2)(0^2) &= (2)(9,8)(0) + \tfrac{1}{2}(2)v^2 \\ 78,4 + 0 &= 0 + 1v^2 \\ v &= \sqrt{78,4} \\ v &= 8,85\ \text{m} \cdot \text{s}^{-1}\ \text{downwards} \end{aligned}$$

EXAMPLE 2: Object moving on an inclined plane
A 2 kg ball rolls at 3 m·s^{-1} on the ground at A, determine the maximum height the ball will reach at B.



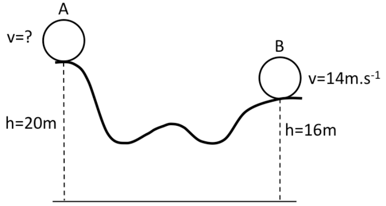
$$\begin{aligned} (E_P + E_K)_A &= (E_P + E_K)_B \\ (mgh + \tfrac{1}{2}mv^2)_A &= (mgh + \tfrac{1}{2}mv^2)_B \\ (2)(9,8)(0) + \tfrac{1}{2}(2)(3^2) &= (2)(9,8)(h) + \tfrac{1}{2}(2)(0^2) \\ 0 + 9 &= 19,6h + 0 \\ \frac{9}{19,6} &= h \\ h &= 0,46\ \text{m} \end{aligned}$$

EXAMPLE 3: Pendulum
The 2 kg pendulum swings from A at 5 m·s^{-1} to B, on the ground, where its velocity is 8 m·s^{-1}. Determine the height at A.



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

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 m·s^{-1}. Calculate its starting velocity at A.



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

WORK, ENERGY AND POWER

WORK

Work 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.**

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

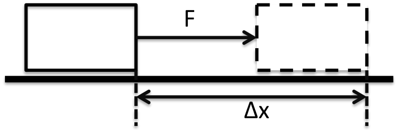
W = work (J)
F = force applied (N)
Δx/ = displacement (m)

NOTE:
Work is a scalar quantity,
i.e. NO DIRECTION!

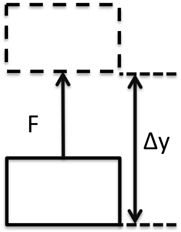
The joule is the amount of work done when a force of one newton moves its point of application one metre in the direction of the force.

Work always involves two things:

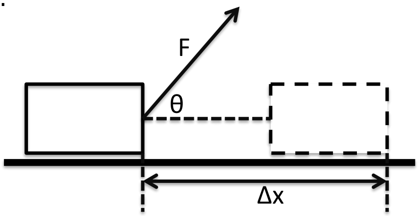
1. A force which acts on a certain object. (F)
2. The displacement of that object. (Δx / Δy)



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.

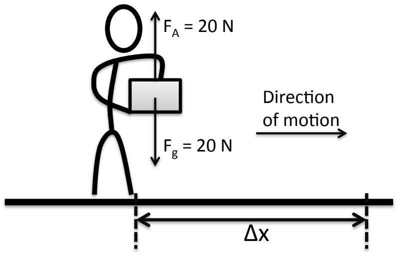


Work is only done in the direction of the displacement. Work is done by the component of the force that is parallel to the displacement. The angle between the force and the displacement is θ.

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 20N on a 'travelator' moving at a constant velocity.

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

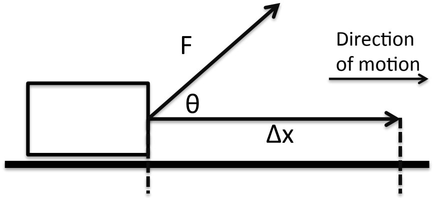


F_A is perpendicular to the displacement: θ = 90° ; cos 90° = 0.

No force in the plane of the displacement, hence, NO WORK IS DONE and no energy is transferred. We can also say that the applied force 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.



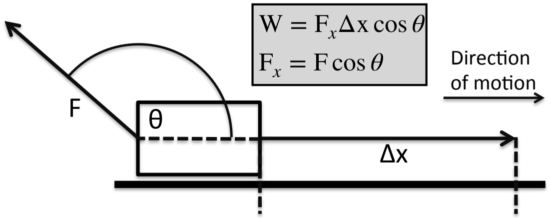
$$W = F_x\Delta x \cos\theta$$
$$F_x = F\cos\theta$$

$0° \le \theta < 90°$; $+1 \ge \cos\theta > 0$

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.

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



$90° < \theta \le 180°$; $0 > \cos\theta \ge -1$

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:

$$W_A = F\Delta x\cos\theta = (30)(3)\cos 0 = 90\text{ J}$$

Work done by frictional force:

$$W_f = F_f\Delta x\cos\theta = (5)(3)\cos 180 = -15\text{ J}$$

Work done by gravity

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

Work done by normal force:

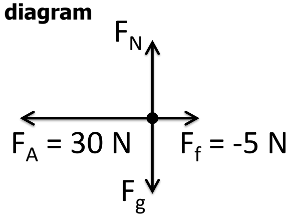
$$W_N = F_N\Delta x\cos\theta = (F_N)(3)\cos 90 = 0\text{ J}$$

$$W_{net} = W_A + W_f + W_N + W_g = 90 - 15 + 0 + 0 = 75\text{ J}$$

Alternative method for determining net work:

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

Step 1: Freebody diagram



Take left as positive:

Step 2: Calculate F_{net}

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

Step 3: Net work

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

WORK, ENERGY AND POWER

WORK ENERGY THEOREM

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 $E_k = ½ mv^2$

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

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

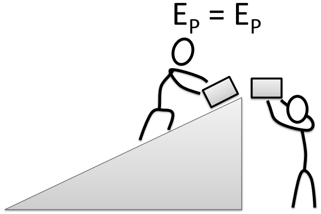
$$F_{net}\Delta x = \frac{1}{2}m(v_f - v_i)^2$$

CONSERVATIVE FORCES

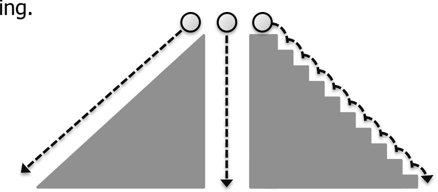
A force is a conservative force if:

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 the tension in a spring.



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

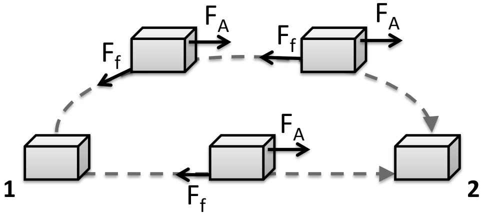
NON-CONSERVATIVE FORCES

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 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.

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

POWER

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

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

P = power (Watt)
W = work (J)
Δt = time (s)

EXAMPLE:

Calculate the power expended when a barbell of mass 100 kg is lifted to a height of 2,2 m in a time of 3 s.

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

AVERAGE POWER (CONSTANT VELOCITY)

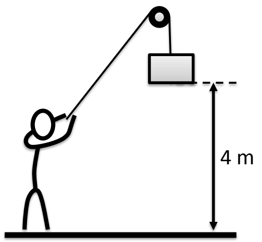
We can calculate the average power needed to keep an object moving at <u>constant speed</u> using the equation:

$$P_{average} = Fv_{average}$$

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

EXAMPLE:

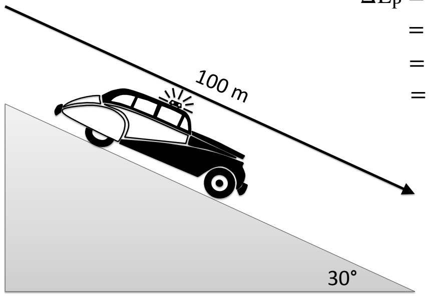
A man lifts a 50 kg bag of cement from ground level up to a height of 4 m above ground level in such a way that the bag of cement moves at constant velocity (i.e. no work is done to change kinetic energy). Determine his average power if he does this in 10 s.



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

EXAMPLE:

An 800 kg car traveling at 15 m·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.



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

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

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

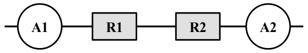
ELECTRICITY

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

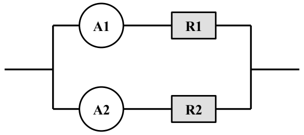
CURRENT is **the rate of flow of charge**.

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

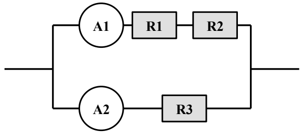
I is the current strength, **Q** the charge in coulombs and **t** the time in seconds. SI unit is ampere (A).



$I_T = I_1 = I_2$



$I_T = I_1 + I_2$



$I_T = I_1 + I_2$

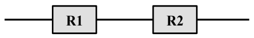
$I_1 = I_{R1} = I_{R2}$

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

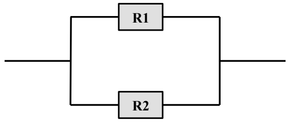
$V = IR$

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

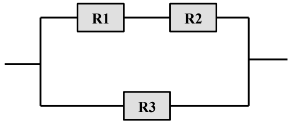
Resistance (R) is the quotient of the **potential difference (V)** across a conductor and the **current (I)** in it. The unit of resistance is called the **ohm (Ω)**.



$R_s = R_1 + R_2$



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



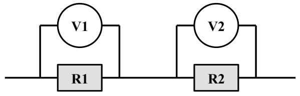
$\frac{1}{R_p} = \frac{1}{R_1 + R_2} + \frac{1}{R_3}$

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

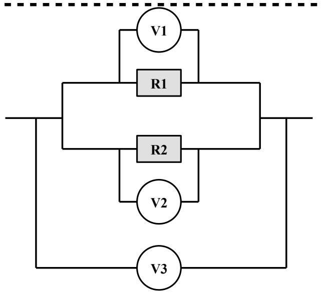
$V = \frac{W}{Q}$

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

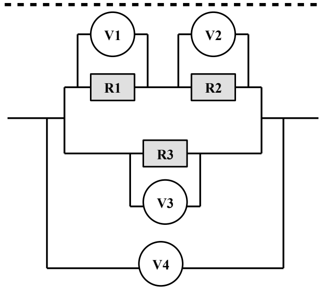
NOTE:
1. Emf (Ɛ): voltage across cells when no current is flowing (open circuit).
2. V_{term} or pd: voltage across cells when current is flowing.



$V_s = V_1 + V_2$



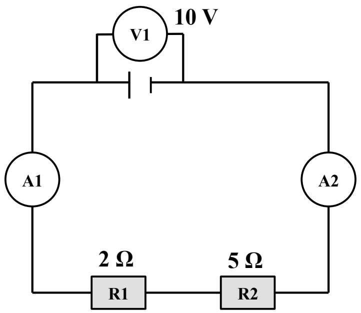
$V_p = V_1 = V_2 = V_3$



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

CALCULATIONS (NO INTERNAL RESISTANCE)

Series circuit



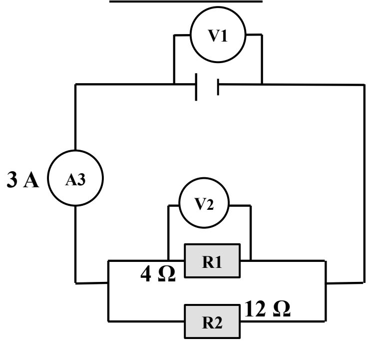
a) Determine the total resistance.

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

b) Determine the reading on A1 and A2.

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

Parallel circuit



a) Determine the total resistance.

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

b) Determine the reading on V1 and V2.

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

Combination circuits

Consider the circuit given. (Internal resistance is negligible)

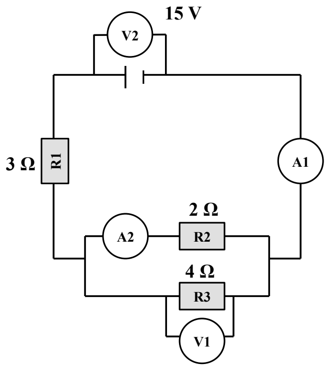
Calculate:

a) the effective resistance of the circuit.

b) the reading on ammeter A1.

c) the reading on voltmeter V1.

d) the reading on ammeter A2.



a)

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

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

b)

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

c)

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

d)

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

ELECTRICITY

OHM'S LAW

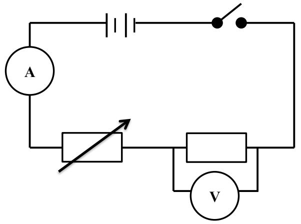
Current through a conductor is directly proportional to the potential difference across the conductor at constant temperature.

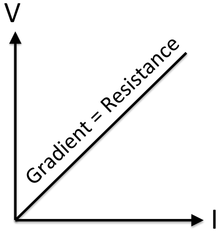
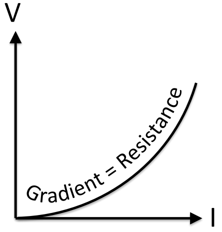
$$R = \frac{V}{I}$$

Proof of Ohm's law:

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

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



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

POWER

Power is the rate at which work is done.

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

$$P = I^2R$$

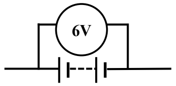
$$P = VI$$

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

P = power (W)
W = work (J)
Δt = time (s)
I = current (A)
V = potential difference (V)
R = resistance (Ω)

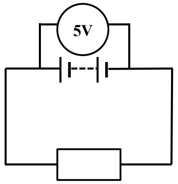
INTERNAL RESISTANCE

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



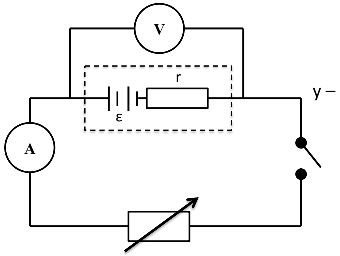
Emf is the total energy supplied per coulomb of charge by the cell.

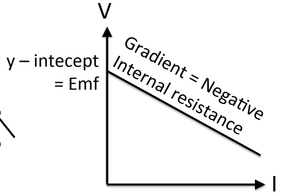
When connected in a circuit the potential difference drops due the internal resistance of the cells.



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.

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

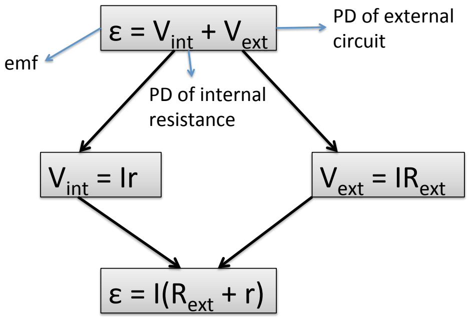
Note:
P in kW
t in hours

Example

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

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

CALCULATIONS (WITH INTERNAL RESISTANCE)



$\varepsilon = V_{int} + V_{ext}$

emf

PD of external circuit

PD of internal resistance

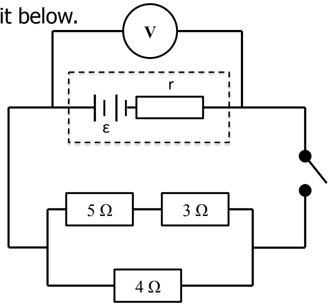
$V_{int} = Ir$

$V_{ext} = IR_{ext}$

$\varepsilon = I(R_{ext} + r)$

EXAMPLE:

Consider the circuit below.



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

a) Calculate the total current of the circuit.

b) Calculate the internal resistance of the battery.

a)

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

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

$$\begin{aligned}\therefore I_{top} &: I_{4\Omega}\\ 1 &: 2\end{aligned}$$

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

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

b)

$$\begin{aligned}\frac{1}{R_p} &= \frac{1}{R_{top}} + \frac{1}{R_{4\Omega}}\\ &= \frac{1}{8} + \frac{1}{4}\\ &= \frac{3}{8}\\ R_p &= \frac{8}{3} = 2{,}67\ \Omega\end{aligned}$$

$$\begin{aligned}\varepsilon &= I(R + r)\\ 12 &= 3(2{,}67 + r)\\ r &= 1{,}33\ \Omega\end{aligned}$$

ELECTROSTATICS

FLASHBACK!!

Principle of conservation of charge.

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

Principle of charge quantization.

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

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

COULOMB'S LAW

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

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

F = force of attraction between objects (N)
k = Coulomb's constant (9×10^9 N·m²·C⁻²)
Q = object charge (C)
r = distance between objects (m)

RATIOS

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

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

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

CALCULATIONS- Electrostatic force

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

- Direction specific
- Can be added or subtracted

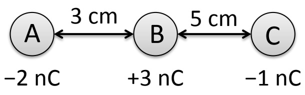
The force can be calculated using

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

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

1 Dimensional

Determine the resultant electrostatic force on Q_B.



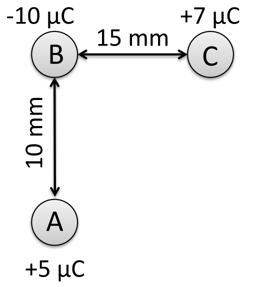
$$\begin{aligned} F_{AB} &= \frac{kQ_AQ_B}{r^2} \\ &= \frac{9 \times 10^9(2 \times 10^{-9})(3 \times 10^{-9})}{(3 \times 10^{-2})^2} \\ &= 6 \times 10^{-5} \text{ N left (A attracts B)} \end{aligned}$$

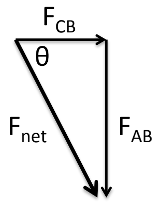
$$\begin{aligned} F_{CB} &= \frac{kQ_CQ_B}{r^2} \\ &= \frac{9 \times 10^9(1 \times 10^{-9})(3 \times 10^{-9})}{(5 \times 10^{-2})^2} \\ &= 1{,}08 \times 10^{-5} \text{ N right (C attracts B)} \end{aligned}$$

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

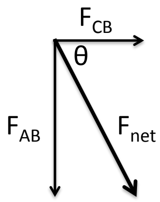
2 Dimensional

Determine the resultant electrostatic force on Q_B.





OR



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

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

PYTHAGORAS :

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

$$\begin{aligned} \tan\theta &= \frac{o}{a} \\ \theta &= \tan^{-1}\frac{F_{AB}}{F_{CB}} \\ \theta &= \tan^{-1}\frac{4\ 500}{2\ 800} \\ \theta &= 58{,}11° \end{aligned}$$

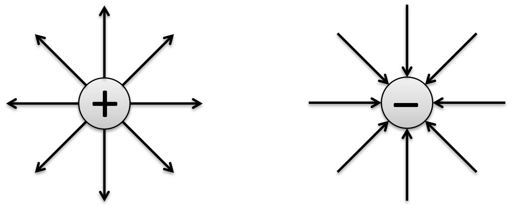
$$\therefore F_{net} = 5\ 300 \text{ N at } 58{,}11° \text{ below the negative y} - \text{axis}$$

ELECTROSTATICS

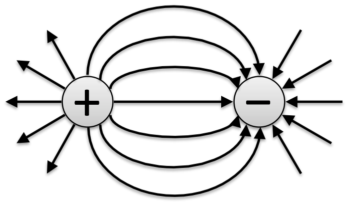
ELECTRIC FIELDS

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

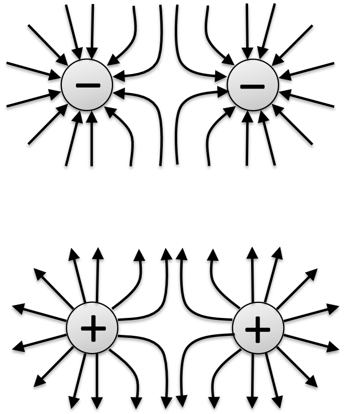
Single point charges



Unlike charges



Like charges



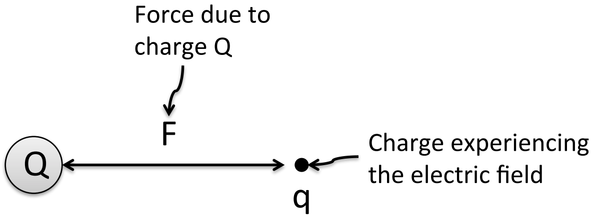
ELECTRIC FIELD STRENGTH

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

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

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

q is the charge that experiences the force.



EXAMPLE:

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

$$\begin{aligned} E &= \frac{F}{q} \\ &= \frac{2}{5\times10^{-6}} \\ &= 4\times10^{5}\ N\cdot C^{-1} \text{ to the right} \end{aligned}$$

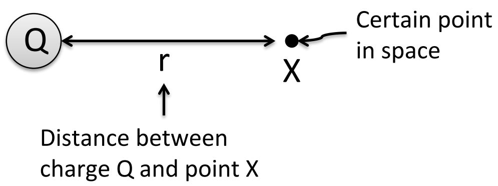
DIRECTION:

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

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

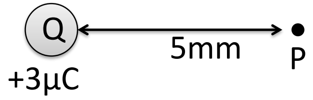
E = electric field strength ($N\cdot C^{-1}$)
k = Coulomb's constant ($9\times10^9\ N\cdot m^2\cdot C^{-2}$)
Q = object charge (C)
r = distance between objects (m)

Q is the charge that creates the electric field.



EXAMPLE:

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



$$\begin{aligned} E &= \frac{kQ}{r^2} \\ &= \frac{9\times10^{9}(3\times10^{-6})}{(5\times10^{-3})^{2}} \\ &= 1{,}08\times10^{9}\ N\cdot C^{-1} \text{ to the right} \end{aligned}$$

DIRECTION:

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

NOTE:

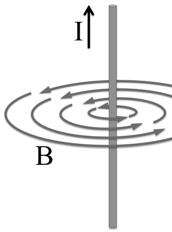
Electric field strength is a VECTOR. All vector rules and calculations apply. (linear addition, 2D arrangement, resultant vectors, etc.)

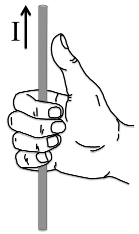
ELECTROMAGNETISM GRADE 11 RECAP

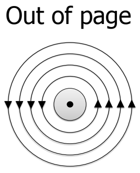
INDUCTION OF A MAGNETIC FIELD

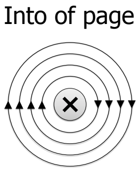
When current passes through a conductor, a magnetic field is induced around the wire.

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.

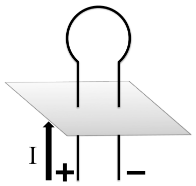


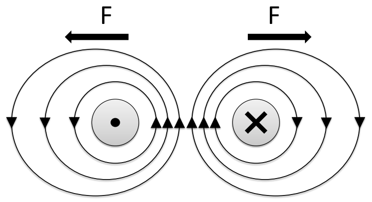


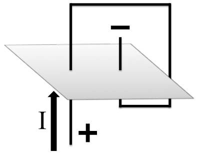


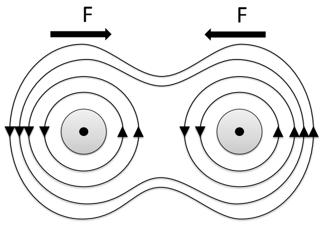


For a wire loop, the magnetic field is the sum of the individual magnetic fields around the single wires at each end. Use the right hand rule for a single wire at each end of the loop.

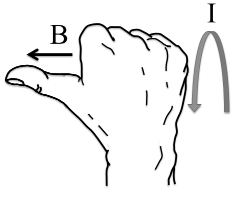


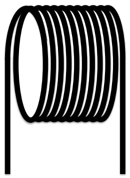


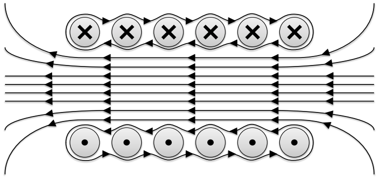




For a solenoid, curl your fingers around the solenoid in the direction of the conventional current and your thumb will point in the direction of the North pole. This is know as the **right hand solenoid rule.**







INDUCTION OF AN ELECTRIC CURRENT

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

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

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

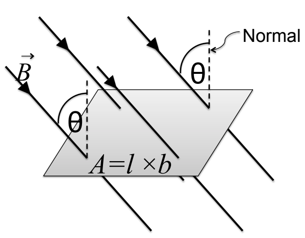
$$\varepsilon = \frac{-N\Delta\phi}{\Delta t}$$

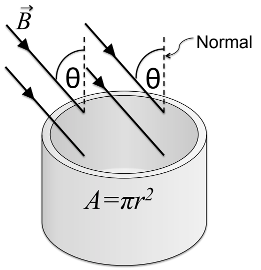
ε = emf (V)
N= number of turns/windings in coil
Δϕ= change in magnetic flux (Wb)
Δt= change in time (s)

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

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

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

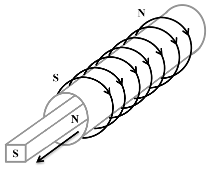


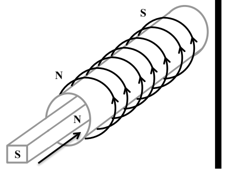


DIRECTION OF INDUCED CURRENT

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

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





INCREASING THE INDUCED EMF

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

ENVIRONMENTAL IMPACT OF OVERHEAD CABLES

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

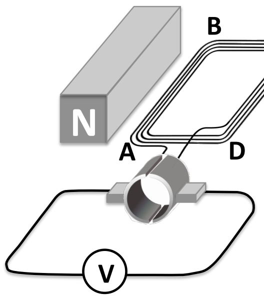
ELECTRODYNAMICS

GENERATORS

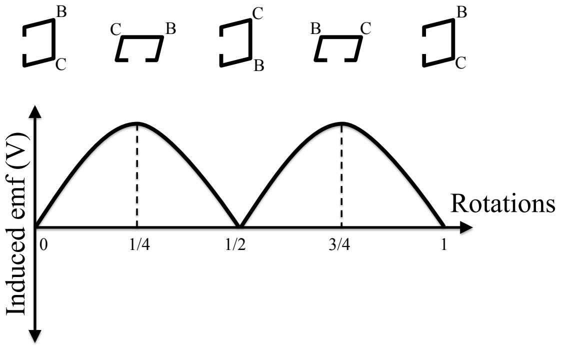
Generators convert mechanical energy into electrical energy. A generator works on the principal of mechanically rotating a conductor in a magnetic field. This creates a changing flux which induces an emf in the conductor.

Direct

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

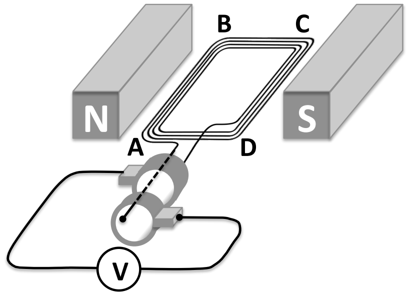


The current in the external circuit does not change direction and is known a direct current (DC).

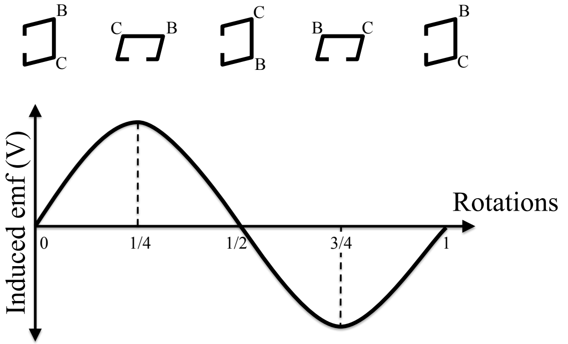


Alternating

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.



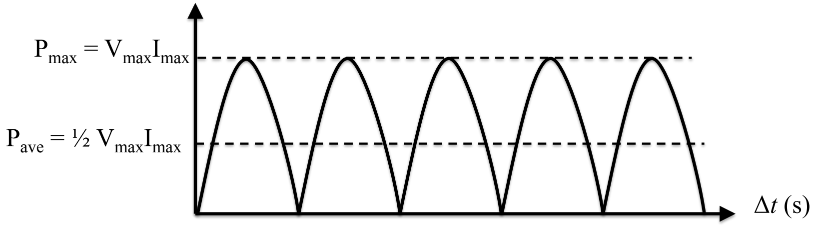
The direction of the current changes with every half turn of the coil. The current that is produced is known as alternating current (AC).



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.



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

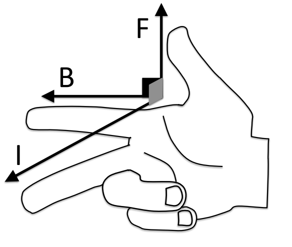
The potential difference for an alternating current is therefore defined by the root mean square of the maximum potential difference (V_{rms}) and the current for an alternating current is defined as the root mean square of the maximum current (I_{rms}). These values can be calculated from the maximum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

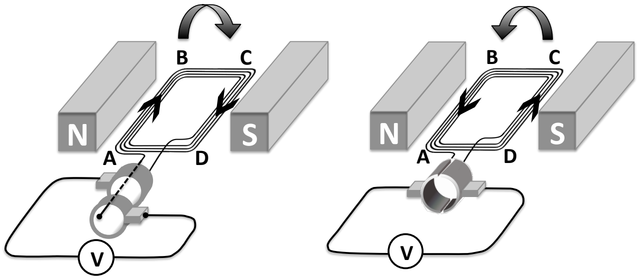
$$V_{rms} = \frac{V_{max}}{\sqrt{2}}$$

$$I_{rms} = \frac{I_{max}}{\sqrt{2}}$$

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 90° 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.





INCREASING THE INDUCED EMF

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

From the equation, the induced emf can be increased by

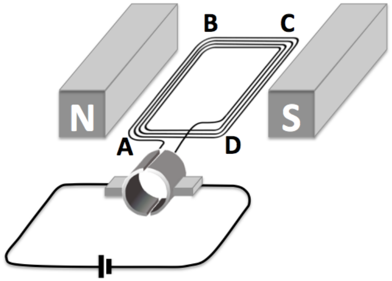
- Increasing the number of turns in the coil.
- Increasing the area of the coil.
- Increasing the strength of the magnets.
- Decreasing the time it takes to change the magnetic flux.

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

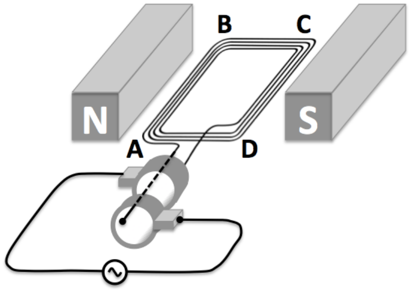
A direct current motor uses a split ring commutator to connect the conductor to the external circuit instead of a slip ring.



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.

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.

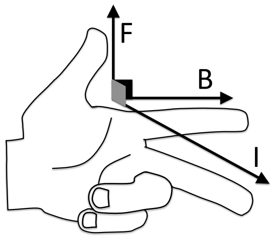


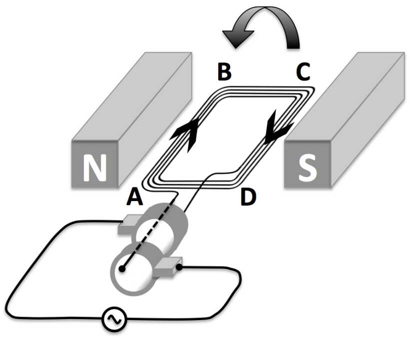
The direction of the current in the coil is constantly changing, which allows the coil to continue to rotate in the same direction.

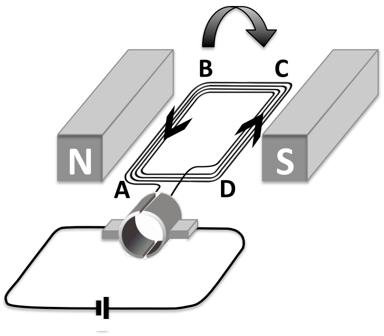
When a charge moves in a magnetic field it experiences a force. The force experienced on both sides of the armature creates torque which makes it turn. The direction of the force can be explained using the left hand rule.

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 90° 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.



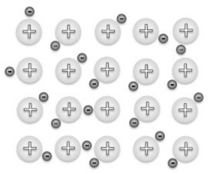




PHOTOELECTRIC EFFECT

PARTICLE NATURE OF LIGHT

The photoelectric effect occurs when light is shone on a metals 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:

$$\boxed{E = hf} \qquad \boxed{E = \frac{hc}{\lambda}}$$

E = energy of the photon measured in Joules (J)
h = Planck's constant, 6,63 × 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})

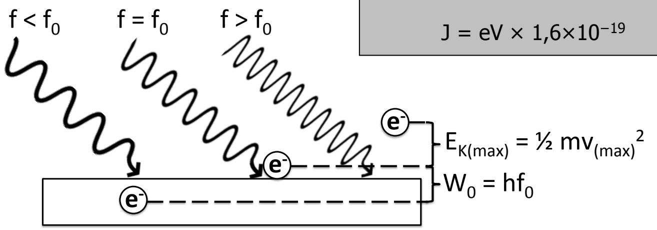
THRESHOLD FREQUENCY (f_0), WORK FUNCTION (W_0) AND PHOTON ENERGY

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:

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

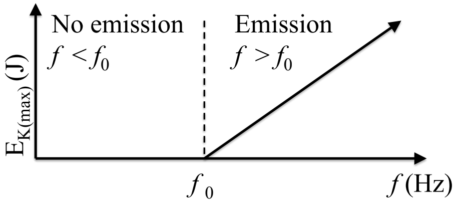


NOTE:
Sometimes work function is given in eV. Convert from eV to J:

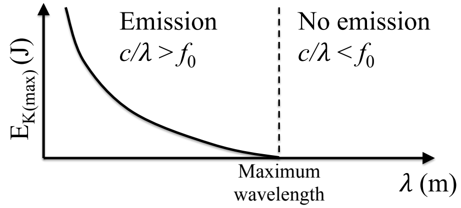
J = eV × 1,6×10^{-19}

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 y-intercept indicates the threshold frequency.

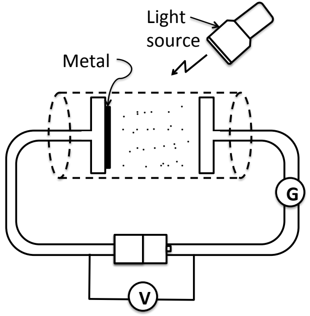


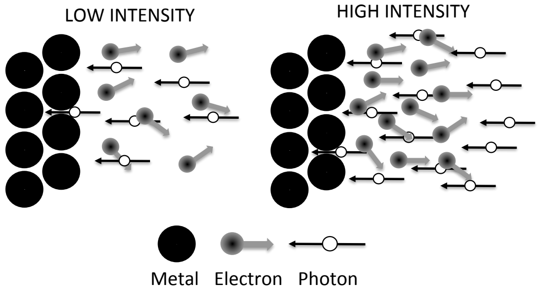
Similarly, on the graph of $E_{k(max)}$ vs wavelength, the y-intercept indicates the maximum wavelength of light that can emit an electron (wavelength is inversely proportional to frequency).



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.

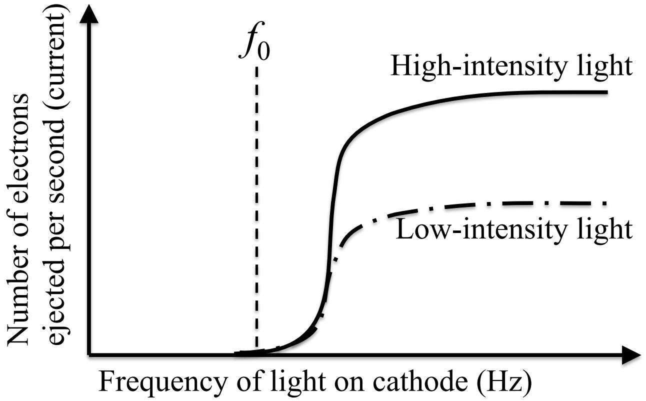
INCREASE **INTENSITY** AT CONSTANT FREQUENCY = INCREASE **AMOUNT** OF EMITTED ELECTRONS

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.

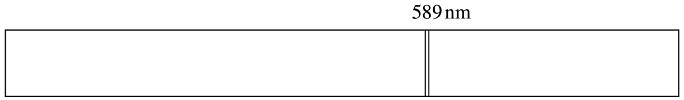
R	**O**	**Y**	**G**	**B**	**I**	**V**
red	orange	yellow	green	blue	indigo	violet

The white light is emitted from a bulb, therefore the continuous spectrum is an emission spectrum.

ATOMIC EMISSION SPECTRA

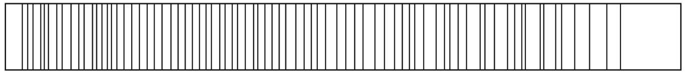
When an element in the gaseous phase is heated, it emits light. If the light produced is passed through a prism, a spectrum is produced. However, this spectrum is not continuous, but consists of only some lines of colour. This is known as **line emission spectrum**.

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



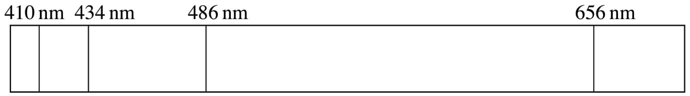
(a) sodium

(b) helium



(c) iron

(d) neon



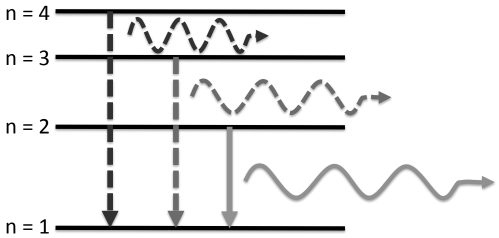
(e) hydrogen

blue → red

wavelength

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.

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

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 ($-0{,}61\times10^{-19}$ J) to E_2 ($-5{,}46\times10^{-19}$). Determine the wavelength of light emitted.

$$\Delta E = E_6 - E_2$$
$$= -0{,}61\times10^{-19} - (-5{,}46\times10^{-19})$$
$$= 4{,}85\times10^{-19}\ \text{J}$$

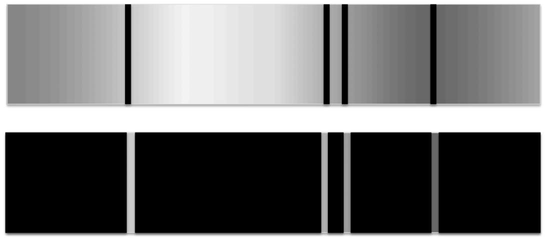
$$E = \frac{hc}{\lambda}$$
$$4{,}85\times10^{-19} = \frac{(6{,}63\times10^{-34})(3\times10^{8})}{\lambda}$$
$$\lambda = 4{,}1\times10^{-7} = 410\ \text{nm}$$

ATOMIC ABSORPTION SPECTRA

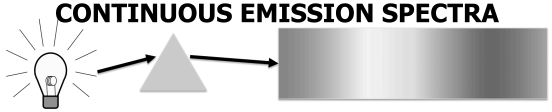
As white light is passed through a cold gaseous element, the electrons inside the atoms of the element absorb the energy of the light (photons). The energy is absorbed in specific bands which corresponds to the energy required by electrons to transition between energy levels.

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.

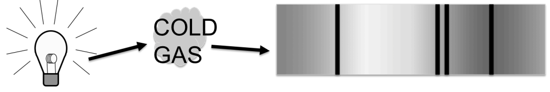
The absorption spectra for a specific element will be the inverse of its emission spectra.



CONTINUOUS EMISSION SPECTRA



ATOMIC ABSORPTION SPECTRA

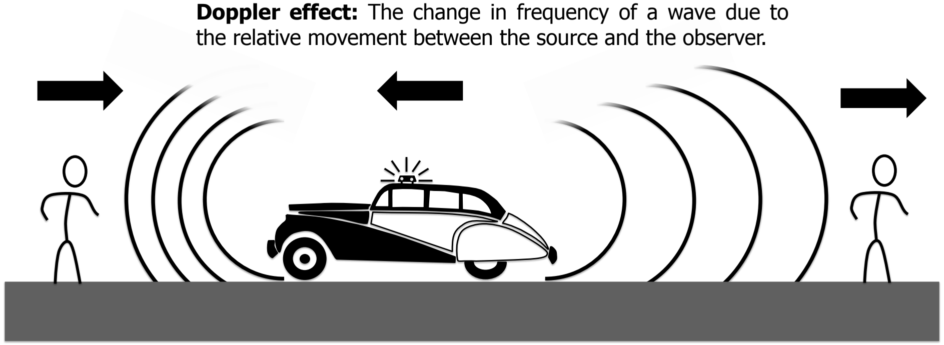


ATOMIC EMISSION SPECTRA

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 frequency of a wave due to the relative movement between the source and the observer.



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)

Listener away from source (−)

Decrease in observed frequency.

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

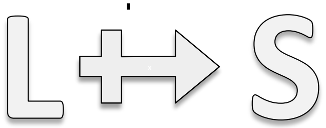
$$f_L = \frac{v - v_L}{v} f_s$$

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.

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

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

EQUATIONS

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

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

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

To convert between frequency and wavelength:

Material waves (i.e. sound)

$$\boxed{v = f\lambda}$$

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

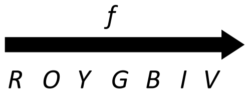
Electromagnetic radiation

$$\boxed{c = f\lambda}$$

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

DOPPLER EFFECT AS PROOF OF EXPANDING UNIVERSE

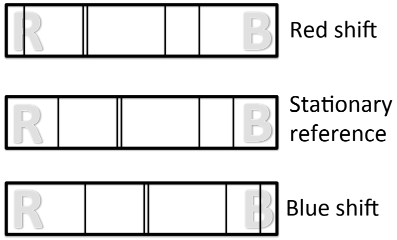
The visible range of the electromagnetic spectrum is as follow:



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 wave 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 fetus heart rate

Maritime

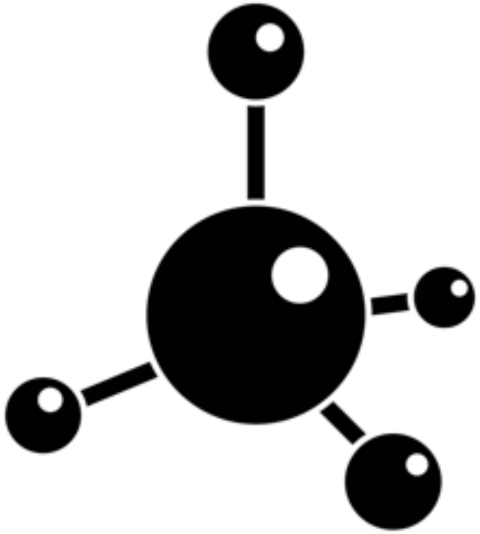
- SONAR positioning underwater

Law enforcement

- Radar monitoring of speeding cars

NOTES:

NOTES:



Grade 12 Chemistry

Information sheets – Paper 2 (Chemistry)

TABLE 1: PHYSICAL CONSTANTS

NAME	SYMBOL	VALUE
Standard pressure	p^{θ}	$1,013 \times 10^{5}$ Pa
Molar gas volume at STP	V_m	$22,4\ dm^{3} \cdot mol^{-1}$
Standard temperature	T^{θ}	273 K
Charge on electron	e	$-1,6 \times 10^{-19}$ C

TABLE 2: FORMULAE

$n = \frac{m}{M}$	$n = \frac{N}{N_A}$
$c = \frac{n}{V}$ OR $c = \frac{m}{MV}$	$n = \frac{V}{V_m}$
$\frac{c_a V_a}{c_b V_b} = \frac{n_a}{n_b}$	$pH = -\log[H_3O^+]$
$K_w = [H_3O^+][OH^-] = 1 \times 10^{-14}$ at 298 K	
$E^{\theta}_{cell} = E^{\theta}_{cathode} - E^{\theta}_{anode}$ $E^{\theta}_{cell} = E^{\theta}_{reduction} - E^{\theta}_{oxidation}$ $E^{\theta}_{cell} = E^{\theta}_{oxidising\ agent} - E^{\theta}_{reducing\ agent}$	

TABLE 3: THE PERIODIC TABLE OF ELEMENTS

KEY/*SLEUTEL*

Atomic number
Atoomgetal

Electronegativity
Elektronegatiwiteit

Symbol
Simbool

Approximate relative atomic mass
Benaderde relatiewe atoommassa

29
1,9 Cu
63,5

1 (I)	2 (II)	3	4	5	6	7	8	9	10	11	12	13 (III)	14 (IV)	15 (V)	16 (VI)	17 (VII)	18 (VIII)
1 2,1 **H** 1																	2 **He** 4
3 1,0 **Li** 7	4 1,5 **Be** 9											5 2,0 **B** 11	6 2,5 **C** 12	7 3,0 **N** 14	8 3,5 **O** 16	9 4,0 **F** 19	10 **Ne** 20
11 0,9 **Na** 23	12 1,2 **Mg** 24											13 1,5 **Aℓ** 27	14 1,8 **Si** 28	15 2,1 **P** 31	16 2,5 **S** 32	17 3,0 **Cℓ** 35,5	18 **Ar** 40
19 0,8 **K** 39	20 1,0 **Ca** 40	21 1,3 **Sc** 45	22 1,5 **Ti** 48	23 1,6 **V** 51	24 1,6 **Cr** 52	25 1,5 **Mn** 55	26 1,8 **Fe** 56	27 1,8 **Co** 59	28 1,8 **Ni** 59	29 1,9 **Cu** 63,5	30 1,6 **Zn** 65	31 1,6 **Ga** 70	32 1,8 **Ge** 73	33 2,0 **As** 75	34 2,4 **Se** 79	35 2,8 **Br** 80	36 **Kr** 84
37 0,8 **Rb** 86	38 1,0 **Sr** 88	39 1,2 **Y** 89	40 1,4 **Zr** 91	41 **Nb** 92	42 1,8 **Mo** 96	43 1,9 **Tc**	44 2,2 **Ru** 101	45 2,2 **Rh** 103	46 2,2 **Pd** 106	47 1,9 **Ag** 108	48 1,7 **Cd** 112	49 1,7 **In** 115	50 1,8 **Sn** 119	51 1,9 **Sb** 122	52 2,1 **Te** 128	53 2,5 **I** 127	54 **Xe** 131
55 0,7 **Cs** 133	56 0,9 **Ba** 137	57 **La** 139	72 1,6 **Hf** 179	73 **Ta** 181	74 **W** 184	75 **Re** 186	76 **Os** 190	77 **Ir** 192	78 **Pt** 195	79 **Au** 197	80 **Hg** 201	81 1,8 **Tℓ** 204	82 1,8 **Pb** 207	83 1,9 **Bi** 209	84 2,0 **Po**	85 2,5 **At**	86 **Rn**
87 0,7 **Fr**	88 0,9 **Ra** 226	89 **Ac**															

58 **Ce** 140	59 **Pr** 141	60 **Nd** 144	61 **Pm**	62 **Sm** 150	63 **Eu** 152	64 **Gd** 157	65 **Tb** 159	66 **Dy** 163	67 **Ho** 165	68 **Er** 167	69 **Tm** 169	70 **Yb** 173	71 **Lu** 175
90 **Th** 232	91 **Pa**	92 **U** 238	93 **Np**	94 **Pu**	95 **Am**	96 **Cm**	97 **Bk**	98 **Cf**	99 **Es**	100 **Fm**	101 **Md**	102 **No**	103 **Lr**

TABLE 4A: STANDARD REDUCTION POTENTIALS

Increasing oxidising ability

Increasing reducing ability/

Half-reactions			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
$C\ell_2(g) + 2e^-$	$\rightleftharpoons$	$2C\ell^-$	+ 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
$Br_2(\ell) + 2e^-$	$\rightleftharpoons$	$2Br^-$	+ 1,07
$NO_3^- + 4H^+ + 3e^-$	$\rightleftharpoons$	$NO(g) + 2H_2O$	+ 0,96
$Hg^{2+} + 2e^-$	$\rightleftharpoons$	$Hg(\ell)$	+ 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
$A\ell^{3+} + 3e^-$	$\rightleftharpoons$	$A\ell$	– 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

TABLE 4B: STANDARD REDUCTION POTENTIALS

Increasing oxidising ability ↓

Increasing reducing ability ↑

Half-reactions			E^{θ} (V)
$Li^+ + e^-$	⇌	Li	– 3,05
$K^+ + e^-$	⇌	K	– 2,93
$Cs^+ + e^-$	⇌	Cs	– 2,92
$Ba^{2+} + 2e^-$	⇌	Ba	– 2,90
$Sr^{2+} + 2e^-$	⇌	Sr	– 2,89
$Ca^{2+} + 2e^-$	⇌	Ca	– 2,87
$Na^+ + e^-$	⇌	Na	– 2,71
$Mg^{2+} + 2e^-$	⇌	Mg	– 2,36
$A\ell^{3+} + 3e^-$	⇌	$A\ell$	– 1,66
$Mn^{2+} + 2e^-$	⇌	Mn	– 1,18
$Cr^{2+} + 2e^-$	⇌	Cr	– 0,91
$2H_2O + 2e^-$	⇌	$H_2(g) + 2OH^-$	– 0,83
$Zn^{2+} + 2e^-$	⇌	Zn	– 0,76
$Cr^{3+} + 3e^-$	⇌	Cr	– 0,74
$Fe^{2+} + 2e^-$	⇌	Fe	– 0,44
$Cr^{3+} + e^-$	⇌	Cr^{2+}	– 0,41
$Cd^{2+} + 2e^-$	⇌	Cd	– 0,40
$Co^{2+} + 2e^-$	⇌	Co	– 0,28
$Ni^{2+} + 2e^-$	⇌	Ni	– 0,27
$Sn^{2+} + 2e^-$	⇌	Sn	– 0,14
$Pb^{2+} + 2e^-$	⇌	Pb	– 0,13
$Fe^{3+} + 3e^-$	⇌	Fe	– 0,06
$2H^+ + 2e^-$	**⇌**	**$H_2(g)$**	**0,00**
$S + 2H^+ + 2e^-$	⇌	$H_2S(g)$	+ 0,14
$Sn^{4+} + 2e^-$	⇌	Sn^{2+}	+ 0,15
$Cu^{2+} + e^-$	⇌	Cu^+	+ 0,16
$SO_4^{2-} + 4H^+ + 2e^-$	⇌	$SO_2(g) + 2H_2O$	+ 0,17
$Cu^{2+} + 2e^-$	⇌	Cu	+ 0,34
$2H_2O + O_2 + 4e^-$	⇌	$4OH^-$	+ 0,40
$SO_2 + 4H^+ + 4e^-$	⇌	$S + 2H_2O$	+ 0,45
$Cu^+ + e^-$	⇌	Cu	+ 0,52
$I_2 + 2e^-$	⇌	$2I^-$	+ 0,54
$O_2(g) + 2H^+ + 2e^-$	⇌	H_2O_2	+ 0,68
$Fe^{3+} + e^-$	⇌	Fe^{2+}	+ 0,77
$NO_3^- + 2H^+ + e^-$	⇌	$NO_2(g) + H_2O$	+ 0,80
$Ag^+ + e^-$	⇌	Ag	+ 0,80
$Hg^{2+} + 2e^-$	⇌	$Hg(\ell)$	+ 0,85
$NO_3^- + 4H^+ + 3e^-$	⇌	$NO(g) + 2H_2O$	+ 0,96
$Br_2(\ell) + 2e^-$	⇌	$2Br^-$	+ 1,07
$Pt^{2+} + 2e^-$	⇌	Pt	+ 1,20
$MnO_2 + 4H^+ + 2e^-$	⇌	$Mn^{2+} + 2H_2O$	+ 1,23
$O_2(g) + 4H^+ + 4e^-$	⇌	$2H_2O$	+ 1,23
$Cr_2O_7^{2-} + 14H^+ + 6e^-$	⇌	$2Cr^{3+} + 7H_2O$	+ 1,33
$C\ell_2(g) + 2e^-$	⇌	$2C\ell^-$	+ 1,36
$MnO_4^- + 8H^+ + 5e^-$	⇌	$Mn^{2+} + 4H_2O$	+ 1,51
$H_2O_2 + 2H^+ + 2e^-$	⇌	$2H_2O$	+1,77
$Co^{3+} + e^-$	⇌	Co^{2+}	+ 1,81
$F_2(g) + 2e^-$	⇌	$2F^-$	+ 2,87

Grade 12 Chemistry Definitions

Intermolecular Forces Revision	**Interatomic forces:** the forces between atoms within a molecule **Intermolecular forces:** the forces between two molecules **Van der Waal forces**: weak intermolecular forces **Dipole-dipole forces:** forces between two polar molecules **Induced dipole forces (London Dispersion):** forces between two non-polar molecules **Hydrogen bonding:** forces between molecules which hydrogen is covalently bonded to nitrogen, oxygen or fluorine
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 CH_2 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 **Activation energy:** the minimum energy required for a reaction to take place. Colliding molecules must have, apart from the correct orientation, a kinetic energy equal to or bigger than the activation energy of a reaction before the reaction can take place. **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^+)/hydronium ions (H_3O^+) 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 H3O+ 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 MOLECULES

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

$C - C$ $C = C$ $C \equiv C$

NOTE:

Carbon atoms have to form 4 bonds, but not necessarily with 4 other atoms

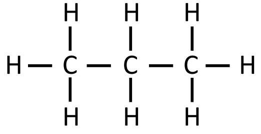
HYDROCARBONS

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:

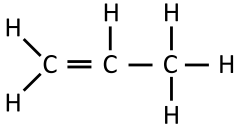
A compound in which all of the bonds between carbon atoms are single bonds.



(Alkanes)

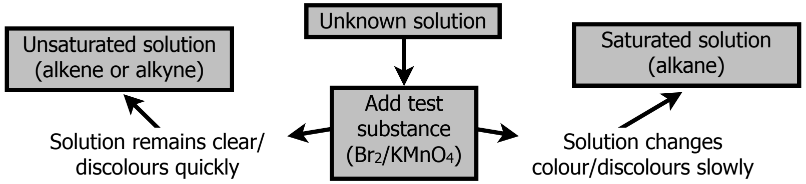
Unsaturated compound:

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



(Alkenes and alkynes)

Saturation test with Br_2 (aq) or $KMnO_4$ (aq)



Unknown solution

Add test substance (Br_2/$KMnO_4$)

Solution remains clear/ discolours quickly

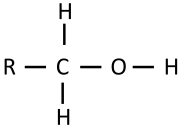
Unsaturated solution (alkene or alkyne)

Solution changes colour/discolours slowly

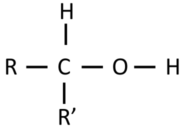
Saturated solution (alkane)

CLASSIFICATION OF ALCOHOL

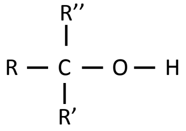
Primary
One C bonded to the C bonded to the OH



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

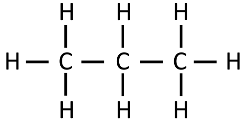


Tertiary
Three C's bonded to the C bonded to the OH



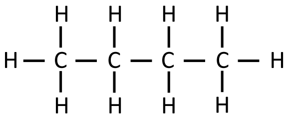
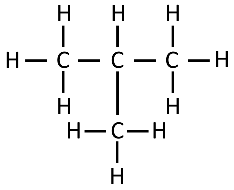
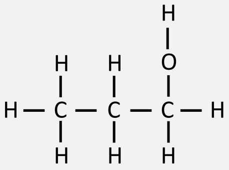
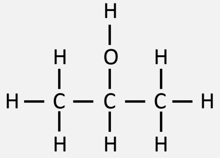
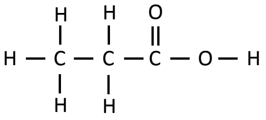
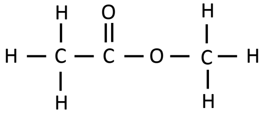
REPRESENTING ORGANIC COMPOUNDS

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	Does not show any bonds, only the number of each atom present in the compound	C_3H_8
Condensed formula	This formula does not show all the bonds but shows the important bonds and general structure	$CH_3CH{=}CH_2$
Structural formula	This formula shows all the bonds and atoms in the molecule.	

ISOMERS

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

Chain isomers	These have the same molecular formula but different chains	butane 	2-methylpropane 
Positional isomers	These have the same molecular formula but the functional group is in a different position	propan-1-ol 	propan-2-ol 
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 	methyl ethanoate 

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 CH_2 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:

Substituent Prefix — **Root name** — **Functional group suffix**

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:

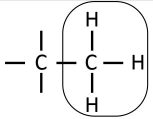
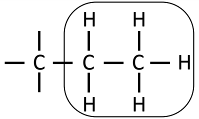
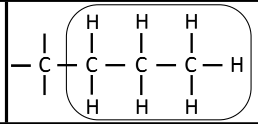
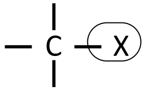
1. Identify the longest continuous carbon chain which must contain the functional group.
2. Number the longest carbon chain beginning at the carbon (carbon 1) nearest to the functional group with the alkyl substituents on the lowest numbered carbon atoms of the longest chain.
3. Name the longest chain 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

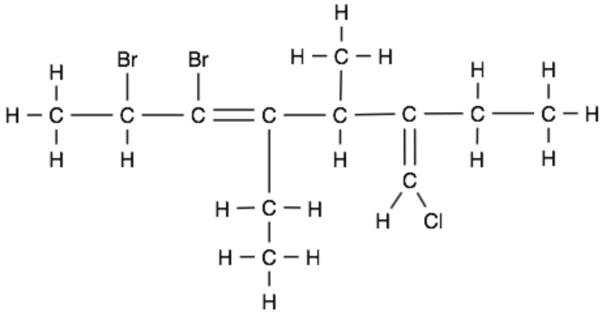
NOTE:
A maximum of THREE substituent chains (alkyl substituents) are allowed on the main chain

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

Substituent	**Formula**	**Structural formula**	**Name**
Alkyl	CH_3–		methyl–
	CH_3CH_2–		ethyl–
	$CH_3CH_2CH_2$–		propyl–
Halogen	X–		X repesents a halogen: Fluorine: fluoro– Chlorine: chloro– Bromine: bromo– Iodine: iodo–

EXAMPLE:

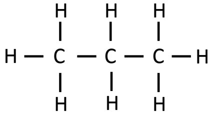
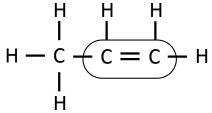
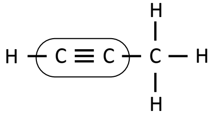
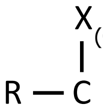
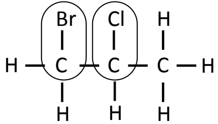
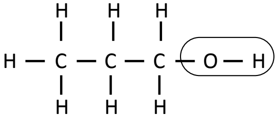
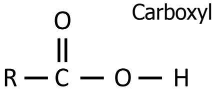
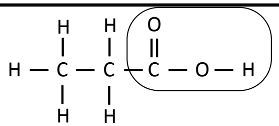
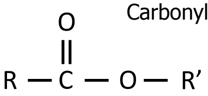
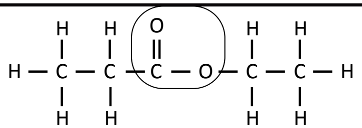
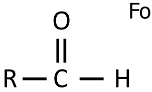
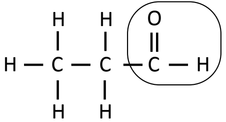
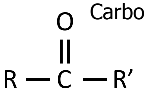
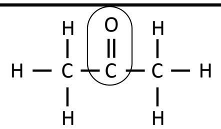
Write down the name of the molecule below:



Substituents	**Main chain**	**Functional group**
1–**c**hloro	7 = hept	1,4–diene
2,4–di**e**thyl		
3–**m**ethyl		
5,6–di**b**romo		

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		$CH_3CH_2CH_3$	prop**ane**	**Polarity:** Non-Polar **IMF:** Weak London **Reactions**: Substitution, Elimination, Combustion
Alkenes C_nH_{2n}	Double bonds $R - C = C - R'$	-ene		$CH_3CH{=}CH_2$	prop**ene**	**Polarity:** Non-polar **IMF:** London **Reactions:** Addition, combustion
Alkynes C_nH_{2n-2}	Triple bonds $R - C \equiv C - R'$	-yne		$CH\equiv CCH_3$	prop**yne**	**Polarity:** Non-polar **IMF:** London **Reactions:** Addition
Haloalkane/ Haloalkene (Alkyl halide)	 $R - \overset{\overset{X}{\mid}}{C} - R'$ Halogens (Group 17)	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		$CH_3CH_2CH_2\mathbf{OH}$	propan–1–**ol**	**Polarity:** Polar **IMF:** Strong Hydrogen bonds **Reactions:** Substitution, Elimination, Esterification, Combustion
Carboxylic acids $C_nH_{2n}O_2$	 $R - \overset{\overset{O}{\parallel}}{C} - O - H$ Carboxyl	-oic acid		$CH_3CH_2\mathbf{COOH}$	propan**oic acid**	**Polarity:** Polar **IMF:** Strong Hydrogen bonds **Reactions:** Esterification
Esters R–COO–R′	 $R - \overset{\overset{O}{\parallel}}{C} - O - R'$ Carbonyl	-yl -oate (alch.) (carbox.)		$CH_3CH_2\mathbf{COOC}H_2CH_3$ (carbox.) (alch.)	eth**yl** propan**oate**	**Polarity:** Polar **IMF:** Dipole–Dipole **Reactions:** Formed by esterification
Aldehydes $C_nH_{2n+1}CHO$	 $R - \overset{\overset{O}{\parallel}}{C} - H$ Formyl	-al		$CH_3CH_2\mathbf{CHO}$	pronan**al**	**Polarity:** Polar **IMF:** Dipole–Dipole
Ketone R–COC–R′	 $R - \overset{\overset{O}{\parallel}}{C} - R'$ Carbonyl	-one		$CH_3\mathbf{CO}CH_3$	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)
	Van der Waals forces	Dipole-Dipole Forces	●Stronger than Dispersion 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
		Dispersion (London) Forces	●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

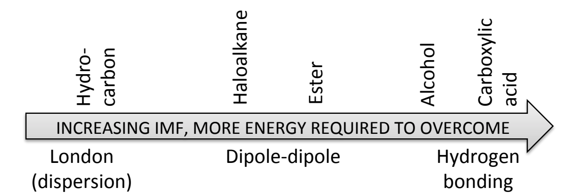
PHYSICAL PROPERTY	RELATIONSHIP TO IMF
Melting Point: The temperature at which the solid and liquid phases of a substance are at equilibrium. It is the temperature where solid particles will undergo a phase change (melt) and become a liquid.	Directly proportional
Boiling Point: The temperature at which 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.

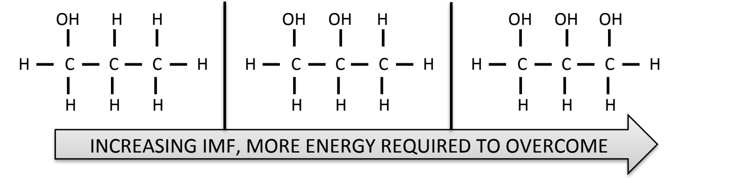
① TYPE OF FUNCTIONAL GROUP

The more polar the molecule, the stronger the IMF



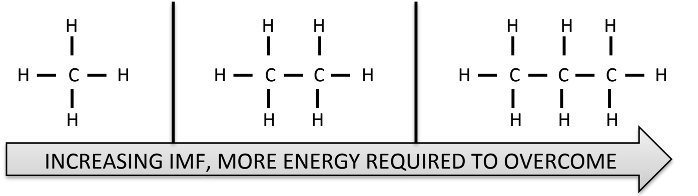
② NUMBER OF FUNCTIONAL GROUPS

An increase in functional groups increase the IMF



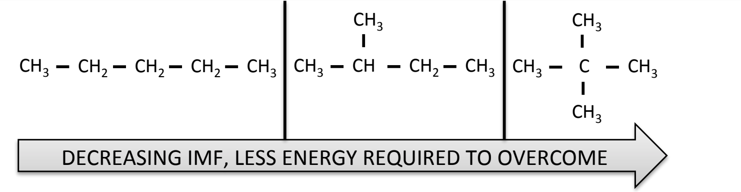
③ CHAIN LENGTH: MOLECULAR MASS

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 surface area and lower the strength of the IMF



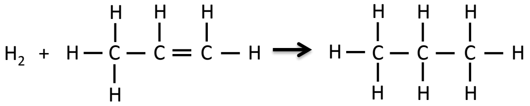
ORGANIC REACTIONS

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 (H_2), a halogen (Group 7 – e.g. Cl_2), a Hydrogen halide or water H_2O. In addition reactions alkenes or alkynes form an alkane chain as a product.

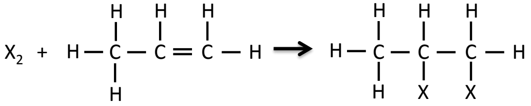
1) Hydrogenation – add H_2



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.

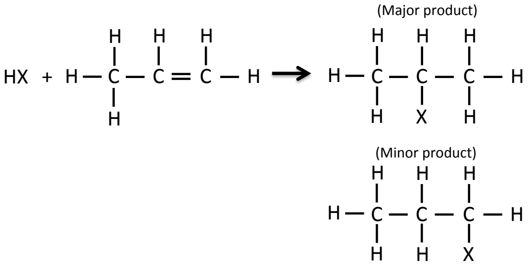
2) Halogenation – add X (X = Halogen: F_2, Cl_2, Br_2, I_2)



halogen + alkene/alkyne → haloalkane

Reaction conditions:
No water to be present if it is to take place

3) Hydrohalogenation – add HX (X = Halogen: F_2, Cl_2, Br_2, I_2)

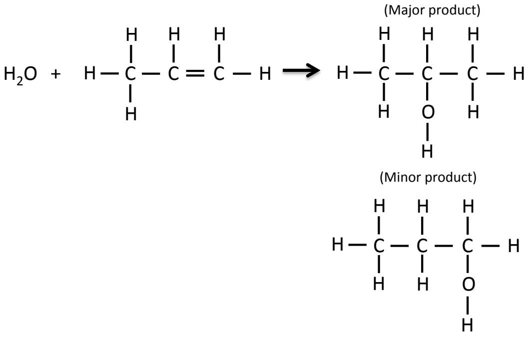


hydrogen halide + alkene/alkyne → haloalkane

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 H_2O



water (H_2O) + alkene/alkyne → alcohol

Reaction conditions:
Strong but dilute acid catalyst e.g. H_2SO_4 or H_3PO_4
Heat in the form of steam (H_2O) reactant

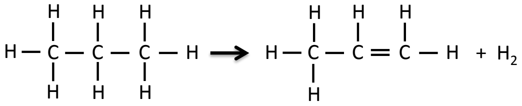
Markovnikov's rule: The H atom will bond to the carbon atom which has the greater number of H atoms bonded to it. (Form biggest H groups)

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 (H_2), a halogen (Group 7 – e.g. Cl_2), a hydrogen halide or water H_2O. In elimination reactions, alkanes form either an alkene or alkyne chain as a product.

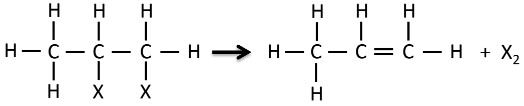
1) Dehydrogenation – remove H_2



alkane → alkene + halogen

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

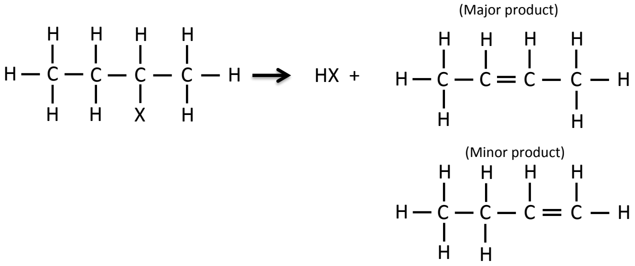
2) Dehalogenation – remove X (X = Halogen: F_2, Cl_2, Br_2, I_2)



haloalkane → alkene + halogen

Reaction conditions:
Takes place in an unreactive solvent

3) Dehydrohalogenation – remove HX (X = Halogen: F_2, Cl_2, Br_2, I_2)



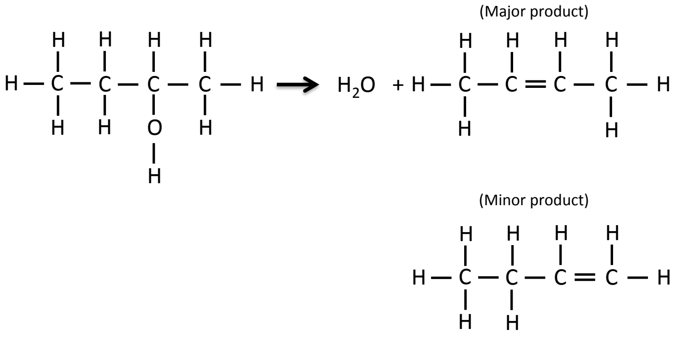
haloalkane → hydrogen halide + alkene

Reaction conditions:
Takes place in the presence of concentrated NaOH/KOH in ethanol as the solvent.

Heat

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 H_2O



alcohol → water (H_2O) + alkene

Reaction conditions:
Requires the heating of an alcohol with concentrated acid catalyst eg. H_2SO_4 or H_3PO_4. The acid should be in excess

Sulfuric acid is known as a dehydrating agent.

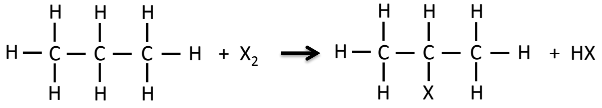
Zaitzev's rule: H atom is removed from the carbon atom with the least number of H atoms. (Keeps biggest H groups)

ORGANIC REACTIONS

SUBSTITUTION REACTIONS (SATURATED → SATURATED)

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

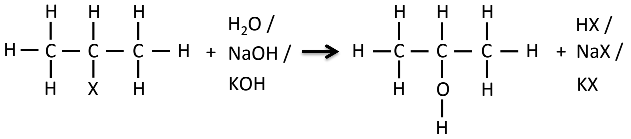
1) Alkanes: Halogenation- Substitute X_2 (X = Halogen: F_2, Cl_2, Br_2, I_2)



alkane + halogen → haloalkane + hydrogen halide

Reaction conditions:
Reaction takes place in the presence of sunlight/heat

2) Haloalkanes: Hydration- Substitute H_2O

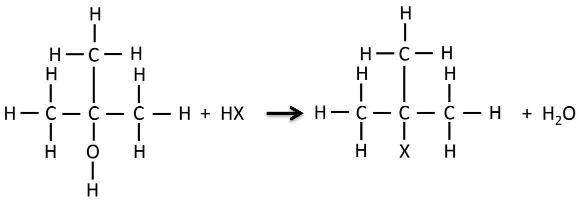


haloalkane + H_2O/NaOH/KOH → alcohol + HX/NaX/KX

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: F_2, Cl_2, Br_2, I_2)

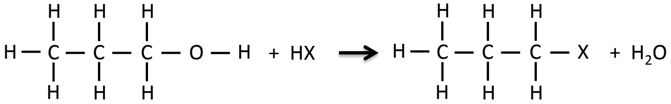
Tertiary alcohols



alcohol + hydrogen halide → haloalkane + water

Reaction conditions:
Require HX present at room temperature.

Primary and secondary alcohols



alcohol + hydrogen halide → haloalkane + water

Reaction conditions:
High temperatures and need to be treated with NaBr and concentrated H_2SO_4.

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.

Complete combustion (excess oxygen): $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O + \text{energy}$

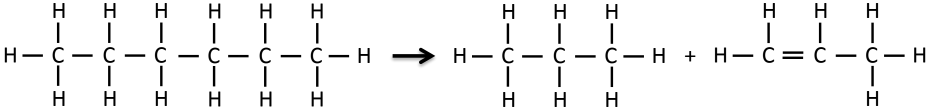
Incomplete combustion (insufficient oxygen): $2C_3H_8 + 7O_2 \rightarrow 6CO + 8H_2O + \text{energy}$

Balancing: C → H → O

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.



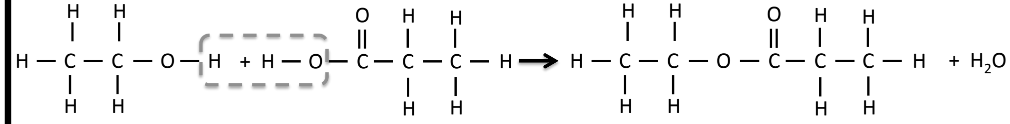
alkane → alkane + alkene

Thermal cracking
This method makes use of high pressures and high temperatures to crack the long hydrocarbon chains with no catalyst.

Catalytic cracking
This method uses a catalyst to crack long carbon chains at low pressure 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.

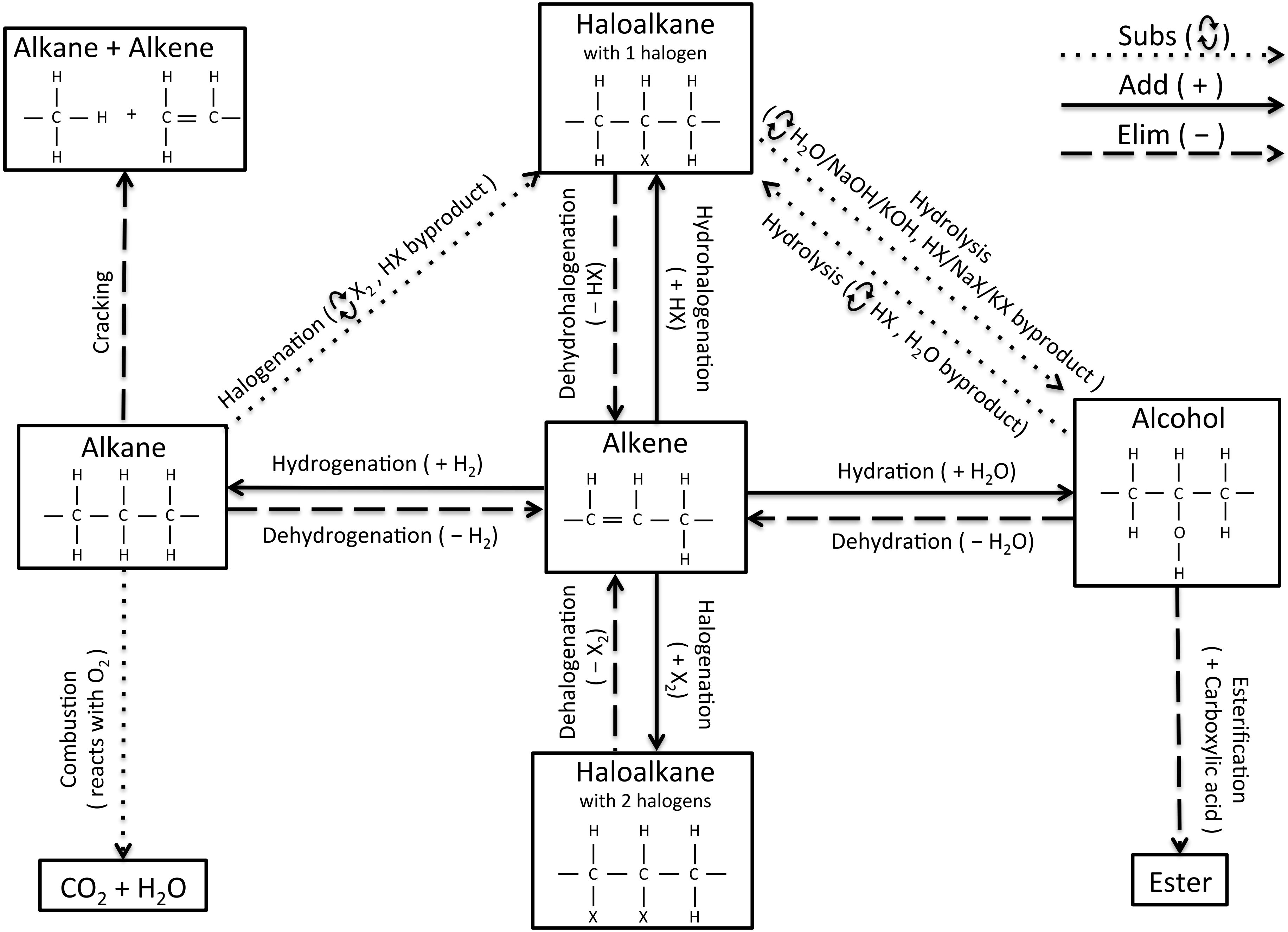
ESTERIFICATION

This is a reaction between an alcohol and a carboxylic acid in the **presence of a concentrated acid catalyst, H_2SO_4**. 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.



alcohol + carboxylic acid → ester + water

SUMMARY OF ORGANIC REACTIONS

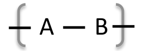


POLYMERS

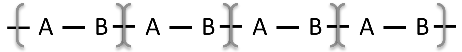
POLYMERS

Polymers are very large organic molecules. They are made up of hundreds or thousands of atoms. Polymers are structured from repeated smaller units called monomers.

Monomer: Small organic molecules that can be covalently bonded to each other in a repeating pattern



Polymer: A large molecule composed of smaller monomer units covalently bonded to each other in a repeating pattern



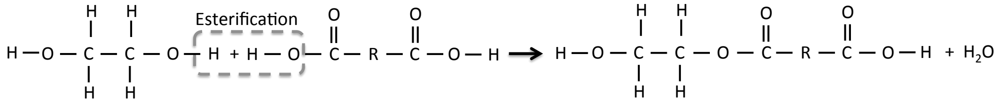
CONDENSATION POLYMERIZATION

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.

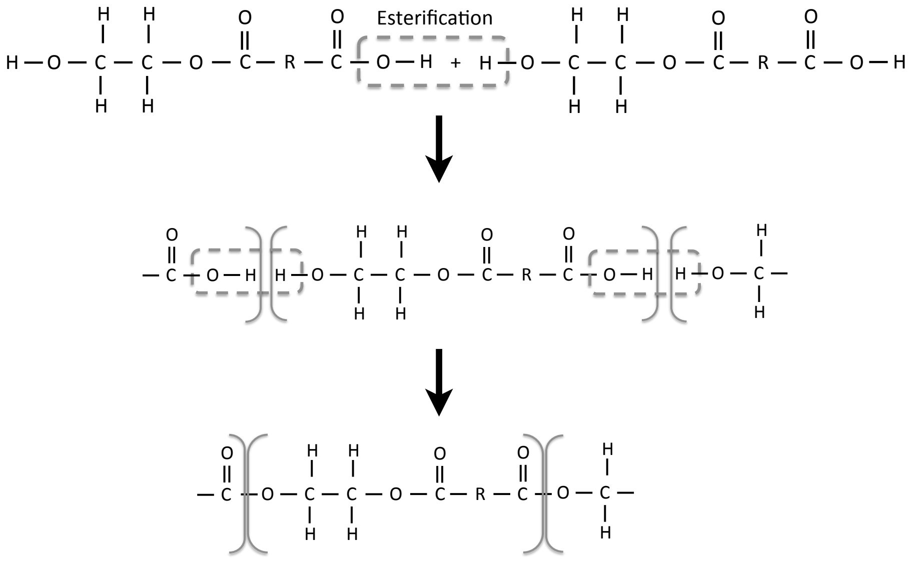
Formation of polyesters

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.

Monomer (ester) formation



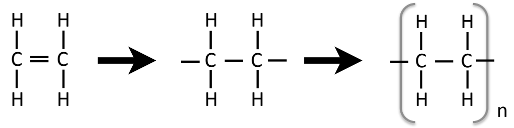
Polymer formation



ADDITION POLYMERIZATION

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 monomer

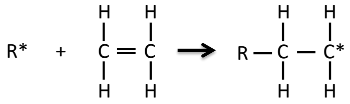
ethene polymer (polyethene)

Steps of addition polymerization of polyethene (polyethylene)

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

1) Initiation

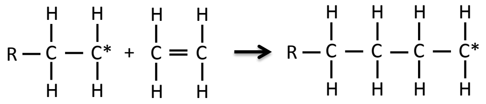
The presence of a free radical initiates the double bond of the monomer to break open. A free radical is a molecule that has an unpaired electron. When the monomer reacts with the free radical it creates another free radical.



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

2) Propagation

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.

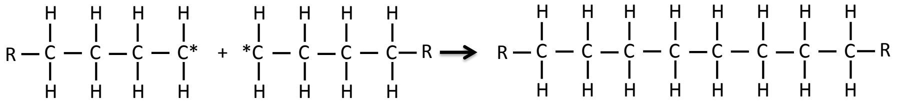


*** : Free radical (unpaired electron)**

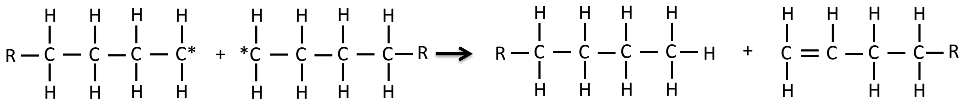
3) Termination

There are two ways in which the polymerization can terminate.

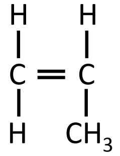
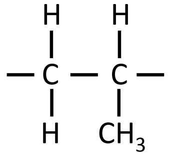
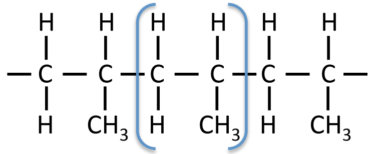
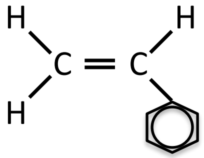
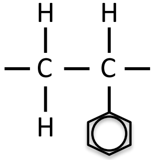
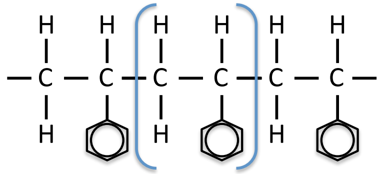
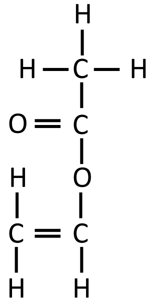
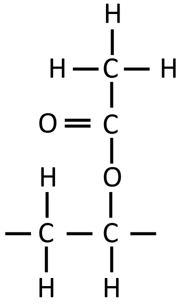
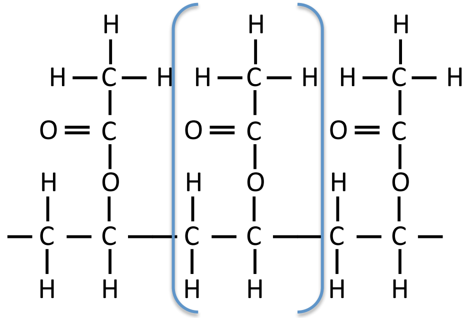
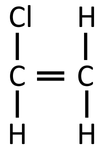
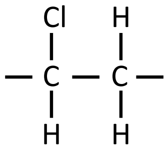
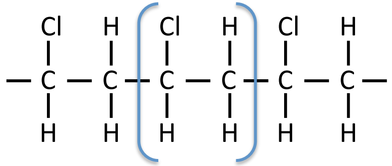
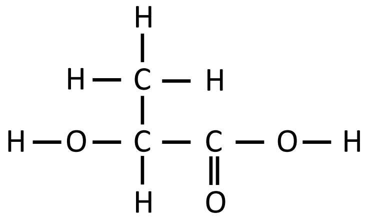
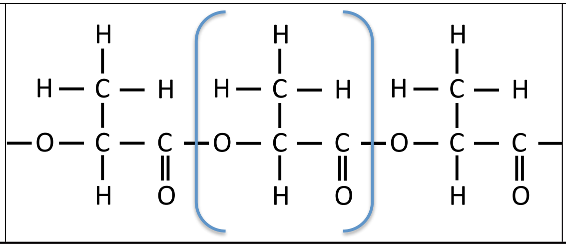
•Two radicals join together and terminate.



• 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).



POLYMERS

MONOMER NAME	MONOMER STRUCTURE	FREE RADICAL BUILDING BLOCK	POLYMER STRUCTURE	POLYMER NAME
Addition polymerization				
Propene				**Polypropylene**
Styrene				**Polystyrene**
Vinyl acetate				**PVA (polyvinyl acetate)**
Chloroethene				**PVC (polyvinyl chloride)**
Condensation polymerization				
Lactic acid		**Polymer formed by esterification.** **REMEMBER: Water is formed as byproduct.**		**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.

A **mole** of particles is an amount of 6,02 x 10^{23} particles. **6,02 x 10^{23} is known as Avogadro's number, N_A.**

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

number of mole (mol) ← n

N → number of particles

N_A → Avogadro's number (6,02 x 10^{23})

EXAMPLE:

Determine the amount of H^+ ions in 3 mol of H_2SO_4.

$$\begin{aligned} N(H_2SO_4) &= nN_A \\ &= 3(6{,}02 \times 10^{23}) \\ &= 1{,}81 \times 10^{24}\ H_2SO_4\ \text{molecules} \end{aligned}$$

$$\begin{gathered} H_2SO_4 : H^+ \\ 1 : 2 \\ 1{,}81 \times 10^{24} : 3{,}62 \times 10^{24} \\ \therefore N(H^+) = 3{,}62 \times 10^{24}\ \text{ions} \end{gathered}$$

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.mol^{-1}.

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

number of mole (mol) ← n

m → mass of substance (g)

M → molar mass (g · mol^{-1})

EXAMPLE:

Determine the number of moles in 13 g of $CuSO_4$.

$$\begin{aligned} M(CuSO_4) &= 63{,}5 + 32 + 4(16) \\ &= 159{,}5\ \text{g} \cdot \text{mol}^{-1} \end{aligned}$$

$$\begin{aligned} n &= \frac{m}{M} \\ &= \frac{13}{159{,}5} \\ &= 0{,}082\ \text{mol} \end{aligned}$$

Percentage Composition

Percentage composition of element=$\frac{\textbf{molar mass of element}}{\textbf{M}_\textbf{R}\textbf{ of compound}} \times$ **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 x 56) + (3 x 16) =160	(3 x 56) + (4 x 16) =232
% iron by mass	[(2 x 56) /160] x 100 = 70%	[(3 x 56) / 232] x 100 = 72%

∴ 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 · dm^{-3}) ← c

n → number of moles (mol)

V → volume (dm^3)

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·dm^{-3}. If a solution of **potassium permanganate $KMnO_4$** has a concentration of 2 mol.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.

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

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

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

EXAMPLE:

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

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

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

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

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

Molar Volumes of Gases

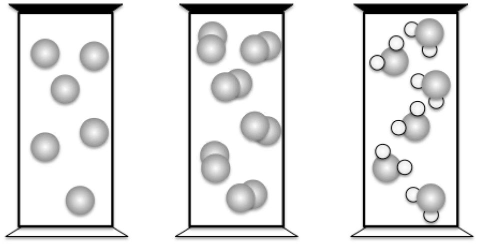
If different gases have the same volume under the same conditions of temperature and pressure, they will have the same number of molecules.

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

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

Standard Temperature and Pressure (STP) is 273 K (0°C) and 1,01×10^5 Pa.

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



$$\begin{array}{ccccc} N_2 & + & 2O_2 & \rightarrow & 2NO_2 \\ 1\ \text{mol} & + & 2\ \text{mol} & \rightarrow & 2\ \text{mol} \\ 1\ \text{dm}^3 & + & 2\ \text{dm}^3 & \rightarrow & 2\ \text{dm}^3 \end{array}$$

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

V → volume of gaseous substance (dm^3)

n → number of moles (mol)

V_M → molar gas volume at STP (22,4 dm^3 · 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?

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

QUANTITATIVE ASPECTS OF CHEMICAL CHANGE

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 mol	n = m / M = 60 / 16 = 3,75 mol
Step 4: Divide by smallest mol ratio	1,25 / 1,25 =1	3,75 /1,25 =3

Empirical formula: SO_3

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 mol	n = m / M = 1 / 16 = 0,0625 mol
Step 3: Atom ratio (divide by smallest no in ratio)	0,125/0,0625 ≈2	0,0625/0,0625 =1

Empirical formula: Cu_2O

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

1. Empirical formula given: CH_2

2. Determine the molar mass of the empirical formula.

$$\begin{aligned} M(CH_2) &= 12+1+1 \\ &= 14 g\cdot mol^{-1} \end{aligned}$$

3. Determine the ratio between molecular and empirical.

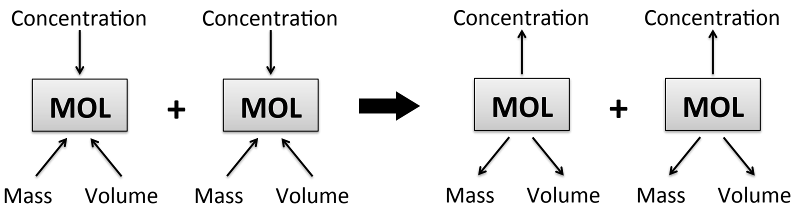
$$\begin{aligned} \text{ratio number} &= \frac{\text{molecular formula mass}}{\text{empirical formula mass}} \\ &= \frac{56}{14} \\ &= 4 \end{aligned}$$

4. Multiply the ratio into the empirical formula

$$CH_2 \times 4 = C_4H_8$$

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

$$Mg(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2(g)$$

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

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

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

The amount of limiting reactant will determine:

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

Determining limiting reactants

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

NOTE:

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

EXAMPLE:

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

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

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

(a)

1.

$$\begin{aligned} n(N_2) &= \frac{m}{M} \\ &= \frac{8,4}{28} \\ &= 0,3 \text{ mol} \end{aligned}$$

$$\begin{aligned} n(H_2) &= \frac{m}{M} \\ &= \frac{1,5}{2} \\ &= 0,75 \text{ mol} \end{aligned}$$

2.

$$\begin{array}{ccc} N_2 & : & H_2 \\ 1 & : & 3 \\ \underline{0,3 \text{ mol}} & : & 0,9 \text{ mol} \\ 0,25 \text{ mol} & : & \underline{0,75 \text{ mol}} \end{array}$$

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:

$$\begin{array}{ccc} H_2 & : & NH_3 \\ 3 & : & 2 \\ 0,75\text{mol} & : & 0,5\text{mol} \end{array}$$

$$\begin{aligned} m(NH_3) &= nM \\ &= (0,5)(17) \\ &= 8,5\text{g} \end{aligned}$$

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:

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

STEPS TO DETERMINE THE PERCENTAGE PURITY

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

EXAMPLE:

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

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

1. $n(CO_2) = \frac{V}{V_M} = \frac{1,2}{22,4} = 0,054\text{mol}$

2.

$$\begin{array}{ccc} CaCO_3 & : & CO_2 \\ 1 & : & 1 \end{array}$$

3.

$$\begin{array}{ccc} CaCO_3 & : & CO_2 \\ 1 & : & 1 \\ 0,054 & : & 0,054 \end{array}$$

$\therefore 0,054\text{mol } CaCO_3$ reacted

4.

$m(CaCO_3) = nM = (0,054)(40 + 12 + 16 + 16 + 16) = 5,4\text{g}$

5.

$$\begin{aligned} \text{Percentage purity} &= \frac{\text{Mass of pure substance}}{\text{Mass of impure substance}} \times 100 \\ \text{Percentage purity} &= \frac{5,4}{6,0} \times 100 \\ \text{Percentage purity} &= 90\,\% \end{aligned}$$

Percentage Yield

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

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

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

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

STEPS TO DETERMINE THE PERCENTAGE YIELD

1. Determine moles of reactants.
2. From the **balanced** formula, determine the ratio between reactants and products.
3. Using the ratio, determine the number of moles of products and convert to mass.
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:

$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$$

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

1. $n(SO_2) = \frac{m}{M} = \frac{128}{64} = 2\text{mol}$

2.

$$\begin{array}{ccc} SO_2 & : & SO_3 \\ 2 & : & 2 \\ 1 & : & 1 \end{array}$$

3.

$$\begin{array}{ccc} SO_2 & : & SO_3 \\ 1 & : & 1 \\ 2 & : & 2 \end{array}$$

$\therefore 2\text{mol } SO_3$

4. $m(SO_3) = nM = (2)(32 + 16 + 16 + 16) = 160\text{g}$

5.

$$\begin{aligned} \text{Percentage yield} &= \frac{\text{Mass of product produced}}{\text{Maximum theoretical mass of product}} \times 100 \\ \text{Percentage yield} &= \frac{140}{160} \times 100 \\ \text{Percentage yield} &= 87.5\,\% \end{aligned}$$

ENERGY AND CHEMICAL CHANGE

ENERGY CHANGE

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

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

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

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

ACTIVATION ENERGY

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

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

ENTHALPY AND ENTHALPY CHANGE

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

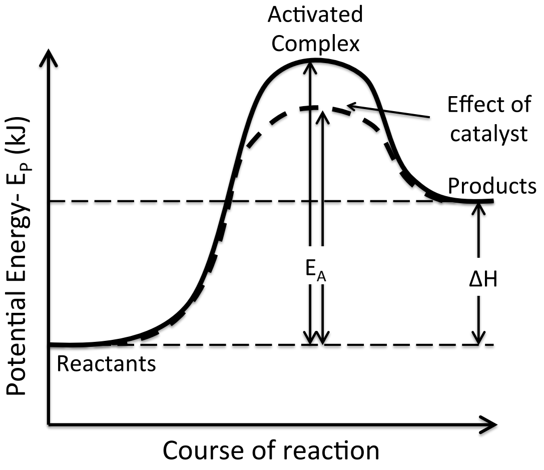
The heat of reaction (ΔH) is the net change of chemical potential energy of the system.

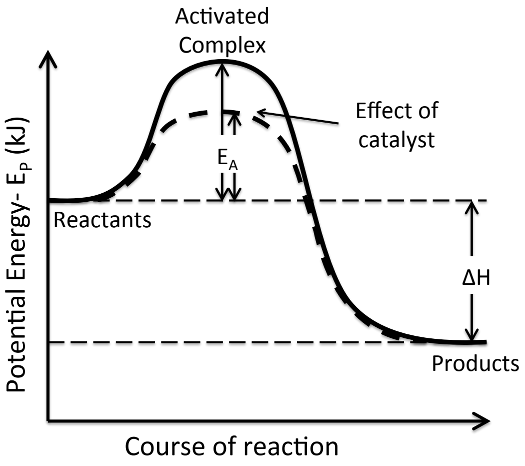
CHEMICAL SYSTEM AND THE ENVIRONMENT

The chemical system is the reactant and product molecules.

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

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





CATALYST

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

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

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

IMPORTANT REACTIONS

ENDOTHERMIC

Photosynthesis

$6CO_2 + 6H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6O_2$; ΔH>0

EXOTHERMIC

Cellular respiration

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$; ΔH<0

Combustion

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$; ΔH<0

$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$; ΔH<0

RATES OF REACTIONS

RATES OF REACTIONS

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

$$\text{Rate} = \frac{\Delta[\text{products}]}{\Delta t} \qquad \text{Rate} = \frac{\Delta[\text{reactants}]}{\Delta t}$$

Unit: Change in concentration over time ($mol{\cdot}dm^{-3}{\cdot}s^{-1}$)

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

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.

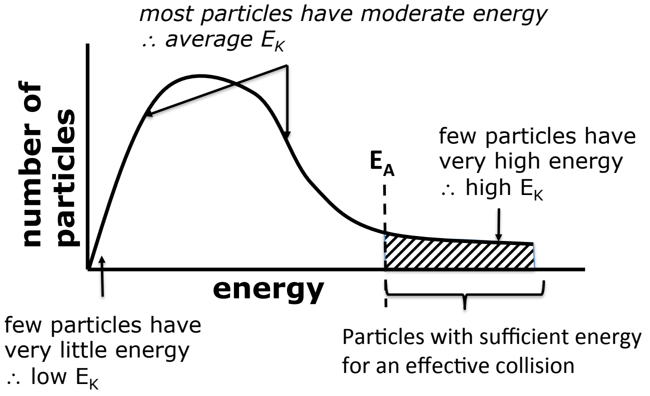
COLLISION THEORY

In order for a reaction to occur, molecules need to collide under specific conditions. 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 (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

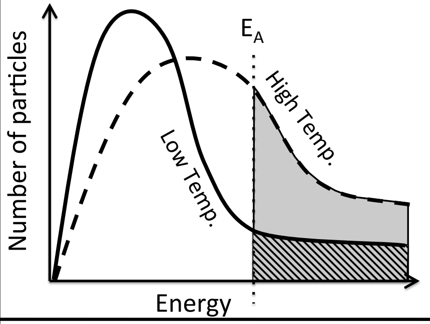
The Maxwell-Boltzman distribution curve shows the distribution of the kinetic energy of molecules. The area under the graph to the right of the E_A line represents the particles with sufficient kinetic energy.

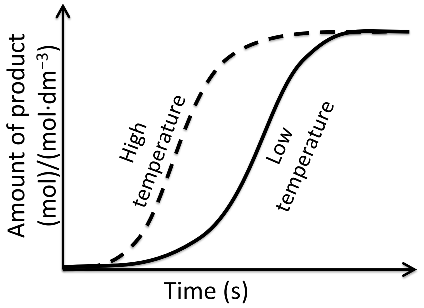


FACTORS INFLUENCING REACTION RATE

Temperature

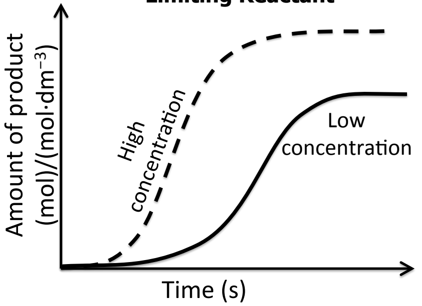
Increasing temperature increases rate of reaction. When the temperature is increased, more particles have energy greater than the activation energy, and **more effective collisions** can take place.

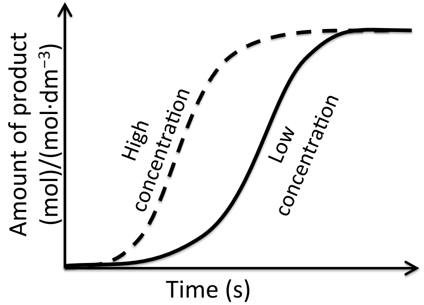




Concentration (gases and solutions only)

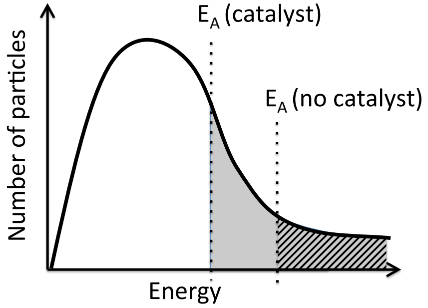
Increasing concentration increases rate of reaction. The greater the concentration, the more particles are confined in a smaller space. This leads to more collisions, and subsequently **more effective collisions**. If the concentration of a limiting reactant is increased, more product can be formed.

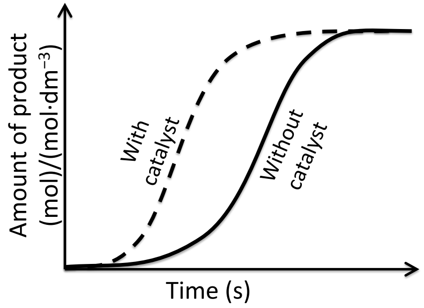

Limiting Reactant


Excess Reactant

Catalyst

The presence of a catalyst decreases the activation energy (E_A). The particles require less collision energy to undergo an effective collision, leading to **more effective collisions**.





Nature of reactants

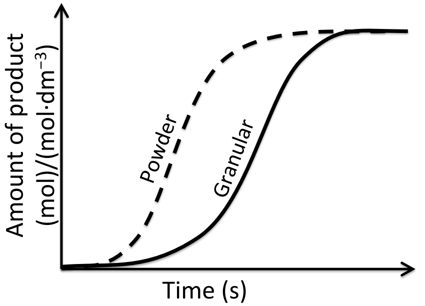
The physical and chemical properties of certain molecules make them more likely to react.

For example:

- O_2 has many effective orientations
- F's electronegativity makes it more reactive
- Tertiary alcohols have limited effective orientations due to molecule structure
- Simple (Ca^{2+}) and complex ($C_2O_4^-$) ions.

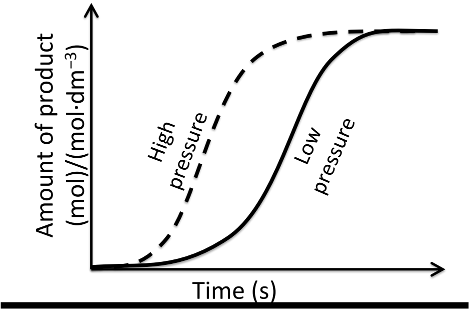
State of division / surface area (solids only)

Increase state of division (powder instead of chunks) increases rate of reaction by increasing effective orientations and surface area.



Pressure (gases only)

Increase pressure (by decreasing volume) increases the concentration of the gas thus increasing the rate of reaction



WAYS TO MEASURE RATE

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

CHEMICAL EQUILIBRIUM

An **open system** continuously interacts with its environment.

A **closed system** is isolated from its surroundings and is one where no reactants 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:

$H_2(g) + I_2(g) \rightarrow 2HI(g)$

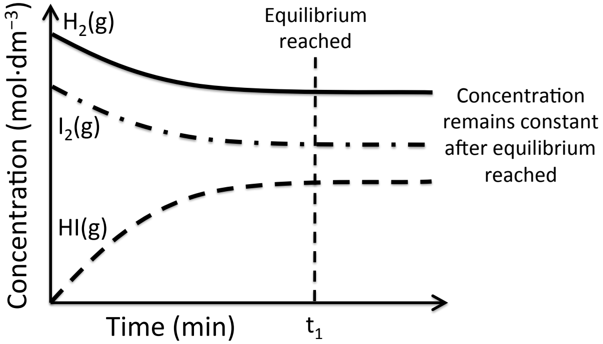
Hydrogen iodide can decompose to form hydrogen and iodine:

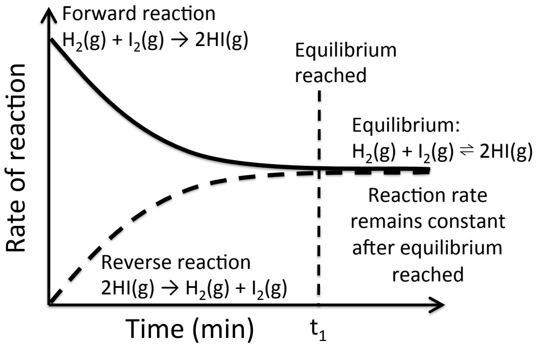
$2HI(g) \rightarrow H_2(g) + I_2(g)$

Therefore the reversible reaction can be written as:

$$\underset{\xleftarrow{\text{Reverse reaction}}}{\overset{\xrightarrow{\text{Forward reaction}}}{H_2(g) + I_2(g) \rightleftharpoons 2HI(g)}}$$

Chemical equilibrium is a dynamic equilibrium when the rate of the forward reaction equals the rate of the reverse reaction. Chemical equilibrium can only be achieved in a close system.





LE CHATELIER'S PRINCIPLE

When an external stress (change in pressure, temperature or concentration) is applied to a system in chemical equilibrium, the equilibrium point will change in such a way as to counteract the stress.

Factors which affect equilibrium position

1. Concentration

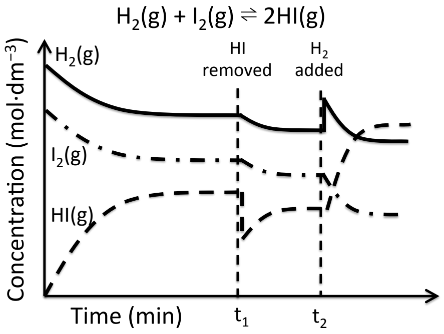
Equilibrium will shift to decrease any increase in concentration of either reactants or products.

- 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.



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):

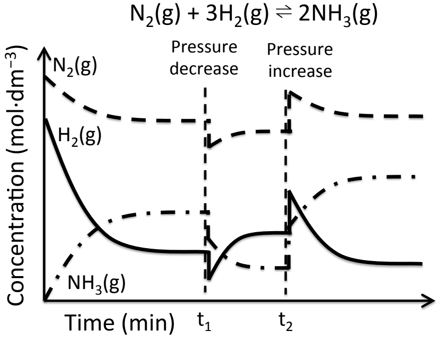
When adding H₂, the system re-establishes equilibrium by favouring the reaction that uses H₂. Because the forward reaction is favoured, the reactants are used and more products form.

2. Pressure (gases only)

Equilibrium will shift to decrease any increase in pressure by favouring the reaction direction that produces less molecules.

Equilibrium will shift to increase any decrease in pressure by favouring the reaction that produces more molecules.

To identify the reaction direction, use the ratios in the balanced equation.



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, forming 4 moles of reactant for every 2 mole of product used.

Pressure increases (t₂):
When the pressure is increased, the system re-establishes equilibrium by favouring the reaction that will produce less moles of gas, forming 2 moles of product for every 4 moles of reactants used.

3. Temperature

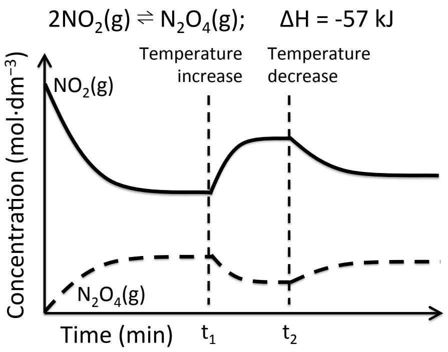
Equilibrium will shift to the endothermic reaction if the temperature is increased.

Equilibrium will shift to the exothermic reaction if the temperature is decreased.

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 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 colourless.

CHEMICAL EQUILIBRIUM

COMMON ION EFFECT

When ionic substances are in solution, they form ions:

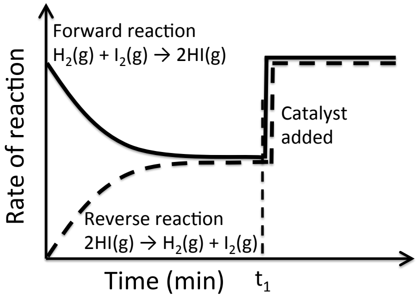
$$\underset{white}{NaCl(s)} \rightleftharpoons \underset{colourless}{Na^+(aq) + Cl^-(aq)}$$

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 Kc value at all, but allows the reaction to reach equilibrium faster.



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.

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:

$$\underset{blue}{CoCl_4{}^{2-}(aq)} + H_2O(l) \rightleftharpoons \underset{pink}{Co(H_2O)_6{}^{2+}(aq)} + 4Cl^-(aq) \qquad \Delta H < 0$$

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 as 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 as 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 dm^3 container and the following equilibrium is established:

$2NO_2(g) \rightleftharpoons N_2O_4(g)$

If no volume is given, assume volume = 1 mol·dm^{-3}

At equilibrium it was found that 0,3 mol of NO_2 were 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 (mol·dm^{-3})	0,3/1,5 = 0,2	1,35/1,5 =0,9

$$K_c = \frac{[N_2O_4]}{[NO_2]^2} = \frac{(0,9)}{(0,2)^2} = 22,5$$

APPLICATIONS OF CHEMICAL EQUILIBRIUM

The Haber Process: $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\Delta H<0$

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 favour the production of products. Thus this reaction is done under a high pressure of 200 atm.

Catalyst: Iron or Iron Oxide

The Contact Process: $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ $\Delta H < 0$

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 products. However, in practice a very high yield is obtained at atmospheric pressure.

Catalyst: Vanadium pentoxide (V_2O_5)

ACIDS AND BASES

ACID/BASE DEFINITIONS

Arrhenius

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

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

Bronsted-Lowry

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

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

ACID PROTICITY

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

1 proton- monoprotic	2 protons- diprotic	3 protons- triprotic
$HCl \rightleftharpoons Cl^- + H^+$	$H_2SO_4 \rightleftharpoons HSO_4^- + H^+$	$H_3PO_4 \rightleftharpoons H_2PO_4^- + H^+$
	$HSO_4^- \rightleftharpoons HSO_4^{2-} + H^+$	$H_2PO_4^- \rightleftharpoons HPO_4^{2-} + H^+$
		$HPO_4^{2-} \rightleftharpoons PO_4^{3-} + H^+$

CONJUGATE ACID-BASE PAIRS

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

acid $\rightleftharpoons$ conjugate base + H^+

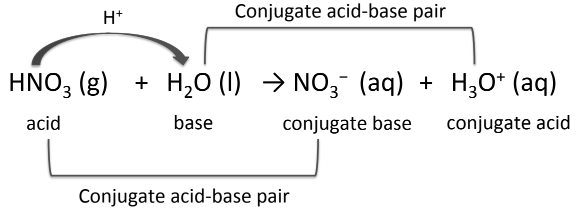
A base forms a conjugate acid when it accepts a proton.

base + H^+ $\rightleftharpoons$ conjugate acid

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

EXAMPLE:

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



AMPHOLYTE/ AMPHOTERIC SUBSTANCES

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

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

HSO_4^- as an ampholyte:

Acid: $HSO_4^- + H_2O \rightleftharpoons SO_4^{2-} + H_3O^+$

Base: $HSO_4^- + H_2O \rightleftharpoons H_2SO_4 + OH^-$

CONCENTRATED VS DILUTE ACIDS AND BASES

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

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

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

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

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

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

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

STRONG VS WEAK ACIDS AND BASES

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

ACIDS

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

$HCl (g) + H_2O (l) \rightleftharpoons H_3O^+ (aq) + Cl^- (aq)$

(strong acid → weak conjugate base)

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

$2H_2CO_3 (l) + 2H_2O (l) \rightleftharpoons 2H_3O^+ (aq) + CO_3^{2-} (aq) + H_2CO_3 (aq)$

(weak acid → strong conjugate base)

BASES

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

$NaOH (s) \rightleftharpoons Na^+ (aq) + OH^- (aq)$

(strong base → weak conjugate acid)

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

$2Mg(OH)_2 (s) \rightleftharpoons Mg^{2+} (aq) + 2OH^- (aq) + Mg(OH)_2 (aq)$

(weak base → strong conjugate acid)

NH_3 is an exception, it ionises.

$NH_3 (g) + H_2O (l) \rightleftharpoons OH^- (aq) + NH_4^+ (aq)$

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 ($NaHCO_3$)	WEAK
Hydrofluoric acid (HF)	WEAK		
Sulfurous acid (H_2SO_3)		Calcium carbonate ($CaCO_3$)	
Carbonic acid (H_2CO_3)			
Acetic acid / ethanoic acid (CH_3COOH)		Sodium carbonate (Na_2CO_3)	
Phosphoric acid (H_3PO_4)		Ammonia (NH_3)	

THE pH SCALE

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

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

The pH scale is a range from 0 to 14.

ACIDS AND BASES

PROTOLYTIC REACTIONS

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

acid + metal → salt + hydrogen

$HA + M \rightarrow A^- + M^+ + H_2$

Eg. $2HNO_3(aq) + 2Na(s) \rightarrow 2NaNO_3(aq) + H_2(g)$

acid + metal hydroxide (base) → salt + water

$HA + MOH \rightarrow A^- + M^+ + H_2O$

Eg. $H_2SO_4(aq) + Mg(OH)_2(aq) \rightarrow MgSO_4(aq) + 2H_2O(l)$

acid + metal oxide → salt + water

$HA + MO \rightarrow A^- + M^+ + H_2O$

E.g. $2HCl\ (aq) + MgO(s) \rightarrow MgCl_2(aq) + H_2O(l)$

acid + metal carbonate → salt + water + carbon dioxide

$HA + MCO_3 \rightarrow A^- + M^+ + H_2O + CO_2$

E.g. $2HCl\ (aq) + CaCO_3(s) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

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

HYDROLYSIS OF SALTS

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

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

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

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

INDICATORS

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

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

Neutral: pH 7

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

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

TITRATIONS

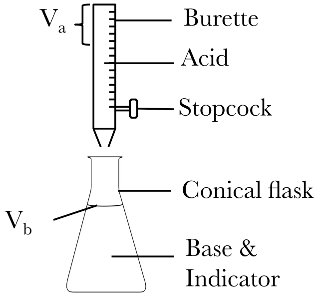
A titration is a practical laboratory method to determine the concentration of an acid or base. The concentration of an acid or base can be determined by accurate neutralisation using a **standard solution- a solution of known concentration**. Neutralisation occurs at the equivalence point, when the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

$$\boxed{\frac{n_a}{n_b} = \frac{c_aV_a}{c_bV_b}}$$

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

1 mL = 1 cm^3
1 L = 1 dm^3
1000 mL = 1 L
1000 cm^3 = 1 dm^3

Titration setup



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

EXAMPLE:

During a titration, 25 cm^3 of dilute H_2SO_4 neutralises 40 cm^3 of NaOH solution. If the concentration of the H_2SO_4 solution is 0,25 mol.dm^{-3}, calculate the concentration of the NaOH.

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$$

$n_a = 1$
$c_a = 0{,}25\ mol \cdot dm^{-3}$
$V_a = 25\ cm^3 = 0{,}025\ dm^3$

$n_b = 2$
$c_b = ?$
$V_b = 40\ cm^3 = 0{,}04\ dm^3$

By titration equations

$$\frac{n_a}{n_b} = \frac{c_aV_a}{c_bV_b}$$

$$\frac{1}{2} = \frac{(0{,}25)(0{,}025)}{c_b(0{,}04)}$$

$$c_b = 0{,}31\ mol \cdot dm^{-3}$$

By first principles:

Acid:

$$\begin{aligned} n &= cV \\ &= (0{,}25)(0{,}025) \\ &= 6{,}25 \times 10^{-3}\ mol \end{aligned}$$

Base:

$$\begin{aligned} c &= \frac{n}{V} \\ &= \frac{6{,}25 \times 10^{-3} \times 2}{0{,}04} \\ &= 0{,}31\ mol \cdot dm^{-3} \end{aligned}$$

ACIDS AND BASES

CALCULATING PH VALUES

$pH = -\log[H_3O^+]$ $pOH = [OH^-]$ $pH + pOH = 14$

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.

Monoprotic:	$HCl(g)$	→	$H^+(aq)$	+	$Cl^-(aq)$
	1 mol	:	1 mol	:	1 mol
	0,3 $mol\cdot dm^{-3}$	:	0,3 $mol\cdot dm^{-3}$	:	0,3 $mol\cdot dm^{-3}$
Diprotic:	$H_2SO_4(g)$	→	$H+(aq)$	+	$SO_4^{2-}(aq)$
	1 mol	:	2 mol	:	1 mol
	0,3 $mol\cdot dm^{-3}$	:	0,6 $mol\cdot dm^{-3}$	:	0,3 $mol\cdot dm^{-3}$
Triprotic:	$H_3PO_4(g)$	→	$H^+(aq)$	+	$PO_4^{3-}(aq)$
	1 mol	:	3 mol	:	1 mol
	0,3 $mol\cdot dm^{-3}$	:	0,9 $mol\cdot dm^{-3}$	:	0,3 $mol\cdot dm^{-3}$

EXAMPLE:

Calculate the pH of a H_2SO_4 solution with a concentration of 0,25 $mol\cdot dm^{-3}$

Step 1: Write down the ionisation reaction:

$$H_2SO_4 + 2H_2O \rightleftharpoons 2H_3O^+ + SO_4^{2-}$$

Step 2: determine the ratio of acid to H_3O^+ ions

$$H_2SO_4 : H_2O$$
$$1 : 2$$

Step 3: determine the $[H_3O^+]$

$$[H_3O^+] = 2[H_2SO_4]$$
$$= 2(0{,}25)$$
$$= 0{,}5 mol\cdot dm^{-3}$$

Step 4: Calculate the pH

$$pH = -\log[H_3O^+]$$
$$= -\log(0{,}5)$$
$$= 0{,}3$$

AUTO-IONISATION OF WATER AND K_W

Water ionises to form hydronium and hydroxide ions in the following reaction:

$2H_2O (l) \rightleftharpoons H_3O^+ (aq) + OH^- (aq)$

The concentration of H_3O^+ (aq) and OH^- (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:

$[H_3O^+][OH^-] = 1{,}00 \times 10^{-14} mol\cdot dm^{-3}$

$[H_3O^+] = 1{,}00 \times 10^{-7} mol\cdot dm^{-3}$

$[OH^-] = 1{,}00 \times 10^{-7} mol\cdot dm^{-3}$

When the concentration of H_3O^+ (aq) and OH^- (aq) are equal, the solution is neutral and has a pH of 7.

EXAMPLE:

Calculate the pH of a $Ba(OH)_2$ solution with a concentration of 0,35 $mol\cdot dm^{-3}$.

Step 1: Write down the dissociation reaction

$$Ba(OH)_2\ (s) \overset{H_2O}{\rightleftarrows} Ba^+(aq) + 2OH^-(aq)$$

Step 2: Determine the mole ratio of base to OH^- ions

$$1\ mol\ Ba(OH)_2 : 2\ mol\ OH^-$$

Step 3: Determine the $[OH^-]$

$$[OH^-] = 2[Ba(OH)_2]$$
$$= 2(0{,}35)$$
$$= 0{,}7\ mol\cdot dm^{-3}$$

Step 4: Determine the $[H_3O^+]$

$$[H_3O^+][OH^-] = 1{,}00 \times 10^{-14}$$
$$[H_3O^+](0{,}7) = 1{,}00 \times 10^{-14}$$
$$[H_3O^+] = 1{,}43 \times 10^{-14}\ mol\cdot dm^{-3}$$

Step 5: Calculate the pH

$pH = -\log [H_3O^+]$

$= -\log (1{,}43 \times 10^{-14})$

$= 13{,}84$

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

$HA + H_2O \rightleftharpoons A^- + H_3O^+$

$$K_a = \frac{[A^-][H_3O^+]}{[HA]}$$

$CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$

$$K_a = \frac{[CH_3COO^-][H_3O^+]}{[CH_3COOH]}$$

Calculating K_b

$B + H_2O \rightleftharpoons BH^+ + OH^-$

$$K_b = \frac{[BH^+][OH^-]}{[B]}$$

$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$

$$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]}$$

DETERMINING CONCENTRATION FROM PH

To determine the $[H_3O^+]$ when the pH is known:

$$pH = -\log[H_3O^+]$$
$$\therefore [H_3O^+] = 10^{-pH}$$

EXAMPLE:

0,1 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:

$$H_2O + HF (aq) \rightleftharpoons H_3O^+ (aq) + F^- (aq)$$

$$pH = -\log[H_3O^+]$$
$$[H_3O^+] = 10^{-2{,}1}$$
$$[H_3O^+] = 7{,}94 \times 10^{-3}\ g\cdot mol^{-3}$$

	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 ($mol\cdot dm^{-3}$)	0,092	$7{,}94 \times 10^{-3}$	$7{,}94 \times 10^{-3}$

$$K_a = \frac{[H_3O^+][F^-]}{[HF]}$$
$$= \frac{(7{,}94 \times 10^{-3})(7{,}94 \times 10^{-3})}{0{,}092}$$
$$= 6{,}85 \times 10^{-4}$$

ELECTROCHEMISTRY-REDOX

REDOX REACTION

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

Oxidation is the loss of electrons (oxidation number increases)

Reduction is the gain of electrons (oxidation number decreases)

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

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

The anode is the electrode where oxidation takes place.

The cathode is the electrode where reduction takes place.

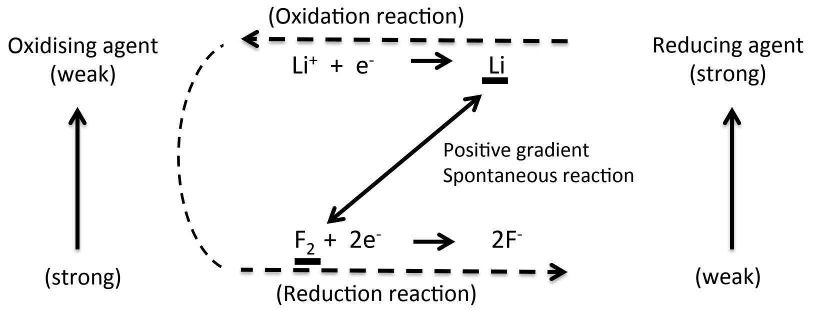
OIL: Oxidation is loss
RIG: Reduction is gain

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. →).



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. 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, $H^+(aq)$ to produce hydrogen gas. Using the oxidation and reduction half reactions write a balanced equation for this reaction.

STEP 1: IDENTIFY THE REACTANTS

$Zn(s)$ and $H^+(aq)$

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: $Zn \rightarrow Zn^{2+} + 2e^-$

Red half-reaction: $2H^+ + 2e^- \rightarrow H_2$

STEP 5: BALANCE ELECTRONS IF NECESSARY

STEP 6: WRITE OVERALL REACTION (LEAVE OUT SPECTATORS)

Overall: $Zn + 2H^+ \rightarrow Zn^{2+} + H_2$

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: $Mg \rightarrow Mg^{2+} + 2e^-$
Red half-reaction: $Cl_2 + 2e^- \rightarrow 2Cl^-$

Overall reaction: $Mg + Cl_2 \rightarrow Mg^{2+} + 2Cl^-$

EXAMPLE:

Using half reactions, complete and balance the following reaction: $Pb + Ag^+$

Ox half reaction: $Pb \rightarrow Pb^{2+} + 2e^-$
Red half reaction: $Ag^+ + e^- \rightarrow Ag$

Ox half reaction: $Pb \rightarrow Pb^{2+} + 2e^-$
(x2 red half reaction): $2Ag^+ + 2e^- \rightarrow 2Ag$

Overall reaction: $Pb + 2Ag^+ \rightarrow Pb^{2+} + Ag$

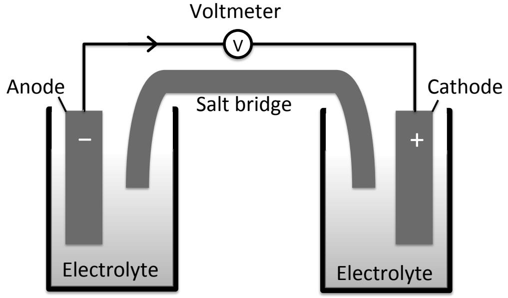
ELECTROCHEMISTRY- GALVANIC/VOLTAIC CELL

A galvanic cell reaction is always a spontaneous, exothermic reaction during which **chemical energy is converted to electrical energy**.

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:

Filled with a saturated ionic salt of either KCl, NaCl, KNO_3 or Na_2SO_4

End 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 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. When the cell potential decreases the current in the circuit will also decrease

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".

EMF OF THE CELL

The emf of the cell is calculated using one of the following equations:

$$E^{\theta}_{\text{cell}} = E^{\theta}_{\text{cathode}} - E^{\theta}_{\text{anode}}$$

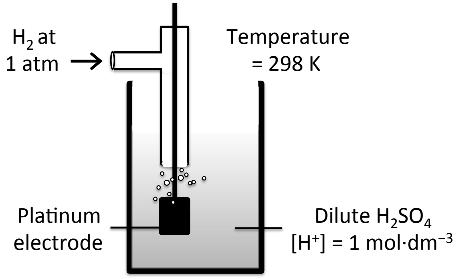
$$E^{\theta}_{\text{cell}} = E^{\theta}_{\text{reduction}} - E^{\theta}_{\text{oxidation}}$$

$$E^{\theta}_{\text{cell}} = E^{\theta}_{\text{oxidising agent}} - E^{\theta}_{\text{reducing agent}}$$

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.



H_2 is bubbled through the electrolyte over the platinum electrode.

<u>Reduction potentials are measured under standard conditions:</u>

temperature 25 °C; 298 K
concentration of the solutions 1 mol·dm^{-3}
pressure 1 atm; 101,3 kPa.

When writing cell notation, the hydrogen half-cell is **written first** if it is the anode. The cell-notation for the hydrogen half-cell is:

$$\text{Pt}, H_2\ (g)\ /\ H^+\ (aq)\ (1\ \text{mol·dm}^{-3})$$

EXAMPLE

Consider the cell notation of the following electrochemical cell:

$\text{Pt}, H_2(g)/H_2SO_4(aq)\ (0{,}5\ \text{mol·dm}^{-3})//\ CuSO_4(aq)\ (1\ \text{mol·dm}^{-3})/Cu(s)$

The experimentally determined cell potential is 0,34 V at 25 °C.

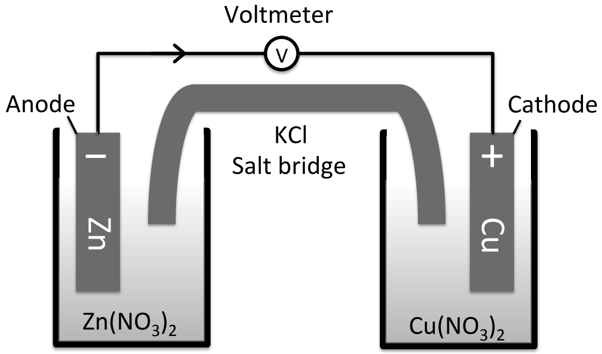
If a value of 0,00 V is given to the hydrogen half-cell, it means that the value of the copper half-cell must be 0,34 V.

$$E^{\theta}\text{cell} = E^{\theta}\text{cathode} - E^{\theta}\text{anode}$$

$$0{,}34 = E^{\theta}(\text{Cu}) - 0{,}00$$

$$E^{\theta}(\text{Cu}) = 0{,}34\ \text{V}$$

ZINC-COPPER CELL



The zinc half-cell:

- Zinc electrode
- Zinc salt solution (e.g. zinc (II) nitrate)
- Oxidation reaction occurs: $Zn \rightarrow Zn^{2+} + 2e^-$
- Anode
- Electrode decreases in mass

The copper half-cell:

- Consists of a copper electrode
- Copper salt solution (e.g. copper (II) nitrate)
- Reduction reaction occurs: $Cu^{2+} + 2e^- \rightarrow Cu$
- Cathode
- Electrode increases in mass

Ox: $Zn\ (s) \rightarrow Zn^{2+}\ (aq) + 2e^-$
Red: $Cu^{2+}\ (aq) + 2e^- \rightarrow Cu\ (s)$

Nett cell: $Zn\ (s) + Cu^{2+}(aq) \rightarrow Zn^{2+}\ (aq) + Cu\ (s)$

Cell notation

Anode ↓ **Salt Bridge** ↓ **Cathode** ↓

$Zn(s)\ /\ Zn^{2+}(aq)\ (1\ \text{mol·dm}^{-3})\ //\ Cu^{2+}(aq)\ (1\ \text{mol·dm}^{-3})\ /\ Cu(s)$

↓ $\mathbf{Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-}$ ↓ $\mathbf{Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)}$

For the zinc-copper cell:

The anode reaction is: $Zn^{2+}\ (aq) + 2e^- \rightarrow Zn\ (s)$; $E^{\theta} = -0{,}76$ V
The cathode reaction is: $Cu^{2+}\ (aq) + 2e^- \rightarrow Cu\ (s)$; $E^{\theta} = +0{,}34$ V

$$E^{\theta}\text{cell} = E^{\theta}\text{cathode} - E^{\theta}\text{anode}$$

$$= 0{,}34 - (-0{,}76)$$

$$= +\ 1{,}1\ \text{V}$$

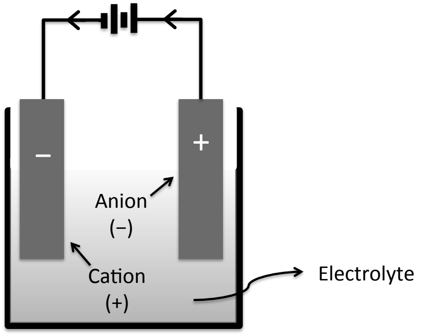
ELECTROCHEMISTRY- ELECTROLYTIC CELLS

An electrolytic cell reaction is always a non-spontaneous, endothermic reaction which requires a battery. **The electrical energy is converted to chemical energy.**

STRUCTURE

Two electrodes (in the same container):
Anode – where oxidation takes place – positive electrode
Cathode – where reduction takes place – negative electrode

The anode and cathode are connected to an external circuit, which is connected to a DC power source.



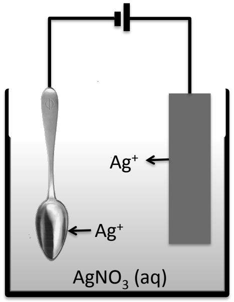
ELECTROPLATING

Electroplating is the process of depositing a layer of one metal onto another metal.

EXAMPLE: Silver plating of a metal spoon

The anode is silver, it will be oxidised to Ag^+ ions. The mass of the silver electrode decreases.

The cathode is the object (spoon) to be plated. The Ag^+ ions from the electrolyte will be reduced to form silver metal, which plates the spoon.



The anode and electrolyte always contains the plating metal.

Oxidation (anode): $Ag(s) \rightarrow Ag^+(aq) + e^-$
Reduction (cathode): $Ag^+(s) + e^- \rightarrow Ag(s)$

Nett cell: $Ag^+(aq) + Ag(s) \rightarrow Ag^+(aq) + Ag(s)$

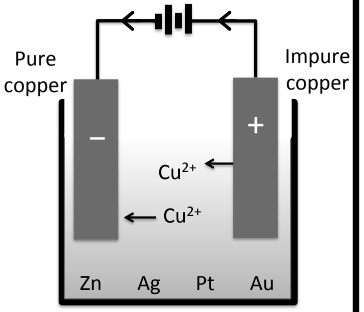
REFINING OF COPPER

When copper is purified, the process is similar to electroplating.

Impure copper is used as the anode and the cathode is pure copper.

At the anode the copper is oxidised to produce Cu^{2+} ions in the electrolyte. The mass of the impure copper anode decreases.

At the cathode the Cu^{2+} ions in the electrolyte is reduced to form a pure copper layer on the cathode. The mass of the cathode increases.

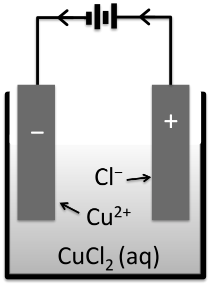


The other elements and compounds found in the impure copper anode are precipitated to the bottom of the reaction vessel.

Oxidation (anode): $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$
Reduction (cathode): $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

Nett cell: $Cu^{2+}(aq) + Cu(s) \rightarrow Cu^{2+}(aq) + Cu(s)$

ELECTROLYSIS OF COPPER (II) CHLORIDE



Oxidation (anode): $2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$
Reduction (cathode): $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

Nett cell: $2Cl^-(aq) + Cu^{2+}(aq) \rightarrow Cl_2(g) + Cu(s)$

Chlorine gas is produced at the anode, while copper metal is produced at the cathode.

EXTRACTION OF ALUMINIUM (HALL-HEROLT PROCESS)

Aluminium is found in the mineral known as bauxite which contains primarily aluminium oxide (Al_2O_3) in an impure form.

Bauxite is not found in South Africa so is imported from Australia for refining.

Step 1: Converting impure Al_2O_3 to pure Al_2O_3

Bauxite treated with NaOH – impure Al_2O_3 becomes $Al(OH)_3$

$Al(OH)_3$ is heated (T > 1000 °C)

$Al(OH)_3$ becomes pure Al_2O_3 – alumina

Step 2: Melting Al_2O_3

Alumina is dissolved in cryolite (sodium aluminium hexafluoride – Na_3AlF_6).

Melting point reduced from over 2000 °C to 1000 °C.

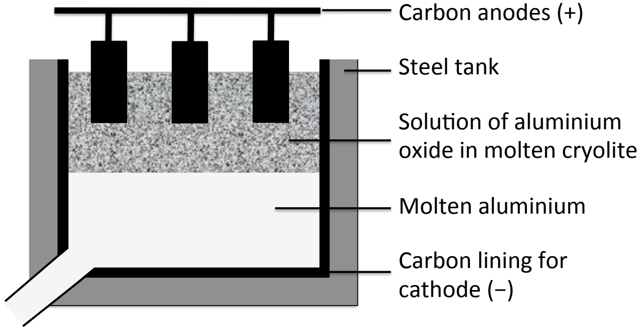
Reduces energy requirements, costs and less environmental impact.

Step 3:
Molten Alumina (Al_2O_3) – cryolite mixture placed in reaction vessel

Anodes (+) are carbon rods in mixture

Cathode (-) is the carbon lining of the tank

At cathode Al^{3+} ions are reduced to Al metal



Oxidation (Anode): $2O^{2-}(aq) \rightarrow O_2(g) + 4e^-$
Reduction (Cathode): $Al^{3+}(aq) + 3e^- \rightarrow Al(l)$

Nett cell: $2Al_2O_3(aq) \rightarrow 4Al(l) + 3O_2(g)$

Due to the high temperature of the reaction, the oxygen produced reacts with the carbon electrodes to produce carbon dioxide gas. The carbon electrodes therefore need to be replaced regularly.

Aluminium extraction uses a large amount of electrical energy, therefore the cost of aluminium extraction is very high.

ELECTROCHEMISTRY- ELECTROLYTIC CELLS

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:

OXIDATION (ANODE):

Either the anion or H_2O 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, water is oxidised according to:
$2H_2O\ (l) \rightarrow O_2\ (g) + 4H^+\ (aq) + 4e^-$

REDUCTION (CATHODE):

Either the cation or H_2O will be reduced.

If a GROUP I OR GROUP II METAL CATION is present, WATER will be reduced according to:

$2H_2O\ (l) + 2e^- \rightarrow H_2\ (g) + 2OH^-\ (aq)$

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 be reduced and not water.

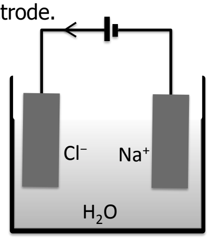
ELECTROLYSIS OF NaCl (CHLOR-ALKALI INDUSTRY)

Brine (concentrated NaCl solution) is placed in an electrolytic cell to produce chlorine gas, hydrogen gas and sodium hydroxide solution.

Overall reaction: $2NaCl(aq) + 2H_2O(l) \rightarrow Cl_2(g) + 2NaOH(aq) + H_2(g)$

At the anode, Cl^- ions are oxidised to form Cl_2 (g). Cl_2 gas bubbles form on the electrode.

At the cathode, water is reduced to form H_2 (g) and OH^- (aq). H_2 (g) bubbles form on the electrode.



Oxidation (anode): $2Cl^-\ (aq) \rightarrow Cl_2\ (g) + 2e^-$
Reduction (cathode): $2H_2O\ (l) + 2e^- \rightarrow H_2\ (g) + 2OH^-\ (aq)$

Nett cell: $2Cl^-\ (aq) + 2H_2O\ (l) \rightarrow Cl_2\ (g) + H_2\ (g) + OH^-\ (aq)$

Overall reaction:
$2NaCl\ (aq) + 2H_2O\ (l) \rightarrow Cl_2\ (g) + 2NaOH\ (aq) + H_2\ (g)$

The electrolysis is conducted in specialised electrolytic cells to control the reaction process and allow reactions to occur under controlled conditions.

MEMBRANE CELL

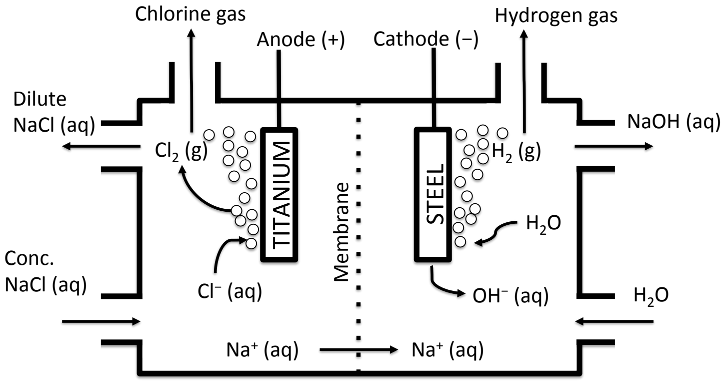
An ion-exchange membrane is used to separate the sodium and chloride ions of the sodium chloride. The selectively permeable ion-exchange membrane is a fluoro-polymer which allows only Na^+ ions to pass through it. The cell consists of two half cells separated by the membrane. The electrolytic cell has 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:
$2H_2O\ (l) + 2e^- \rightarrow H_2\ (g) + 2OH^-$

The anode is filled with the brine solution

At anode - Oxidation:
$2Cl^-\ (aq) \rightarrow Cl_2\ (g) + 2e^-$



Nett cell: $2Cl^-\ (aq) + 2H_2O\ (l) \rightarrow Cl_2\ (g) + H_2\ (g) + OH^-\ (aq)$

Overall reaction: $2NaCl\ (aq) + 2H_2O\ (l) \rightarrow Cl_2\ (g) + 2NaOH\ (aq) + H_2\ (g)$

FERTILISERS

PLANT NUTRIENTS

Non-mineral nutrients

Some non-mineral nutrients are not derived from soil:

Carbon (C): From CO_2 in the atmosphere
Oxygen (O): From CO_2 and O_2 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 fertilsers.

- 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 is 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)

% N: $\frac{2}{11} \times 40 = 7,27\%$

% P: $\frac{6}{11} \times 40 = 21,82\%$

% K: $\frac{3}{11} \times 40 = 10,91\%$

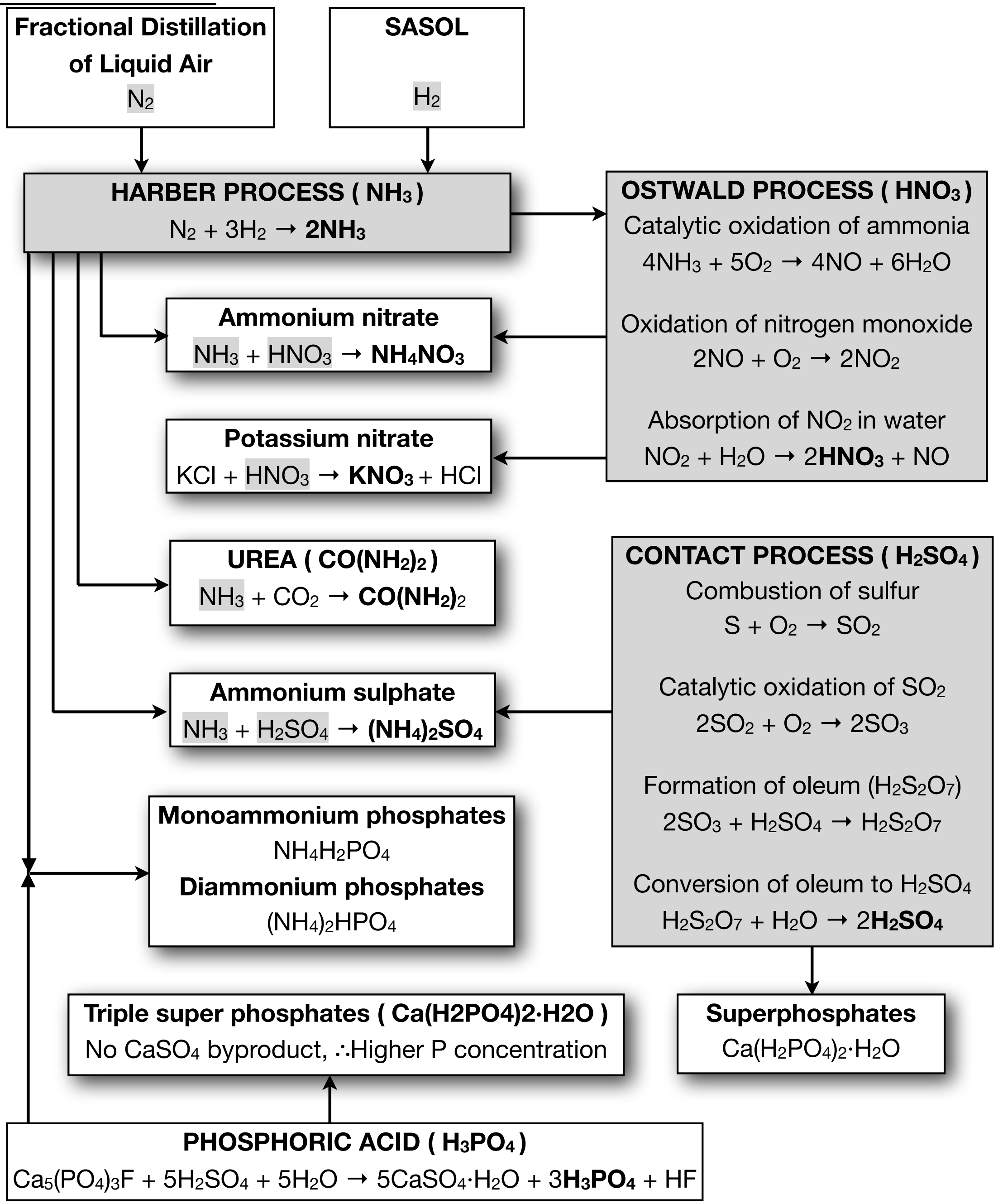
ENVIRONMENTAL IMPACT OF FERTILISERS

(EUTROPHICATION)

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 O_2 in the water. Fish and other water-life die.

Excess nitrates in drinking water is also harmful to humans.



Fractional Distillation of Liquid Air
N_2

SASOL
H_2

HARBER PROCESS (NH_3)
$N_2 + 3H_2 \rightarrow \mathbf{2NH_3}$

OSTWALD PROCESS (HNO_3)
Catalytic oxidation of ammonia
$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$
Oxidation of nitrogen monoxide
$2NO + O_2 \rightarrow 2NO_2$
Absorption of NO_2 in water
$NO_2 + H_2O \rightarrow 2\mathbf{HNO_3} + NO$

Ammonium nitrate
$NH_3 + HNO_3 \rightarrow \mathbf{NH_4NO_3}$

Potassium nitrate
$KCl + HNO_3 \rightarrow \mathbf{KNO_3} + HCl$

UREA ($CO(NH_2)_2$)
$NH_3 + CO_2 \rightarrow \mathbf{CO(NH_2)_2}$

Ammonium sulphate
$NH_3 + H_2SO_4 \rightarrow \mathbf{(NH_4)_2SO_4}$

CONTACT PROCESS (H_2SO_4)
Combustion of sulfur
$S + O_2 \rightarrow SO_2$
Catalytic oxidation of SO_2
$2SO_2 + O_2 \rightarrow 2SO_3$
Formation of oleum ($H_2S_2O_7$)
$2SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$
Conversion of oleum to H_2SO_4
$H_2S_2O_7 + H_2O \rightarrow 2\mathbf{H_2SO_4}$

Monoammonium phosphates
$NH_4H_2PO_4$
Diammonium phosphates
$(NH_4)_2HPO_4$

Triple super phosphates (Ca(H2PO4)2·H2O)
No $CaSO_4$ byproduct, ∴Higher P concentration

Superphosphates
$Ca(H_2PO_4)_2 \cdot H_2O$

PHOSPHORIC ACID (H_3PO_4)
$Ca_5(PO_4)_3F + 5H_2SO_4 + 5H_2O \rightarrow 5CaSO_4 \cdot H_2O + 3\mathbf{H_3PO_4} + HF$

NOTES:

NOTES:

If you have any comments, corrections or suggestions, please log these at **http://tinyurl.com/SmartPrepComment**