



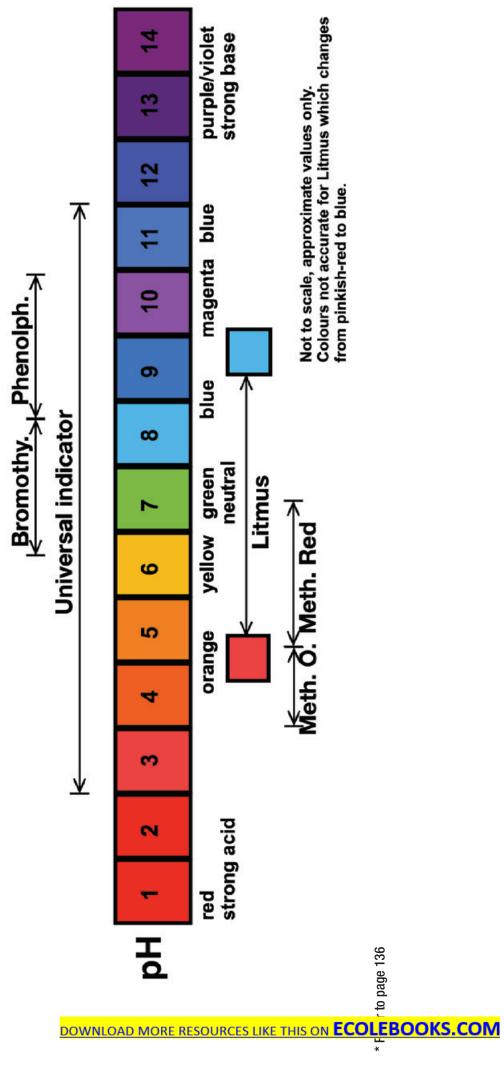


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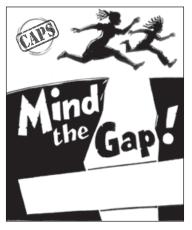
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Department: Basic Education **REPUBLIC OF SOUTH AFRICA**

Colour Diagrams: Acid-base Indicators*



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Curriculum and Assessment Policy Statement (CAPS) Grade 12 Mind the Gap study guide for Physical Science Part 2: Chemistry ISBN 978-1-4315-1937-8

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Copyright © Department of Basic Education 2015 222 Struben Street, Pretoria, South Africa Contact person: Dr Patricia Watson Email: watson.p@dbe.gov.za Tel: (012) 357 4502 http://www.education.gov.za Call Centre: 0800202933

Call Centre: 0800202933 The first edition, published in 2012, for the Revised National Curriculum Statement (RNCS) Grade 12 Mind the Gap study guides for Accounting, Economics, Geography and Life Sciences; the second edition, published in 2014, aligned these titles to the Curriculum and Assessment Policy Statement (CAPS) and added more titles to the series in 2015, including the CAPS Grade 12 Mind the Gap study guide for Physical Science Part 2: Chemistry

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Ministerial foreword

The Department of Basic Education (DBE) has pleasure in releasing the second edition of the *Mind the Gap* study guides for Grade 12 learners. These study guides continue the innovative and committed attempt by the DBE to improve the academic performance of Grade 12 candidates in the National Senior Certificate (NSC) examination.

The study guides have been written by teams of exerts comprising teachers, examiners, moderators, subject advisors and coordinators. Research, which began in 2012, has shown that the *Mind the Gap* series has, without doubt, had a positive impact on grades. It is my fervent wish that the *Mind the Gap* study guides take us all closer to ensuring that no learner is left behind, especially as we celebrate 20 years of democracy.

The second edition of *Mind the Gap* is aligned to the 2014 Curriculum and Assessment Policy Statement (CAPS). This means that the writers have considered the National Policy pertaining to the programme, promotion requirements and protocols for assessment of the National Curriculum Statement for Grade 12 in 2014.

The CAPS aligned *Mind the Gap* study guides take their brief in part from the 2013 National Diagnostic report on learner performance and draw on the Grade 12 Examination Guidelines. Each of the *Mind the Gap* study guides defines key terminology and offers simple explanations and examples of the types of questions learners can expect to be asked in an exam. Marking memoranda are included to assist learners to build their understanding. Learners are also referred to specific questions from past national exam papers and examination memos that are available on the Department's website – www.education.gov.za.

The CAPS editions include Accounting, Economics, Geography, Life Sciences, Mathematics, Mathematical Literacy and Physical Sciences Part 1: Physics and Part 2: Chemistry. The series is produced in both English and Afrikaans. There are also nine English First Additional Language (EFAL) study guides. These include EFAL Paper 1 (Language in Context); EFAL Paper 3 (Writing) and a guide for each of the Grade 12 prescribed literature set works included in Paper 2. These are Short Stories, Poetry, *To Kill a Mockingbird, A Grain of Wheat, Lord of the Flies, Nothing but the Truth* and *Romeo and Juliet*. (Please remember when preparing for EFAL Paper 2 that you need only study the set works you did in your EFAL class at school.)

The study guides have been designed to assist those learners who have been underperforming due to a lack of exposure to the content requirements of the curriculum and aim to mind-the-gap between failing and passing, by bridging the gap in learners' understanding of commonly tested concepts, thus helping candidates to pass.

All that is now required is for our Grade 12 learners to put in the hours required to prepare for the examinations. Learners, make us proud – study hard. We wish each and every one of you good luck for your Grade 12 examinations.

Matsie Angelina Motshekga MP Minister of Basic Education 2015



Matsie Angelina Motshekga, MP Minister of Basic Education



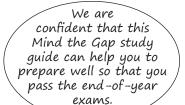
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Dear Grade 12 learner

This *Mind the Gap* study guide helps you to prepare for the end-of-year CAPS Grade 12 exam.

The study guide does NOT cover the entire curriculum, but it does focus on core content of each knowledge area and points out where you can earn easy marks.

You must work your way through this study guide to improve your understanding, identify your areas of weakness and correct your own mistakes.

To ensure a good pass, you should also cover the remaining sections of the curriculum using other textbooks and your class notes.

Overview of the Grade 12 exam

The following topics make up each of the TWO exam papers that you write at the end of the year:

Cognitive level	Description	Paper 2 (Chemistry)
1	Remembering/Recall	15%
2	Understanding/Comprehension	40%
3	Applying and analysing	35%
4	Evaluating and creating (synthesis)	10%

Paper	Type of questions	Duration	Total	Date	Marking
2	Chemistry 10 multiple-choice questions – 20 marks Structured questions – 130 marks	3 hours	150	October/November	External

Paper 2: Chemistry Focus							
Content	Marks	Total	Duration	Wei	ghting of c	ognitive le	vels
Chemical change	84	450					
		150 marks	3 hours	15	40	35	10
		marks					

How to use this study guide

This study guide covers selected parts of the different topics of the CAPS Grade 12 curriculum in the order they are usually taught during the year. The selected parts of each topic are presented in the following way:

- An explanation of terms and concepts;
- Worked examples to explain and demonstrate;
- Activities with questions for you to answer; and
- Answers for you to use to check your own work.



NB	Pay special attention	hint	Hints to help you remember a concept or guide you in solving problems	e.g.	Worked examples
	Step-by-step instructions	exams	Refers you to the exemplar paper	3	Activities with questions for you to answer

- The activities are based on exam-type questions. Cover the answers provided and do each activity on your own. Then check your answers. Reward yourself for things you get right. If you get any incorrect answers, make sure you understand where you went wrong before moving on to the next section.
- In these introduction pages, we will go through the mathematics that you need to know, in particular, algebra and graphs. These are crucial skills that you will need for any subject that makes use of mathematics. Make sure you understand these pages before you go any further.
- Go to <u>www.education.gov.za</u> to download past exam papers for you to practice.



Top 10 study tips



- **1.** Have all your materials ready before you begin studying pencils, pens, highlighters, paper, etc.
- 2. Be positive. Make sure your brain holds on to the information you are learning by reminding yourself how important it is to remember the work and get the marks.
- **3.** Take a walk outside. A change of scenery will stimulate your learning. You'll be surprised at how much more you take in after being outside in the fresh air.
- **4.** Break up your learning sections into manageable parts. Trying to learn too much at one time will only result in a tired, unfocused and anxious brain.
- **5.** Keep your study sessions short but effective and reward yourself with short, constructive breaks.
- **6.** Teach your concepts to anyone who will listen. It might feel strange at first, but it is definitely worth reading your revision notes aloud.
- **7.** Your brain learns well with colours and pictures. Try to use them whenever you can.
- 8. Be confident with the learning areas you know well and focus your brain energy on the sections that you find more difficult to take in.
- **9.** Repetition is the key to retaining information you have to learn. Keep going – don't give up!
- **10.** Sleeping at least 8 hours every night, eating properly and drinking plenty of water are all important things you need to do for your brain. Studying for exams is like strenuous exercise, so you must be physically prepared.

If you can't explain it simply, you don't understand it well enough.

Albert Einstein

Mnemonics

encode information and make it easier to remember

Mnemonics

A mnemonic code is a useful technique for learning information that is difficult to remember.

Here's the most useful mnemonic for Mathematics, Mathematical Literacy, and Physical Science:

BODMAS:

- **B B**rackets
- **0 0**f or Orders: powers, roots, etc.
- **D D**ivision
- M Multiplication
- **A** Addition



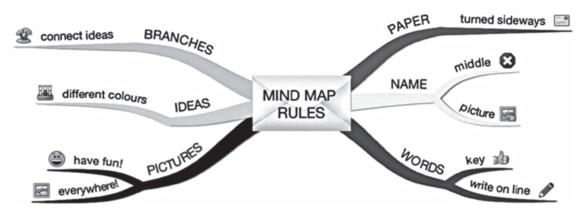
Throughout the book you will be given other mnemonics to help you remember information.

The more creative you are and the more you link your 'codes' to familiar things, the more helpful your mnemonics will be.

Education helps one cease being intimidated by strange situations.
Maya Angelou

Mind maps

There are several mind maps included in the Mind the Gaps guides, summarising some of the sections.



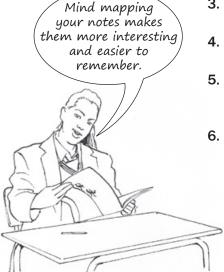
Mind maps work because they show information that we have to learn in the same way that our brains 'see' information.

As you study the mind maps in the guide, add pictures to each of the branches to help you remember the content.

You can make your own mind maps as you finish each section.

How to make your own mind maps:

- **1.** Turn your paper sideways so your brain has space to spread out in all directions.
- 2. Decide on a name for your mind map that summarises the information you are going to put on it.
- **3.** Write the name in the middle and draw a circle, bubble or picture around it.
- **4.** Write only key words on your branches, not whole sentences. Keep it short and simple.
- **5.** Each branch should show a different idea. Use a different colour for each idea. Connect the information that belongs together. This will help build your understanding of the learning areas.
- 6. Have fun adding pictures wherever you can. It does not matter if you can't draw well.



On the day of the exam

- **1.** Make sure you have all the necessary stationery for your exam, i.e. pens, pencils, eraser, protractor, compass, calculator (with new batteries). Make sure you bring your ID document and examination admission letter.
- **2**_ Arrive on time, at least one hour before the start of the exam.
- **3.** Go to the toilet before entering the exam room. You don't want to waste valuable time going to the toilet during the exam.
- **4.** Use the 10 minutes reading time to read the instructions carefully. This helps to 'open' the information in your brain. Start with the question you think is the easiest to get the flow going.
- 5. Break the questions down to make sure you understand what is being asked. If you don't answer the question properly you won't get any marks for it. Look for the key words in the question to know how to answer it. Lists of difficult words (vocabulary) is given a bit later on in this introduction.
- **6.** Try all the questions. Each question has some easy marks in it so make sure that you do all the questions in the exam.
- 7. Never panic, even if the question seems difficult at first. It will be linked with something you have covered. Find the connection.
- 8. Manage your time properly. Don't waste time on questions you are unsure of. Move on and come back if time allows. Do the question that you know the answers for, first.
- **9.** Write big and bold and clearly. You will get more marks if the marker can read your answer clearly.
- **10.** Check weighting how many marks have been allocated for your answer? Take note of the ticks in this study guide as examples of marks allocated. Do not give more or less information than is required.



Question words to help you answer questions

It is important to look for the question words (the words that tell you what to do) to correctly understand what the examiner is asking. Use the words in the table below as a guide when answering questions.

Question word	What is required of you
Analyse	Separate, examine and interpret
Calculate	This means a numerical answer is required – in general, you should show your working, especially where two or more steps are involved
Classify	Group things based on common characteristics
Compare	Point out or show both similarities and differences between things, concepts or phenomena
Define	Give a clear meaning
Describe	State in words (using diagrams where appropriate) the main points of a structure/process/phenomenon/ investigation
Determine	To calculate something, or to discover the answer by examining evidence
Differentiate	Use differences to qualify categories
Discuss	Consider all information and reach a conclusion
Explain	Make clear; interpret and spell out
Identify	Name the essential characteristics PAY SPECIAL ATTENTION
Label	Identify on a diagram or drawing
List	Write a list of items, with no additional detail
Mention	Refer to relevant points
Name	Give the name (proper noun) of something
State	Write down information without discussion
Suggest	Offer an explanation or a solution
Tabulate	Draw a table and indicate the answers as direct pairs

In every exam question, put a CIRCLE around the question word and <u>underline</u> any other important key words. These words tell you exactly what is being asked.



Vocabulary

The following vocabulary consists of all the difficult words used in Mind the Gap Mathematics, Mathematical Literacy, and Physical Science. We suggest that you read over the list below a few times and make sure that you understand each term. Tick next to each term once you understand it so you can see easily where the gaps are in your knowledge.

KEY	
Abbreviation	Meaning
(v)	verb: doing-word or action word, such as "walk"
(n)	noun: naming word, such as "person"
(adj)	adjective: describing word such as "big"
(adv)	adverb: describing word for verbs, such as "fast"
(prep)	preposition: a word describing a position, such as "on", "at"
(sing)	singular: one of
(pl)	plural: more than one of
(abbr)	abbreviation

General terms

Term	Meaning
Α	
abbreviate	(v). Make shorter.
abundant	(adj). Having plenty of something.
accept	(v). Agree to receive something;say yes to; believe; toleratesomething.
account for	(v). Explain why.
adjacent	(adj). Next to something.
affect	(v). Make a difference to; touch the feelings of. Do not confuse with effect. See effect.
analyse	(v). Examine something in detail.
ante-	(prep). Before (e.g., ante-natal – before birth)
anti-	(prep). Against (e.g., anti- apartheid – against apartheid).
apparent	(adj). Clearly visible; the way something seems to be or the way it appears.
appear	(v). Come into sight; seem to be.

approximate	(v. & adj.). Come close to (v); roughly, almost, not perfectly accurate, close but not exact. The verb is pronounced "approxi-mayt" and the adjective is pronounced "approxi-mitt".
aquatic	(adj). Growing or living near or in water.
arbitrary	(adj). Based on random choice; unrestrained and autocratic.
C	
category	(n). Class or group of things.
cause	(v). Make something happen.
cause	(n). The person or thing that makes something happen; an aim or movement to which a person is committed.
causality	(n). Someone or something responsible for a result.
collide	(v). To crash into; to hit.
complex	(adj). Consisting of many different parts; not easy to understand(n) a group or system of things connected in a complicated way.
component	(n). A part.
compose	(v). To make up from parts.
composite	(n). Something made up of parts; (adj) made up of several parts.
condition	(n). The state something is in; the situation that must exist before something else is possible.
conjunction	(n). When two or more things come together at the same point; in grammar, a part of speech that connects words, sentences, phrases or clauses, e.g.: "and"
consider	(v). Think about.
contrast	(v). Show the difference between;(n). something that is verydifferent from what it is beingcompared with.
conversely	(adv). The opposite of.
counteract	(v). Act against something in order to stop it.
D	
data (pl), datum (sing)	(n). Information given or found.
deduce	(v). To work something out by reasoning.

deduction(n). Conclusion or idea that someone has worked out.					
define	(v). Give the meaning of a word or words.				
definition	(n). The meaning of a word or words.				
deliver	(v). To bring and hand over.				
denote	(v). To refer to or mean something.				
determine	(v). Work out, usually by experiment or calculation.				
discreet	(adj). Careful, polite.				
discrete	(adj). Single, separate, distinct, a part.				
E					
effect	(n). Result.				
effect	(v). Carry out, do, enact.				
eject	(v). Force or throw something or someone out violently or suddenly.				
elapse	(v). Pass by or finish, e.g., time.				
establish	(v). Show or prove, set up or create.				
exceed	(v). Go beyond.				
excess	(n). More than necessary.				
excluding	(prep). Not including.				
exclusive	(adj). Excluding or not admitting other things; reserved for one particular group or person.				
exemplar	(n). A good or typical example.				
exempt	(v). To free from a duty.				
exempt	(adj). Be freed from a duty.				
exemption	(n). Being freed from an obligation.				
exhibit (v). To show or display.					
exhibit	(n). A part of an exhibition.				
expel	(v). Force someone or something to leave a place. Eject.				
extent (n). The area covered by something.					

F	
factor	(n). A circumstance, fact or influence that contributes to a result; a component or part.
factory	(n). A place where goods are made or put together from parts.

	[
find	(v). Discover or locate.				
find	(n). Results of a search or discovery.				
finding	(n). Information discovered as the result of an inquiry.(adj). Not able to move, attached; or repaired, not broken.				
fixed					
format	(n). Layout or pattern; the way something is laid out.				
G					
global	(adj). Found all over the world (globe).				
н					
hazard	(n). Something dangerous.				
heterogeneous	(adj). Made up of many different parts.				
homogeneous	(adj). Uniform, made up of the same types of parts.				
hypothesis	(n). A theory or proposed explanation.				
hypothetical	(adj). Theoretical or tentative; waiting for further evidence.				
1					
identify	(v). Recognise or point out.				
illustrate	(v). Give an example to show what is meant; draw.				
impair	(v). Weaken or damage.				
imply	(v). Suggest without directly saying what is meant.				
indicate	(v). Point out or show.				
initial	(n). First.				
initiation	(n). The action of beginning something; the action of admitting somebody into a group or organisation.				
initiation insufficient	something; the action of admitting somebody into a group or				
	something; the action of admitting somebody into a group or organisation.				
insufficient interchange-	something; the action of admitting somebody into a group or organisation. (adj). Not enough. (adj). Can be swapped or				
insufficient interchange- able	something; the action of admitting somebody into a group or organisation. (adj). Not enough. (adj). Can be swapped or exchanged for each other.				
insufficient interchange- able investigate	something; the action of admitting somebody into a group or organisation. (adj). Not enough. (adj). Can be swapped or exchanged for each other. (v). Carry out research or a study.				

8.4				
Μ				
macroscopic	(adj). Visible without being made bigger.			
manipulate	(v). Handle or control (a thing or a person).			
microscopic	(adj). Very small, not visible without being made bigger.			
motivate	(v). Give someone a reason for doing something.			
multiple	(adj). Many.			
Ν				
negligible	(adj). Small and insignificant; can be ignored. From "neglect" (ignore).			
numerical	(adj). Relating to or expressed as a number or numbers.			
numerous	(adj). Many.			
0				
observe	(v). Look at; watch carefully.			
obtain	(v). Get.			
occur	(v). Happen.			
operate	(v). Work; drive; control.			
optimal	(adj). Best; most favourable.			
optimum	(adj). Best; (n) the most favourable situation for growth or success.			
overabundance	(n). More than enough; too much.			
Р				
phenomenon	(n). A fact or situation that is seen to exist or happen.			
phenomena	(n). Plural of phenomenon.			
prefix	 (n). Part of a word that is attached to the beginning of many different words, changing their meaning, e.g., prehistoric – before written records were kept. 			
prepare	(v). Make ready before an event; set things up.			
principal	(n). Head of a school.			
principal	(adj). Main or most important.			
principle	(n). A basic truth that guides the way a person behaves.			

Q						
quality	(n). The standard of something compared to other similar things; a characteristic of someone or something.					
R						
reciprocal	(adj). Given or done in return.					
record	 (v). Make a note of something in order to refer to it later (pronounced ree-cord). (n). A note made in order to refer to it later; evidence of something; a copy of something (pronounced rec-cord. 					
record						
relative	(adj). Considered in relation to something else; compared to.					
relative	(n). A family member.					
represent	(v). Be appointed to act or speak for someone; amount to.					
resolve	(v). Finalise something or make it clear; bring something to a conclusion.					
respect	(v). Admire something or someone; consider the needs or feelings of another person.					
respectively	(adj). In regards to each other, in relation to items listed in the same order.					
S						
-						
simultaneously	(adv). At the same time.					
site	(n). Place.					
suffice	(v). Be enough.					
surplus	(adj). More than is needed.					
survey	(n). A general view, examination, or description of someone or something.					
survey	(v). Look closely at or examine; consider a wide range of opinions or options.					
т						
tendency	(n). An inclination to do something in a particular way; a habit.					
tertiary	(adj). Third level.					

U		
uniform	(n). Standardised clothing.	
uniform	(adj). Remaining all the same at all times; unchanging.	
V		
verify	(v). Show to be true; check for truth; confirm.	
vice versa	(adv). The other way round.	
versus	(prep). Against. Abbreviated "vs" and sometimes "v".	

Technical terms

Α			
absorption	(n). To take into; the process of taking something in.		
account	(n. & v.). Finance: A record of income and expenditure. To explain (v), e.g. "Account for why the sky is blue".		
acetic	(adj). Pertaining to vinegar; an organic molecule containing two carbons. See organic, eth- for more.		
acetone	(n). Propanone. CH_3COCH_3 ; the ketone of acetic acid. See ketone for more.		
acetylene	(n). Ethyne, C_2H_2 . Used in welding torches (blowtorches). See also alkene.		
acid	(n). A proton donor or substance that ionises into H^+ or H_3O^+ when dissolved in water; sour-tasting substance; corrosive; pH below 7. See also base and alkali.		
acidified	(adj). To have been made acidic.		
acidity	(n). How acid something is.		
activated	(adj). Made to function. Chemistry: something moved into an unstable higher-energy level or state. Usually "activated complex", the combination of reactants just before they turn into products. See also reactant, reagent, product.		
activation	(n). The process of activating something. "Activation energy", the required energy to create an activated complex.		
aerosol	(n). A solution of substances in air or other gas, e.g. as in an aerosol can.		

	affinity	(n). A liking for something;an attraction to something; atendency to react with something(chemistry). See also paraffin.(n). In common usage, ethanol					
	alcohol	(n). In common usage, ethanol C_2H_5OH . Technically, any organic substance or molecule containing an -OH group. See organic.					
	aldehyde	(n). Any organic molecule containing-CHO, formed by oxidising alcohols.See alcohol and organic.					
	algae	(n). Adjective: algal (pertaining to algae); an aquatic plant (lives in water), which lacks leaves, stems, roots.					
	algebra	(n). A mathematical system where unknown quantities are represented by letters, which can be used to perform complex calculations through certain rules.					
	alkali	(n). See base.					
	alkane	 (n). See base. (n). An organic molecule or compound or substance which contains only single bonds between carbons. See organic. 					
	alkene	(n). An unsaturated organic molecule, compound or substance, which contains at least one double bond between carbons. See organic and unsaturated.					
	alkyl	(n). A prefix (word part) which shows that the word after it has an alkane group attached to it, by removing one hydrogen from the alkane.					
	alkyne	(n). An unsaturated organic molecule, compound or substance, which contains at least one triple bond between carbons. See organic and unsaturated.					
	amalgam	(n). General use: a mixture. In chemistry, specifically a mercury alloy.					
	amide	(n). An organic compound containing the group -C(O)NH ₂ ; an inorganic compound containing the group NH ₂ ⁻ .					
	amine	(n). The same as an amide except the $-NH_2$ can be attached to anything, and does not have the CO group shown above.					
ĺ	ammonia	(n). NH ₃ .					
	ammonium	(adj). NH_4^+ , found as a cation or as part of a salt. See salt and cation.					
	amphiprotic	(n). See ampholyte.					
	ampholyte	(n). A substance that can act as an acid or base. See acid, base.					

anions	(n). A negative ion. See cation, ion.]	axis (sing),	(n). A line along which points can be
anode	 (n). The negative electrode of a cell or current supplier; the positive electrode of an electrolytic system; attracts negative ions. See electrode, cathode. 	-	axes (pl, pronounced "akseez")	plotted (placed), showing how far they are from a central point, called the origin. See origin. "Vertical axis" or "y-axis" refers to how high up a point is above the origin (or how far below). "Horizontal axis" or "x-axis"
antacid	(n). A substance used to neutralise (react with) acid. E.g. chalk. See acid, neutralise.			refers to how far left or right a point is away from the origin.
apparatus	(n). Equipment; parts of a scientific experiment.		В	
aqueous	(n). Dissolved in water.			
Arrhenius	(n). Arrhenius' theory of acids and bases: That acids produce H^+ or H_3O^+ in water, and bases produce OH^- . See Brønsted-Lowry.	a a s: e, or	bakelite	(n). A type of hard, brittle plastic that can't melt once it has set or taken shape (thermosetting), made from phenol C_6H_5OH , and formaldehyde (methanal), CH_2O .
asbestos asbestosis	 (n). A fireproof fibrous substance containing silicon used for fireproofing. (n). A lung disease caused by 		balance	(v. & n.). To make two things equal(v); a scale to weigh objects (n).Chemistry: to compare two sides
	inhaling asbestos fibres, can lead to cancer.			of a chemical equation and make sure that there are the same numbers of atoms on both sides.
atm	 (n). Abbreviation: atmospheres of pressure (1 atm = 101,3 kPa). The pressure of the air at sea level. Same as "bar" (barometric pressure). 		base	(n). A proton acceptor, or substance that ionises into OH ⁻ when dissolved in water; a bitter-tasting substance, corrosive, pH above 7. See also acid. Do not confuse with
ATM	(n). Abbreviation: automatic teller machine.			common everyday use, meaning "the bottom" or "low".
atmosphere	(n). The air or the gases surrounding a planet; the sky; as a unit of measurement, see atm.		basic	(n). Bitter or made of a base. Do not confuse with popular use, meaning "low" or "simple" or "crude".
atmospheric atom	 (adj). To do with the atmosphere. (n). The smallest unit of a chemical element, which, if broken down further, no longer behaves in the same way chemically. Consists of a nucleus or centre part which is positively charged, and an electron 		battery	(n). A collection of cells connected in series (end-to-end). See cell. In common use, "battery" is used to mean the same as "cell" (e.g. a penlight or AA cell), but this use is incorrect except for a car battery, which consists of a series of cells.
	cloud (negatively charged) which surrounds the nucleus. See nuclear.		benzoic	(adj). Contains benzene or a benzene ring.
attract	(v). To bring something closer.		bi-	(prefix). Two.
average	(n). Mathematics: The sum of parts divided by the quantity of parts. In common use: neither very good, strong, etc., but also neither very weak, bad, etc; the middle. In Physical Science and Mathematics:		bicarbonate	(n). Any salt containing the ion -HCO ₃ ⁻ . So called because the carbonate (CO_3^{2-}) attaches to another ion and the hydrogen (two bonds). The name "hydrogen carbonate" is now preferred.
	if you are asked to find the average, you always have to calculate it using the information you have. For example, the average of (1;2;3) is 2,			biodegradable
	because $(1+2+3)/3 = 2$. See also mean, median and mode.		biodiesel	(n). Diesel (a type of petrol) made from plants rather than fossil fuels (coal, oil).
avogadro (constant or number)	(n). 6,023 \times 10 ²³ particles; one mole. See mole and mol.			

ſ	I	
BODMAS	(abbr). Brackets, of/orders (powers, squares, etc), division, multiplication, addition, subtraction. A mnemonic (reminder) of the correct order in which to do mathematical operations.	
boil	(v). Physics: to cause a liquid's vapour pressure to exceed the pressure of the gas in the container, usually by heating it, but it can be done by lowering the pressure of the gas in the container, too. See vapour pressure. In common usage, to make a liquid hot until it bubbles.	
bond	(n). A connection. In physics and chemistry, between atoms and molecules.	
breadth	(n). How wide something is. From the word "broad".	
brine	(n). A saturated salt solution (a mixture of water and salt which can't dissolve any more salt).	
bromide	(n). Something containing bromine, usually one ion. See ion.	
bromo-	(prefix). Something containing bromine.	
bromothymol (blue)	(n). A type of acid-base indicator used to tell whether something is an acid or base. Turns blue (in base) or yellow (in acid).	ol
Brønsted-Lowry	(n). A theory of acids and bases which says that acids are proton donors (they give away protons), and bases are proton acceptors (they take protons). Since H ⁺ is just a proton, this does not mean something different from the Arrhenius theory that an acid is a substance that dissolves into H ⁺ in water. See proton, Arrhenius.	
but-	(prefix). Four carbons. Pronounced "beaut". E.g. butane is a four- carbon alkane.	
C		
calibrate	(v). To adjust a measuring tool or measurement against a known accurate measurement to ensure that the measuring tool or measurement is accurate; to check a measurement or measuring tool's accuracy; to mark with accurate measurements using a standard scale like cm, mm, mℓ, etc. Common use: to assess or evaluate carefully.	

carbohydrate	(n). Organic compounds containing carbon and hydrogen, occurring in foods and living tissues and including sugars, starch, and cellulose. They contain hydrogen and oxygen in the same ratio as water (2:1). Not the same as hydrocarbons, which are any substances containing mostly hydrogen and carbon.			
carbonate	(n)CO ₃ ²⁻			
carbonic	(adj). Anything containing carbon, or more specifically, $\rm CO_2$			
carbonyl	(adj). Containing double bonded carbon and oxygen: =C=O.			
carboxyl	(adj). Containing -COOH.			
carboxylic	(adj). Carboxyl-containing.			
Cartesian	(adj). Anything believed or proposed by Rene Descartes. In particular, the x-and-y axis coordinate system.			
catalyst	 (n). A substance that alters the rate of a chemical reaction without itself being consumed in the reaction. Without qualification, or as "positive catalyst", something that starts or speeds up a reaction. A "negative" catalyst slows down a reaction. 			
catalytic	(n). Containing or using a catalyst.			
cathode	(n). The positive electrode of a cell or current supplier; the negative electrode of an electrolytic system; attracts positive ions. See electrode, anode, ion.			
cathodic	(adj). Involving a cathode. Cathodic protection: To use a more reactive metal to protect a less reactive metal from oxidation. See anode, cathode, oxidise.			
cation	(n). A positively charged ion. See anion, ion.			
caustic	(adj). Basic; a base.			
cell	(n). An apparatus that generates electricity using electrochemistry. An AA or Penlight battery, as it is commonly called, is a cell. A car battery consists of a number of cells inside a single container.			
CFC	(n). A chlorofluorocarbon. A substance containing carbon, chlorine and fluorine. Responsible for breaking down ozone (O_3) which protects us from too much UV radiation from the sun.			

chain	(n). Chemistry: a long series of atoms bonded together, usually carbon.		compound	(n). A substance made up of molecules consisting of more than one different type of atom, chemically bonded in a constant ratio. E.g. Water (H_2O) is a compound, but Sulphur powder (S) is not. In a compound, the original chemicals (reactants) have reacted or merged to form a new substance. Compare to mixture.	
charge					
	a basic feature of all physical electromagnetic particles, except,		compressed	(adj). Subjected to pressure, squashed.	
	e.g. neutrons and photons, which have zero charge. All protons have a positive charge, all electrons have a negative charge.		concentration	(n). The number of moles of substance per unit volume. See mol, moles. How "strong" a solution is. See solution.	
chart	(v). To draw a diagram comparing values on Cartesian axes.		condensation	(n). When a vapour or gas cools down and starts to collect into	
Le Châtelier's Principle	(n). That in reversible reactions, chemical systems will favour the forward or reverse reaction to minimise the change imposed on the system. If a chemical			larger droplets; changing phase from vapour or gas to liquid. Condensation reaction: to produce a larger molecule from two smaller ones.	
	equilibrium is disturbed by changing the conditions, the position of equilibrium moves to counteract the change.		conditions (STP)	(n). Physics and Chemistry: how the environment is: temperature and pressure. STP (Standard Temperature and Pressure is 25°C	
chloro- chlorofluoro-	(prefix). Containing chlorine. See CFC.		conjugate	and 1 atm). (n). To join together. Chemistry: two	
carbons chloroform	(n). CHC ℓ_2 . A liquid formerly used		_		things that belong together, e.g. conjugate acid-base pairs.
chlorophyll	 as an anaesthetic. (n). A green substance found in plants which enables photosynthesis (broadly, generating food from CO₂). See photosynthesis. (n). A constant value placed 		conservation	 (n). A law which describes something that does not change. E.g. the conservation of matter- energy says that matter-energy cannot be created or destroyed, only transformed from one form into another. There are a number 	
	next to an algebraic symbol as a multiplier. Same as constant (see		constant	of other conservations, e.g. momentum and torque. (n). See coefficient. Means	
	below). Or: a multiplier or factor that measures a property, e.g.			"unchanging".	
combustion	coefficient of friction.(n). The process of burning, usually in oxygen. Rapid oxidation.		contaminate	(v). Chemistry: to introduce impurities or other substances which are not meant to be part of a reaction.	
completion	(n). Chemistry: when a reaction no longer proceeds (continues) because it has run out of one or more of the reactants. See reactant, reaction.		control	(n. and v.). To ensure something does not change without being allowed to do so (v); an experimental situation to	
complex (activated)	(n). See activated.			which nothing is done, in order to compare to a separate experimental situation, called the 'experiment', in which a change is attempted. The control is then compared to the experiment to see if a change happened.	

control variable	(n). A variable that is held constant in order to discover the relationship		degradable	(adj). Capable of breaking down or being broken down.
	between two other variables. "Control variable" must not be confused with "controlled variable" (see independent variable).		dehydrating (agent)	(adj). To remove water from. A "dehydrating agent" is a substance which can remove water from another substance. E.g. H_2SO_4 ,
coordinate	(n). The x or y location of a point on a Cartesian graph, given as an x or y value. Coordinates (pl) are given as an ordered pair (x, y).		dehydration	ethanol.(n). The process of removing water from a substance.
correlate	(v). To see or observe a relationship between two things,		dehydrogena- tion	(n). The process of removing hydrogen from a substance.
	without showing that one causes the other.		dehydrohalo- genation	(n). To remove hydrogen and a halogen from a substance. See halogen.
correlation	(n). That there is a relationship between two things, without showing that one causes the other.		denominator	(n). See divisor. In popular speech: a common factor.
correspond	(v). To pair things off in a correlational relationship. For two things to agree or match. E.g. A		depend	(v). To be controlled or determinedby something; to require somethingto happen or exist first.
	corresponds to 1, B corresponds to 2, C corresponds to 3, etc.		dependent (variable)	(adj/n). A variable whose value depends on another; the thing that comes out of an experiment,
corrode	(v). Chemistry: to destroy by gradual chemical action. Usually refers to acidic action. Compare to erode. General use: to destroy gradually.			the effect; the results. See also independent variable and control variable. The dependent variable has values that depend on the independent variable, and we plot
corroding	(adj). A process or substance that corrodes; to be subject to corrosion.	ol	depleted	it on the vertical axis. (adj). Having been used up; run
corrosion	(n). To corrode.			out of.
corrosive	(adj). To be capable of corroding something.		deposit	(n). Finance: to place money into an account. Physical Science: to cover a surface of one substance
counteract	(v). Oppose or resist.			with another substance, e.g. metal
covalent	(adj). Chemistry: a bond which results from sharing electrons between atoms. Compare ionic		determine(s) (causation)	(v). To cause; to ensure that; to set up so that; to find out the cause of.
	bond.		di-	(prefix). Two.
cracking	(n). A process of breaking a complex organic molecule into		diamine	(n). A substance containing two amine groups. See amine.
cubed	simpler parts using heat and pressure. (adj). The power of three;		diammonium	(n). Having two ammonium (NH ₄) groups. See ammonium.
cubeu	multiplied by itself three times.		diaphragm	(n). A thin sheet of any substance
cubic	(adj). Shaped like a cube; having been multiplied by itself three times.			covering a gap. Biology: the musclebelow the lungs which moves tocause breathing. Electrochemistry:a thin sheet inside a cell which
current D	(n). Flowing electrons.			separates the electrodes. It is porous and allows solutions containing ions through, but serves
decompose	(v). To break down into		difference	to separate gas products.(n). Mathematics: subtraction.Informally: a dissimilarity. How
	components.			things are not the same.

		1
dilute	(adj. & v). To lower the concentration of a solution. See solution and concentration (v): a solution which has had its concentration lowered (adj).	
dilution	(n). The opposite of concentration; how low a concentration is, measured in mol/dm ³ ; the process of diluting.	
dimer	(n). A molecule made of two identical parts. See also polymer.	
diode (n). A semiconductor device with two terminals (electrodes), usually allowing current to flow in one direction only.		
diol	(n). A molecule with two alcohol/ hydroxyl (OH) groups.	
dipole	(n). A polarised molecule with a distinctly positive and distinctly negatively-charged end.	
diprotic	(n). Having two protons.	
displace	(v). To move or relocate something.	
dissipate	 (v). To disperse or scatter (e.g. gas). Thermodynamics (Energy): to cause energy to be lost as heat. Popular use: to disappear. 	
dissociate	(v). To break apart; to no longer be associated with.	
dissolve	 (v). To break up into ions within a solution (usually water); to mix a solid (usually powder) into a liquid, to form a solution. See solution, ion. Alternative popular use: to bring to an end. 	
distil(I)	(v). To purify through repeated heating of a liquid and collection of condensation. The heating process causes the liquid to form gas or vapour, which condenses on the side of the heating vessel (container) or an exit tube, leaving impurities behind in the heating vessel.	-
distribution	ution (n). How something is spread out. Mathematics: the range and variety of numbers as shown on a graph.	
disturb	(v). Chemistry: to mix or stir a liquid or solution; to shake it up.	
divisor	(n). The number below the line in a fraction; the number that is dividing the other number above the fraction line. See numerator, denominator.	

domain	(n). The possible range of x-values for a graph of a function. See range.
durable	(adj). Tough; something that can endure.
dynamic	(adj). Changing often. Relating to forces that produce motion. Opposite of static. See static and electrostatic.
E	
ecosystem	(n). An integrated, complex, interacting, mutually dependent living system or environment.
electric	(adj). Containing electricity (electrons).
electro- chemical	(adj). Where chemical reactions cause the release of electrons, usually into a circuit. General use: anything relating to electrical and chemical phenomena.
electrode	 (n). General use: the point where electrons enter or exit a power source or a circuit. Specifically (Electrochemistry): Part of a circuit dipped into a solution to receive or release electrons. See anode and cathode.
electrolysis	(n). The splitting of a chemical into ions. (The chemical is usually dissolved in water or another solution.) It is done by means of electricity. See electrochemical.
electrolyte	(n). A substance (usually liquid or gel solution) which contains a compound that will be split by electricity. Ionisable solutions or components.
electromotive	(adj). Usually electromotive force or emf. The potential difference caused by electromagnetism, which causes current to flow. Producing a current with electromagnetism. See emf.
electron	(n). A fundamental physical particle bearing a negative charge, weighing approximately 9×10^{-28} g, which is found around atomic nuclei in areas called 'orbitals'. Responsible for electricity and chemical reactions. Symbol e ⁻ . See proton, nucleus.

electroplate	(v). To cover a surface of a less valuable substance with a more valuable metal, using electrolysis.	energy	(n). Work or the ability to do work. There are various forms of energy: motion (E_k) , light energy		
element	(n). Mathematics: part of a set of numbers. Physics: a pure substance made only of atoms of one type, with the same number of protons in each nucleus. An		(photons), electrical energy, heat, etc. Energy can neither be created nor destroyed, but only converted from one form to another. See conservation.		
	element cannot be broken down further without losing its chemical properties. Each element has a	enthalpy	(n). The total heat content of a system, H, including the chemical energy.		
unique atomic number which is the number of protons in the nucleus. See nucleus, atom, isotope. Popular use: part of.		equilibria (pl), equilibrium (sing)	(n). The state of being in balance. Chemistry: when the forward reaction rate is equal to the reverse reaction rate. See Le Châtelier's Principle.		
out of one side of an equation by dividing by that factor throughout.		erode	(v). To wear away by means of friction (rubbing).		
		ester	 (n). An organic compound produced by bonding an alcohol to a carboxylic (organic) acid, by means of dehydration. See carboxylic, organic, alcohol, dehydration. Responsible for fruit flavours and many pleasant odours (smells). 		
emf (abbr). Same as electromotive		esterfication	(n). The production of esters.		
emission	force. Always written in lowercase (small letters). (n). Something released, e.g. gas,	estimate	(n., v.). To give an approximate value close to an actual value; an imprecise calculation.		
emission	light, heat.	eth-	(prefix). Containing two carbons.		
emit empirical	(v). To release.(adj). Relating to the senses or to things that you can see, touch,	eutrophicatio	 n (n). Excess nutrients in water causing excessive plant growth and strangulation of a waterway. 		
	taste, etc. Chemistry: empirical formula: a formula giving the proportions of the elements	evaporate	(v). To change phase of matter from liquid to gas. Compare sublimate and boil.		
	present in a compound but not the actual numbers or arrangement of atoms; the lowest ratio of	excited	(n). The state of being in a higher energy level (higher than ground state).		
	elements without giving structure or quantities.	exo-	(prefix). Outside of.		
emulsion	(n). Small particles or droplets of a substance or liquid which do	exothermic	(adj). Giving off heat, $\Delta H < 0$. See enthalpy, endothermic.		
	not dissolve in a different liquid; suspended or floating within that liquid, e.g. to mix oil and water by shaking them up.	exponent	(n). When a number is raised to a power, i.e. multiplied by itself as many times as shown in the power (the small number up above the		
endothermic	(adj). Taking in heat, $\Delta H > 0$. See enthalpy, exothermic.		base number). So, 2^3 means $2 \times 2 \times 2$. See also cubed.		
energetic	(adj). Having a lot of energy; performing a lot of work.	exponential	(adj). To multiply something many times; a curve representing an exponent.		

further, into values not empirically documented, to project a future event or result. In plain language:		ormic	(prefix). Same as meth Contains one carbon. From Latin "formica": ant, referring to formic acid, which is found in an ant's sting.	
based on past results which were obtained (gotten) by experiment and measurement. If you have a graph and have documented certain results (e.g. change vs time), and you draw the line further in the same curve, to say what future results you will get, that is called 'extrapolation'. See predict.extrude, extrusion(v., n.). To push something through a mould or shape, usually a liquid or gel through a hole, to create a new shape.F		raction	(n). Mathematics: Not a whole number; a representation of a division. A part. E.g. the third fraction of two is 0,666 or ² / ₃ . meaning two divided into three parts. Chemistry: a part of a solution or mixture separated out by distillation. See distil.	
		unction	(n). Mathematics: when two attributes or quantities correlate. If y changes as x changes, then y = f(x). See correlate, graph, Cartesian, axis, coordinate. Also: a relation with more than one variable (mathematics). Chemistry: functional group: part of a molecule that gives the substance its chemical properties in common	
(n). A temperature scale based on human body temperature.			with other similar chemicals.	
Water freezes at 32°F and boils		3		
		u		
formula to centigrade/celcius is: (°F - 32) × $5/_9 = °C$ avoured(adj). Preferred. Chemistry: in a chemical reaction, the direction of the reaction after the equilibrium is broken.		galvanic	(adj). Relating to currents caused by a chemical reaction. See electrochemistry.	
		galvanising	(n). To electroplate so as to protect, e.g. cover iron with zinc to prevent rust.	
(n). The conversion of a sugar or carbohydrate to an alcohol, usually by yeast or bacteria.	E	gas	(n). The third phase of matter. When a solid is heated it turns into liquid, and when a liquid is heated	
(n). The process of adding			it turns into gas.	
			(adj). In a gas form.	
cells) into a zygote (group of cells that will become a foetus or other living organism).	8	gradient	(n). A slope. An increase or decrease in a property or measurement. Also the rate of such a change. In the formula for a line	
nutritional reasons.		gradually	graph, y = mx + c, m is the gradient. (adv). To change or move slowly.	
(n). The process of fixing on something or someone.			(n). A diagram representing experimental or mathematical	
(n). The process of attaching one chemical or compound to another. E.g. nitrogen fixing is the bonding of free N_2 to organic chemicals.	£	graphic	values or results. See Cartesian. (n., adj.). A diagram or graph (n). Popular use: vivid or clear or remarkable (adj.).	
(n). Any substance that can flow and take the shape of a container; liquid, some gels, and gas.			(adv). Using a diagram or graph. Popular use: to explain very clearly.	
(n). Bright, colourful, due to	8	groundwater	(n). Water held in the earth (underground).	
changes in energy levels of		zvosum	(n). Calcium sulphate.	
electrons, as seen in fluorescent tubes, ink, etc. See reflective.				
	documented, to project a future event or result. In plain language: to say what is going to happen based on past results which were obtained (gotten) by experiment and measurement. If you have a graph and have documented certain results (e.g. change vs time), and you draw the line further in the same curve, to say what future results you will get, that is called 'extrapolation'. See predict. (v., n.). To push something through a mould or shape, usually a liquid or gel through a hole, to create a new shape. (n). A temperature scale based on human body temperature. Water freezes at 32°F and boils at 212°F under standard conditions. The conversion formula to centigrade/celcius is: $(^*F - 32) \times ^{5}/_{9} = ^{\circ}C$ (adj). Preferred. Chemistry: in a chemical reaction, the direction of the reaction after the equilibrium is broken. (n). The conversion of a sugar or carbohydrate to an alcohol, usually by yeast or bacteria. (n). The process of adding nutrients to soil. Biology: the fusion of male and female gametes (sex cells) into a zygote (group of cells that will become a foetus or other living organism). (n). The process of fixing on something or someone. (n). The process of attaching one chemical or compound to another. E.g. nitrogen fixing is the bonding of free N ₂ to organic chemicals. (n). Any substance that can flow and take the shape of a container; liquid, some gels, and gas. (n). Bright, colourful, due to changes in energy levels of electrons, as seen in fluorescent	documented, to project a future event or result. In plain language: to say what is going to happen based on past results which were obtained (gotten) by experiment and measurement. If you have a graph and have documented certain results (e.g. change vs time), and you draw the line further in the same curve, to say what future results you will get, that is called 'extrapolation'. See predict. (v., n.). To push something through a mould or shape, usually a liquid or gel through a hole, to create a new shape. (n). A temperature scale based on human body temperature. Water freezes at 32°F and boils at 212°F under standard conditions. The conversion formula to centigrade/celcius is: (°F - 32) × $5'_9$ = °C (adj). Preferred. Chemistry: in a chemical reaction, the direction of the reaction after the equilibrium is broken. (n). The conversion of a sugar or carbohydrate to an alcohol, usually by yeast or bacteria. (n). The process of adding nutrients to soil. Biology: the fusion of male and female gametes (sex cells) into a zygote (group of cells that will become a foetus or other living organism). (n). A substance added to soil for nutritional reasons. (n). The process of fixing on something or someone. (n). The process of fixing on something or someone. (n). The process of fixing on something or someone. (n). The process of attaching one chemical or compound to another. E.g. nitrogen fixing is the bonding of free N ₂ to organic chemicals. (n). Any substance that can flow and take the shape of a container; liquid, some gels, and gas. (n). Bright, colourful, due to changes in energy levels of electrons, as seen in fluorescent	documented, to project a future event or result. In plain language: to say what is going to happen based on past results which were obtained (gotten) by experiment and measurement. If you have a graph and have documented certain results (e.g. change vs time), and you draw the line further in the same curve, to say what future results you will get, that is called 'extrapolation'. See predict. function (v., n.). To push something through a mould or shape, usually a liquid or get through a hole, to create a new shape. function (n). A temperature scale based on human body temperature. Water freezes at 32° F and boils at 212°F under standard conditions. The conversion formula to centigrade/celcius is: (`F - 32) × ⁵ / ₉ = °C G (adj). Preferred. Chemistry: in a chemical reaction, the direction of the reaction after the equilibrium is broken. galvanising (n). The process of adding nutrients to soil. Biology: the fusion of male and female gametes (sex cells) into a zygote (group of cells that will become a foetus or other living organism). gaseous (n). The process of fixing on something or someone. gradually (n). The process of fixing on something or someone. graphic (n). Any substance that can flow and take the shape of a container; liquid, some gels, and gas. graphically (n). Bright, colourful, due to changes in energy levels of electrons, as seen in fluorescent graphically	

Н			
Haber (process)	(n). An industrial process to produce ammonia from nitrogen and hydrogen, using an iron catalyst at high temperature and pressure.		
haemoglobin	(n). A compound containing iron, found in red blood cells, responsible for carrying oxygen.		
half-cell	(n). One of the sides of an electrochemical cell; one of the electrodes and the chemical solution around it.		
half-reaction	(n). The equation for the chemical reaction occurring in a half-cell.		
halide	(n). A compound containing a single halogen, e.g. NaC ℓ . See halogen.		
halo-	(prefix). Containing a halogen. See halogen.		
haloalkane	(n). An alkane bonded to a halogen. See halogen.		
halogen	(n). Any of the elements fluorine (F), chlorine ($C\ell$), bromine (Br), iodine (I), and astatine (At), in group VIIA (17) of the periodic table. They combine with metals to produce salts. See salt.		
halogenation	(n). Adding a halogen.		
hardness	 (n). (Water). Containing salts, usually calcium carbonate. If water contains too many such salts, soap does not function properly and doesn't produce bubbles or foam. "Water's hardness is determined by the concentration of multivalent cations in the water. Multivalent cations are cations (positively charged metal complexes) with a charge greater than 1+. Usually, the cations have the charge of 2+. Common cations found in hard water include Ca²⁺ and Mg²⁺." (Wikipedia). 		
heat	 (n). Physics: a measure of the average kinetic energy of the molecules or atoms in a substance; enthalpy; the energy of an object as molecular motion. Alternatively, infra-red radiation (heat radiation) coming off a body. See body. 		
homologous	 (n). Belonging to the same group of things; analogous. Biology: a flipper is homologous with a leg or arm. Chemistry (organic): belonging to the same series of molecules, e.g. alkanes: methane, ethane, propane; having the same functional group. 		

hydrate	(n). To add water to.	
hydration	(n). Having had water added.	
	Some salts are hydrated, meaning that they have a number of water molecules bonded to them, which can be removed by heat. Heating a hydrated salt changes its colour but not the chemical reactions it will undergo. See salt.	
hydrocarbon	(n). Any compound consisting mainly of hydrogen and carbon. Compare carbohydrate.	
hydrochloric	(adj). Any chemical containing HC ℓ .	
hydrohalogen- ation	(n). Adding a hydrogen and halogen atom to a molecule.	
hydrolysis	(n). Splitting by reacting with water. Applies to salts and organic chemicals. E.g. A haloalkane plus water or a dilute NaOH gives an alcohol and either a hydrohalide or sodium salt. Dissolving a salt in water can be considered hydrolysis.	
hydronium	(n). H_3O^+ ion.	
hydroxide	(n). OH ⁻ ion. This usage applies specifically to bases (see acid, base). In organic molecules, OH ⁻ is an alcohol functional group called the hydroxyl group. See alcohol, hydroxyl, diol.	
hydroxyl	(n). See hydroxide.	
hydroxylamine	(n). An amine with a hydroxyl group.	
1		
ideal	(adj). Not as seen in real life; theoretical. Ideal gas: a hypothetical gas whose molecules occupy negligible space and have no interactions, and which consequently obeys the gas laws (PV = nRT) exactly.	
ignition	 (n). The start of a combustion reaction. Common use: to start a car (which has an internal combustion engine). See engine, combustion. 	
illuminate (v). To explain or light up.		
immerse (v). To cover in liquid.		
impair	(v). Prevent; hinder; slow down.	
impure	(adj). Containing a variety of additional chemicals in smaller amounts in addition to the main chemical.	

In a null set of	(adi) Oining off light - II f	1	
incandescent	(adj). Giving off light as a result of being heated.		
independent (variable)	(n). The things that act as input to the experiment, the potential causes. Also called the controlled variable. The independent variable is not changed by other factors, and we plot it on the horizontal axis. See control, dependent variable.		
indicator	(n). Chemistry: a substance used to check for pH levels, which changes colour according to pH. See acid, base, pH.		
indigo	(n). The colour between violet and blue; purplish-blue.		
inert	(adj). Chemistry: a chemical or element which does not react or is difficult to cause to react, e.g. Ne, Xe, He. N ₂ is sometimes described as inert but it's not in the group of Noble Gases. Common use: lazy, unwilling to move.		
inflammable	(adj). Same as flammable; easily set on fire (combustion).		
inhibitor	(n). Something that slows down or prevents.		
inorganic	(adj). Not containing carbon; mineral. Exceptions are C, CO, CO ₂ , which, whilst they contain carbon, are not considered organic as they can be produced during inorganic chemical reactions.		
insoluble	(adj). Not able to dissolve.		
insufficient	(adj). Not enough.	1	
interact	(v). To affect each other, to be directly involved with or act on each other.		
intermediate	(adj). A state in between.		
intermolecular	(adj). Between molecules. See molecule, intramolecular.		
intramolecular	(adj). Within or inside a molecule. See molecule, intermolecular.		
inversion	(n). Chemistry: turning something upside down.		
ion	 (n). An atom or molecule or part of a molecule which has an electrical charge due to gaining or losing one or more electrons. 		
ionic (bond)	(adj.). A bond in which electrons have been transferred from one side of the molecule to another resulting in a cation and anion, which then attract. E.g. NaC ℓ .		
ionisation	(n). The process of ionising. See ionise.		
ionise	(v). To turn into an ion. See ion.	1	

irreversible	(adj). Cannot be reversed. Said of certain chemical reactions, in which case it specifically means that the reaction does not spontaneously reverse (not an equilibrium reaction). The reaction only proceeds in one direction. Example: combustion.
isolate	 (v). To separate from. Usual use in Physical Science means to separate one chemical from another. Compare insulate, distil.
isomer	(n). A substance with the same empirical formula but a different structural formula. See empirical, structural.
isotope	(n). An element which has a different number of neutrons from the usual number of neutrons in the element. E.g. ¹² C has 6 protons and 6 neutrons, but ¹⁴ C has 8 neutrons and 6 protons, and is radioactive.
	(abbr). International Union of Pure and Applied Chemistry. Standardised naming conventions for chemicals.
J	
joule	(n). Unit of energy.
К	
kelvin	(n). Unit of temperature, with absolute zero being the point where no molecular motion occurs, at -273,15 °C. Hence, the freezing point of water is 273,15 K. Note that there is no degree sign before K.
ketone	(n). An organic compound with the carbonyl group = $C = 0$. Made by oxidising secondary alcohols. E.g. acetone.
L	
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law	(n). In Physical Science, a formula or statement, deduced (discovered) from observation (watching). The formula or statement will then predict that under the same conditions the same thing will always happen. E.g. the first law of thermodynamics says that matter and energy cannot be destroyed, but only changed from one form to another.

	1		
leach	(v). When a substance drains out of soil, e.g. into rivers. Similar to "leak".		
litmus	(n). A type of acid/base indicator. See indicator. It is red when exposed to acid and blue when exposed to a base.		
Μ			
macromolecule	(n). A large molecule, usually a polymer or protein.		
macroscopic	(adj). Large enough to be visible to the unaided human eye; big enough to be seen.		
magenta	(n). A bright purple/pink colour.		
manipulate	(v). To change, or rearrange something. Usually in Mathematics it means to rearrange a formula to solve for (to get) an answer.		
material	(n). Any substance, not just cloth.		
matter	(n). Substance; stuff. Opposite of vacuum (nothing).		
mean	(n). See average.		
median	(n). Mathematics: the number in the middle of a range of numbers written out in a line or sequence.		
metal	(n). A substance which is malleable (can be hammered flat), is ductile (can be drawn into a wire), which conducts electricity and heat well and which is reflective (most light striking it is emitted again). Most elements are metals except the few on the right hand side of the periodic table starting at Boron (B) and running diagonally down to Astatine (At).		
meth-	(prefix). Having one carbon. See formic.		
methylated	(adj). Having had a single carbon or methyl group added.		
metric	 (adj). A measurement system, using a base of 10 (i.e. all the units are divisible by 10). The USA uses something known as the Imperial system, which is not used in science. The Imperial system is based on 12. Examples: 2,54 cm (metric) = 1 inch (imperial). 1 foot = 12 inches = approx. 30 cm; 1 metre = 100 cm. 1 FI.Oz (fluid ounce) = approx 30 m ℓ. 		
microscopic	(adj). Too small to be seen by the unaided human eye.		

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minimum	(n). The smallest amount possible.		
mixture	(n). When you mix or combine		
	substances without them		
	undergoing a chemical reaction. In other words, the substances mixed		
	stay separate (chemically) and do		
	not bond. Different to compound.		
	See compound, reaction.		
modal	(adj). Pertaining to the mode, or		
	method. Can mean: about the		
	mathematical mode or about the method used. See mode.		
mada			
mode	(n). Mathematics: the most common number in a series of		
	numbers. See also mean, median.		
mol	(abbr). Mole.		
molar	(adj). About a mole. See mole.		
mole	(n). A unit describing an amount		
	of substance. $6,023 \times 10^{23}$		
	molecules or atoms of the		
	substance.		
	E.g. 18 g of water is 1 mol of $(1 - 1, 0 - 1)$		
	water (H = 1, 0 = 16, H_2^0 = 18).		
molecular	(adj). About molecules. See molecule.		
molecule	(n). The smallest amount of a		
	compound; a single particle		
	composed of the elements that make up the compound. E.g. in		
	water, a single particle consisting		
	of two hydrogen atoms and one		
	oxygen atom.		
mono-	(prefix). One.		
monomer	(n). Part of a macromolecule; the		
	simplest repeating unit. Monomers		
	bond to form polymers. See polymer, isomer.		
monoprotic	(adj). Having one proton.		
N			
14			
noutrol	(adi) Chamiatry all 7.0 Naithar		
neutral	(adj). Chemistry: pH 7,0. Neither acid nor base. E.g. water. In		
	common use: not biased. See bias.		
neutralise	(v). To make something neutral; to		
	complete an acid/base titration.		
neutron	(n). A subatomic particle with		
	no charge, mass approximately		
	the same as a proton, found in the		
	nucleus of an atom. Symbol nº. If there are too many protons in		
	a nucleus, the substance will be		
	radioactive as it releases		
	alpha particles (helium nuclei,		
	$2p^+ + 2n^0$).		

nitrate	(n). Containing NO_3^{-} .		parallel
nitrite	(n). Containing NO_2^{-} .	1	
nomenclature	(n). A system of describing things; a naming system, designed to make a name unambiguous or unique.		
nonmetal	(n). Any of the elements that are not metals, e.g. Boron (B), Silicon		particle
	(Si), Sulphur (S), Oxygen (O), etc.		pascal
nucleus (sing),	(n).The centre of something		pent-
nuclei (pl), nuclear (adj)	(generally), specifically the centre of an atom, consisting of at least one proton (hydrogen), or two protons and two neutrons (helium). Plural nuclei is pronounced "noo- klee-eye".		per
numerator	(n). The opposite of a denominator;		peroxide
	the number on top in a fraction.		perpend
0			phase
-oate	(suffix). An ester.		
odour	(n). A smell.		
optimal	(adj). Best, most.		
organic	(adj). Containing carbon, except C, CO, CO_2 .		
origin	(n). Mathematics: the centre of a Cartesian coordinate system.General use: the source of anything, where it comes from.	ole	
outlier	(n). Statistics: a data point which lies well outside the range of related or nearby data points.		photosy
oxalic (acid)	(n). Ethanedioic acid; chem. formula: (COOH) ₂ .		pi
oxidation	(n). Specifically, adding an oxygen atom to a molecule, but more general use: losing electrons from any substance in a redox reaction.		plastic
oxide	See redox. (n). A compound containing an oxygen atom, especially if it previously did not contain one, e.g. iron (metal), vs iron oxide (rust).		
oxidise	(v). To add an oxygen or remove electrons from a substance.		plot
Ρ			poly-
			polyeste
paraffin	(n). Any waxy organic substance, previously the general name for alkanes. Formula ranges from		polymer
	$C_{20}H_{42}$ to $C_{40}H_{82}$.		polymer
		,	polyprot

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parallel	(adj). Keeping an equal distance along a length to another item (line, object, figure). Mathematics: two lines running alongside each other which always keep an equal distance between them.
particle	(n). Any small part, e.g. a proton, an atom, a molecule.
pascal	(n). The unit of pressure, abbreviated Pa, units: N/m ²
pent-	(prefix). Five.
per	(prep). For every, in accordance with. Chemistry: the maximum amount of an element possible for the number of bonds available. See e.g. peroxide.
peroxide	(n). H ₂ O ₂ .
perpendicular	(adj). Normal; at right angles to (90°).
phase	(n). Time, period; a state of matter (solid, liquid, gas); the relationship in time between the cycles of a system (such as an alternating electric current or a light or sound wave) and either a fixed reference point or the states or cycles of another system with which it may or may not be synchronised (simultaneous). I.e. if two systems vibrate at the same time at the same rate, they're "in phase".
photosynthesis	(n). The process of converting CO_2 into carbohydrates using atmospheric CO_2 , chlorophyll, and light.
pi	(n). π , the Greek letter p, the ratio of the circumference of a circle to its diameter. A constant without units, value approximately 3,14159.
plastic	(n., adj.). An artificial substance made from hydrocarbon polymers which is often flexible and able to be moulded and is often a poor electrical conductor (n); flexible (adj).
plot	(v). To place points on a Cartesian coordinate system; to draw a graph.
poly-	(prefix). Many.
polyester	(n). A polymer made from esters.
	(II). A polymer made nom esters.
polymer	(n). A synthetic substance madefrom many monomers (repeating units). See monomer.
polymer polymerisation	(n). A synthetic substance made from many monomers (repeating

porous	(adj). Having many holes that allow
μοιοαδ	fluids through.
positive	(adj). Having many protons not paired with electrons; a lack of electrons.
potential	(n). Having the ability to do work, in particular, E_p (potential energy, the tendency to fall or start moving, as in a spring), or emf (voltage). General use: potential exists when there is an energy difference between two points, e.g. due to gravity or electrical charge. In the context of electricity, read it as "voltage".
precipitate	(n). Chemistry: A product of a reaction that cannot dissolve in the solution and settles at the bottom of the reaction vessel (container).
predict	(v). General use: to foresee.Physical Science: to state what will happen, based on a law. See law.
pressure	(n). A continuous force exerted on an object over a certain area, in pascals, Pa. N/m ² . See pascal.
product	(n). Chemistry: the substance or compound made as a result of a chemical reaction. See reaction. Mathematics: the result of multiplying two numbers.
project	 (n. & v.). A project (n., pronounced PRODJ-ekt) is a plan of action or long-term activity intended to produce something or reach a goal. To project (v., pronounced prodj-EKT), is to throw something, or to guess or predict (a projection). To project a result means to predict a result. See extrapolate.
prop-	(prefix). Three carbons. Pronounced "prope" (rhymes with "rope").
proportion	(n). To relate to something else in a regular way, to be a part of something in relation to its volume, size, etc; to change as something else changes. See correlate and respectively.
protein	(n). A large, complex organic molecule containing nitrogen, usually making up structural elements of living things (building blocks of cells, antibodies, etc).
protolytic	(adj). Capable of removing a proton; proton transfer. Compare acid.

 (n). The positively-charged particle that forms the centre of an atomic nucleus, weighing 1 836 times as much as an electron, but having the same and opposite charge. Symbol p⁺. See also nucleus, neutron, electron.
(n). A machine that uses energy to transfer a fluid from one place to another. In Biology one finds cellular pumps, which are biological machines for transferring ions and nutrients.
(adj). Containing only the compound or element in question, without any other compounds or elements mixed in. See impure.
(n). The process of removing impurities. See distil.
(adj). Relating to the quality or properties of something. A qualitative analysis looks at changes in properties like colour, that can't be put into numbers. Often contrasted with quantitative.
(adj). Relating to, or by comparison to, quantities. Often contrasted with qualitative. A quantitative analysis is one in which you compare numbers, values and measurements.
(n). Amount; how much.
(n). Having an unpleasant smell due to having started to ferment or rot, usually said of meat, oil or butter.
(n). Unpredictable, having no cause or no known cause. Done without planning.
(n). Mathematics: the set of values that can be supplied to a function. The set of possible y-values in a graph. See domain.
(n). How often per second (or per any other time period). Physics: number of events per second; see frequency.

	1
ratio	(n). A fraction; how one number relates to another number; exact proportion. If there are five women for every four men, the ratio of women to men is 5:4, written with a colon (:). This ratio can be represented as the fraction $\frac{5}{4}$ or $1\frac{1}{4}$ or 1,25; or we can say that there are 25% more women than men.
react	(v). Chemistry: when two or more elements or compounds are brought into a mixture and form chemical bonds, creating new compounds.
reactant	(n). A chemical before it bonds with another chemical. See reagent.
reaction	 (n). Chemistry: The process of reacting; a state in which chemicals react. See endothermic and exothermic. Physics (nuclear): When a nucleus of an atom breaks down and subsequently releases energy and/or bonds with another nucleus. In the first case, it is a fission (splitting) reaction, in the second case a fusion (joining) reaction.
reactive	(adj). Tending to react easily.
reactivity	(n). How reactive a substance is (unreactive or reactive).
reagent	(n). A reactant when it is still in its bottle or container, before being mixed.
redox	(abbr). Chemistry: reduction- oxidation reaction; a chemical reaction in which one substance is reduced (gains electrons), and another is oxidised (loses electrons). See reduce, oxidise, anode, cathode, electrode, electrochemistry.
reduce	(v). To make smaller. Chemistry: to gain electrons (negative charges).
reflux	 (n., v.). A substance that flows back into its container after coming out. Chemistry: the process of boiling a liquid so that any vapour is liquefied and returned to the stock (source).
refraction	 (n). Bending light when it travels from one medium (e.g. air) into another medium (e.g. water or glass). Changing the direction of propagation of any wave as a result of its travelling at different speeds at different points along the wave front. See Huygens' principle, diffraction.

S	
salt	(n). In common usage, NaC ℓ . Chemistry: any compound formed from the reaction of an acid with a base, with the hydrogen of the acid replaced by a metal or other cation. A non-metal ion bonded to a metal ion.
saturated	(adj). Organic chemistry: Having no available bonds or only single bonds. Common use: cannot take any more, usually said of a cloth and liquid.
SI	(abbr). Système International. The international system of metric units used by scientists. See metric, IUPAC.
simplify	(v). To make simpler. Mathematics: to divide throughout by a common factor (number or algebraic letter) that will make the equation easier to read and calculate.
slaked (lime)	(n). Calcium Hydroxide, Ca(OH) ₂ .
solubility	(n). How easily something dissolves (mixes into a liquid).
soluble	(adj). See solubility.
solute	(n). The substance that you place in a liquid (the solvent) so as to dissolve it. E.g. salt. See solvent.
solution	 (n). A mixture of a solute and a solvent. A liquid which has had something dissolved in it (mixed). Mathematics: the step-by-step displaying of calculations to arrive at answers. Common use: the answer to a problem, in the sense of dissolving (removing) a problem.
solvent	(n). The liquid that dissolves the substance placed into it. E.g. water.
spectator	(n). Chemistry: a compound or chemical which does not get involved in a chemical reaction.
spontaneous	(adj). Randomly, without provocation or cause or prior planning.
stable	(adj). Chemistry and Nuclear Physics: not likely to break down or react further.
standardised	(adj). Chemistry: a solution of known concentration, e.g. 1 molar (1 mol/dm ³).

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steam	 (n). Water vapour, microscopic droplets of water. Not a gas, a suspension of water droplets in air. See suspension, gas, liquid, phase, aerosol. 	
STP	(abbr). Standard temperature and pressure; 101,3 kPa and 25 °C.	
structural (isomer)	(adj.). Pertaining to structure; a series of molecules whose structures are different but their chemical or empirical formulae are the same.	
sublimate	(v). To change phase of matter from solid straight to gas without the intermediate phase of liquid. See the case of dry ice (CO_2) .	
subscript	(n). A number placed below the rest of the line, e.g. CO_2 .	
substance	(n). Matter. Physical things.	
substituent	(n). Chemistry: an ion or functional group or group of atoms that replaces a hydrogen on an organic molecule.	
substitute	(v). To replace.	
substitutents	(n). Something that gets replaced.	
substitution	 (n). The process of substituting. Mathematics: to replace an algebraic symbol in a formula with a known value or another formula, so as to simplify the calculation. See simplify. Chemistry: to cause a substituent to bond to a substance. 	ol
superscript	(n). A number placed above the rest of the line, e.g. πr^2 .	
synthesis	(n). The process of manufacturing (making) something. Chemistry: to bond smaller molecules together to create a larger molecule, e.g. methanol from CO and H_2 . Synthesis gas: a gas mixture (e.g. CO, H_2), which when heated produces a new compound, e.g. methanol.	
synthetic	(adj). Artificial, man-made.	
system	(n). Any closely associated and inter-related or inter-dependent group of things; a set of things working together. Chemistry: a vessel (container) which contains a chemical reaction.	

т	
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terminal	(n). Final; end point.
termination	(n). Coming to an end.
tetra-	(prefix). Four.
theory	(n). A usually mathematical representation of an explanation for something in the sciences, which does not depend on the thing being explained. A theory differs from a law in that theories are prone to empirical (visible or measurable) refutation (rejection); meaning that they can be discarded if evidence comes in that they are wrong. See law.
thermoplastic	(n). Chemistry: will melt if heated.
thermoset	(n). Once set into a shape it cannot melt again.
thiosulphate	(n). A salt containing the anion $S_2O_3^{2-}$.
threshold	 (n). Physical Science: the magnitude or limit of something, which, if exceeded, will cause something else, e.g. release of radiation, a chemical reaction, etc; the minimum amount of energy required to cause something. Medicine: the maximum safety level of a dose.
titrate	(v). To measure off a reagent precisely drop by drop into a vessel (container) containing another reagent, so as to work out the concentration of the reagent in the vessel.
toxic, toxin	(adj., n.). Poisonous, poison.
transfer	(n). To move from one place to another. Chemistry: usually refers to moving an electron from one compound to another. Finance: usually refers to a payment or credit. See credit, debit, transaction.
trends	(n). Mathematics: regular patterns within data.
tri-	(prefix). Three.
trial	(n). Chemistry: to repeat an experiment, an iteration, or particular attempt at an experiment. (From "try", to try once).

triprotic	(n). Having three protons.
turbidity	(n). How muddy, muddled or opaque or disturbed a liquid is.
U	
unit	(n). A subdivision of a scale. See scale.
universal (indicator)	(n). A chemical which can indicate how acid or basic a solution is, ranging from reds (acidic) to violets (basic), including most of the colour spectrum.
unsaturated	(n). Organic chemistry: having double or triple bonds present.
unstable	(n). Chemistry or Nuclear Physics: prone to disintegrating or reacting.
urea	(n). $CO(NH_{2})_{2}$. The substance used to remove excess nitrogen from animals via urination. Useful as a fertiliser.
V	
vapour pressure	(n). The pressure above a liquid caused by molecules evaporating from the surface of its liquid form, when in phase equilibrium (i.e. as many molecules leaving the liquid surface are condensing back into the liquid).
variable	(n., adj.). A letter used to represent an unknown quantity in algebra (n); a quantity that changes (n); subject to change (adj).

vessel	(n). Any container. Common use: a container or ship.
visible	(adj). Able to be seen by the human eye, opposite of invisible. Compare microscopic, macroscopic.
viscosity	(n). The thickness of a fluid. A viscous fluid flows slowly, e.g. syrup. Pronounced "viss-KOSS- itee" and "viss-k's".
volatility	(n). How easily something evaporates. E.g. Ether (C ₂ H ₅ OC) is more volatile than water.
volt	(n). Unit of potential difference in electricity. The difference of potential (E_p) that would carry one ampere of current against one ohm resistance. Same as emf. See emf, resistance, ohm, ampere.
voltage	(n). The measurement of volts.
voltaic	(n). The production of electricity in a cell. See battery, cell, electrochemistry, electrode, cathode, anode, galvanic.
volume	(n). A measure of the space occupied by an object, equal to length x breadth x height.
Y	
yield	(n., v.). The amount of substance produced in a chemical reaction (n); products of a process (n); to hand over or give up (v).

The maths you need

This section gives you the basic mathematical skills that you need to pass any subject that makes use of mathematics. Whether you're studying for Physical Science, Mathematics, or Mathematical Literacy, these basic skills are crucial. Do not go any further in this book until you have mastered this section.

1. Basic pointers

- If a formula does not have a multiplication (×) sign or a dot-product (·), and yet two symbols are next to each other, it means "times". So, m_1m_2 means mass 1 times mass 2. You can also write it as $m_1 \times m_2$, or $m_1 \cdot m_2$
- Comma means the same as decimal point on your calculator (i.e. 4,5 = 4.5). Do not confuse the decimal point with dot product (multiply): $4.5 = 4\frac{1}{2}$ but 4.5 = 20. Rather avoid using the dot product for this reason.
- In science it is common to write divisors with an exponent. This means, for example, that 0,5 metres per second is usually written 0,5 m·s⁻¹ rather than 0,5 m/s. Both notations are perfectly correct, however, and you may use either. It is important, however, that you either use -1 or / . If you just put 0,5 ms, that means 0,5 milliseconds, which is not a velocity (speed in a direction); it is a time.
- A variable is something that varies (means: changes). So, for example, the weather is a variable in deciding whether to go to the shops. Variables in science and mathematics are represented with letters, sometimes called algebraic variables. The most common you see in maths is *x*, probably followed by *y*, *z*. In science, variables are given their letter symbols specifically depending on what they stand for; so, for example, *M* or *m* are used for mass (amount of substance in kilograms); *v* is used for velocity (speed in a certain direction); *a* is used for acceleration (change in velocity), etc. You can guess for the most part what a variable is for by what its letter is; so *V* is voltage, *R* is resistance, *P* is pressure, and so on.

2. Subject of formula or solving for

Very often you have to "make something the subject of a formula" or "solve for something". This refers to finding the value of an unknown quantity if you have been given other quantities and a formula that shows the relationship between them.

e.g.) Worked example 1

If John has 5 apples, and he gives some to Joanna, and he has two apples left, how many did he give to Joanna? Well, the formula would be something like this:

5 - x = 2

To solve for x, we simply have to swap the x and the 2. What we're actually doing is adding "x" to both sides:

5 - x + x = 2 + x

this becomes:

5 = 2 + x

then we subtract 2 from both sides to move the 2 over:

5-2=2-2+x 5-2=x3=x ... so John gave Joanna three apples.

The same procedures apply no matter how complex the formula looks. Just either add, subtract, square, square root, multiply, or divide throughout to move the items around.

Worked example 2

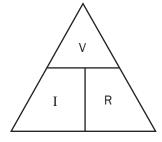
Let's take an actual example from Electricity: V = IR. This means, the voltage in a circuit is equal to the current in the circuit times the resistance.

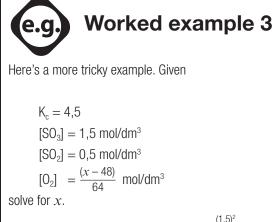
Suppose we know the voltage is 12 V, and the resistance is 3 $\Omega.$ What is the current?

V = IR $12 = 3 \times I$ divide throughout by 3 so as to isolate the I $\frac{12}{3} = \left(\frac{3}{3}\right) I$ remember that anything divided by itself is 1, so: $\frac{12}{3} = (1) \times I \dots \text{ and } \frac{12}{3} = 4 \dots \text{ so}$ 4 = I or $I = 4 \text{ A} \dots \text{ The circuit has a current of 4 amperes.}$

It is possible to remember how to solve for these equations using a triangle mnemonic as follows:

If you're solving for V, cover V with your hand. Then, I next to R means I times R, or IR. So, V = IR. If you're solving for R, cover R with your hand. V is over I. So R = $\frac{V}{I}$. While this is an easier way to do it, remember that many formulas do not consist of only three parts, so it is better to know how to make something the subject of a formula, or solve for something.





$$= \frac{[SO_3]^2}{[SO_2]^2[O_2]} \qquad \therefore 4,5 = \frac{\frac{(1,5)^2}{(0,5)^2 (x-48)}}{64}$$

How did we get that answer?

Кс



Let's see how it works.

First, solve for the exponents (powers):

$$4,5 = \frac{2,25}{(0,25)\frac{(x-48)}{64}}$$

Now, we can see that 2,25 and 0,25 are similar numbers (multiples of five), so let's divide them as shown.

$$4,5 = (2,25 / 0,25) \times ((x - 48) / 64)$$

That leaves us with

$$4,5 = 9 \times ((x - 48) / 64)$$

But if we're dividing a divisor, that second divisor can come up to the top row. Here's a simple example:

$$1 \div (2 \div 3) = \frac{1}{\frac{2}{3}} = \frac{1 \times 3}{2} = \frac{3}{2} = 1,5$$

If you doubt this, try it quickly on your calculator: $1 \div (2 \div 3)$... this means, one, divided by two-thirds. Well, two-thirds is 0,6667, which is almost one. So how many "twothirds" do you need to really make up one? The answer is <u>one and a half</u> "two-thirds"... i.e. 0,6667 + (0,6667 ÷ 2) = 1. Hence the answer is <u>1,5</u>.

So, back to the original problem, we can bring the 64 up to the top line and multiply it by nine:

 $4,5 = 9 \times ((x - 48) / 64)$ $4,5 = \frac{9 \times 64}{x - 48}$ $4,5 = \frac{576}{x - 48}$

Now we can inverse the entire equation to get the *x* onto the top:

$$\frac{1}{4,5} = x - \frac{48}{576}$$

```
Now we multiply both sides by 576 to remove the 576 from the bottom row

\frac{576}{4,5} = \frac{(x-48)}{576}
and we cancel the 576's on the right hand side as shown above.

Now, if 576 ÷ 4,5 = 128, then

128 = x - 48

Now we add 48 to both sides to move the 48 across

128 + 48 = x - 48 + 48 ... hence, 128 + 48 = x = 176.
```

3. Statistics

Many experiments in science use statistics. You should therefore at least know the following:

Dependent variable: The thing that comes out of an experiment, the effect; the results.

Independent variable(s): The things that act as input to the experiment, the *potential* causes. Also called the *controlled* variable.

Control variable: A variable that is held constant in order to discover the relationship between two other variables. "Control variable" must not be confused with "controlled variable".

It is important to understand that in science, correlation does not mean causation. That is, if two variables seem to relate to each other (they seem to co-relate), it doesn't mean that one causes the other. A variable only causes another variable if one of the variables is a function f(x) of the other. We will see more about this when we look at graphs, below.

Mean: The average. In the series 1, 3, 5, 7, 9, the mean is 1 + 3 + 5 + 7 + 9 divided by 5, since there are 5 bits of data. The mean in this case is 5.

Median: The datum (single bit of data) in the precise middle of a range of data. In the series 1, 3, 5, 7, 9, the median value is 5.

Mode: The most common piece of data. In the series 1, 1, 2, 2, 3, 3, 3, 4, 5, the mode is 3.

Often in scientific formulas it is said that things are proportional to each other. However, we cannot calculate the value of a force or energy output or mass etc., if we only know what things are in proportion (i.e. which things correlate).

Let's take momentum for example. Momentum (how forcefully something moves, more or less), is proportional to velocity (speed in a direction). So the faster something's moving, the more momentum it has. But p (momentum) can't be calculated if we only know velocity; we need to know mass as well. Why? Because momentum is also proportional to mass; the more massive something is, the more momentum it has. Thus, to get rid of the proportionality sign (∞), we have to come up with a formula.

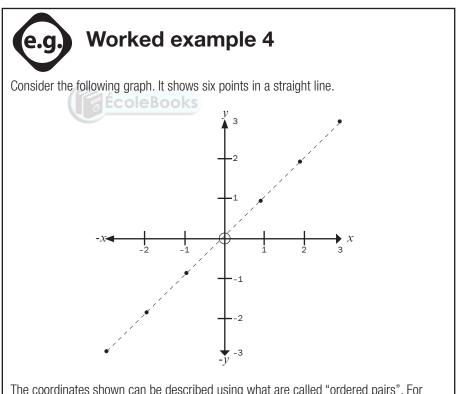
Many experiments in science serve to find out what the relationship is between two variables, i.e. if they're merely correlated - proportional - or if they're causally related. In the case of momentum, it's easy, because

there are no further variables: p = mv. However, in the case of gravity or electric or magnetic field strengths, it's not that easy. In those cases, we have to introduce something called a "constant". A constant is a fixed value that is always multiplied into an equation. Constants are often written k. However, some specific constants, such as in the Law of Gravity, have their own symbol, in this case, G. These constants are given in the tables later in this book.

4. Graphs

A lot of work in science involves interpreting graphs. You get graphs of motion, graphs of rates of chemical reactions, graphs of distance-relative strengths of force fields, and so on. Before you can understand these graphs, it's probably best to start from scratch with Cartesian Coordinates.

"Coordinates" are numbers that refer to the distance of a point along a line, or on a surface, or in space, from a central point called the "origin". Graphs that you will use have only two dimensions (directions). The positions of points on these graphs are described using two coordinates: how far across (left-to-right) the point is, called the x-coordinate, and how far up-or-down on the page the point is, called the y-coordinate.



The coordinates shown can be described using what are called "ordered pairs". For example, the furthest point in this graph is 3 units across on the "x-axis" or horizontal line. Likewise, it is also 3 units up on the y-axis, or vertical (up and down) line. So, its coordinates are (3;3). The point just below the midpoint or "origin", is one unit down of the x-axis, and one unit left of the y-axis. So its coordinates are (-1;-1). Note that anything to the left or below of the origin (the circle in the middle), takes a minus sign. In most cases in science, you'll only have graphs showing positive axes (plural of axis, pronounced aks-eez), since most graphs are of time.

This series of dots look like they're related to each other, because they're falling on a straight line. If you see a result like this in an experimental situation, it usually means that you can predict what the next dot will be, namely, (4;4). This kind of prediction is called "extrapolation". If you carry out the experiment, and find that the result is (4;4), and then (5;5), you've established that there is a strong relation or correlation. You can therefore start thinking about a formula to describe your findings. For example, this might be a graph showing a measurement of voltage (x) against a measurement of resistance (y).

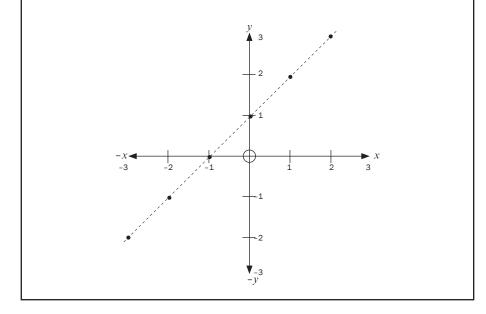
Now, another way of saying that x relates to y, or x is proportional to y, is to say that y is a function of x. This is written y = f(x). So, in the example given above, voltage is a function of resistance. But how is y related to x in this graph? Well, it seems to be in a 1 to 1 ratio: y = x. So the formula for this graph is y = x. In this case, we're only dealing with two factors; x and y. In other graphs you'll find that sometimes more factors are involved, such as acceleration graphs, which have units of m/s². Don't worry about that; you treat them the same way (for example, m/s² vs. time).



Worked example 5

Now, let's take a slightly more complex case, illustrated next to this paragraph.

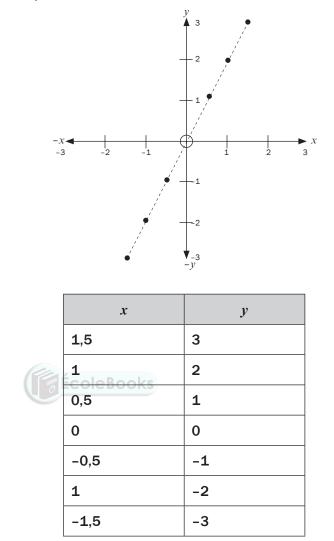
In this graph, we see that wherever x is equal to something, y is one more. So, trace your finger from the bottom left dot upwards. It meets the x-axis at the point -3. Do the same for the same point towards the y-axis. You'll see it meets the y-axis at -2. You'll see the next coordinates are (-2;-1), then (-1;0), then (0;1), (1;2), and finally (2;3). From this we can see that whatever x is, y is one more. So, y = x + 1 is the formula for this line.





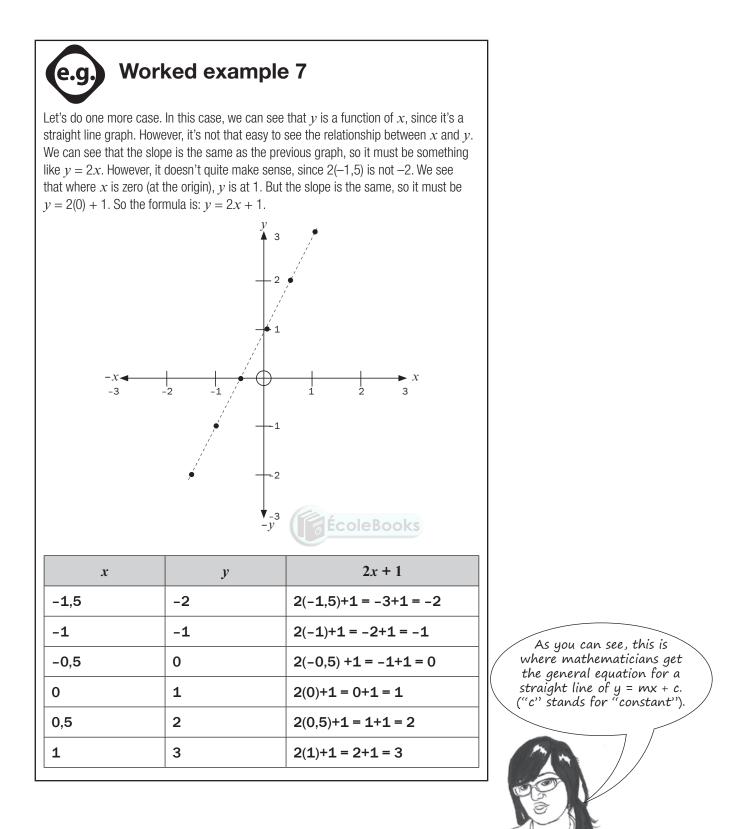
Worked example 6

Let's take another case. In this next case, we see the following values: where x has a certain value, y has double that value. Let's tabulate it.



So, when x is 1,5, y is 3, when x is 1, y is 2. Thus, the formula for this line is: y = 2x. This value next to x is called the "gradient" or "slope" of the line. The larger the value next to x is, i.e. the larger the gradient, the steeper the slope. The gradient is usually abbreviated as "m" when it is unknown.

Now, how this applies to science is simple: if we are looking, for example, at a case of a graph of a chemical reaction, we will usually have the *x*-axis as time. And the *y*-axis will usually be the quantity (amount) of substances produced. So, if we have a graph of a chemical reaction with a large gradient, it means that the reaction is fast; a lot of substance (*y*) is produced in a short time (*x*). If, for example, we heated the reaction, and saw that the gradient increased even more, that would show that the chemical reaction was sped up by heat, or, that reaction rate is proportional to heat. Likewise, if the gradient sloped downwards, it would show that the reaction slowed down over time, because *y*, the amount of substance produced, was decreasing, as *x* (time) increased, e.g. because the reactants were being used up.



Resource sheets

The following information sheets will be supplied to you in the exam. You do not need to memorise them.

SI Units: Multipliers

Prefix	Symbol	Value	Value written in full
tera	Т	1012	1 000 000 000 000
giga	G	10 ⁹	1 000 000 000
mega	М	10 ⁶	1 000 000
kilo	k	10 ³	1 000
hecto	h	10 ²	100
deka	da	101	1
deci	d	10-1	0,1
centi	с	10-2	0,01
milli	m	10-3	0,00 1
micro	μ	10-6	0,00 000 1
nano	n	10-9	0,00 000 000 1
pico	р	10-12	0,00 000 000 000 1
femto	f	10-15	0,00 000 000 000 000 1

Constants

Name	SI Unit Symbol	Approximate Value	Easier to Understand
STP (Standard Temperature and Pressure), (in Physics).	not applicable, two conditions	1 ATM (101,3 kPa), 25°C (298 Kelvin (K))	You generally put two ATM (bar) pressure in car tyres, i.e. the pressure in a car tyre is twice atmospheric pressure
Standard Conditions (Chemistry)	not applicable, three conditions	STP plus 1 mol/dm ³	As above
Gas constant	R	8,3 J / mol·K	The R in PV = nRT
Molar gas volume at STP	Vo	22,4 dm ³ / mol	22,4 Litres of gas is made by a mole of a substance
Avogadro's constant	N _A	6,022045 × 10 ²³ units/mol	6 022 000 000 000 000 000 000 00 particles is one mole

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Formulas

Moles, Gas Laws, Chemical Equilibria:

- R = gas constant
- n = number of moles
- m = mass
- T = temperature
- V = volume
- c = concentration, also []

n =
$$\frac{m}{M}$$
 c = $\frac{n}{V}$ c = $\frac{m}{MV}$
PV = nRT $\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$
(2P + 3R \rightleftharpoons 2S + 4T
 $K_c = \frac{[S]^2 \times [T]^4}{[P]^2 \times [R]^3}$

Where [S] is the concentration of S in mol/dm³

Notes:

• In most cases in chemistry, subscripts refer to how many atoms there are; e.g. H_2O = two atoms of H & 1 atom of O.



Standard reduction potentials

ncreasing oxidising ability

Notes:

- E^{θ} means the same as E^{0} .
- There are two versions of this table; they are identical except one is upside-down. Just memorise that Fluorine (F) has the greatest oxidising ability.
- A strong reducing agent will displace a weaker reducing agent from its salt.
- Always start with the oxidation half reaction.
- A redox reaction will take place when a reducing agent reacts with an oxidising agent.
- Balance the electron charge of each halfreaction by multiplying each with a suitable coefficient.
- Add the two half-reactions together, eliminating electrons from both sides.
- Eliminate common ions or molecules from both sides of the equation e.g. H⁺ and H₂O.
- You can then combine the E⁰ voltages to get the total voltage of a cell. Use the values exactly as they are; do not round off.

$$E^{0}_{cell} = E^{0}_{cathode} - E^{0}_{anode}$$

OR

 $E^{0}_{cell} = E^{0}_{oxidising agent} - E^{0}_{reducing agent}$

 A positive answer means that the reaction will proceed spontaneously from left to right. A negative value means that it is not spontaneous.

Half-rea	cti	ons	E ⁰ (V)
F ₂ (g) + 2e-	⇒	2F-	+ 2,87
Co ³⁺ + e-			+ 1,81
H ₂ O ₂ + 2H ⁺ +2e ⁻			+1,77
MnO ⁴ + 8H ⁺ + 5e ⁻			+ 1,51
C{2(g) + 2e-	_	201-	+ 1,36
			+ 1,50
Cr ₂ O ²⁻ + 14H ⁺ + 6e ⁻		2Cr ³⁺ + 7H ₂ O	+ 1,33
O ₂ (g) + 4H⁺ + 4e⁻		2H₂O	+ 1,23
MnO ₂ + 4H ⁺ + 2e ⁻			+ 1,23
Pt ²⁺ + 2e-	`	Pt	+ 1,20
Br ₂ (<i>l</i>) + 2e ⁻	≑	2Br	+ 1,07
NO ³ + 4H⁺ + 3e-		NO(g) + 2H ₂ O	+ 0,96
Hg²+ + 2e-	⇒	Hg(l)	+ 0,85
Ag⁺ + e-			+ 0,80
-		-	
NO ³ + 2H ⁺ + e ⁻ Fe ³⁺ + e ⁻		NO ₂ (g) + H ₂ O Fe ²⁺	+ 0,80
			+ 0,77
O ₂ (g) + 2H ⁺ + 2e ⁻			+ 0,68
l ₂ + 2e-	-		+ 0,54
Cu+ + e-			+ 0,52
SO ₂ + 4H ⁺ + 4e ⁻			+ 0,45
2H ₂ O + O ₂ + 4e-		40H-	+ 0,40
Cu ²⁺ + 2e-	≓	Cu	+ 0,34
2- SO 4 + 4H+ + 2e-		SO ₂ (g) + 2H ₂ O	+ 0,17
EcoleBocCú3+ + e-		Cu⁺	+ 0,16
Sn ⁴⁺ + 2e-			+ 0,15
S + 2H+ + 2e-	⇒	H ₂ S(g)	+ 0,14
2H⁺ + 2e-	≑	$H_2(g)$	0,00
Fe ³⁺ + 3e-	\rightleftharpoons	Fe	- 0,06
Pb ²⁺ + 2e-	≒	Pb	- 0,13
Sn ²⁺ + 2e-	≓	Sn	- 0,14
Ni ²⁺ + 2e-		Ni	- 0,27
Co ²⁺ + 2e-		со	- 0,28
Cd ²⁺ + 2e-			- 0,40
Cr ³⁺ + e-			- 0,41
Fe ²⁺ + 2e-			- 0,44
Cr ³⁺ + 3e-		Cr	- 0,74
Zn ²⁺ + 2e-			- 0,74
		∠n H₂(g) + 2OH-	- 0,83
Cr ²⁺ + 2e-			- 0,83
Mn ²⁺ + 2e-			
Al ³⁺ + 3e-		Mn	- 1,18
		Ał	- 1,66
Mg ²⁺ + 2e-		Mg	- 2,36
Na+ + e-		Na	- 2,71
Ca ²⁺ + 2e-		Ca	- 2,87
Sr ²⁺ + 2e-			- 2,89
Ba ²⁺ + 2e-		Ba	- 2,90
Cs+ + e-		Cs	- 2,92
K⁺ + e-			- 2,93
Li⁺ + e-	≓	Li	- 3,05





Organic compounds and macromolecules

Organic chemistry is the chemistry of carbon compounds in living and non-living systems.

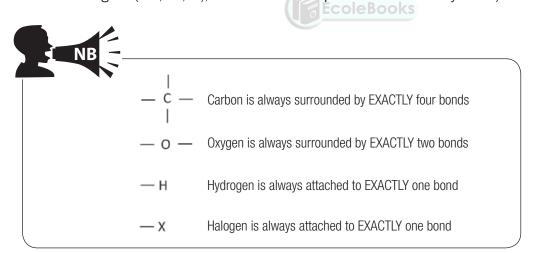
Organic molecules: molecules containing carbon atoms

Note: Carbon dioxide (CO₂), carbon monoxide (CO), carbonates (CO₃²⁻) and cyanides (CN⁻) are exceptions because they are considered inorganic compounds. Organic compounds typically have a backbone of linked carbon atoms that other atoms attach to.

1.1 Organic compounds

1.1.1 Chemical bonding

The organic compounds that we study consist of Carbon, Hydrogen, Oxygen atoms and the Halogens (-Br, -C ℓ , -I), which are often represented collectively as -X).



1.1.2 The homologous series



DEFINITIONS

A **homologous series** is a series of compounds (molecules) that has the same general formula and the same functional group. Each member of a homologous series differs from the previous member by $a - CH_2$ group.

Saturated: compounds in which there are no multiple bonds between carbon atoms in their hydrocarbon chains

Unsaturated: compounds with one or more multiple bonds between carbon atoms in their hydrocarbon chains.

A **functional group** is a bond, an atom or a group of atoms that determine(s) the physical and chemical properties of a group of organic compounds.

Classification of organic molecules according to homologous series

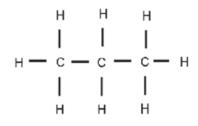
Ho	omologous series	General formula	Functional Group	Suffix	Example name	Structural formula	Condensed structural formula	Molecular formula
ons	Alkanes	C_nH_{2n+2}	 -c-c- 	-ane	propane	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	CH ₃ CH ₂ CH ₃	C_3H_8
Hydrocarbons	Alkenes	C _n H _{2n}	c=c	-ene	propene coleBooks		CH ₂ =CHCH ₃	C ₃ H ₆
Ť	Alkynes	C_nH_{2n-2}	— c≡c —	-yne	propyne	$H - C \equiv C - C - H$	CH≡CCH ₃	C_3H_4
	oalkanes/ yl halides	$C_{n}H_{2n+}1X$ $(X = F, C\ell, Br, I)$	-c-x	-ane	2-bromopropane	н вк н н — с — с — с — н н н н	CH₃CHBrCH₃	C ₃ H ₇ Br
Alco	ohols	C _n H _{2n+1} OH	 _ с_о-н 	-ol	propan-2-ol	н — с — с — с — о — н н — н н н н н н н н н н н н н н н н	CH ₃ CHOHCH ₃	C ₃ H ₇ OH
Alde	ehydes	C _n H _{2n} O n =1, 2,	о — с_с_н I	-al	propanal	н н о н І І ІІ н С С С С Н	CH ₃ CH ₂ CHO	C ₃ H ₆ O
Ket	ones	$C_{n}H_{2n}O$ n = 3, 4,	н н о н с с с с с н н н	-one	propanone	н о н н - с - с - с - н 	CH ₃ COCH ₃	C ₃ H ₆ O
Carboxylic acids		$C_n H_{2n} O_2$ n = 1, 2,	о - с_с_о-н	-oic acid	propanoic acid	н н о н - с - с - с - он 1 н н	CH ₃ CH ₂ COOH	C ₃ H ₆ O ₂
Esters		$C_n H_{2n} O_2$ n = 2, 3,		-oate	ethyl methanoate	H H O H O H O O O O O O O O O O O O O O	CH₃CH₂OOCH	C ₃ H ₆ O ₂

NOTE:

Alkanes have the general formula C_nH_{2n+2} In propane n = 3 and therefore the general formula is $C_3H_{2(3)+2} = C_3H_8$

In a **structural formula** all the bonds in the compound are shown. If any of these bonds are omitted, it is called a **condensed structural formula**.

E.g. structural formula for propane



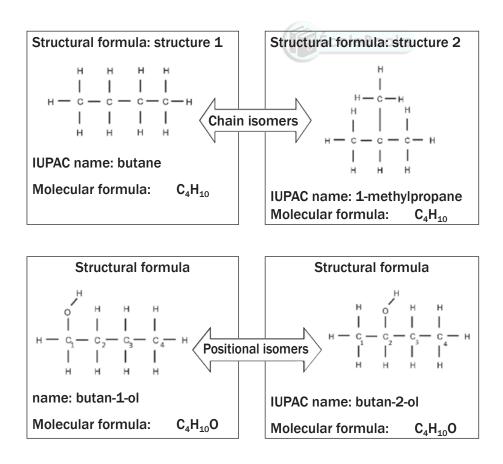
possible condensed structural formula for propane

 $CH_3 - CH_2 - CH_3$ or $CH_3CH_2CH_3$

1.1.3 Isomers

In isomers, the same atoms are used in different compounds, but they are assembled or connected in different ways. There are different kinds of isomers in organic chemistry. Structural isomers refer to the order in which different atoms in a compound are combined.

We will focus on three types of structural isomers, namely chain isomers, positional isomers and functional isomers.





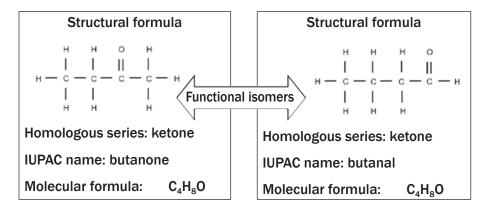
DEFINITIONS

- 1. **Structural isomers** are compounds with the same molecular formulae, but different structural formulae.
- Chain isomers: Molecules with the same molecular formula and in the same homologous series but different types of chains e.g. butane and methyl propane.
- 3. **Positional isomers:** Molecules with the same molecular formula and in the same homologous series but the position of the functional group differs (e.g. **butan-1-ol** and **butan-2-ol**) or the *substituent* or *side chains* differ.
- Functional isomers: Molecules with the same molecular formula but in different homologous series or have different functional groups e.g. ketones and aldehydes.



The numbering of the carbon chain:

In the naming of the organic compound, the longest carbon chain is numbered in such a way that the –OH functional group is attached to the carbon that is assigned the smallest number. Therefore, in this example, the first organic compound is called butan-1-ol.



In this example both organic compounds consist of the same number of carbon, hydrogen and oxygen atoms, but in the structure of the first compound, the (=) is attached to the middle of the carbon chain, which makes it a ketone. In the second example, the (=0) is attached to the beginning of the carbon chain, which makes it an aldehyde.



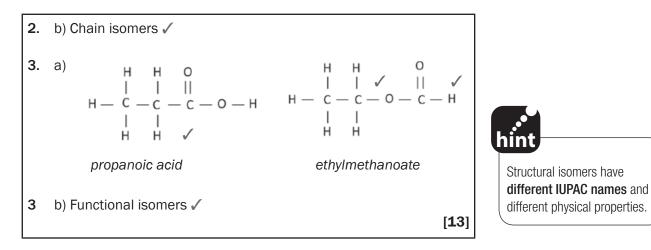
For each of the following isomers:

- a) Write down the structural formula
- b) Identify the type of isomer
- **1.** 2-methylpentane and 3-methylpentane.
- 2. 1-chlorobutane and 1-chloro-2-methylpropane
- 3. Propanoic acid and ethyl methanoate

(13) [**13**]

Solutions 1. a) н | 🗸 -с — н c - c— C -c - c - H- C -- C н н н н н н н н — с — Н — С _ Н √ н Ĥ 2-methylpentane 3-methylpentane **1.** b) Positional isomers \checkmark 2. a) н н н н -с-с-с-н Cℓ — C - $C\ell - C - C$ - C -Т н н Н н н н н — с — н Н 1-chlorobutane 1-chloro-2-methylpropane

4 UNIT 1 ORGANIC COMPOUNDS AND MACROMOLECULES



1.1.4 Nomenclature (naming conventions or rules)

Each IUPAC name consists of three parts:

Prefix:	Root:	Suffix:
Position and names of substituents (side chains), listed alphabetically.	Number of C-atoms in the main C-chain.	Determined by the homologous series.

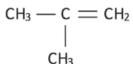
Organic compounds are named according to the IUPAC (International Union of Pure and Applied Chemistry) system.



General steps for the IUPAC naming of all organic compounds

Step 1:

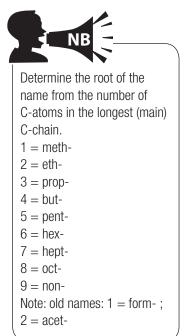
Identify the functional group in the compound and the homologous series it belongs to. This determines the suffix (ending). Example: Naming of 2-methylprop-1-ene



In this case there are only carbons and hydrogens, with a double bond between the carbons. This indicates that this compound is an alkene and will end with the suffix -ene

Step 2:

- Find the longest chain of carbon atoms. It **must include the functional group**, and need not be in a straight line.
- Number the carbon atoms in this chain from the side nearest to the functional group e.g. a double or triple bond, a hydroxyl group, a carbonyl group or a carboxyl group.
- In the case of **alkanes or haloalkanes**, start numbering from the carbon **nearest to a substituent (side chain)** e.g. an alkyl group or halogen atom.



• Indicate the **position of the functional group** (except in the case of the alkanes). For alkenes and alkynes, give the smaller of the numbers of the C-atoms between which the double or triple bond exists. **Example: Naming of 2-methylprop-1-ene**

$$CH_3 - C = CH_2$$

 $2 | 1$
 CH_3

Example: The longest chain that includes the functional group, is numbered in the example above. Since the double bond is to the right of this example, we number the longest chain from right to left. The longest chain with the functional group contains three carbons and we know it must be a propene. Since the double bond is attached to the first carbon, it must be a *prop-1-ene*.

Step 3:

- Determine whether there are any substituents.
- Count the **number of C-atoms** in the substituent to determine the prefix and end it on **-yl**.
- Write the **number of the C-atom** on the main chain where the alkyl group is attached, in front of the alkyl name.
- Separate the number and the name with a **hyphen**, e.g. 2-methyl.
- If a substituent occurs more than once, use the appropriate prefix: twice – di; three times – tri; four times – tetra e.g. 3,4-dimethyl
- If there is more than one substituent, write their names and positions in **alphabetical order**.

$$CH_3 - C = CH_2$$

 $3 2 | 1$
 CH_3

Example: The methyl group is attached to the second carbon, hence the name 2-methyl prop-1-ene

Step 4:

Naming the organic compound *with substituent*(s) *in front of the parent chain.* Example: the IUPAC name of the compound discussed above: 2-methylprop-1-ene

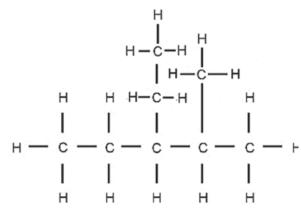


Worked example 1

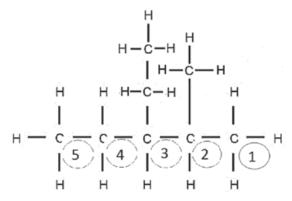
Give the IUPAC name for the following organic compound:

Step 1: Identify the functional group, and the homologous series to which this compound belongs. *There are only C-atoms and H-atoms present, so this is a hydrocarbon. There are only single bonds between the C-atoms, therefore this is an alkane and the suffix will be –ane.*

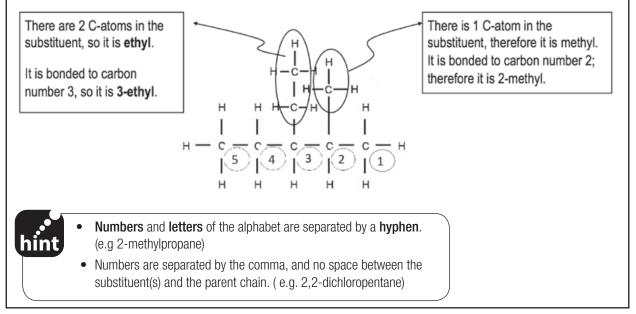
Unit

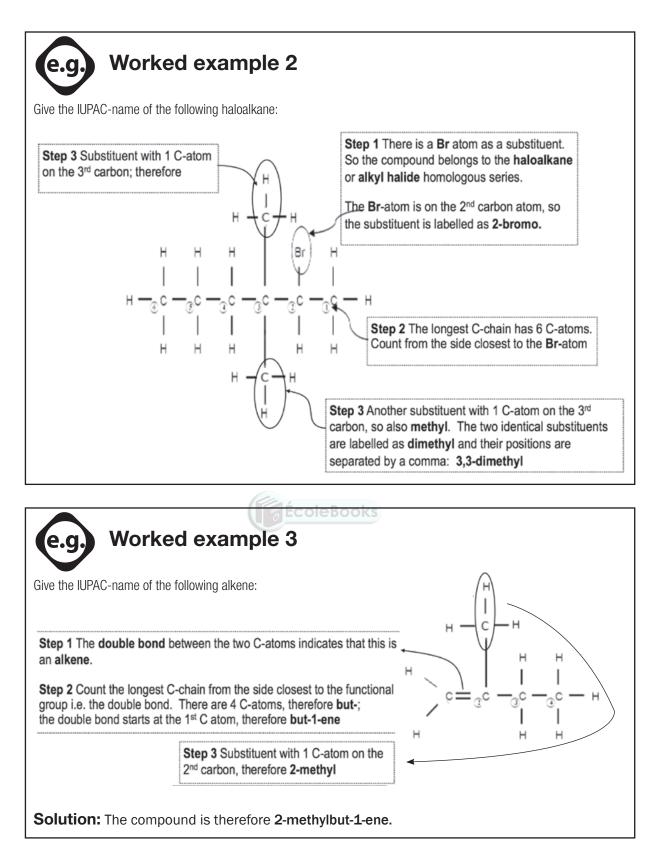


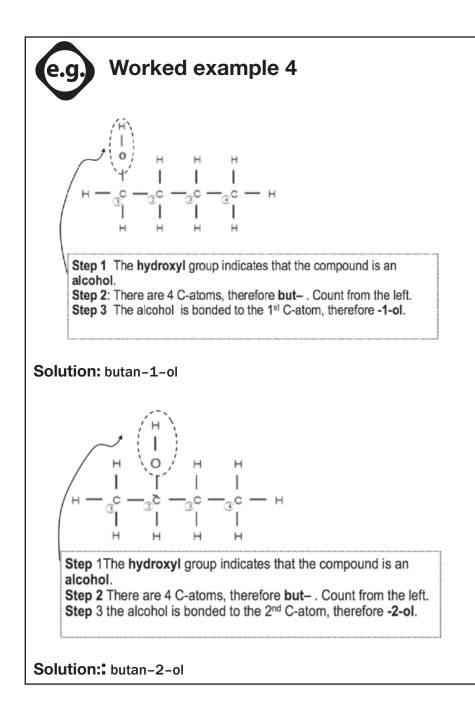
Step 2: Find the longest C-chain and count the C-atoms in it, starting at the side closest to the functional group. *This is an alkane, so we start numbering from the side closest to a substituent*

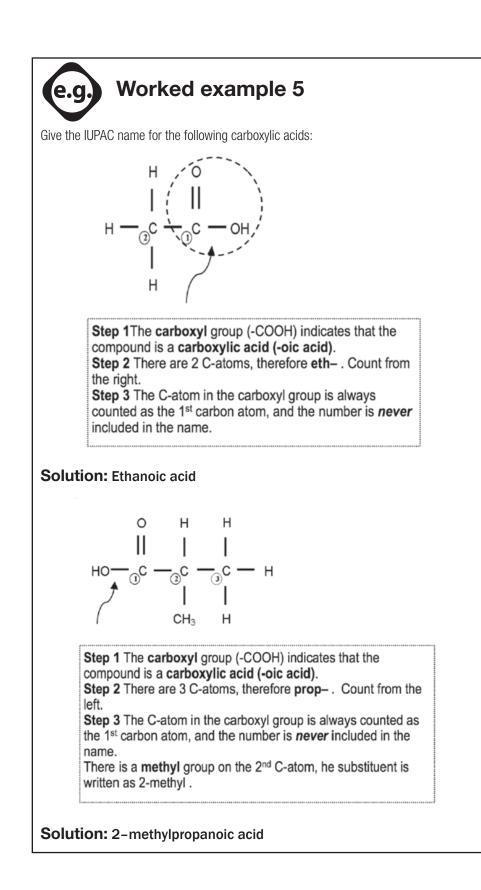


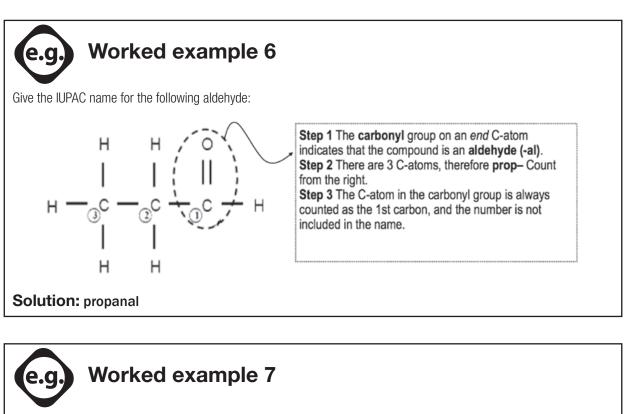
Step 3: Look at the substituents. Count the C-atoms in each substituent, determine the prefix and end it on –yl. *The alkyl groups must be listed alphabetically, so we write the ethyl before the methyl*





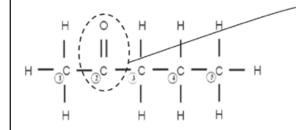




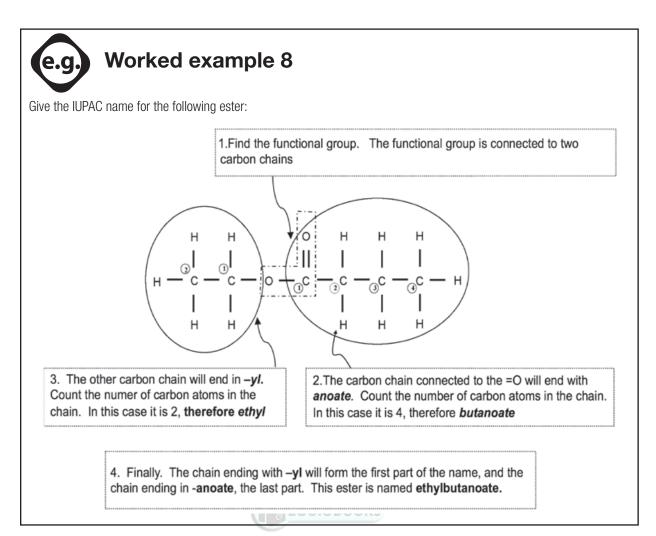


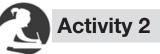
Give the IUPAC name for the following ketone

Solution: pentan-2-one



Step 1 The carbonyl group on a *middle* C-atom indicates that the compound is a **ketone (-one)**. Step 2 There are 5 C-atoms, therefore **pent–**. Step 3 Count from the side closest to the carbonyl group (in this case, from the left) and indicate the number of the C-atom of the carbonyl group (in this case the 2nd), in the name. Unit





Write down the IUPAC names for the following organic molecules.

1.
$$CH_3 - CH_2 - CH_2 - C = C - CH - CH_3$$

|
 CH_3 (1)

2. H OH H H| | | |H - C - C - C - C - H| | | |H H H H (1)

 $3. \quad C_3H_7COC_2H_5 \tag{1}$

4.
$$O$$

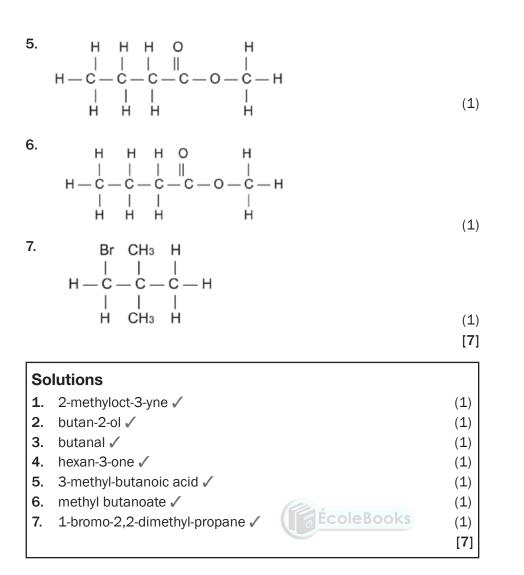
$$\parallel$$

$$CH_3 - CH - CH_2 - C - O - H$$

$$\parallel$$

$$CH_3$$

$$(1)$$

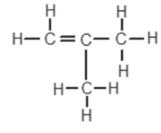


IMPORTANT TO REMEMBER:

- When naming haloalkanes, the halogen atoms do not get preference over alkyl groups – numbering should start from the side nearest to the first substituent, either the alkyl group or the halogen. In haloalkanes, where e.g. a Br and a Cl have the same number when numbered from different sides of the chain, Br gets alphabetical preference.
- When writing IUPAC names, substituents appear as prefixes written alphabetically (bromo, chloro, ethyl, methyl), but the prefixes di- and tri- should not be used to determine the alphabetical order.
- In molecules where the functional group is ALWAYS on the first carbon (such as in the case of carboxylic acids, aldehydes there is NO number added to indicate the position of the fuctional group. (e.g. Ethanoic acid or pentanal.)



- 1. Which ONE of the following formulae represents an alkane?
 - A C_2H_2
 - B C₃H₄
 - C C₃H₆
 - $D C_3H_8$
- 2. An organic compound has the structural formula shown below:



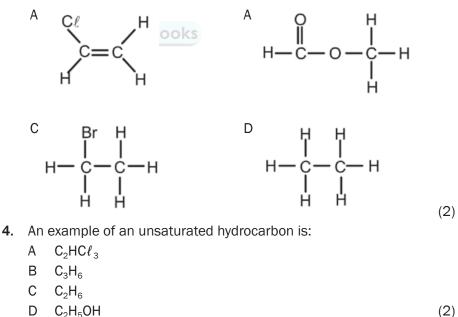
The correct systematic (IUPAC) name for the compound is ...

- A but-1-ene.
- B but-2-ene.
- C methylpropene.
- D methylpropane.

(2)

(2)

3. Which ONE of the following compounds can exist as an isomer?



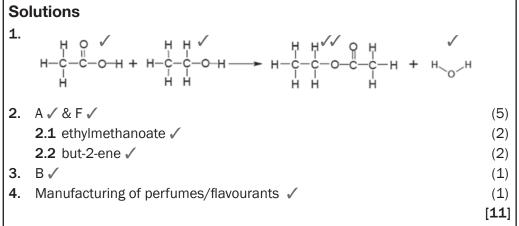
(2) [**8**]

Solutions	
1 . D √ √	(2)
2. C √ √	(2)
3. B √ √	(2)
4. B √ √	(2)
	[8]



Consider the following list of organic compounds:

	A:	$CH_3 - CH_2 - CH_2 - CH_3$	В:	$CH_3 - C - OH$	
	C:	СН ₃ -СН ₂ -О-С-Н О	D:	CH_3 - CH - CH - CH_3	
	E:	CH ₃ -CH ₂ OH	F:	СН ₃ —СН—СН ₃ СН ₃	
	G:	$CH \equiv C - CH - CH_3$ \downarrow CH_3			
1.	of an este	uctural formulae, write an er. Choose the reactants fi	rom t	he above list.	(5)
2.	are isome 2.1 C	letters representing TWO ers.	comp	oounds in this list that	(2)
•	2.2 D				(2)
3.		vn the letter that represen /hen ethanol is oxided.	ts the	e compound that is	(1)
4.		use of esters.			(1) (1)
			J	ÉcoleBooks	[11]

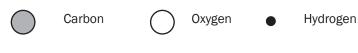


1.2 Physical properties and structure

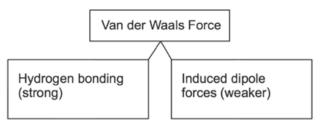
The structure of an organic compound — that includes the order in which atoms are connected in the compound, as well as the forces that is present between different molecules — has an influence on the physical properties of the compound. These physical properties include boiling points, melting points and the vapour pressure above a liquid organic compound. In the following section the influence of the structure of molecules on its physical properties will be discussed.

1.2.1 Intermolecular forces in organic compounds

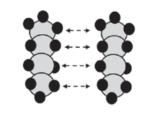
Key for this section:



Intermolecular forces that act between DIFFERENT molecules of a compound are called Van der Waals forces. In the organic chemistry that we study, there are primarily two kinds of forces, namely Hydrogen bonds and Dipole-dipole forces.

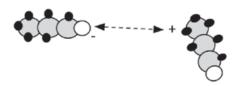


Induced dipole force: When two molecules come very close to each other, the electrons move and the distribution of electrons in the molecules temporarily shifts so that there is a slightly positive side and a slightly negative side on each molecule. The two molecules attract each other with a weak force.



An example of induced-dipole forces between two molecules of butane

Dipole-dipole forces: When a molecule has a slightly positive side and another molecule has a slightly negative side, the two molecules will attract each other with a weak force.



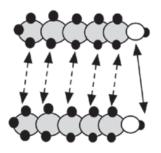
An example of dipole-dipole forces between two molecules of propanal

Hydrogen bonds: A stronger type of dipole-dipole force. The definition of hydrogen bonding was discussed thoroughly in Grade 11, but for the sake of the organic structures studied in Grade 12 it is helpful to observe that hydrogen bonds are mostly found between different molecules where at least one molecule has an –OH group (hydroxide group). Hydrogen bonds are present between the -O atom connected to one molecule (which is slightly negative) and the -H atom of a different molecule (that is slightly positive).

NOTE:

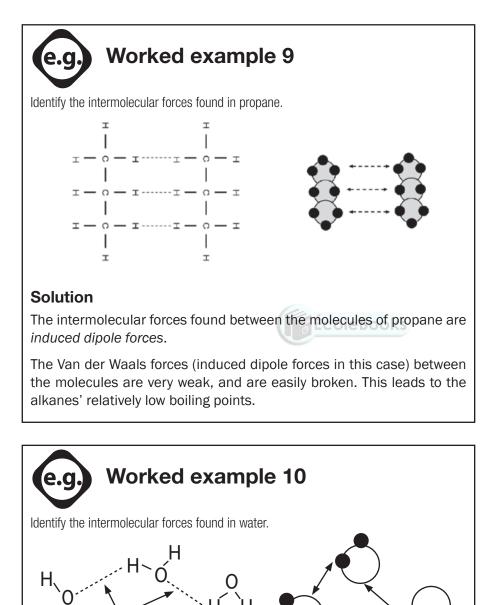
The sketches that represent the forces between atoms relative to the size of the atoms are NOT drawn to scale. In reality, molecules are very close to each other and the intermolecular forces act over small distances.





An example of hydrogen bonds between two molecules of pentan-1-ol

As indicated in this example, more than one type of force can act between molecules simultaneously.



Solution

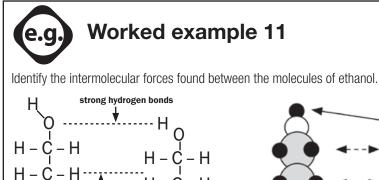
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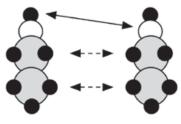
hydrogen bonds

strongest intermolecular force

The intermolecular forces found between the molecules of water are hydrogen bonds.

The water molecules are strongly attracted to each other by the hydrogen bonds. Water has a relatively high boiling point due to the presence of the hydrogen bonds.

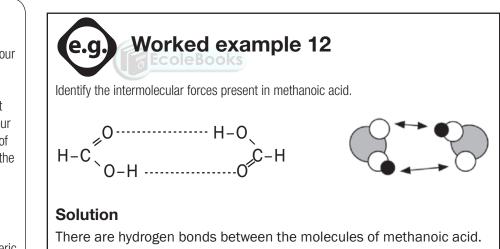




Solution

There are hydrogen bonds between the hydroxyl groups (-OH) of the different molecules. There are dipole-dipole forces between the hydrogen molecules connected to the different molecules.

Both hydrogen bonds and dipole-dipole forces exist between alcohol molecules. The hydrogen bonds exist between the polar OH- groups and the dipole-dipole forces exist between the non-polar hydrocarbon parts.



Intermolecular forces between carboxylic acids are stronger than those in alcohol because the molecules are bonded by two hydrogen bonds.

1.3 Physical properties of organic compounds

- Each chemical compound has **physical properties** such as its **phase**, **melting point**, **boiling point**, **vapour pressure**, **viscosity**, **density and solubility**. Note that the type of bonds affect all these properties.
- These properties are affected by the strength of the intermolecular forces between the molecules in the compounds.



DEFINITIONS

Vapour pressure: The vapour pressure of a liquid is the equilibrium pressure of a vapour above its liquid; that is, the pressure of the vapour resulting from evaporation of a liquid above a sample of the liquid in a closed container.

Boiling point: The

temperature at which the vapour pressure of a substance equals atmospheric pressure. The stronger the intermolecular forces, the higher the boiling point. The boiling point of a substance is the temperature at which it changes from a **liquid** to a **gas** and is reached when the vapour pressure above the liquid equals the atmospheric pressure.

Melting point: The melting point of a substance is the temperature at which it changes from a solid to a liquid. When the intermolecular forces between the molecules of a substance are strong:

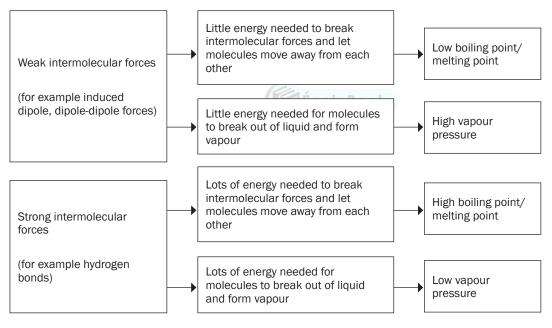
- a lot of energy is required to overcome these intermolecular forces of attraction;
- the molecules aren't easily separated from one another.

1.4 Factors that have an influence on the physical properties of organic compounds

In the Grade 12 exam you will be asked to explain why the physical properties (melting point, boiling point, vapour pressure) of different organic compounds, differ.

In order to determine why the physical properties differ, you will need to find answers to one or more of the following questions:

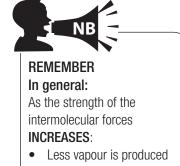
1. What is the influence of the type of intermolecular forces present between the molecules of the organic compound on its physical properties?



2. What is the influence of the type of functional group that is found in the molecule on its physical properties?

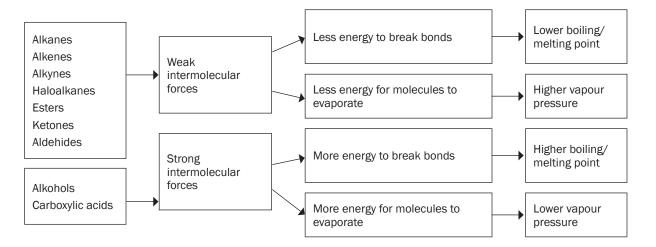
In organic compounds where hydroxyl groups (-OH) are present (for example alcohols, carboxylic acids) you will find **hydrogen bonds and induced dipole forces.**

In organic compound where hydroxyl groups are not present (for example alkanes, alkenes, alkynes, halo-alkanes, aldehydes, ketones and esters) you will find **induced dipole forces** or **dipole-dipole forces**.



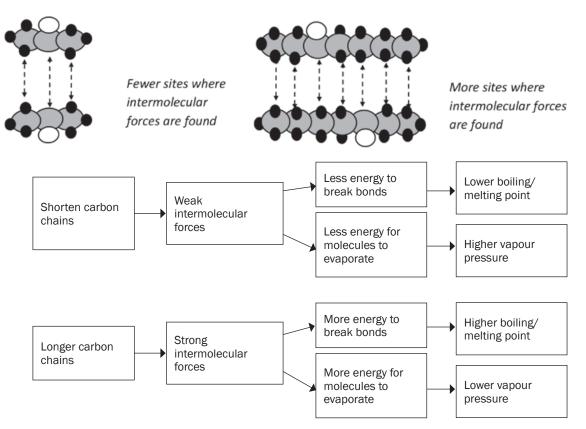
- Less vapour is produced hence vapour pressure above the liquid DECREASES;
- Melting and boiling points INCREASE.

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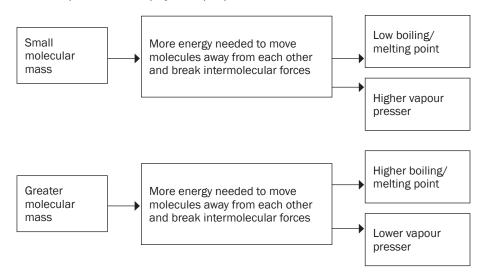


3. What is the influence of the chain length of the molecule on its physical properties?

As the length of the carbon chain in the organic compound increases, the number of sites where you will find the intermolecular forces will increase. Therefore, the longer the carbon chain, the stronger the intermolecular forces between the molecules.

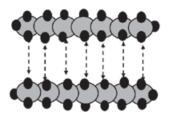


4. What is the influence of the molecular mass of an organic compound on its physical properties?

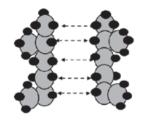


5. What will the influence on the physical properties of an organic compound be if the compound is made up of branched carbon-chains?

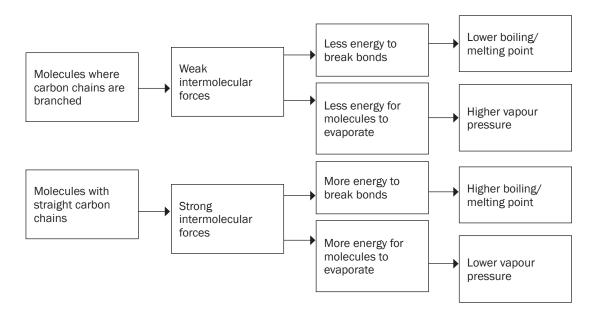
As the number of branches (alkyl groups) increases, the shape of the molecule changes to a more compact, spherical shape with a smaller surface area, resulting in a smaller contact area between the molecules and weaker net Van der Waals forces.

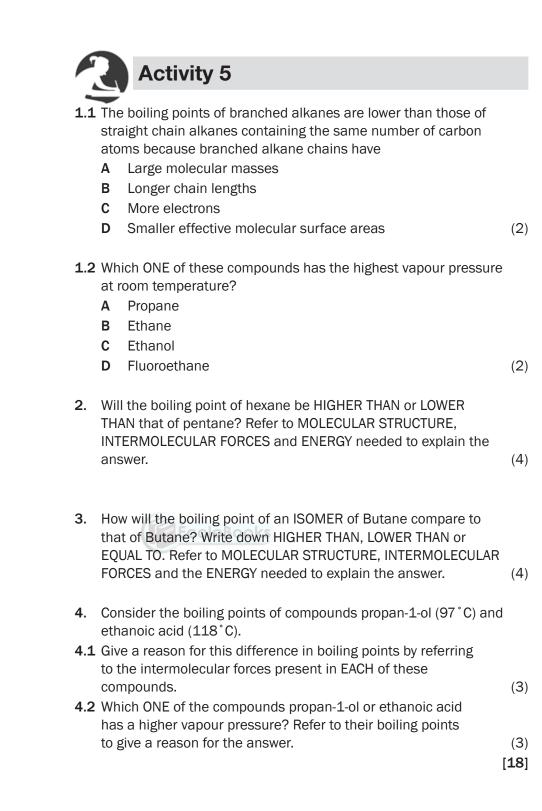


In both substances, the molecules have the same number of carbons



long chain length gives greater surface area over which intermolecular forces can act short or branched chains give less surface area over which intermolecular forces can act





Sol	utions	
1.1	D√√	(2)
1.2	A 🗸 🗸	(2)
2	Higher 🗸	
	Structure: Hexane has a <u>longer chain length</u> than pentane. OR Hexane contain more C- atoms than pentane. OR Hexane has a greater molecular size than pentane. OR Hexane has a larger surface area than pentane. \checkmark	
	<u>Intermolecular forces</u> : Between the different molecules of hexa you will find <u>stronger or more intermolecular forces</u> than betwee the different molecules of pentane. \checkmark	
	Energy : More energy needed to overcome or break intermoleculation forces between hexane molecules than you need between	<u>ılar</u>
	pentane molecules. 🗸	(4)
3.	Lower than 🗸	
	Isomers of Butane: More branching / Smaller surface area (over which the intermolecular forces act.) Weaker/less intermolecular forces. Less energy needed to overcome intermolecular forces.	(4)
	Ethanoic acid: Two sites for hydrogen bonding/forms dimers <i>Propan-1-ol:</i> One site for hydrogen bonding. <i>Therefore it will require more energy to break the bonds between the ethanoic acid molecules than to break the bonds between the propan-1-ol molecules,</i> <i>which explains why ethanoic acid has the lower boiling point.</i> <i>Propan-1-ol has the highest vapour pressure.</i> <i>Because propan-1-ol has a lower boiling point it means less energy is required to break the bond between the particles of propan-1-ol <i>sing the bond between the particles of propan-1-ol sing the properties of the propan-1-ol sing the bond between the particles of the propan-1-ol sing the properties of the properties will be present be properties will be present be properties will be present be properties of the properties will be present be </i></i>	(3)
	in the vapour state and therefore vapour pressure will	
	increase. 🗸	(3)
		[18]

1.5 Solids, liquids and gases

Solids, liquids and gases are all phases of matter.

SOLIDS	LIQUIDS	GASES
Strong intermolecular forces	Weaker intermolecular forces.	Very weak intermolecular forces.
Have a specific shape.	Particles are freer to move, liquid takes the shape its container.	Particles move freely, body of gas takes the shape its container.
Alkanes of C ₁₈ and bigger are waxy solids at STP	Alkane members from $C_5 - C_{17}$ are liquids at STP	The first four members of the alkanes $C_1 - C_4$ (methane to butane) are gases at STP
Alkenes of C ₁₅ and bigger are solids at STP	Alkene members from C_5 – C_{15} are liquids at STP	The first three members of the alkenes $C_2 - C_4$ (ethene to butene) are gases at STP
Haloalkanes are mostly STP.	A few haloalkane gases exist at room temperature.	

SOLIDS

The bigger molecules of alcohols, aldehydes, ketones, ethers, carboxylic acids and esters are solids, as a result of the increasing strength of the Van der Waals forces.

LIQUIDS

The smaller molecules of **alcohols**, **aldehydes**, **ketones**, **ethers**, **carboxylic acids** and **esters** are liquids at STP.

1.6 Chemical properties of organic compounds

Alkanes our most important fossil fuel and are good sources of heat and energy.

1.0	6.1 HYDROCARBON	IS
ALKANES C _n H _{2n+2}	ALKENES C _n H _{2n}	ALKYNES C _n H _{2n-2}
Are saturated hydrocarbons and therefore relatively unreactive.	Are unsaturated hydrocarbons and therefore reactive.	 Are highly unsaturated hydrocarbons and therefore very reactive.
 Have low boiling points and evaporate easily. Cause suffocation if inhaled. Have characteristic odours. Previously known as the 'paraffins' (meaning without affinity or reactivity). Weak Van der Waals intermolecular forces Non-polar 	 Ethene, C₂H₄, is the simplest alkene. Most are produced by cracking of alkanes. Cracking is defined further on. 	• Ethyne
-	e and flammable and are u ygen) is exothermic , and re	
 Butane is used in cigarette lighters. 'Handigas' (in camping gas bottles) is a mixture of propane and butane. Petrol is a mixture of different alkanes, mainly iso-octane and heptane. 	• Ethene is used in the manufacturing of plastic (polymer of ethane).	• Ethyne used to be known as acetylene and is used on a large scale as fuel for the oxyacetylene blowtorch used to cut and weld metals. When ethyne burns in the presence of oxygen, a flame temperature of 2 800 °C can be reached.

1.6.2 HALO	ALKANES
 Are alkanes with halogen (Br, Cℓ or I) subs saturated and therefore relatively unreactive. 	stituents;
Are bonded by weak Van der Waals intern poisonous mostly liquids at room temperature. 	
The more halogen atoms on a haloalkanthe more poisonous the substance ar	
• the less flammable e.g. $CH_3C\ell \rightarrow CH_2$	
 Tetrachloromethane CCl₄ is a non-polar molecule; used as a non-polar solvent; insoluble in water; inflammable and has very weak London Van der Waals intermolecular forces. 	 Other haloalkanes are very slightly polar and have slightly stronger dipole-dipole Var der Waals intermolecular forces.
 Tetrachloromethane CCl₄ used to be used in dry cleaning but is tetrachloride". Trichloromethane (chloroform) CHCl used to be used as an anaesthetic Tetrachloroethene (persolve), C₂H₄, is cleaning industry. 	3
DID YOU KNOW? Chlorofluorocarbons (CFCs) like dichlorop previously used for cooling and as proper their low boiling point. CFCs contribute to the depletion of the co sun's UV radiation; which has contribute therefore being phased out.	ellants in aerosol cans, because of bzone layer that protects us from the

ChlorotrifluoroetheneDichlorodifluoroetheneBy Jynto and Ben Mills [Public domain], via Wikimedia Commons

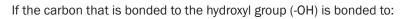
1.6.3 ALCOHOLS $C_nH_{2n+1}OH$

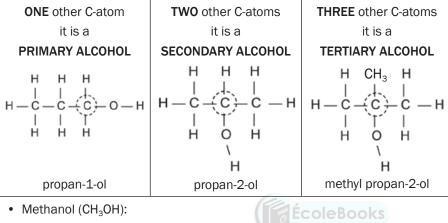
Are

- · saturated and
- have a hydroxyl functional group.

Are

- bonded by strong hydrogen bonds and by weak Van der Waals forces;
- · less polar as the number of C-atoms in the molecule increases;
- generally soluble in polar and in non-polar solvents;
- · flammable;
- mostly liquids at room temperature.





- · a poisonous liquid that can cause blindness;
- used as a solvent and sold as methylated spirits.
- Ethanol (CH₃CH₂OH)
 - a colourless liquid found in alcoholic beverages like beer and wine;
 - prepared through the fermentation of starches (beer) or sugars (wine):

$$C_6H_{12}O_6 \xrightarrow{\text{enzymes}} 2C_2H_5OH + 2CO_2$$

1.6.4 KETONES	1.6.5 ALDEHYDES
C _n F	I _{2n} O
Are saturated molecules with	Are saturated molecules with
 a carbonyl functional group O on a central C-atom. (- C -) In these structures, you will often see an R attached to part of the carbon chain. R refers to the rest of the molecule. It can be (but is not limited to) a chain of carbon atoms or substitutents. 	 a carbonyl functional group (-C-) O (- C -) on the first C-atom. O R - C - H

 Are functional isomers of the aldehydes; liquids at room temperature; abundant in nature and often have pleasant scents (smell); used to produce perfumes. 	 Are functional isomers of the ketones; liquids at room temperature except for methanal which is gaseous; responsible for pleasant smells (long C-chain aldehydes) and odours (unpleasant smells) in short chain aldehydes.
Intermolecular forces: weak induced dipole forces and stronger dipole-dipole forces. 	Intermolecular forces:weak induced dipole forces andstronger dipole-dipole forces.
 Solubility in H₂O: Short C-chain ketones form hydrogen bonds with H₂O molecules ∴ are soluble in H₂O; Long C-chain ketones are insoluble in H₂O. 	 Solubility in H₂O: Short C-chain aldehydes form hydrogen bonds with H₂O molecules ∴ are soluble in H₂O; Long C-chain aldehydes are insoluble in H₂O.
Propanone is also known as acetone and is used as nail polish remover. $\begin{array}{c c} H & O & H \\ & \parallel & \parallel & l \\ H - C - C - C - C - H \\ & \parallel & \parallel \\ H & H \end{array}$	

(ÉÉcoleBooks

1.6.6 CARBOXYLIC ACIDS	1.6.7 ESTERS	
$C_nH_{2n}O_2$		
Are saturated molecules with O • a carboxyl functional group. group. (- C - OH)	Are saturated molecules withan ester functional group.	
 Are functional isomers of the esters; liquids at room temperature; weak acids; very polar molecules. 	 Are functional isomers of the carboxylic acids; liquids at room temperature; produced when an alcohol reacts with a carboxylic acid; responsible for pleasant smells (long C-chain esters); volatile (evaporate easily). 	
 Intermolecular forces: weak induced dipole forces and hydrogen bonds. Soluble in H₂O due to hydrogen bonds that form between the carboxylic acid and H₂O molecules. 	 Intermolecular forces: weak induced dipole forces and stronger dipole-dipole forces but NO hydrogen bonds. Oily and become more so as the C-chain increases in length, due to stronger net intermolecular forces. Only short C-chain esters are soluble in H₂O. 	

Delling a sinte	De llie et a sinte	
 Boiling points: Similar to those of aldehydes and ketones with similar molecular mass. 	 Boiling points: Similar to those of aldehydes and ketones with similar molecular mass; 	
	 Lower than those of alcohols and carboxylic acids with similar molecular mass due to absence of hydrogen bonds. 	
Usage and Occurrence:	Used in the manufacture of:	
Methanoic acid (CHOOH) is	 perfumes (pleasant smell) 	
 known as formic acid (Latin: Formica = ant); found in sting nettles and in the 	 solvents artificial fruit flavours. E.g. butanoic acid + ethanol catalysed by H₂SO₄ 	
poison of ants when they bite.	yields ethyl butanoate, a.k.a apple	NB
 Ethanoic acid (CH₃COOH), also known as acetic acid, is vinegar. (Latin: Acetum = vinegar). 	flavour.	VOCABULARY • rancid: old,
• Butanoic acid (CH ₃ CH ₂ CH ₂ COOH) is		an unpleasa
 also known as butyric acid and 		preservativ
 gives rancid butter its unpleasant smell. 		food from g decaying
Benzoic acid is used as a food preservative.		• readily: eas

rancid: old, stale and with an unpleasant smell preservative: prevents food from going off or

decaying readily: easily

1.7 Reactions of organic compounds

1.7.1 Types of chemical reactions

Organic compounds take part in different types of reactions which can be grouped into:

- Oxidation •
- **Substitution**
- Addition and
- Elimination reactions. •

1.7.1.1 Oxidation reactions:

	Reaction with oxygen (0_2)	
	Exothermic (release energy)	
Excess O ₂	alkane + $O_2(g) \rightarrow CO_2(g) + H_2O(g) +$	energy

1.7.1.2 Substitution reactions:

- Take place when saturated compounds react and an atom bonded to the carbon chain is substituted by another atom or another group of atoms.
- Produce products which are also saturated.
- Are slow. •
- Are not spontaneous additional energy (e.g. sunlight *hf* or heat Δ) • is needed for the reactions to take place.

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Unit

SUBSTITUTION REACTIONS	Reaction conditions	Reaction equations
Halogenation	Endothermic: Sunlight or heat hf or Δ	alkane + halogen $\xrightarrow{\text{hf or } \Delta}$ haloalkane + HX
Hydrolysis	Endothermic VERY slow	haloalkane + $H_20 \rightarrow$ alcohol + HX
	Slow	haloalkane + NaOH (diluted) \rightarrow alcohol + NaX



REMEMBER

Markovnikov's rule:

Two products are formed during addition of water or of HX to an alkene.

The **major product** is formed when the H-atom from the added molecule bonds to the C-atom which is already bonded to the most other H-atoms.

The **secondary product** is formed when the H-atom from the added molecule bonds to the C-atom which is bonded to the least other H-atoms.

1.7.1.3 Addition reactions:

- Take place when atoms attach to the double or triple bond of an **unsaturated compound** (alkenes or alkynes), breaking the double or triple bond during the reaction.
- Form products which are more saturated than the reactants.
- Are faster than substitution reactions.
- Are usually spontaneous.

ADDITION REACTIONS	Reaction conditions	Reaction equations
Hydrogenation	Catalyst: Pt, Pd or Ni	alkene + $H_2(g) \xrightarrow{Pt} alkane$
Halogenation	No catalyst	alkene + $X_2 \rightarrow$ haloalkane
Hydrohalogenation	No catalyst.	alkene + $HX \rightarrow$ haloalkane
Hydration	Concentrated H_2SO_4	alkene + $H_2O \xrightarrow{H_2SO_{4 \text{ (conc)}}}$ alcohol

1.7.1.4 Elimination reactions:

- Occur when two atoms or groups of atoms are removed from adjacent carbon atoms in a saturated compound (like an alkane, a haloalkane or an alcohol) to form two compounds;
- are always **endothermic** i.e. the reactants must be **heated**.

ELIMINATION REACTIONS	Reaction conditions	Reaction equations
Cracking	Catalyst (Pt), Heat	alkane $\xrightarrow{Pt\Delta}$ alkene + alkane (long chains form shorter structures)
Dehydrogenation	Catalyst (Pt), Heat	alkane $\xrightarrow{\text{Pt}\Delta}$ alkene + H ₂
Dehydrohalogenation	Concentrated strong base (NaOH), Heat	haloalkane $\xrightarrow{\text{NaOH}_{(c)}\Delta}$ alkene + HX
Dehydration	Concentrated H_2SO_4 , Heat	alcohol $\xrightarrow{H_2SO_{4(c)}\Delta}$ alkene + H ₂ O

1.8 Reactions of different homologous series

1.8.1 Reactions of the ALKANES

As alkanes are saturated hydrocarbons, they are relatively unreactive.

Alkanes burn in excess oxygen to produce carbon dioxide and in limited oxygen, to produce carbon monoxide. In both cases water vapour is produced and both reactions are exothermic ($\Delta H < 0$). Alkanes are therefore sources of energy and can be used as fuel.

STEPS to balance reaction equations for the oxidation of alkanes, alkenes and alkynes.

1. Write the standard reaction equation, with the correct formula for the alkane.

alkane + (excess) $O_2(g) \rightarrow CO_2(g) + H_2O(g) + energy$

- 2. Put a 2 in front of the alkane, alkene or alkyne.
- 3. Balance the C-atoms on the right hand side.
- 4. Balance the H-atoms on the right hand side.
- 5. Balance the O-atoms on the left hand side.
- 6. Check whether the balancing ratio is in the simplest form.



Worked example 13

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Write the balanced reaction for the reaction of ethane burning in excess oxygen, using molecular formulae.

Solution

 $\begin{array}{rcl} C_2H_6(g) \ + \ O_2(g) \ \rightarrow \ CO_2(g) \ + \ H_2O(g) \ + \ energy \ (unbalanced) \\ \\ 2C_2H_6(g) \ + \ 7O_2(g) \ \rightarrow \ 4CO_2(g) \ + \ 6H_2O(g) \ + \ energy \ (balanced) \end{array}$

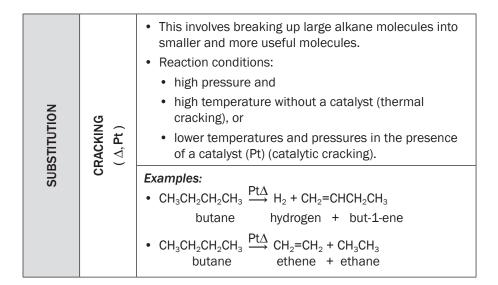
Z	NO	 Alkanes react with halogens X₂ (X = Br, Cℓ) when heated (indicated with Δ) or in the presence of light (indicated with hf). The reaction adds a halogen atom to the molecule, so it is known as halogenation.
SUBSTITUTION	HALOGENATION (+ X_2 , hf, Δ)	 Example: 1. Write a balanced reaction for the reaction of methane with chlorine gas, using molecular formulae. Name the products.
		Solution: $CH_4(g) + C\ell_2(g)$ hf or Δ $CH_3C\ell(g) + HC\ell(g)$ methanechloromethanehydrochloric acid



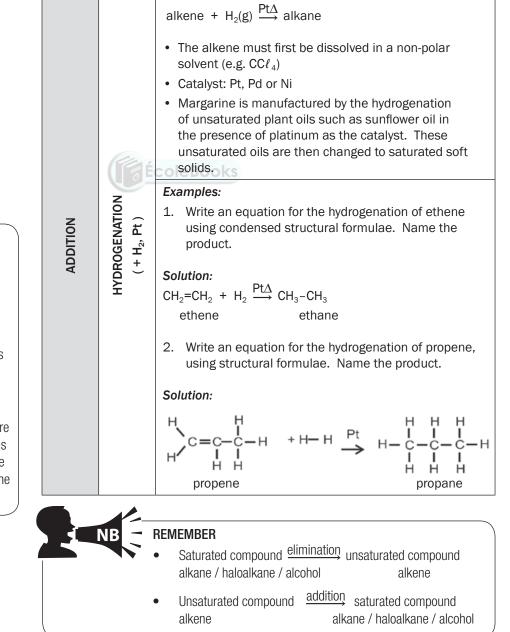
Zaitsev's* rule: If more than one elimination product is possible

- the major product is formed when the H-atom is removed from the C-atom with the least H-atoms bonded to it and
- the secondary product is formed when the H-atom is removed from the C-atom with the most H-atoms bonded to it.

* If you look this rule up online, you might find it is spelled 'Saytseff' as well.



1.8.2 Reactions of the ALKENES



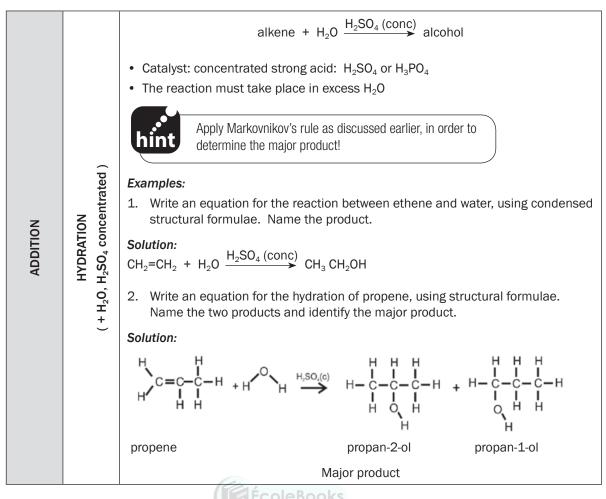


REMEMBER

- The reaction of a haloalkane with water to form an alcohol is called hydrolysis. Any splitting of a molecule by water is also called hydrolysis.
- However other reactions between organic compounds and water are called hydration reactions as the hydrogen from the water becomes part of the product.

alkene + $X_2 \rightarrow$ haloalkane (X = C ℓ , Br, F, I) • NO catalyst is needed - the reaction is spontaneous. • The reaction with fluorine is highly exothermic and explosive. Examples: 1. Write an equation for the addition of bromine to ethene, using condensed structural formulae. Name the product. Solution: HALOGENATION ADDITION $CH_2=CH_2 + Br_2 \rightarrow CH_2Br-CH_2Br$ $(+X_2)$ ethene 1,2-dibromoethane 2. Write an equation for the addition of chlorine to propene, using structural formulae. Name the product. Solution: propene 1,2-dichloropropane alkene + HX \rightarrow haloalkane (X = F, C ℓ , Br, I) NO catalyst is needed – the reaction is spontaneous. · The reaction must take place in the absence of water. Apply Markovnikov's rule as discussed earlier, in order to determine the major product! Examples: 1. Write an equation for the reaction between ethene and hydrogen fluoride, using condensed structural formulae. Name the product. **HYDROALOGENATION** Solution: ADDITION (XH +) $CH_2 = CH_2 + HC\ell \rightarrow CH_3CH_2C\ell$ ethene chloroethane 2. Write an equation for the reaction of propene with hydrogen chloride (hydrochloric acid), using structural formulae. Name the two products and identify the major product. Solution: ČI н CI н propene 2-chloropropane 1-chloropropane Major product (apply Markovnikov)

Unit



1.8.3 Reactions of the HALOALKANES

	ре кон)	 haloalkane + NaOH (dilute) → alcohol + NaX Reactions with dilute strong bases (KOH or NaOH) produce alcohols. The haloalkane must be dissolved in ethanol before treatment with dilute sodium hydroxide (aq) or potassium hydroxide (aq). The halogen atom is removed from the haloalkane and is replaced by the OHion from the KOH or NaOH. The K⁺ or Na⁺-ion bonds to the substituted halogen atom, forming NaX as a by-product.
SUBSTITUTION	WITH DILUTE STRONG BASE (NOH OE KOH) TO PRODUCE AN ALCOHOL	 Examples: 1. Write an equation for the reaction of bromo methane with a dilute sodium hydroxide solution, using condensed structural formulae. Name the products. Solution: CH₃Br + NaOH → CH₃OH + NaBr bromo methane methanol sodium bromide 2. Write an equation for the reaction of 2-bromopropane with a dilute potassium hydroxide solution, using structural formulae. Name the products. Solution: i i i i i i i i i i i i i i i i i i i
		IIII н вг н н н sodium bromide propan-2-ol

34 UNIT 1 ORGANIC COMPOUNDS AND MACROMOLECULES



REMEMBER

The reaction of a haloalkane with water to form an alcohol is called hydrolysis. Generally, splitting any molecule with water is also called **hydrolysis**.

However other reactions between organic compounds and water are called hydration reactions, particularly when OH is added to the compound.

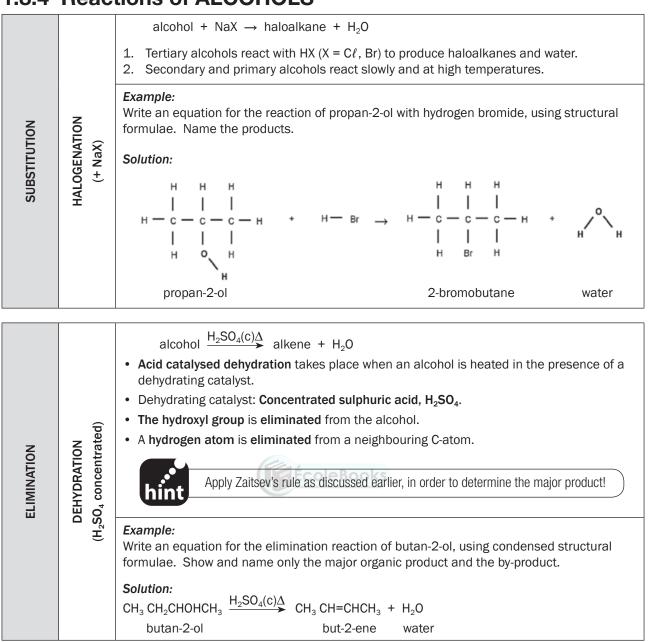


VOCABULARY

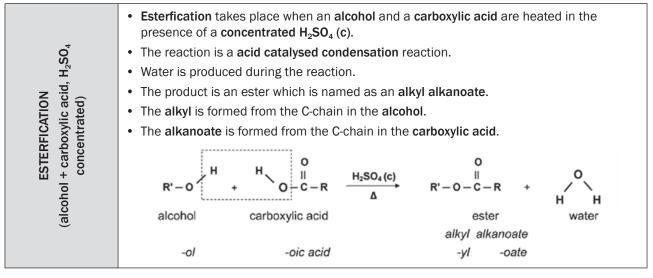
Heated under reflux: A solution is heated and the vapour is cooled down so that it condenses and return to the reaction vessel.

SUBSTITUTION	HYDROLYSIS WITH WATER (H ₂ 0) TO PRODUCE ALCOHOLS	 Haloalkane + H₂O → alcohol + HX Reactions with water (+ heat) produce alcohols. The haloalkane must first be dissolved in ethanol The reaction is slower than the reaction between a haloalkane and a strong base. The halogen atom is removed from the haloalkane and is replaced by the OH-from the water molecule. The H⁺-ion from the water then bonds to the substituted halogen atom, forming HX as a byproduct. Example: Write an equation for the reaction of chloroethane with a dilute sodium hydroxide solution, using condensed structural formulae. Name the products. Solution: Write an equation for the reaction of 1-bromopropane with water, using condensed structural formulae. Name the products. Solution: Write an equation for the reaction of 1-bromopropane with water, using condensed structural formulae. Name the products. 		
ELIMINATION	DEHYDROHALOGENATION (NaOH (c), ∆)	$\begin{array}{c} CH_{3}CH_{2}CH_{2}Br + H_{2}O \rightarrow CH_{3}CH_{2}CH_{2}OH + HBr \\ propan-1-ol hydrogen bromide \end{array}$ Haloalkane $\underbrace{NaOH(c)\Delta}{A}$ alkene + HX (X = Cl, Br, I) • Heating a haloalkane under reflux in a concentrated solution of NaOH or KOH in pure ethanol as the solvent (hot ethanolic NaOH / KOH) produces an alkene. • The halogen atom is eliminated from the haloalkane. • A hydrogen atom is eliminated from a neighbouring C-atom. • A hydrogen atom is eliminated from a neighbouring C-atom. • Apply Zaitsev's rule as discussed earlier, in order to determine the major product! Example: Write an equation for the reaction of 2-chlorobutane with concentrated sodium hydroxide when heated under reflux, using structural formulae. Show the major organic product only and name it and the by-product. Solution: H H H H H H C C C C C C C C H H H H H H		

1.8.4 Reactions of ALCOHOLS



1.8.5 Reactions of ESTERS



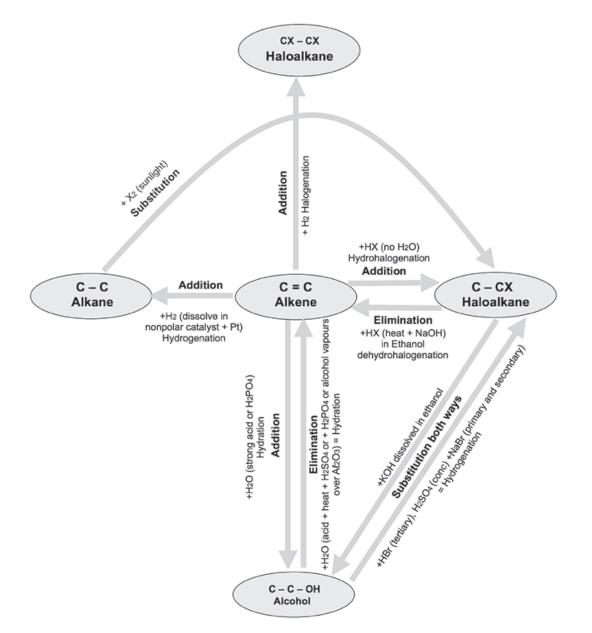
<i>Examples:</i> 1. What ester will form during the acid catalysed reaction of ethanol and propanoic acid?
Solution:
Ethyl propanoate
Which two compounds need to be heated in the presence of concentrated sulphuric acid in order to form butyl methanoate?
Solution: butanol + methanoic acid
<i>butanol</i> + <i>methanoic acid</i> • Reaction conditions in Addition, Elimination and Substitution

• The role of Sulphuric acid in Esterification, Addition & Elimination

Unit

1.9 Creating one hydrocarbon from another

The diagram below illustrates how to use Elimination, Substitution and Addition reactions to create one hydrocarbon from another.





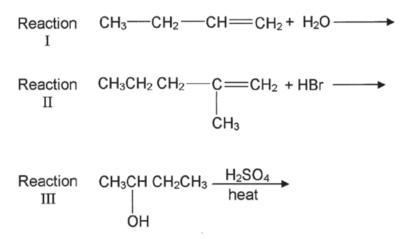
Activity 6

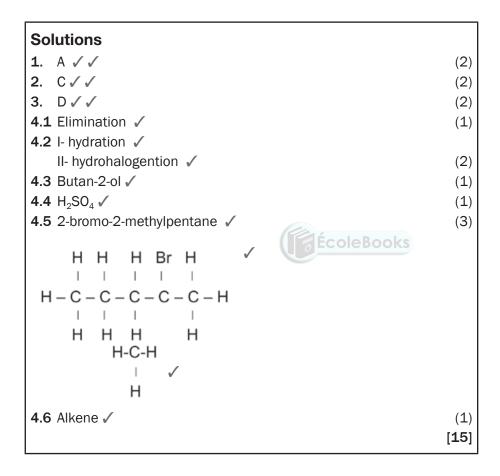
- 1. Unsaturated vegetable oils are hardened to make margarine. The reaction that takes place during the hardening process can be described as:
 - Addition L
 - Hydrogenation
 - III Substitution
 - A land ll
 - B II and III
 - C Only I
 - D Only II

(2)

(2)

- 2. Which ONE of the following compounds has the highest melting point?
 - Α Butane
 - В Butene
 - С 1-bromobutane
 - D (2)1-methylpropane
- 3. Which ONE of the following pairs of compounds correctly represents the products formed during the COMPLETE combustion of Octane?
 - A CO and H₂O Books
 - B CO and H₂
 - **C** CO_2 and H_2
 - D CO₂ and H₂O
- Most organic compounds can undergo substitution or addition or elimination reactions to produce a variety of organic compounds. Some incomplete reactions are shown below:





1.10 Plastics and polymers

1.10.1 Polymers





DEFINITION

Polymers:

- are a type of macromolecule which
- form when monomers bond to each other chemically
- to produce large molecules that are built up of repeating units in chains
- that vary in length depending on the number of monomers that bond.

Many polymers occur in nature (wood, carbohydrates, proteins etc.) while a large number are produced synthetically (most are plastics) as they are very useful.

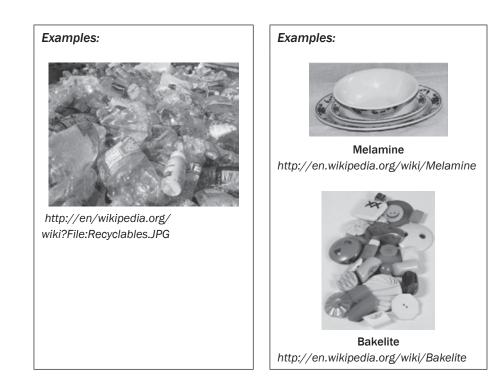
1.10.2 Synthetic polymers: Plastics

- All contain carbon in their basic structure. •
- Are light because they have a less dense structure than other solids.
- Longer polymers have stronger intermolecular forces between them.
- Cross linking between molecules increases their strength. •
- Do not conduct heat or electricity. •
- Are versatile and can be used as foam, can be moulded or extruded into fibres.



Synthetic polymers (plastics) can be divided into two main types, namely thermoplastic and thermoset polymers.

THERMOPLASTIC POLYMERS	THERMOSET POLYMERS
Can be softened by heating and	Are melted when they are made and
hardened by cooling repeatedly therefore can be remoulded into different shapes and so can be recycled.	set into a hard insoluble mass but can't be softened again and therefore can't be remoulded
	into different shapes, so can't be recycled.
Consist of long chains	• Cross-links in the molecule
 that slide past each other when melted. 	 prevent molecules from sliding past each other.
Source: Wikimedia	Source: Wikimedia



1.10.3 Properties of plastics, nylons and polyesters

Plastics	Nylons	Polyesters
Are formed by addition polymerisation	Are formed by condensation polymerisation between a dicarboxylic acid and a diamine.	Are formed by condensation polymerisation between a dicarboxylic acid and a diol.
 If the chains are lined up in a regular way, the plastic is hard and strong. If the chains are irregular or there are many side chains the plastic is softer and can bend. 	 Molecular chains are drawn into thin fibres. Are very strong. 	• Depending on the chain they may be stronger or weaker than nylon.
 Examples: Polyethene (plastic bags, shopping bags, plastic containers) Polypropene Hard (Piping, bottle crates) PVC (water pipes, artificial leather) 	Examples: • Nylon (ropes, carpets, clothes)	 Examples: Used for clothing fibres cold drink bottles

Properties of polymers are determined by the intermolecular forces between the chains.

Polymers

- with carbonyl groups can form strong hydrogen bonds and are strong with high melting points;
- like polyesters have dipole-dipole bonds (that are weaker than hydrogen bonds) between the chains, so have lower melting points and are more flexible (bendable);
- with only Van der Waals forces between the chains have low melting points and are flexible.

1.10.4 Polymerisation

Polymerisation

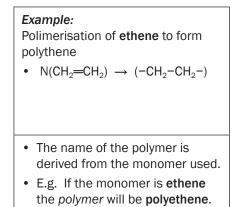
- is a chemical process in which monomers combine to form polymers;
- takes place in three steps:
 - initiation (the step that starts the reaction)
 - propagation (the steps that allow the reaction to continue) and
 termination (the step that ends the reaction).
- is either addition polymerisation or condensation polymerisation.

ADDITION POLYMERISATION

- The monomer must be unsaturated – it must contain a double bond or a triple bond, e.g. an alkene like ethene.
- Is the direct addition of the same monomer molecules to form a single product.
- No atoms are lost or gained during the reaction.
- The empirical (simplest) formulae of the monomer and of the polymer are the same.
- The chain is bonded by strong covalent bonds.
- Reaction conditions:
 - High temperature (± 200 °C)
 - High pressure (± 1000 atm)
 - A small amount of a very reactive initiator.

CONDENSATION POLYMERISATION

- Instead of double bonds, these monomers have functional groups like an alcohol (-diol), or dicarboxylic acid.
- Each monomer must have two or more active groups – to link the molecules.
- Is the reaction between monomers which are not always the same to form two products the polymer and a molecule like H_2O or $HC\ell$.
- The polymers that form are
 - · polyesters or
 - nylon.
- Reaction conditions:
 - High temperature
 - Concentrated sulphuric acid, $\rm H_2SO_4$



Example:

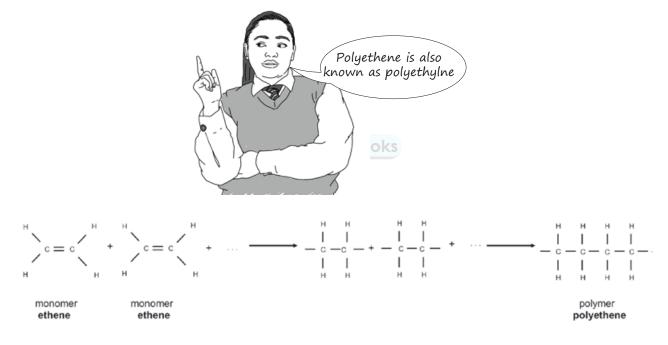
Polymerisation to produce **polyesters** is called **esterfication**

- during which a water molecule H₂O is eliminated and
- the organic product contains an ester functional group.
- The name of the polymer is deduced from the names of the 2 bonding molecules – an organic alcohol and a carboxylic acid.

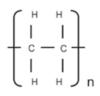
1.10.5 Addition polymerisation of ethene to produce polyethene

Example 1:

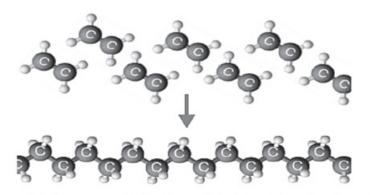
(Note: This is the only addition polymerisation example you need to learn.)



- The length of the polyethene macromolecule depends on the number of ethene monomers that bond.
- The structural formula of the polymer polyethene can therefore be abbreviated as follows:



where n is the number of monomers that joined.



http://www.bbc.co.uk/schools/gcsebitesize/science/images/ocrchem17.gif

	There are two types of polyethene	
	Low density polyethene LDPE	High density polyethene HDPE
Relative strength	Weak	Strong
Number of branches on the polymer	Many	Few
Maximum usable temperature (°C)	85	120
Uses:	Freezer bags Soft bottles Bendable cables Freezer bags Bendable cables Freezer bags Freezer bags Bendable cables Freezer bags Freezer bags Bendable cables Freezer bags Freezer	Shopping bags Plastic crates Plastic pipes Toys
	 Easily moulded Can be made in any colour Light Hardness can be manipulated during manufacture Not affected by water, air etc. Can be used to pack food – hygenic 	

1.10.6 Condensation polymerisation to produce a polyester

- The alcohol has a hydroxyl group on each end of its carbon chain, so it is a -diol.
- A H-atom is removed from the hydroxyl group on the alcohol and a hydroxyl group is lost from the dicarboxylic acid.
- The -H and the -OH bond to form a water molecule, H_2O .
- A new bond forms between the O-atom on the alcohol and the C-atom on the carboxylic acid. This is an ester linkage.
- The carboxyl group on the other end of the dicarboxylic acid can now react further with another -diol, while the hydroxyl on the other end of the -diol can now react with another dicarboxylic acid.
- This results in a long chain-like compound a polymer.
- This polymer is known as polyester.

Example:



• There are many different polyester fibres with a wide range of uses. Kevlar and Mylar are two examples.

	KEVLAR	MYLAR
Properties	Much stronger than nylon or steelFire resistant	Stretched polyester filmHigh tensile strengthTransparent
Uses	Bulletproof vestsBoat hullsAeronautical industry	Helium balloonsSpace / rescue blanketsIsolators
	http://en.wikipedia.org/wiki/ File:Kevlar-vest-ct-wiki.jpg	http://en.wikipedia.org/wiki /File:Balloonsanimals.jpg
	http://en.wikipedia.org/wiki/	http://en.wikipedia.org/wiki/File:
	File:Kevlar_canoe_algonquin.JPG	RescueFoil.jpg



http://en.wikipedia.org/wiki/ File:Canal-pollution.jpg

1.11 Plastics and pollution

1.11.1 Disadvantages of polymer usage

Although synthetic plastics are light, easy to shape and relatively cheap, there is widespread opposition to the use of these materials.

- Most are not bio-degradable.
- When burned to dispose of them, poisonous gases may be released.
- Landfill sites use up land and fill quickly.
- Litter causes ecological problems.

1.11.2 Recycling

- Biodegradable plastics would solve most problems, but are expensive.
- Responsible recycling is essential.

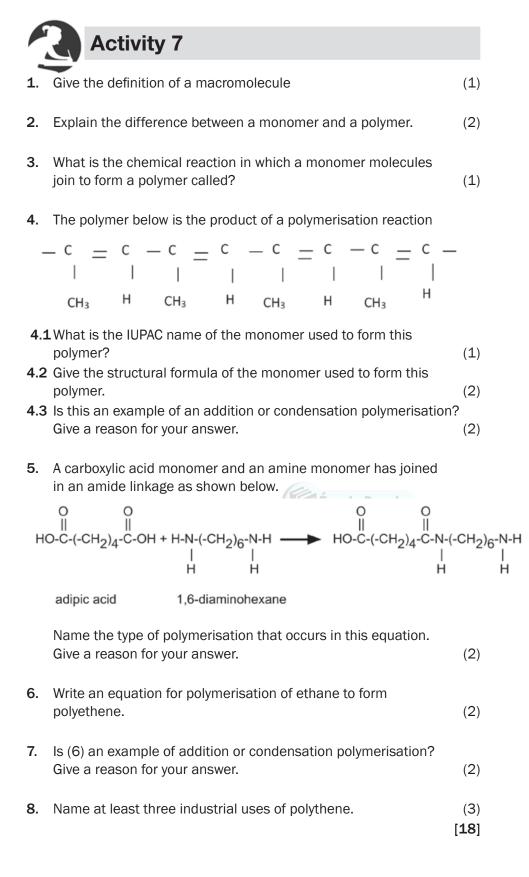


http://www.flickr.com/photos/davegoodman/3609172860/

Problems with Recyclability:

- Not possible in very rural areas.
- High costs.
- Not all plastics can be recycled.
- Communities are not all aware of the problems.

High density polythene (HDPE)	Low density polythene (LDPE)	
PE-HD	04 PE-LD	
Recycled to produce plastic wood for garden furniture rubbish bins rulers 	Recycled to produce fibres for clothing plastic liners for rubbish bins 	



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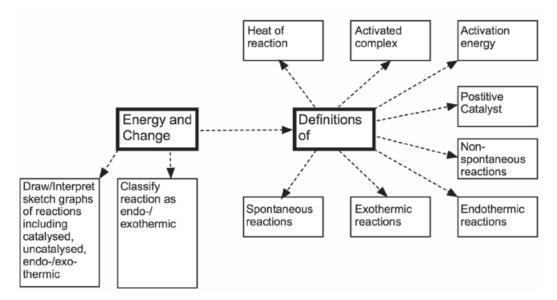
Solutions **1**. A molecule that consists of a large number of atoms. \checkmark (1)2. A polymer is a large molecule that is made up of smaller units, covalently bonded to each other in a repeating pattern. \checkmark Each of these smaller units are called a momomere. \checkmark (2)**3.** Polymerisation \checkmark (1)**4.1** prop-(1)-yne (1)4.2 н С н Н (2)**4.3.** Addition polymerisation \checkmark monomers combined through an addition reaction. 🗸 (2)5. Condensation polymerisation. Two monomers with different functional groups are joined 🗸 and when they join it leads to the "loss" of a small molecule, in this case, water. \checkmark (2)ÉcoleBooks 6. \ -c-c' / Н C = CC = C+ н (2)7. Addition polymerisation 🗸 monomers combinded through an addition reaction. \checkmark (2)8. Any of the following: sandwich bags, \checkmark cling wrap, \checkmark car covers, ✓ squeeze bottles, liners for tanks and ponds, moisture barriers in construction, freezer bags, water pipes, wire and cable insulation, extrusion coating. (3)[18]



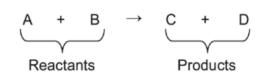


Rate and extent of reactions

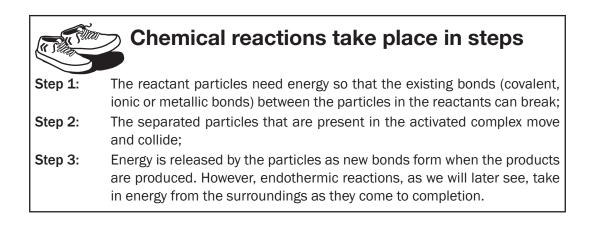
2.1 Summary



2.2 Energy changes during chemical reactions



During a chemical reaction, the **reactants** (written on the left hand side of the equation) react to produce **products** (written on the right hand side of the equation).





DEFINITIONS

Activation energy is the minimum kinetic energy required for a chemical reaction to take place.

The **activated complex** is a temporary, unstable, high energy intermediate state between the reactants and the products.



A spontaneous reaction takes place without any addition of energy.

The mass of a catalyst remains constant during a chemical reaction.



DEFINITIONS

A **catalyst** is a substance that changes the rate of a chemical reaction without undergoing a permanent change during the reaction, by decreasing the activation energy of the reaction.

The heat of reaction or enthalpy (Δ H) is the net change in energy in a chemical system when a chemical reaction takes place.

2.3 Activation energy and the activated complex

Activation energy is usually absorbed in the form of heat, light or mechanical energy and is required to change reactants into an activated complex. It is the energy required to break the bonds in the reactant particles to form the **activated complex**.

- **Spontaneous reactions** take place when the reactants have enough energy to start the reaction without additional heat.
- Non-spontaneous reactions take place when the reactants do not have enough energy themselves to start a reaction, and additional energy needs to be added.



"Spontaneous" means "of its own accord" or "by itself" or "without intervention".

2.4 Catalysts

A positive catalyst increases the rate at which a reaction takes place while a negative catalyst (also called an inhibitor) decreases the reaction rate.

If you hear someone talk about a "catalyst", they usually mean a positive catalyst.

Positive catalysts increase the rate of a chemical reaction...

- by providing an alternative path for the reaction to take place
- which requires less energy for the reactants to change into the activated complex,
- by decreasing the activation energy.

2.5 Energy changes during chemical reactions: ∆H

We know that energy

- is absorbed by the reactant particles when the intramolecular bonds break to form the activated complex, and is
- is released when the particles in the activated complex form new bonds when the products form.

In symbols:

 ΔH = Energy of products – Energy of reactants

= E_{final} – E_{initial} OR

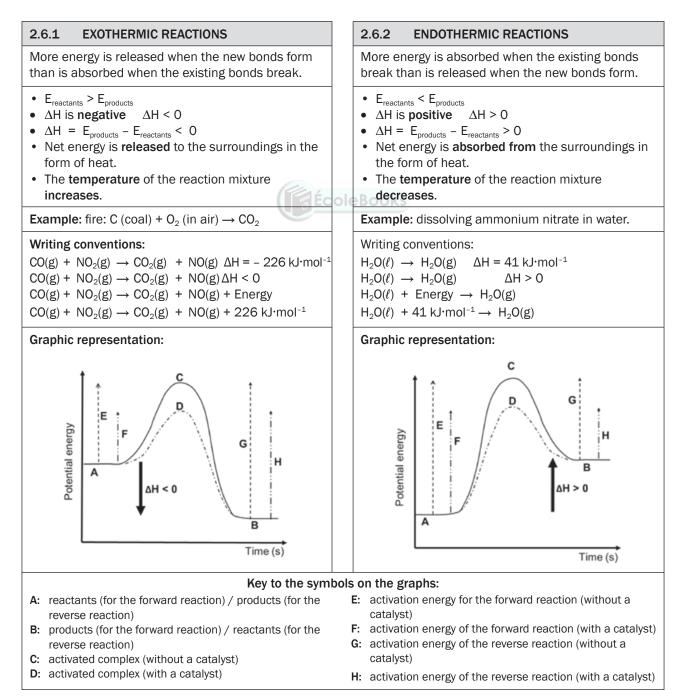
- $\Delta H = H_{\text{products}} H_{\text{reactants}}$
 - = H_{final} H_{initial}

2.6 Endothermic and exothermic reactions

When we refer to a reversible reaction, the enthalpy (ΔH) is always stated for the forward reaction.

It is important:

- to know the differences between exothermic and endothermic reactions
- to be able to identify whether a given reaction is exothermic or endothermic and
- to be able to interpret graphs for exothermic and endothermic reactions.
- Endo- means "into" or "inwards", and "exo-" means "outwards"; so, "endothermic" means heat goes in (the reaction vessel will feel cold after the reaction completes), whereas "exothermic" means "heat goes out", so the reaction vessel will feel hot when the reaction completes.

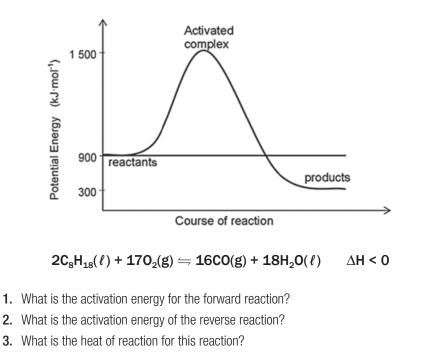


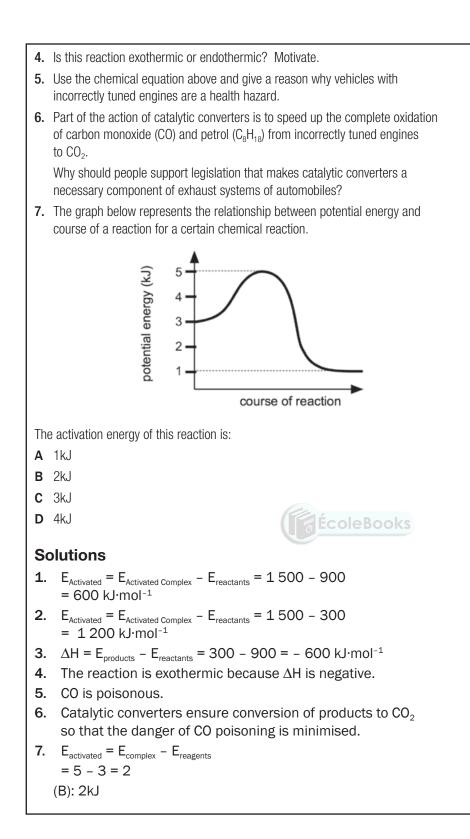
2.6.3 Law of conservation of energy

The release of energy in chemical reactions occurs when the reactants have higher chemical energy than the products. The chemical energy in a substance is a type of potential energy stored within the substance. This stored chemical potential energy is the heat content or enthalpy of the substance. The collection of substances that is involved in a chemical reaction is referred to as a system and anything else around it is called the surroundings. If the enthalpy decreases during a chemical reaction, a corresponding amount of energy must be released to the surroundings. Conversely, if the enthalpy increases during a reaction, a corresponding amount of energy must be absorbed from the surroundings. This is simply the Law of Conservation of Energy. Now, to break a chemical bond, requires energy. Some substances need more and some substances need less energy to break the bond - depending on the bond energy (measure of the bond strength of the chemical bond) i.e. potential energy of the bonds of the initial reactants. Some reactants obtain the energy required to break the bonds from the surroundings, which might include the energy that is released when the bonds in the products are formed. To form a bond releases energy; when the bond is formed in the product, the product releases energy, of which some energy is "given back" to break the bonds of the reactants - so they can break! For our purpose it is enough to simply talk about 'the total energy released' when the product is formed in an exothermic reaction is more (entalphy decreases) than the amount of energy required to break the initial reactants' bonds.



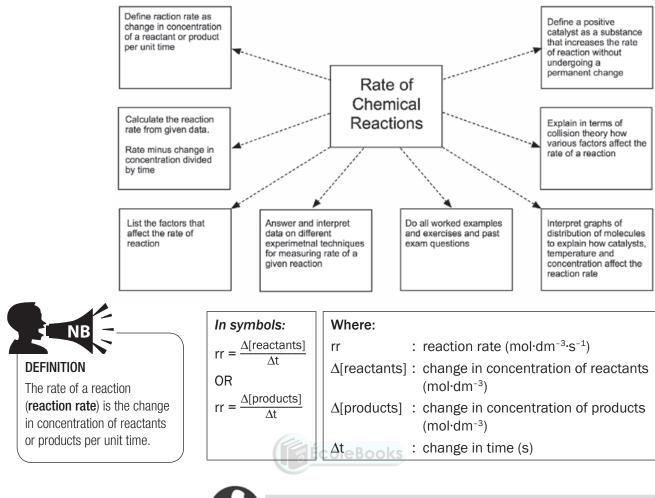
When there is a limited supply of oxygen, such as in a car which is not tuned properly, octane burns incompletely to produce carbon monoxide (amongst other emissions). The graph alongside represents the energy changes that take place during this reaction and the balanced chemical equation is given:





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2.7 Rates of reactions



Activity 1

Consider the reaction

 $\mathbf{H}_{2} + \mathbf{I}_{2} \rightarrow \mathbf{2HI} \qquad (\Delta H < 0)$

- **1.** Is this reaction exothermic or endothermic? (1)
- **2.** State a reason for your answer in 1.1. (1)
- **3.** How does energy of the products compare to that of the reactants? (2) [4]

Solutions

1.	Exothermic (reaction). 🗸	(1)
2.	ΔH < 0 ✓	(1)
3.	The energy of the products is less than \checkmark that of the	
	reactants. 🗸	(2)
		[4]

2.8 Factors which affect reaction rate

The rate at which a chemical reaction takes place depends on the reaction conditions. In industry it is important to make sure that the chemical reactions take place at a rate as high as is safely and economically possible.

The 5 factors that affect the rate of a chemical reaction are:		
FACTOR	EFFECT ON REACTION RATE	
The nature of the reactants.	• The higher the reactivity of a reactant, the higher the reaction rate (E.g. reactive metals like Mg react faster than metals like Cu).	
	 Inorganic reactions are faster than organic reactions. 	
• The concentration of the reactants for gases (g) and aqueous (aq) solutions.	• The higher the concentration of a reactant, the higher the reaction rate.	
The pressure of gas (g) reactants.	 The higher the pressure of a gas reactant, the higher its concentration and the higher the reaction rate. 	
The surface area (state of division) of solid reactants (marked (s)).	A powder has a large surface area.	
	Lumps and strips have a smaller surface area.The larger the surface area, the higher the reaction rate.	
The temperature of the reaction system.	 The higher the temperature of the reaction system, the higher the reaction rate. However, if the temperature goes too high, a different reaction might take place (e.g. the reactants might burn up instead of reacting as expected). 	
The presence of a suitable catalyst.	A suitable positive catalyst increases the reaction rate.	

2.9 The Collision Theory

The **collision theory** is applied to explain **how** these factors affect the rates of chemical reactions.

- According to the Kinetic Molecular Theory, the particles in a reaction mixture are in a state of **perpetual random motion** and therefore **collide** with one another.
- Only effective collisions between reactant particles lead to chemical reactions and the formation of new products.

An effective collision between reactant particles takes place if:

- the colliding particles have **enough kinetic energy** to form an activated complex i.e. if the energy of the colliding particles is equal to or more than the activation energy for the reaction AND
- the particles are **correctly orientated** when they collide.



If a reaction is fast, it has a short reaction time but a high reaction rate.



REMEMBER

The more effective collisions that occur between the reactant particles per second, the faster the reaction will occur. The rate of a chemical reaction depends on the number of effective collisions between the reactant particles per second; the number of collisions for which the particles have energy more than or equal to the activation energy and on the number of collisions that are correctly orientated. Hence, smaller particles e.g. dust or gas, react more violently than larger particles, e.g. crystals, since the reactants can mix more thoroughly and therefore increase the number of effective collisions. Compare, for example, the explosive quality of gunpowder to say, lumps of solid ingredients like sulphur, potassium nitrate, and coal.

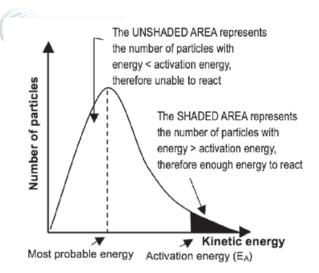
In symbols:

5		
reaction rate	\sim	(number of effective collisions per unit time)
	\sim	(particles with correct orientation)
	\sim	(particles with sufficient (enough) $E_{k})$

2.10 The mechanism of reactions

The Maxwell-Boltzmann distribution diagram shown below shows the distribution of the kinetic energy of the particles in a reaction system. The distribution of the kinetic energies of the reactant particles is used to explain the reaction rate in the system.

• The graph shows the number of particles (on the vertical axis) versus their kinetic energy (on the horizontal axis).



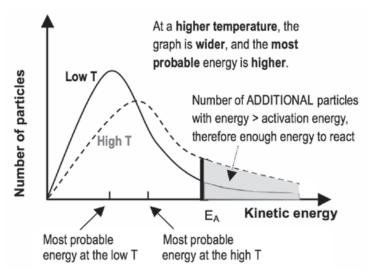
- The curve always passes through the origin this means that no molecules have zero kinetic energy since all molecules are in motion unless they reach the temperature of 0 K or -273°C.
- The curve does not touch the *x*-axis at high kinetic energy i.e. there are always some molecules with very high kinetic energy.
- The energy value that corresponds with the **peak** of the curve represents the **most probable energy**.
- The **area** below the curve is equal to the **total number of molecules** in the system.

- The **shaded area** below the curve and to the **right** of the activation energy, equals the number of reactant particles that have enough energy to collide effectively and therefore **can react**.
- The area below the curve and to the **left** of the activation energy, equals the number of reactant particles that can't collide effectively and therefore **can't react**.
- If the **shaded area is bigger**, there are **more particles** that can **collide effectively** and the **reaction rate** is higher.

a) The effect of increasing the temperature of the reaction mixture

If the temperature increases:

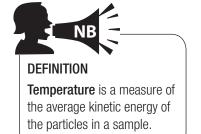
- The particles in the sample have a **higher average kinetic energy** and the **most probable energy** is **higher** than at a low temperature.
- The graph is **wider** and the peak is **lower**.
- The total number of particles is the same, so the **total area** below the graph is the **same**.
- More particles have kinetic energy > than the activation energy (the shaded area is bigger)
- \therefore more effective collisions take place per second and
- the collisions are more energetic
- \therefore the reaction rate increases.



b) The effect of increasing the concentration of the reactants

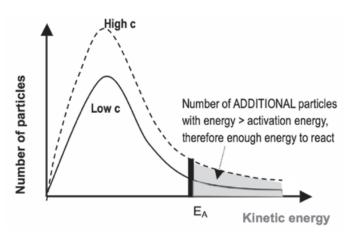
If the concentration of the reactants increases:

- The particles in the sample have the same average kinetic energy and the most probable energy is the same ... the graph has the same curve/shape
- The graph is higher as there are now more particles per unit volume;
- The total number of particles is greater, so the **total area** below the graph is **bigger**.
- More particles have energy > than the activation energy (the shaded area is bigger)
- ... more effective collisions take place per second
- \therefore the reaction rate increases.



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hint REMEMBER

When adding a suitable catalyst:

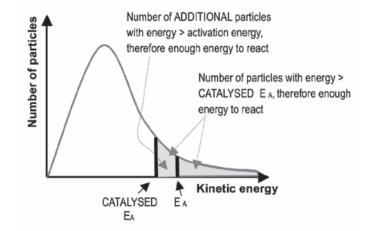
- the total number of reactant particles stays constant and
- the average kinetic energy of the reactant particles remains constant as the temperature does not change.

c) The effect of adding a catalyst

Adding a suitable positive catalyst:

- **decreases** the **activation energy** needed to change the reactants into an activated complex so
- more particles have enough energy to form an activated complex
- ... the **number** of possible **effective collisions per second increases** and
- ... the reaction rate increases.

e.g

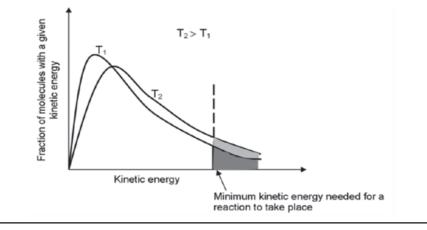


A Maxwell-Boltzman graph has a shallow gradient if the reaction rate is higher BUT in a graph of mass loss vs time, a shallow gradient means the reaction rate



Worked example 2

Consider the following Maxwell-Boltzman distribution diagram for a chemical reaction system and answer the questions that follow.



- 1. Did all the molecules have the same kinetic energy at low temperature? Motivate your answer.
- 2. What does the shaded area to the right of the vertical line represent?
- **3.** If a catalyst is added to the reactants, will it cause the vertical dotted line to move to the left or right? Explain your answer.

Solutions

- **1.** No. Together they will have the same average kinetic energy, but each molecule's kinetic energy is determined by its mass and the square of its own average speed (remember, $E_k = \frac{1}{2} mv^2$).
- 2. It indicates the % of molecules which will have more energy than the activation energy at that temperature. In other words, the % of molecules which are capable of colliding effectively and reacting. At the higher temperature, there is a higher % of molecules which are capable of colliding effectively (bigger area below the graph).
- **3.** To the left. The activation energy of the reaction is decreased by adding a suitable catalyst. The line thus shifts to the left. It implies that at both the low and the high temperatures there will now be a greater % of molecules available for effective collisions.

2.11 Measuring rates of reactions

We measure the rate of a reaction by studying the rate at which (how fast) the products appear or the rate at which the reactants are used up while the reaction takes place.

Experimental techniques for measuring the rate of a given reaction include the following:

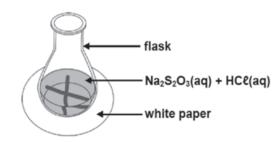
- measuring of gas volumes produced,
- turbidity (e.g. precipitate formation),
- change of colour and
- the change of the mass of the reaction vessel if a gaseous product is allowed to escape from it.

Experimental Technique 1: Measuring turbidity

 $\mathsf{Na}_2\mathsf{S}_2\mathsf{O}_3(\mathsf{aq}) + 2\mathsf{HC}\ell(\mathsf{aq}) \rightarrow 2\mathsf{NaC}\ell(\mathsf{aq}) + \mathsf{H}_2\mathsf{O}(\ell) + \mathsf{SO}_2(\mathsf{g}) + \mathsf{S}(\mathsf{s})$

Sodium thiosulphate reacts with diluted hydrochloric acid to form a yellow sulphur precipitate. The formation of the precipitate can be used to measure the reaction rate.

Apparatus:





DEFINITIONS

Turbidity is the cloudiness or haziness of a fluid (liquid or solution) that is caused by particles in the fluid which prevent light from passing through the liquid.

Opaque: not transparent, does not allow light to pass through.

Method:

- **1**. Draw a black cross on a piece of paper.
- 2. Add an exact volume of $\text{Na}_2\text{S}_2\text{O}_3$ to a conical flask and place it on the cross.
- 3. Quickly add HC ℓ to the solution and start the stopwatch.
- **4.** Swirl (turn) the flask carefully and allow the reaction to continue until the black cross can no longer be seen.
- 5. Record the time.

In this experiment, the concentration of the HC ℓ (aq) and Na₂S₂O₃(aq) can be changed, keeping the temperature constant OR In another experiment, the temperature can be changed, but keeping the concentrations constant. The time it takes for the solution to become **opaque** is a measure of the reaction rate.

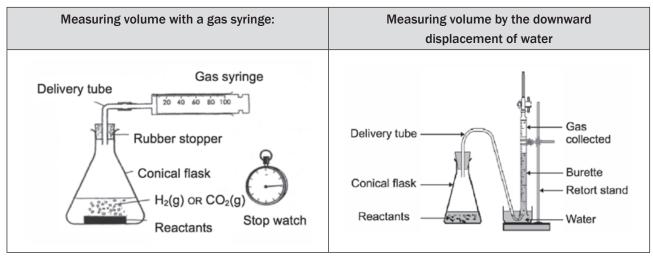
Experimental Technique 2: Measuring the volume of a gas product

Consider the following reactions: $Mg(s) + 2HC\ell(aq) \rightarrow MgC\ell_{2}(aq) + H_{2}(g) \qquad OR$ $CaCO_{3}(s) + 2HC\ell(aq) \rightarrow CaC\ell_{2}(aq) + H_{2}O(\ell) + CO_{2}(g) \qquad OR$ $MnO_{2}(s)$ $2KC\ell O_{3}(s) \rightarrow 2 KC\ell(s) + 3O_{2}(g)$

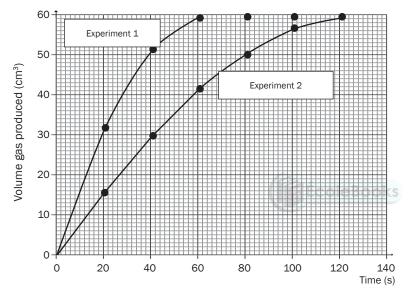
(The catalysed decomposition of potassium chlorate)

- **1.** The rate of the reaction is determined by measuring the volume of the gas produced (the dependent variable) in specific time intervals (the independent variable). If you can't recall what the terms "independent" and "dependent variables" mean, see the introduction section of this book.
- 2. The gas is collected in a graduated gas syringe or by the downward displacement of water in a burette. The volume of the gas produced can be determined accurately.
- **3.** The stopwatch is started when the reactants are added and stopped when no new bubbles form i.e. when the volume of gas produced stays constant.

Apparatus:



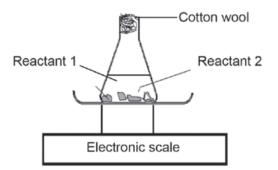




Experimental Technique 3: Measuring the total mass of *reactants and the mass loss:*

Consider the same reactions as used in Technique 2.

Apparatus:



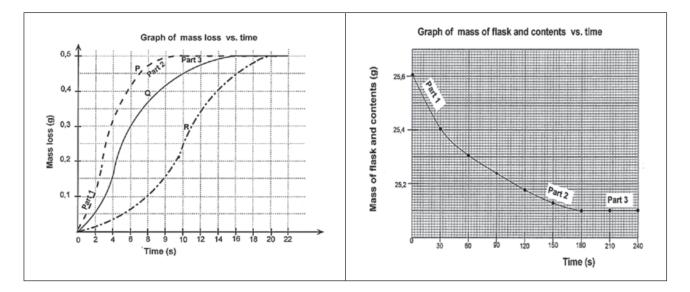
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The mouth of the flask is plugged with cotton wool because it is porous and allows the gas to escape from the reaction system but prevents liquid spray that forms during the reaction, from escaping.

Method:

- The rate of the reaction is determined by measuring the mass of the gas produced (the dependent variable) in specific time intervals (the independent variable).
- The reactants are added to the flask and the mouth of the flask is plugged with some cotton wool.
- The mass of the reaction system (the reactants, flask and cotton wool) is recorded at the start of the experiment and the stop watch is started.
- The gas that is produced passes through the cotton wool plug and escapes from the system, so the mass (the reading on the scale) decreases.
- The mass of the system is recorded at regular time intervals e.g. every 30 seconds.
- The stopwatch is stopped when no new bubbles form i.e. when the mass reading on the scale stays constant.
- The results are used to plot a graph of: mass of the flask and contents versus time OR mass loss (mass of gas escaped) versus time.





- The gradients of the graphs indicate the rates of the reactions.
- The **steeper (more vertical)** the gradient of the graph, the **higher** the reaction rate, because more happens in less time.

Limiting reactant: The reactant that is used up during a chemical reaction – all of the reactant reacts.

Excess reactant: The reactant that is not all used up during a chemical reaction – there is always some of this reactant left in the reaction system once the reaction has stopped.

Interpreting the graphs that use Techniques 2 and 3:

There are three time intervals shown in the graphs:

Stage in the reaction	Explanation
Part 1 of both graphshas the biggest slope (gradient) so	• The concentration of the reactants (usually the acid) is the highest and
 the reaction rate is the highest. 	• the reaction surface area (the solid), is the biggest therefore
	 the number of effective collisions taking place will be high
	 so the reaction rate is high and
	• the volume of gas produced per second is high.
Part 2 showsa gradual decrease in the slope so	The reactants are being used to produce the products so
 the reaction rate decreases gradually. 	the concentration of the acid is decreasing and
	 the reaction surface area of the solid reactant is decreasing therefore
	 the number of effective collisions taking place decreases and
	the reaction rate decreases and
	 the volume of gas produced per second will decrease so that
	 fewer gas molecules escape per second and the rate at which the mass changes, decreases.
Part 3 is where	When the limiting reactant has been used up (all of it
each graph ends horizontally	has reacted)
 which means that the reaction is complete. 	 the reaction is complete and no more products are produced as
	no more products are produced so
	 no more gas escapes from the system and the mass remains constant
	the mass remains constant.

Unit

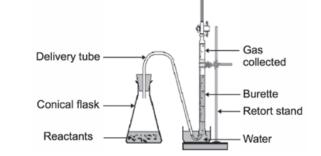


A group of learners use the reaction between hydrochloric acid and magnesium powder to investigate one of the factors that influence the rate of a chemical reaction.

The reaction that takes place is:

 $Mg(s) + 2HC\ell(aq) \rightarrow MgC\ell_2(aq) + H_2(g)$

The learners use the apparatus and follow the method shown below to conduct the investigation.



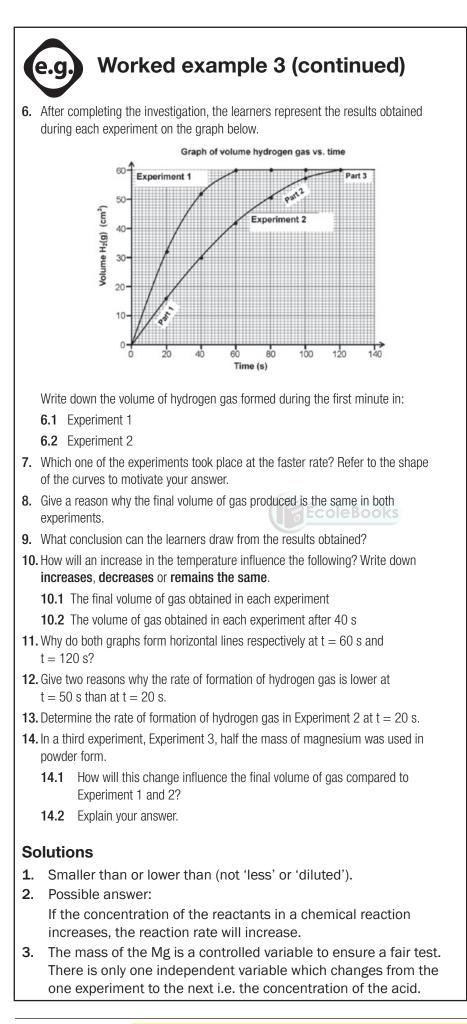
Method for Experiment 1:

- **Step 1:** Place a spatula (spoon) of magnesium powder in a conical flask and add $50 \text{ cm}^3 \text{ HC}\ell(\text{aq})$ of known concentration.
- **Step 2:** Simultaneously start the stopwatch and close the flask with the rubber stopper containing the delivery tube.
- Step 3: Measure the volume of the H₂(g) formed in time intervals of 20 seconds.

Method for Experiment 2:

Repeat steps 1 to 3 above, but use only 25 $\rm cm^3$ of the same HC2(aq) diluted to 50 $\rm cm^3$ with distilled water.

- 1. How does the concentration of the acid used in Experiment 2 differ from the concentration of the acid used in Experiment 1? Write down only greater than, lower than or equal to.
- 2. Write down a hypothesis for this investigation.
- **3.** Why should the learners ensure that equal amounts of magnesium powder are used in each of the two experiments?
- 4. The learners use an excess of HCℓ(aq) for the two experiments. What meaning does the term 'excess' have in this situation? Give a reason why the excess HCℓ(aq) will not influence the results.
- **5.** If the Mg powder used in Experiment 1 was impure with particles of dirt in between, describe and explain how the shape of the graph would be influenced.





The hypothesis must refer to the relationship between dependent and independent variables. It must be a statement that can be proved to be correct or incorrect, it is a prediction based on (prior) knowledge.

Worked example 3 (continued)

- 4. 'Excess' means that there is more than enough hydrochloric acid for the reaction to take place. When the reaction is complete, all the Mg will have reacted, but some of the acid will be left over. The Mg is the limiting reactant and when it has all reacted, the reaction will stop.
- 5. The gradient would be less steep, indicating that the reaction rate is lower. Because the reaction surface area of the magnesium is smaller, fewer particles are available to collide, thus fewer effective collisions will occur. The final volume of hydrogen gas formed will be less, because the magnesium is the limiting reagent and a smaller mass of pure magnesium was reacting, because of the dirt in between.
- **6.1** 60 cm³
- 6.2 42 cm³
- **7.** Experiment 1.The gradient or slope (of the tangent to the graph) is steeper.
- 8. The mass of Mg used in both experiments was the same. Mg is the limiting reagent and the limiting reagent determines the yield of the products.
- **9.** If the concentration of the reactants in a chemical reaction increases, the reaction rate will increase.
- 10.1 Remains the same.

10.2 Increases.

- 11. The horizontal lines mean that the reactions are complete; all the magnesium has reacted with the excess HCl.
 Experiment 1 reaches completion first because of the higher concentration of HCl (more particles per unit volume to react), so more effective collisions will occur and the reaction rate is higher.
- **12.** At 50 s the concentration of $HC\ell$ has already decreased notably, and there is much less magnesium left, with a smaller exposed surface area. Thus the collisions are less effective and the reaction rate is lower.
- **13.** Reaction rate = slope (gradient) = $\frac{\Delta y}{\Lambda r}$

$$= \frac{\Delta \text{volume } H_2}{\Delta \text{time}}$$
$$= \frac{(16-0)}{(20-0)}$$
$$= \frac{0.8 \text{ cm}^3}{\text{s}}$$

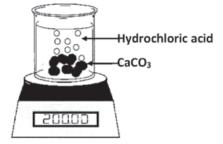
- **14.1** The final volume of hydrogen gas in Experiment 3 will be half the volume of hydrogen gas produced in Experiment 1 and 2.
- **14.2** Mg is the limiting reagent which determines the yield. From the balanced equation: 1 mol Mg(s) produces

1 mol H₂(g), thus $\frac{1}{2}$ mol Mg(s) produces $\frac{1}{2}$ mol H₂(g)

Worked example 4

A certain mass of calcium carbonate chunks is added to a hydrochloric acid solution in an open beaker on a scale as shown here. The equation for the reaction is as follows: 0.000 (x) = 0.001 (x) = 0.001 (x) = 0.001 (x)

 $CaCO_{3}(s) + 2HC\ell(aq) \rightarrow CaC\ell_{2}(aq) + H_{2}O(\ell) + CO_{2}(g)$

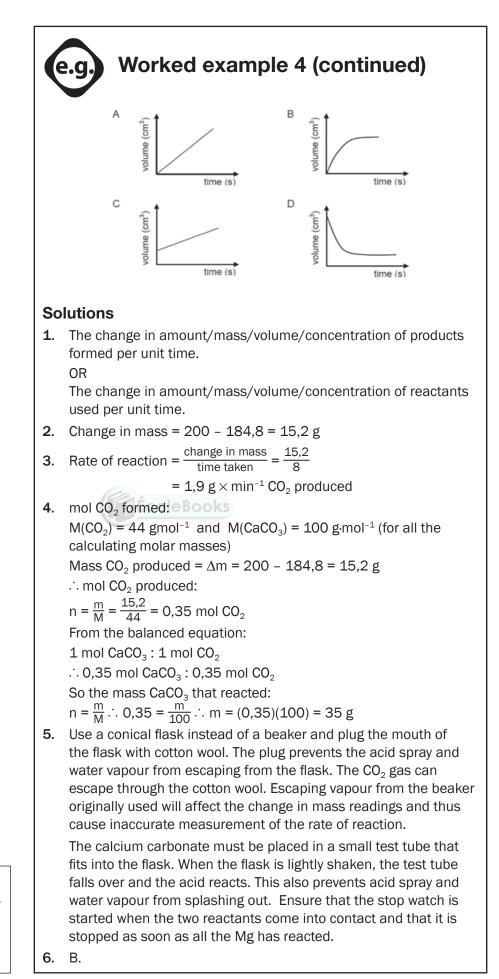


 $\rm CO_2(g)$ is allowed to escape from the beaker. The data in the table below was obtained for a time interval of 8 minutes.

Time (min) Mass of beaker and contents (g)	
0	200,00
1	197,50
2	195,45
3	193,55
4	191,70
5	189,90
6	188,15
7	186,45
8	184,80

- **1.** Explain the term 'reaction rate'.
- **2.** Calculate the change in the mass of the beaker and its contents during the 8 minutes.
- **3.** Use your answer to Question 2 to show that the average reaction rate during the 8 minutes is 1,9 g·min⁻¹.
- 4. Calculate the mass of calcium carbonate which reacted during the 8 minutes.
- 5. "The use of the beaker in this experiment influences the readings and therefore the calculation of the rate of the reaction and mass of the CO₂ formed". Explain this statement and suggest TWO ways to rectify this experimental problem and to make this a reasonable test.
- **6.** One of the products formed in a chemical reaction is a gas. Which ONE of the following graphs of volume versus time best represents the formation of this gas until the reactants are used up?

) Unit



NOTE:

In the calculation, n=0,3454 was rounded off to 0,35 so that:

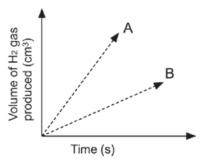
Mass = m(100) = 34,54 g



1. Hydrogen gas may be prepared by the reaction of zinc metal with dilute hydrochloric acid. The chemical equation for this reaction is :

 $Zn(s) + 2HC\ell(aq) \rightarrow ZnC\ell_2(aq) + H_2(g) \quad \Delta H < 0$

A learner determined the volume of the hydrogen produced with time at two temperatures and two grades of Zn; powder and solid pellets. He used the same mass of zinc and the same volume and concentration of hydrochloric acid for each experiment and plotted the following graphs.



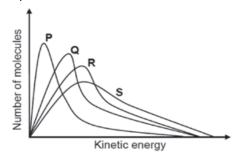
Which combination of temperature and surface area will be represented by A?

	Temperature	State of Zn
Α	High	Pellets
В	High	Powder
С	Low	Pellets
С	Low	Powder

(2)

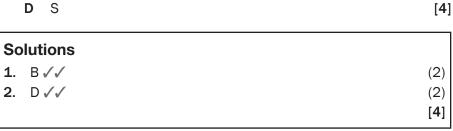
(2)

2. The graphs below represent the molecular distribution for a reaction at different temperatures.



Which ONE of the graphs above represents the reaction at the highest temperature?

- Ρ Α
- В Q
- С R
- D S





Give ONE term for each of the following descriptions by choosing a term from the list above. Write down only the term next to the question number.

Surface Area; Catalyst; Elastic collision; Effective collision; Activated complex; Concentration; Temperature; Heat of reaction; Activation energy.

- 1. A chemical substance that speeds up the rate of a chemical reaction by lowering the net activation energy.
- A collision in which the reacting particles have sufficient kinetic energy and correct orientation. (1)
- The factor responsible for increasing the rate of a reaction when a solid is broken up into smaller pieces. (1)
- The temporary unstable state that is formed during the course of a chemical reaction. (1)
- 5. A measure of the average kinetic energy of the particles in a gas.
- 6. The net amount of energy released or absorbed during a chemical reaction. (1)
 - [6]

(1)

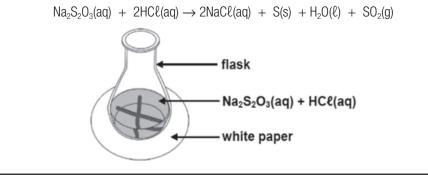
(1)

Solutions

1.	Catalyst. 🗸	(1)
2.	Effective collision.	(1)
3.	Surface Area. 🗸	(1)
4.	Activated complex. 🗸	(1)
5.	Temperature. 🗸	(1)
6.	Heat of reaction. 🗸	(1)
		[6]



Learners use hydrochloric acid and a sodium thiosulphate (Na $_2$ S $_2$ O $_3$) solution to investigate the relationship between rate of reaction and temperature. The reaction that takes place is represented by the following equation:



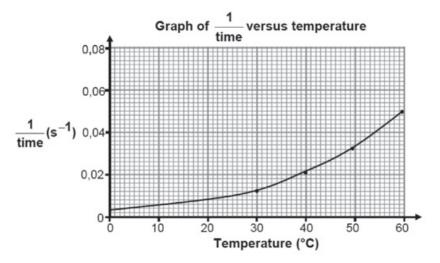


Worked example 5 (continued)

They add 5 cm³ 2 mol·dm⁻³ hydrochloric acid solution to 50 cm³ sodium thiosulphate solution in a flask placed over a cross drawn on a sheet of a white paper, as shown in the diagram below. The temperature of the mixture is 30°.

They measure the time it takes for the cross to become invisible. The experiment is repeated with the temperature of the mixture at 40° C, 50° C and 60° C.

- 1. Write down:
 - **1.1** The possible hypothesis for this investigation.
 - **1.2** NAME or FORMULA of the product that requires the need to work in a well-ventilated room.
 - **1.3** NAME or FORMULA of the product that causes the cross to become invisible.
- **2.** Apart from the volume of the reactants, state ONE other variable that must be kept constant during this investigation.
- **3.** Why is it advisable that the same learner observes the time that it takes for the cross to become invisible?
- 4. What experimental technique was used to measure the rate of reaction in this investigation?
- 5. The shown graph below is obtained from the results.



5.1 What is the relationship represented by $\frac{1}{\text{time}}$ on the vertical axis?

- 5.2 What conclusion can be drawn from the results obtained?
- **6.** The learners collected washed and dried sulphur. They weighed the dry sulphur and its mass was 0,12g. Calculate the percentage yield of sulphur.

Solutions

- **1.1** E.g. The <u>rate of reaction increase</u> with <u>increase</u> in <u>temperature</u>.
- **1.2** Sulphur dioxide/SO₂.
- 1.3 Sulphur/S.
- **2.** Concentration of reactants (HC ℓ and Na₂S₂O₃).
- **3.** Different people have different sight abilities/reaction times. (To ensure that the results are reliable).
- 4. Turbidity.
- 5.1 Reaction rate.
- 5.2 The reaction rate increases with increase in temperature.



```
Na_2S_2O_3(aq) + 2HC\ell(aq) \rightarrow 2NaC\ell(aq) + S(s) + H_2O(\ell) + SO_2(g)
6.
                = CV
     n<sub>(HCℓ)</sub>
                = (2)(0,005)
     n<sub>(HCℓ)</sub>
     n_{(HC\ell)}
              = 0,01 mol
     2 n_{(HC\ell)} = 1 n(S)
     n(S)
                = 0,005 mol
                = \frac{m}{M}
     n
     0,005 = \frac{m}{32}
              = 0,16 g
     m(s)
     Percentage Yield = \left(\frac{0.12}{0.16}\right) \times 100
     Percentage Yield = 75 (%)
```



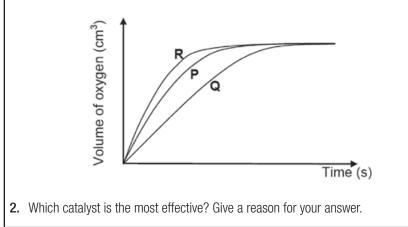
A hydrogen peroxide solution dissociates slowly at room temperature according to the following equation:

 $2H_2O_2(aq) \rightarrow 2H_2O(\ell) + O_2(g)$

During an investigation, learners compare the effectiveness of three different catalysts on rate of decomposition of hydrogen peroxide. They place EQUAL AMOUNTS of sufficient hydrogen peroxide into three separate containers. They add EQUAL AMOUNTS of THREE catalyst, P, Q and R, to the hydrogen peroxide in the three containers respectively and measure the rate at which oxygen gas is produced.

1. For this investigation, write down the:

- **1.1** Independent variable.
- **1.2** Dependent variable.





Worked example 6 (continued)

3. Fully explain, by referring to the collision theory, how the catalyst increases the rate of reaction.

In another experiment, the learners obtain the following results for the decomposition of hydrogen peroxide:

TIME(s)	H ₂ O ₂ CONCENTRATED (mol·dm ⁻³)	
0	0,0200	
200	0,0160	
400	0,0131	
600	0,0106	
800	0,0086	

- **4.** Calculate the AVERAGE rate of decomposition (in mol·dm⁻³) of $H_2O_2(aq)$ in the first 400s.
- **5.** Will the rate of decomposition at 600 s be GREATER THAN, LESS THAN or EQUAL TO the rate calculated in QUESTION 4.4? Give a reason for the answer.
- **6.** Calculate the mass of oxygen produced in the first 600 s if the 50 cm³ of hydrogen peroxide decomposes in this time interval.

Solutions

1.1 (Type of) catalyst.



- **1.2** Rate (of reaction).
- R. It has the fastest reaction rate./ steepest gradient or slope./ Produces oxygen in a fastest or in shorter time. (Any of these reasons)
- **3.** A catalyst provides an alternative reaction path with a lower activation energy.

More molecules have sufficient/enough kinetic energy. OR

More molecules have kinetic energy equal to or greater than activation energy.

More effective collisions per unit time./Rate of effective collisions increases.

4. Average rate =
$$\frac{\Delta[H_2O_2]}{\Delta t}$$

$$=\frac{(0,0131-0,020)}{400-0}$$

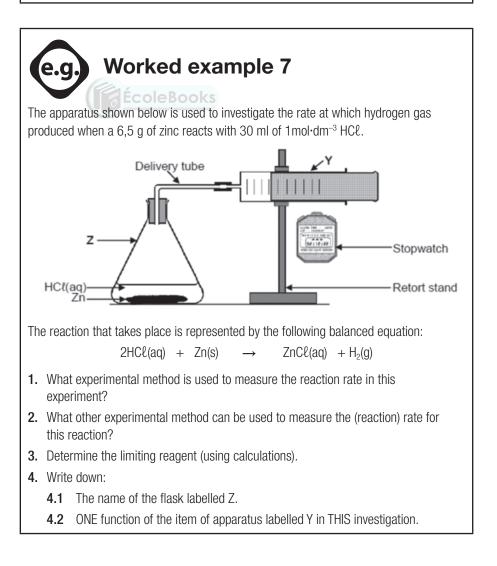
=
$$1,73 \times 10^{-5}$$
 mol·dm⁻³·s⁻¹

5. Less than. The concentration of hydrogen peroxide is decreasing as the reaction proceeds.

```
6. OPTION 1

c = \frac{n}{V}
(0,0200 - 0,0106) = \frac{n}{(50 \times 10^{-3})}
n(O_2) = \frac{1}{2} n(H_2O_2) = \frac{1}{2} (4,7 \times 10^{-4})
n(O_2) = 2,35 \times 10^{-4} \text{ mol}
n = \frac{m}{M}
2,35 \times 10^{-4} \text{ mol} = \frac{m}{32}
m(O_2) = 0,008g \approx 0,01g
OPTION 2

\Delta c(H_2O_2) = (0,0200 - 0,0106) = 0,0094
\Delta c(O_2) = \frac{1}{2} n(H_2O_2) = \frac{1}{2} (0,0094)
= 4,7 \times 10^{-4}
c = \frac{m}{MV}
m(O_2) = cMV
m(O_2) = (0,0047)(3)(50 \times 10^{-3})
m(O_2) = 0,008g \approx 0,01g
```





Worked example 7 (continued)

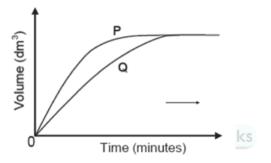
Two experiments are conducted using apparatus above. The conditions for each experiment are given below.

	Experiment 1	Experiment 2
Zinc	powdered	powdered
Hydrochloric acid	2 mol·dm⁻³	2 mol·dm ⁻³
Temperature	25°C	40°C

5. FROM THE TABLE ABOVE, write down:

- **5.1** The independent variable for this investigation.
- 5.2 ONE controlled variable.

The volume of hydrogen gas produced is measured in each experiment. The graphs below show the results obtained.



- **6.** Which graph, P or Q, represents Experiment 2? Refer to the data given in the table, as well as the shape of the graph, to explain how you arrived at the answer.
- **7.** Give a reason why the rate of hydrogen production slows down towards the end in both experiments.
- **8.** Calculate the mass of zinc used to prepare 0,024 dm³ of hydrogen of hydrogen at room temperature. Assume that 1 mole of hydrogen gas has a volume of 24,04 dm³ at room temperature.

Solutions

- 1. Measuring the <u>volume</u> of a <u>gas</u> produced.
- 2. Measuring change in mass of reactants.

3.
$$n = \frac{n}{M}$$

 $n = \frac{3,25}{65}$
 $n = 0.05$

$$Zn + 2HC\ell \rightarrow ZnC\ell_2 + 2H_2$$

$$n = CV = (2) \left(\frac{30}{1000} \right)$$

n = 0,06 mol

Therefore the limiting agent is $\text{HC}\ell$

- **4.1** Conical/Erlenmeyer (flask).
- **4.2** Measure the volume of gas produced./ Collect the gas produced.
- **5.1** Temperature (of reactants).



5.2 Concentration (of $HC\ell$)

6. P.

Experiment 2 has the highest temperature.

The same volume of a gas was produced in a <u>shortest</u> period of <u>time</u>.

OR

Experiment 2 has the <u>highest temperature</u>. Graph has the steepest slope.

7. The concentration of reactants decreases as the reaction proceeds.

8.

Calculations	Mark Allocation
$n(H_2) = \frac{V}{Vm}$	 Substitute volume. ✓
$n(H_2) = \left(\frac{0.24}{24.01}\right)$	• Substitute molar volume. 🗸
$n(H_2) = 0.01 \text{ mol}$	• 0,01mol √
$n(H_2) = \frac{n}{M}$	• n(Zn) = n(H₂) ✓
$0,01 = \frac{m}{65}$ m = 0,65 g	 Substitute 65 g⋅mol⁻¹ ✓
ORÉÉCOLEBOOKS	• Answer. 🗸
1 mol H_2 gas = 24,04 dm ³	
0,01 mol H_2 gas = 0,24 dm ³	
65 g Zn = 1 mol	
0,65 g = 0,01 mol	



81,1 g of nicotine consists of 60,07 g of carbon, 14,01 g of nitrogen and 7,02 g of hydrogen.

Determine the:

- 1. The empirical formula of nicotine. (13)
- 2. Molecular formula of nicotine if its molar mass is 162,26g. (4)

[17]

Solutions
 Determining the percentage composition by molar mass of each element:
 C = 60,07/81,1 × 100 = 74,04% ✓

$$N = \frac{14,01}{81,1} \times 100 = 17,27\% \checkmark$$
$$H = \frac{7,02}{81,1} \times 100 = 8,65\% \checkmark$$

Element	g per 100g	$n = \frac{m}{M}$ for 100g	$n = \frac{m}{M}$ for 81,1g	Simplest Ratio
С	74,07	n = $\frac{74,04}{12}$ = 6,17 \checkmark	$\frac{60,07}{12} = 5$ 🗸	5
N	17,28	$n = \frac{17,27}{14} \checkmark$ = 1,23 \checkmark	$\frac{14,01}{14} = 1 \checkmark$	1
н	8,65	$n = \frac{8,65}{1} \checkmark$ = 8,65 \checkmark	$\frac{7,02}{1} = 7 \checkmark$	7

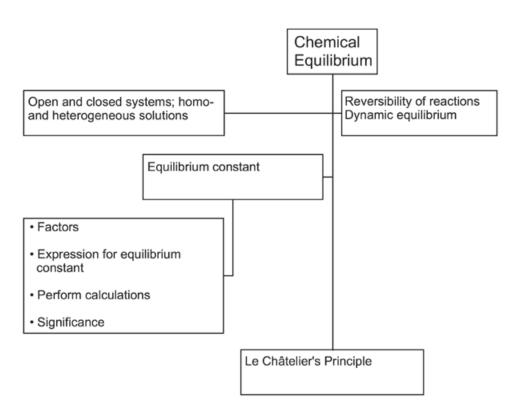
Empirical formula of nicotine is C_5NH_7 (13) 2. Now calculate the molar mass of the substance using empirical formula $M(C_5NH_7) = 81 \text{ g/mol } \checkmark$ $x(81) = 162,2 \checkmark$ x = 2 (meaning every atom in the empirical formula must be multiplied by 2) \checkmark Molecular formula of nicotine is $C_{10}N_2H_{14}\checkmark$ (4) [17]



Chemical equilibrium

When a chemical reaction takes place, the atoms or ions in the reactants form new bonds and new products with different chemical formulas and different chemical properties.

3.1 Summary



3.2 Key concepts

In this section, we will be revising the basic concepts involved in chemical equilibria (plural of equilibrium). In a **chemical** reaction, **chemical equilibrium** is the state in which both reactants and products are present in concentrations which have no further tendency to change with time. Usually, this state results when the forward reaction proceeds (continues) at the same rate as the reverse reaction. **NB**. This does not mean the reaction has stopped; instead it means that it is continuing to react, but the reactants and products are being produced (and re-produced) at a constant rate.

HOMOGENEOUS REACTIONS

- are reactions where all the reactants and products are in the same phase,
- i.e. all are solids, or all are liquids, or all are gases

$$SO_2(g) + O_2(g) \rightleftharpoons SO_3(g)$$

HETEROGENEOUS REACTIONS

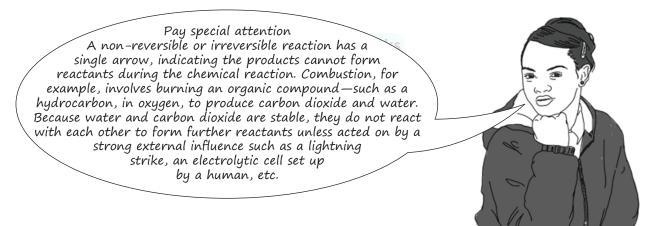
• are reactions where not all species in the reaction vessel are in the same phase.

 $CaCO_3(s) + HC\ell(aq) \rightarrow CaC\ell_2(aq) + CO_2(g) + H_2O(\ell)$

Most chemical reactions are non-reversible or irreversible – this means that the products cannot change back into the reactants.

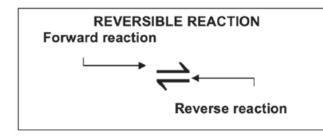
These reactions are essentially like baking. The ingredients, acting as the reactants, are mixed and baked together to form a cake, which acts as the product. This cake cannot be converted back to the reactants (the eggs, flour, etc.), just as the products in an irreversible reaction cannot convert back into the reactants (without e.g. human intervention). An example of an irreversible reaction is combustion. When carbon burns in oxygen to form carbon dioxide, the reaction is said to be **non-reversible**.

$$C(s) + O_2(g) \rightarrow CO_2(g)$$



Some chemical reactions are **reversible**. The products **react with each other** to form the **original reactants** under suitable conditions. (E.g. change in pressure, temperature, reactant concentration, etc.).

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





Therefore:

Forward reaction		Reverse reaction
$N_2(g)$ + 3 $H_2(g) \rightarrow$ 2 $NH_3(g)$	Reaction	$2 \text{ NH}_3(g) \rightarrow \text{N}_2(g) + 3 \text{ H}_2(g)$
$N_2(g) + 3 H_2(g)$	Reactants	2 NH ₃ (g)
2 NH ₃ (g)	Products	$N_2(g) + 3 H_2(g)$

Learn these definitions. They are used to explain what happens during a chemical reaction.

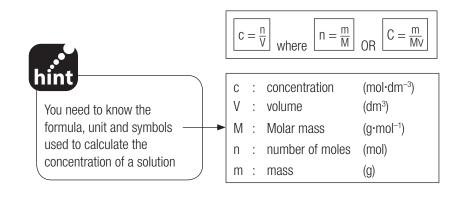


NB	-

- Open chemical system: reactants / products can escape from reaction vessel
- Closed chemical system: reactants / products cannot escape from reaction vessel
- **Macroscopic changes:** measurable or visible changes e.g. changes in colour, temperature, pressure, volume, concentration
- Yield: the amount of product formed during a chemical reaction

DEFINITIONS

- An **open system** continuously interacts with its environment (conditions are not kept constant).
- A closed system is isolated from its surroundings (conditions are kept constant)
- A reversible reaction occurs when the products can be converted back to reactants
- **Chemical equilibrium** is dynamic when the rate of the forward reaction equals the rate of the reverse reaction
- The **concentration** of a solution or of a gas is the number of moles of substance per unit volume (per dm³).
- A dynamic chemical equilibrium is established in a closed system when the forward and reverse reactions of a reversible chemical reaction take place at the same time (simultaneously) and at the same rate. The conditions in the system must also remain constant.

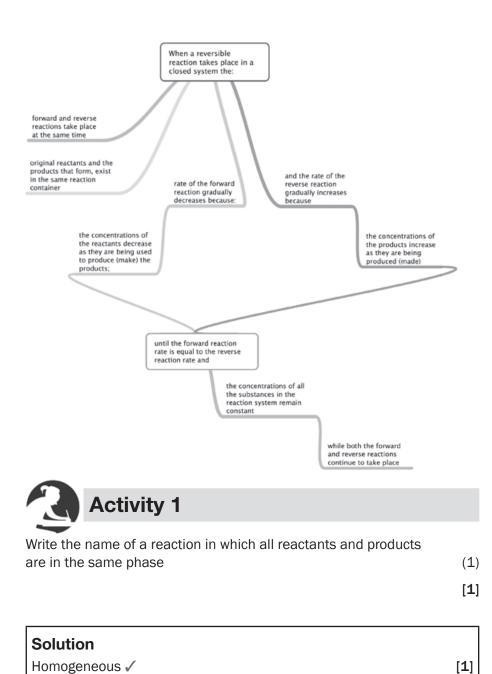




You need to understand what a **chemical equilibrium** is and know the conditions needed for a chemical equilibrium.

Chemical equilibrium

- When a chemical system reaches dynamic chemical equilibrium, both the forward and the reverse reactions continue they do **NOT** stop.
- There are no **macroscopic** (visible with the eye) changes when the system is in equilibrium, but on a **microscopic** (atomic) level, the changes (reactions) continue.
- Neither the reactants nor the products are ever used up in an equilibrium system (incomplete reaction – i.e. "incomplete" in the sense that there are still species of the original/starting species (reactants.))



) Unit

3.3 Factors that influence chemical equilibrium position

Temperature (T): Increasing or decreasing the temperature of the equilibrium mixture

Concentration (c): Adding a substance to or removing a substance from the system at constant volume. This only applies to solutions (aq) and to gases (g).

Pressure (p):Increasing or decreasing the pressure on an equilibrium
mixture (this ONLY applies to gases).

3.4 Le Châtelier's Principle

If a **closed system** is in a state of **dynamic chemical equilibrium**, and one of the factors that influences the equilibrium (temperature, concentration or pressure) is changed:

- the equilibrium position will be disturbed;
- either the forward or the reverse reaction will be favoured;
- the applied change will be opposed;
- the reaction rates will change and eventually
- a new equilibrium will be established
- so that the forward and the reverse reactions again take place at the same rate.



that:

If any factor changes, we can apply Le Châtelier's Principle to determine which changes will happen to the system in equilibrium (what upsets the balance).

3.4.1 Applying Le Châtelier's Principle to changes in equilibrium conditions

Changing the temperature of the reaction mixture (ΔT)

Increasing the temperature of the reaction system (i.e. heating it)

- favours the reaction that decreases the temperature of the system (absorbs heat)
- ∴ favours the endothermic reaction.

Decreasing the temperature of the reaction system (i.e. cooling it)

- favours the reaction that increases the temperature of the system (releases heat)
- ... favours the **exothermic** reaction.

Changing the concentration of a solution or gas reactant (Δc)

Increasing the concentrationof a (g) or (aq) reactant (or product)

- favours the reaction that decreases the concentration of that substance
- ∴ the reaction that **uses** that substance as a **reactant**.

Decreasing the concentration of a (g) or (aq) reactant (or product)

- favours the reaction that increases the concentration of that substance
- ... the reaction that **makes** that substance as a **product**.



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.

Changing the pressure of a gaseous system (Δp)

Increasing the pressure (or decreasing the volume) of a gaseous system

- favours the reaction that decreases the pressure of the system
- by decreasing the total number of **gaseous moles** in the system.

Decreasing the pressure (or increasing the volume) of a gaseous system

- favours the reaction that increases the pressure of the system
- by increasing the total number of **gaseous moles** in the system.

Steps to follow

Follow these steps to predict the change in a **closed** chemical system in **dynamic** equilibrium:

Check that the reaction:

- **Step 1:** Is reversible (\Longrightarrow) (info given must indicate it is a dynamic equilibrium).
- Step 2: Equation is balanced.
- **Step 3:** Count the number of gaseous (g) **moles** on each side of the \leftrightarrows .

Determine:

- Step 4: If the forward reaction is exothermic or endothermic
- Step 5: If the reverse reaction is exothermic or endothermic
- **Step 6:** The change (which factor?) disturbs the equilibrium

Decide:

- **Step 7:** According to Le Châtelier's Principle, which reaction is favoured (forward or reverse)? (Follow the reasoning in the table above.)
- **Step 8:** How the concentrations of the reactants and products change.



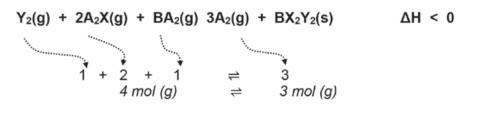
By closed we do not mean a closed container. Rather we mean a closed system where the conditions are kept constant.



Activity 2

Consider the following reversible reaction that is in equilibrium in a closed system (the symbols represent chemicals which are unnamed; if you see symbols like X or Y which aren't on the Periodic Table, it often means you've got to work out what kinds of substances they are).

Step 1, 2 & 3:



Step 4/5:

 $\Delta H < 0$ - the forward reaction is exothermic

- the reverse reaction is endothermic

In each of the following cases:

- Explain how the equilibrium will be affected (which reaction will be favoured)
- State how the concentration of the product $A_2(g)$ will change.

CASE 1

The reaction system is heated.

(3) [**3**]

Solution

Case 1.

If the reaction system is heated, the **temperature** of the system **increases**.

According to Le Châtelier's Principle, increasing the temperature of the

reaction system (i.e. heating it) favours the reaction that will **decrease** the temperature of the system

- \therefore favours the **endothermic** \checkmark reaction but $\Delta H < 0$
- \therefore the reverse reaction is endothermic
- \therefore the reverse reaction is favoured \checkmark
- : the $3A_2(g) + BX_2Y_2(s)$ reacts faster than it is produced
- : the concentration of the A_2(g) decreases. \checkmark

(Remember: The opposite is true if the reaction vessel is cooled.)

[3]



You must be able to use Le Châtelier's Principle to **identify** the **factor** that will increase the yield of the products and what **influence** that factor will have on the reaction **AT EQUILIBRIUM**

CASE 2	$Y_2(g)$ is added to the vessel at constant pressure
	and temperature

(3) [**3**]

[3]

(3) [**3**]

Case 2.

Adding $Y_2(g)$ increases the concentration of the $Y_2(g).$ \checkmark

According to Le Châtelier's Principle, **increasing** the concentration of $Y_2(g)$ favours the reaction that **decreases** the concentration of $Y_2(g)$

 $\ \, \therefore \qquad \mbox{the reaction that uses of } Y_2(g) \mbox{ as a reactant} \\ \mbox{the forward reaction is favoured. } \checkmark \\ \mbox{the rate at which } A_2(g) \mbox{ and } BX_2Y_2(s) \mbox{ is produced, increases} \\ \mbox{the concentration of the } A_2(g) \mbox{ increases. } \checkmark$

ed from	the vessel	l at constan	t pressure

$A_2(g)$ is removed from the vessel at constant pressure
and temperature.

CASE 3

Solution
Case 3. Removing $A_2(g)$ decreases the concentration of the $A_2(g)$.
According to Le Châtelier's Principle, decreasing the concentration of the $A_2(g)$ favours the reaction that increases the concentration of the $A_2(g)$;
the reaction that makes $A_2(g)$ as a product
\therefore the forward reaction is favoured. \checkmark
the rate at which $A_2(g)$ and $BX_2Y_2(s)$ is produced, increases
the concentration of the $A_2(g)$ increases. \checkmark [3]

CASE 4	Some of the BX2Y2(s) is removed from the system at		
	constant pressure and temperature.	(3)	
		[3]	

Solution

Case 4.

Removing $BX_2Y_2(s)$ has no effect on the **equilibrium** as it is a **solid**. \checkmark

Removing a solid from an equilibrium system does not disturb the concentration. \checkmark (Solids in equilibrium reactions have very little change in mass, hence they are ignored)

The concentration of $A_2(g)$ remain the same. \checkmark

[3]

CASE 5 The pressure on the system is increased (or the volume is decreased)

hint

There are 4 gaseous moles on the left, and 3 gaseous moles on the right.

Solution

Case 5.

According to Le Châtelier's Principle, **increasing** the **pressure** (or decreasing the volume) of a gaseous system favours the reaction that decreases the pressure of the system by decreasing the total number of gaseous moles in the system. \checkmark

the forward reaction is favoured. \checkmark

the rate at which $A_2(g)$ and $BX_2Y_2(s)$ is produced, increases

the concentration of the $A_{\rm 2}(g)$ increases. \checkmark



(3) [**3**]



Activity 3

Say whether the statement is TRUE or FALSE: If the equilibrium constant for the reaction $A_2(g) + B_2(g) \rightleftharpoons 2AB(g)$ is equal to K, then the equilibrium constant for the reverse reaction $2AB(g) \rightleftharpoons A_2(g) + B_2(g)$ is also equal to K. (3)

[3]

[3]

Solution ÉcoleBooks

FALSE. ... for the reverse reaction $2AB(g) \rightleftharpoons A_2(g) + B_2(g)$ is equal to $\frac{1}{K} \checkmark \checkmark OR$... less (smaller) than K



Activity 4

The industrial preparation of hydrogen gas is represented by the equation below:

$$\mathsf{CH}_4(\mathsf{g}) + \mathsf{H}_2\mathsf{O}(\mathsf{g}) \leftrightarrows \mathsf{CO}(\mathsf{g}) + \mathsf{3H}_2(\mathsf{g}) \qquad \Delta \mathsf{H} \geq \mathsf{0}$$

The reaction reaches equilibrium at 1 000 °C in a closed container.

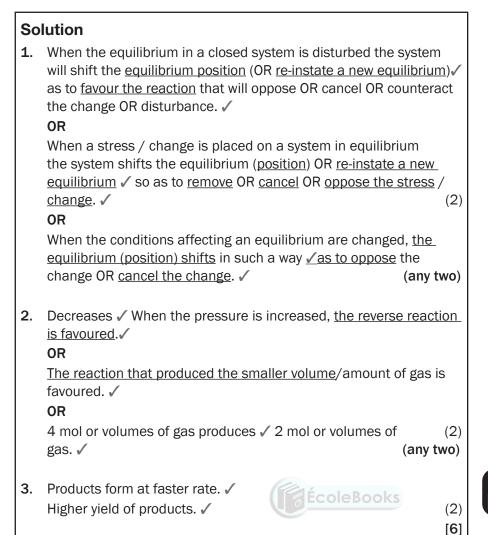
- **1**. State Le Châtelier's principle.
- How will an increase in pressure at 1 000 °C (by decreasing the volume) affect the yield of hydrogen gas? Write down only INCREASES, DECREASES OR NO EFFECT. Explain the answer. (2)
- **3.** Give TWO reasons why high temperatures are used for this reaction. (2)

[6]

(2)



There are various ways to state Le Châtelier's Principle correctly.



3.4.2 Dynamic chemical equilibrium in solutions

A dynamic chemical equilibrium in a solution:

- is only possible if the solution is saturated
 - is only affected by changing the
 - concentration of the ions in the solution or
 - temperature of the solution.

The common ion effect

•



When a solution is added to a reaction system:

Step 1: Identify the common ion in the solution and the system

Step 2: Explain the effect of the common ion (addition) on the chemical equilibrium.

hint

In physical chemistry, **saturation** is the point at which a solution of a substance can dissolve no more of that substance. Additional amounts of the solute will appear as a separate phase (usually as a precipitate solid). This point of maximum concentration, the saturation point, depends on the temperature and pressure of the solution as well as the chemical nature of the substances involved.

I	nt-

When two different solutions contain the same ion, this ion is called a common ion

Solution added to the equilibrium mixture:	Effect on equilibrium mixture: $H^+(aq) + OH^-(aq) \leftrightarrows H_2O(\ell)$
Hydrochloric acid, HCℓ(aq)	 Increases the hydrogen ion concentration, [H⁺] or hydronium ion concentration [H₃O⁺] Increases the chloride ion concentration, [Cℓ⁻] Decreases the hydroxyl ion concentration [OH⁻]
Sulphuric acid, $H_2SO_4(aq)$	 Increases the hydrogen ion concentration, [H⁺] or hydronium ion concentration [H₃O⁺] Increases the sulphate ion concentration, [SO₄²⁻] Decreases the hydroxyl ion concentration [OH⁻] because:
Concentrated sulphuric acid, $H_2SO_4(\ell)$	 Extracts water (H₂O) from the system (this is also known as dehydration)
A base like NaOH(aq) or KOH(aq)	 Increases the hydroxyl ion concentration [OH⁻]
A solution containing Cℓ(aq) ions e.g. NaCℓ(aq)	 Increases the chloride ion concentration, [Cℓ⁻] Decreases the silver ion concentration in a solution because Ag⁺(aq) + Cℓ⁻(aq) → AgCℓ(s)



Worked example 1

Consider the following equilibrium:

$CoC\ell_4^{2-}(aq) + 6H_2O(\ell) \rightleftharpoons Co(H_2O)_6^{2+}(aq) + 4C\ell^{-}(aq)$			$\Delta H < 0$
blue	purple-pink	pink	

When cobalt chloride crystals ($CoC\ell_2 \cdot 6H_2O$) are dissolved in ethanol (the solvent) in a flask, a **blue** solution is formed with $CoC\ell_4^{2-}$ ions. By carefully adding water to the blue solution until it just turns **purple-pink** because of the formation of the **pink** $Co(H_2O)_6^{2+}$ ions, the above equilibrium is reached.

Five test tubes each contain a small amount of the above purple-pink equilibrium solution. Describe and explain the colour change observed in each of the following instances:

1. The solution is cooled down.

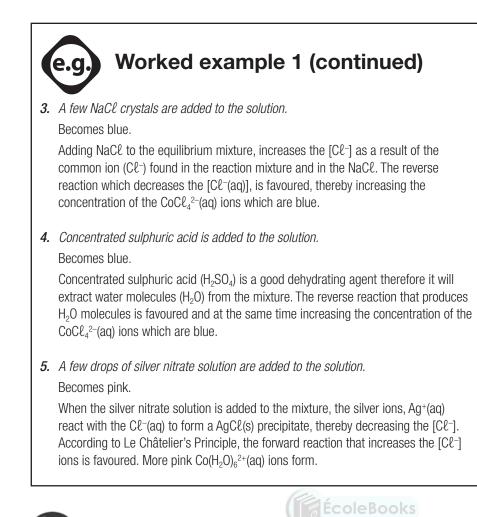
Becomes pink.

According to Le Châtelier's Principle, a decrease in temperature favours the exothermic, forward reaction therefore increasing the $[Co(H_2O)_6^{2+}(aq)]$ which is pink.

2. Water is added to the solution.

Becomes pink.

According to Le Châtelier's Principle, adding H₂O will favour the production of more $Co(H_2O)_{6^{2+}}(aq)$ ions so that the number of H_2O molecules will decrease, therefore the forward reaction is favoured. The concentration of the $Co(H_2O)_6^{2+}(aq)$ ions which are pink, increases.





Activity 5

1. The following hypothetical reaction reaches equilibrium in a closed container at a certain temperature:

 $X_2(g) + Y_2(g) \Longrightarrow 2XY(g) \qquad \Delta H < 0$

Which ONE of the following changes will increase the AMOUNT of XY(g)?

- A. Decrease in temperature
- B. Increase in temperature
- C. Increase in pressure
- D. Decrease in pressure

(2)

(2)

2. The equation below represents a chemical reaction at equilibrium in a closed container.

 $\mathsf{H}_2(g)+\mathsf{I}_2(g)\leftrightarrows 2\mathsf{HI}(g) \qquad \Delta\mathsf{H}<0$

Which ONE of the following changes will increase the yield of $\mathrm{HI}(g)$ in the above reaction?

- A. Increase the temperature
- **B.** Decrease the temperature
- C. Increase the pressure by decreasing the volume
- D. Decrease the pressure by increasing the volume

- **3.** A chemical reaction reaches equilibrium. Which ONE of the following statements regarding this equilibrium is TRUE?
 - A. The concentrations of the individual reactants and products are constant.
 - **B.** The concentrations of the individual reactants and products are equal.
 - **C.** The concentrations of the individual reactants are zero.
 - C. The concentrations of the individual products increase until the reaction stops. (2)
- **4.** The reaction represented by the equation below reaches equilibrium. $2CrO_2^{4-}(aq) + 2H^{+}(aq) \rightleftharpoons Cr_2O_2^{7-}(aq) + H_2O(\ell)$ yellow orange

Which ONE of the following changes to the reaction mixture will change its colour from yellow to orange?

- A. Add a catalyst.
- **B.** Add water to the reaction mixture.
- **C.** Add a few drops of sodium hydroxide solution to the reaction mixture.
- Add a few drops of concentrated hydrochloric acid to the reaction mixture. (2)
- 5. Give one word for the following phrase: The stage reached in a reversible chemical reaction when the rate of the forward reaction is equal to the rate of the reverse reaction. (2)

[10]

Solution

00	Solution				
1.	A 🗸 🗸	(2)			
2.	B√√	(2)			
3.	A 🗸 🗸	(2)			
4.	D√√	(2)			
5.	(Dynamic/Chemical) equilibrium 🗸 🗸	(2)			
		[10]			

3.5 The Equilibrium Constant (K_c) (The Law of Mass Action)

The concentrations of all the compounds (solutions and gases) in a closed system in dynamic chemical equilibrium are related by a mathematical equation. The numerical value of this equation is called the **equilibrium constant** (K_c).

In the hypothetical equation below the equilibrium expression for this reaction is:

 $2P + 3R \rightleftharpoons 2S + 4T$

 $\mathsf{K}_{\mathsf{c}} = \frac{[\mathsf{S}]^2 \times [\mathsf{T}]^4}{[\mathsf{P}]^2 \times [\mathsf{R}]^3}$



Solids and pure liquids are omitted from the K_c expression as their concentration is [1], as multiplying by 1 has no effect.



K_c: equilibrium constant (no unit) [substance]: concentration of reactant or product (in mol·dm⁻³) mol: number of moles

of each compound in the balanced reaction equation.



- This is the correct way of writing the K_c expression
- The coefficients are the moles of each reactant and product in the balanced equation
- The product of the concentration of **reactants** (not to be added, but **multiplied**!!), raised to the power of the number of moles is the numerator
- The product of the concentration of **products** (not to be added, but multiplied!!), raised to the power of the number of moles is the denominator
- The concentrations used in the Law of Mass Action is the [reactant]_{equilibrium} and [product]equilibrium (NOT initial concentrations!! i.e. the concentrations of reactants and products at equilibrium)

Activity 6

Write K_c expressions for each of the following reactions:

1.	$N_2(g)$ + $3H_2(g) \rightleftharpoons 2NH_3(g)$	(1)
2.	$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$	(1)

(1)

- **2.** $CaCO_3(s) \implies CaO(s) + CO_2(g)$
- **3.** $P_4(s) + 6C\ell_2(g) \Rightarrow 4PC\ell_3(\ell)$

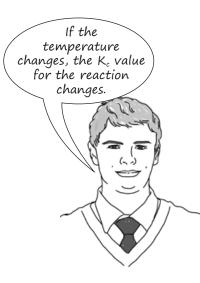


3.5.1 Factors that influence the equilibrium constant

For a closed system in equilibrium:

 Only the concentrations of aqueous solutions (aq) and gases (g) appear in the K_c expression; Solids (s) and pure liquids (<i>l</i>) are NOT included in the K_c expression. 	 The value of K_c DOES change if the temperature of the system changes.
You need to know the: • conditions and • factors that play a role in HOW/WHEN K _c changes/does NOT change	 The value of K_c DOES NOT change if: the pressure in the system changes; the concentration of a reactant or product in the system changes; a catalyst is added to the system.

) Unit



a) The effect of a change in temperature on K_c K_c for a specific reaction is **constant** at a **specific temperature**.

If the change in the temperature of a closed equilibrium system:

favours the forward reaction:

- more products form;
- [products] increases;
- [reactants] decreases and
- K_c increases

favours the **reverse** reaction:

- more reactants form;
- [products] decreases;
- [reactants] increases and
- K_c decreases

3.5.2 The meaning of K_c-values

The significance of the K_c value is important in industrial processes. The economic viability of an industrial process in the chemical industry depends on the manufacturing costs, the product yield (amount of product produced), and the retail cost. These factors determine the profit a company would make.

 $\ensuremath{\mathsf{K}_{\mathsf{c}}}$ values are used to determine if the possible yield at a specific temperature is low or high.



The value of K_c is directly linked to the **yield** of the reaction.

If K_c is small (K_c	<	1) the:	
---------------------------	---	---------	--

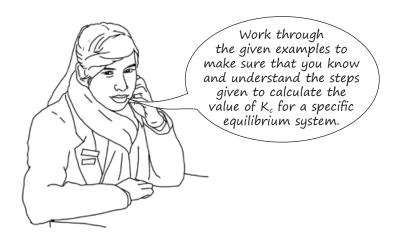
- equilibrium concentrations of the products are relatively low compared to those of the reactants
- product yield is low
- industrial process is not economically viable.

If K_c is large ($K_c > 1$) the:

- equilibrium concentrations of the products are relatively high compared to those of the reactants
- · product yield is high
- industrial process may be economically viable.

3.5.3 Calculating the value of K_c for a closed system in dynamic equilibrium

There are THREE types of calculations that you may be asked to perform. They will be covered in the following pages.





i) Type 1: The initial amount (mol) of each reactant is given

e.g.) Worked example 2

1. Consider the following balanced reaction for the formation of sulphur trioxide, in the second step of the Contact Process:

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

Exactly **8 mol SO**₂ and 10 mol **O**₂ are sealed in a **500 cm**³ reaction vessel which is initially empty. The compounds react to produce SO₃. **At equilibrium**, the vessel contains **6 mol SO**₃.

1.1 Calculate the equilibrium concentrations of each of the compounds in the reaction vessel.

Solution

The Contact

Process is a three step process in the manufacturing of sulphuric acid.

Step 1:

Always start by drawing a table with a column for the descriptions and a column for each of the reactants and products. Fill in the formulas of the reactants and products and the number of moles of each in the balanced reaction equation in the top line. The table should always consist of 5 rows with names as indicated.

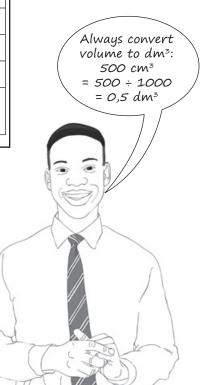
			JOKS
	Read	tants	Products
balanced equation	2SO ₂ (g)	O ₂ (g)	2 SO ₃ (g)
initial mol			
mol used or produced			
final mol at equilibrium			
final [] at equilibrium			
$c = \frac{n}{V}$			

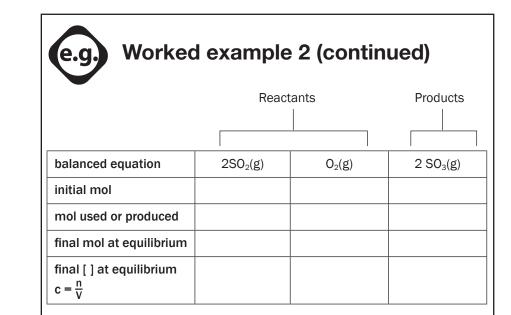


 Use a table

 (as indicated) to show each of the calculation steps when calculating the number of mol of each compound at equilibrium.

- DO NOT use abbreviations such as I, C and E in your table.
- Clearly indicate if you work with mol or concentration of each substance at equilibrium in the table.





Step 2:

Now fill in all the values given in the question. If only reactants were added at the beginning of the reaction, the initial mol of the products is zero.

balanced equation	2SO ₂ (g)	0 ₂ (g)	2SO ₃ (g)
initial mol	8	10	0
mol used / produced			
final mol at equilibrium	Books		6
final [] at equilibrium	$c = \frac{n}{V} = \frac{n}{0.5}$	$c = \frac{n}{V} = \frac{n}{0.5}$	$c = \frac{n}{V} = \frac{n}{0.5}$

Step 3:

Find the column with 2 values. Complete the mol used or produced line for this compound.

balanced equation	2SO ₂ (g)	0 ₂ (g)	2SO ₃ (g)
initial mol	8	10	0
mol used / produced			6 -
final mol at equilibrium			6
final [] at equilibrium	$c = \frac{n}{V} = \frac{n}{0.5}$	$c = \frac{n}{V} = \frac{n}{0.5}$	$c = \frac{n}{V} = \frac{n}{0,5}$

Step 4:

Compare the ratio of moles according to which the reactants react and to which the products are produced, according to the balanced reaction equation: $SO_2: O_2: SO_3 = 2: 1: 2$

Consider the actual mol used or produced for the compound which is **known**.

We have just calculated that 6 mol SO_3 has been produced.

This means that the ratio of $SO_2: O_2: SO_3 = 2: 1: 2$ (balanced equation) = 6 : 3: 6



Worked example 2 (continued)

Fill in these values.

н					
	balanced equation	2 SO ₂ (g)	1 O ₂ (g)	2 SO ₃ (g)	
	initial mol	/ 8	. 10	<i>i</i> 0	
	mol used / produced	6	3	6	
	final mol at equilibrium	`` `	· · •	``• 6	
	final [] at equilibrium	$c = \frac{n}{V} = \frac{n}{0,5}$	$c = \frac{n}{V} = \frac{n}{0,5}$	$c = \frac{n}{V} = \frac{n}{0,5}$	

Step 5:

For the reactants: initial mol – mol used = final mol at equilibrium. For the products: initial mol + mol produced = final mol at equilibrium.

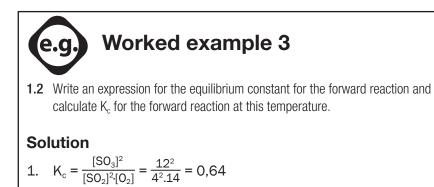
balanced equation	2SO ₂ (g)	0 ₂ (g)	2SO ₃ (g)
initial mol	8	10	0
mol used / produced	6	3	6
final mol at equilibrium	8 - 6 = 2	10 - 3 = 7	6
final [] at equilibrium	$c = \frac{n}{V} = \frac{n}{0.5}$	$c = \frac{n}{V} = \frac{n}{0.5}$	$\frac{6}{0,5} = 12$

Step 6:

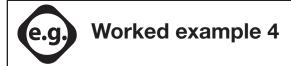
Substitute the final mol values in the last line, and calculate the final concentrations.

These are the answers to Question 1.1 above.

balanced equation	2SO ₂ (g)	0 ₂ (g)	2SO ₃ (g)
initial mol	8	10	0
mol used / produced	6	3	6
final mol at equilibrium	2	7	6
final [] at equilibrium	$\frac{2}{0.5} = 4$	$\frac{7}{0,5} = 14$	12
∴ at equilibrium:			
$[SO_2(g)] = 4 \text{ mol}\cdot dm^{-3} \text{ and } [O_2(g)] = 14 \text{ mol}\cdot dm^{-3} \text{ and } [SO_3(g)] = 12 \text{ mol}\cdot dm^{-3}$			



ii) Type 2: The initial amount (mol) of one reactant and the concentration of a reactant or product are given



2 mol of NO₂(g) and an unknown amount of N₂O₄(g) are sealed in a **2** dm³ container, that is fitted with a plunger, at a certain temperature. The following reaction takes place:

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

At equilibrium it is found that the NO_2 concentration is 0,4 mol·dm⁻³. The equilibrium constant (K_c) at this temperature is **2**.

1. Calculate the initial amount (in mol) of $N_2O_4(g)$ that was sealed in the container.

Solution

Step 1:

Draw the table as before. Fill in the formulas of the reactants and products and the number of moles of each in the balanced reaction equation in the top line.

Now fill in all the values given in the question. If only reactants were added at the beginning of the reaction, the initial mol of the products is zero. When the initial amount (mol) of a reactant or product is NOT zero and the value is not given (in this case the amount of N_2O_4) is **not** given, let this amount equal x. Write the statement regarding 'x' down, "Let be x".

Let the initial amount of N_2O_4 in the reaction vessel be *x*.

balanced equation	2 NO ₂	N ₂ O ₄
initial mol	2	
mol used / produced		
final mol at equilibrium		
final [] at equilibrium $c = \frac{n}{V}$	0,4	

Step 2:

Use the concentration given and the formula for concentration ($c = \frac{n}{V}$) to calculate the number of moles of NO₂ in the equilibrium mixture. The volume of the container (2 dm³) was given. Show the calculation and substitute the calculated value in the table.

$$c = \frac{n}{V}$$
 : $0,4 = \frac{n}{2}$: $n = (2)(0,4) = 0,8$ mol

Step 3:

Find the column with Find the column with **2** values. Complete the mol used or produced line for this compound.

2 mol NO₂ initially – ? mol NO₂ used = 0,8 mol \therefore mol NO₂ initial = 1,2 mol

A minus sign is used for the reactants (in this case), because the number of moles of the reactants decreases as they are used up. A **plus sign** is used for the products (in this case), because the number of moles of the products increases as they are formed.





Worked example 4 (continued)

Step 4:

From the balanced equation ratio 2 : 1 determine the ratio of the moles used and produced. Therefore 2 : 1 becomes 1,2 (as calculated in Step 3): 0,6

Step 5:

For the reactants: initial mol – mol used = final mol at equilibrium. For the products: initial mol + mol produced = final mol at equilibrium.

Step 6:

Substitute the final mol values into the last line, and calculate the final concentration of the N_2O_4 .

	2N0 ₂	N ₂ O ₄
balanced equation	2	
initial mol	1,2 (Step 3)	0,6 (Step 4)
mol used / produced	0,8 (Step 2)	+ 0,6 (Step 5)
final mol at equilibrium	0,4	$\frac{\left(\frac{x+0,6}{2}\right)}{(Step 6)}$
(ÉcoleBooks		

Step 7:

Write the expression for K_c and substitute all the known values – remember that the value of K_c was given. Solve for x.

$$K_{c} = \frac{[N_{2}O_{4}]}{[NO_{2}]^{2}} \therefore 2 = \frac{\left(\frac{x+0.6}{2}\right)}{0.4^{2}}$$

∴ (2)(0,4²) = $\frac{x+0.6}{2}$
∴ x = 0,4 mol

The plunger is now pushed into the container and the volume of the container **decreases**.

2. How will this change influence the amount of nitrogen dioxide at equilibrium? Only write down increases, decreases or remains the same.

Solution

Decreases

3. Use Le Châtelier's principle to explain your answer to Question 2.2.

Solution

When the volume of the container decreases, the pressure increases. According to Le Châtelier's Principle the reaction that decreases the pressure will be favoured \therefore the (forward) reaction that produces fewer gas moles, 2 mol (g) \leftrightarrows 1 mol (g), is favoured.

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Unit

iii) Type 3: The initial mass of a reactant and the value of K_c are given and the mass of the reactant that remains unreacted, is asked



The thermal decomposition of calcium carbonate $(CaCO_3)$ is an example of a heterogeneous equilibrium. The decomposition that takes place in a closed container can be represented by the following equation:

$$CaCO_3(s) = CaO(s) + CO_2(g)$$

Initially 5 g of CaCO₃(s) is placed in a closed 500 cm³ container and then heated. Equilibrium is reached at 900°C.

- Why is the above decomposition referred to as a heterogeneous equilibrium? (1)
- 2. Calculate the mass of unreacted CaCO₃(s) that remains in the container at equilibrium if K_c for the reaction is 0,0108 at 900°C.
- 3. It is found that the value of K_c increases when the container is heated. Is the forward reaction exothermic or endothermic? Use Le Châtelier's principle to explain your answer. (5)
- The volume of the container is now decreased to 250 cm³ while the temperature is kept constant. How will each of the following be affected? Give a reason for your answer.
 - 3.4.1 The value of K_c.
 - **3.4.2** The number of mol $CaCO_3(s)$ present in the equilibrium mixture.
 - **3.4.3** The concentration of $CO_2(g)$ at the new equilibrium.
- 5. More CaCO₃(s) is now added to the equilibrium mixture in the 500 cm³ container.

How will this change influence the number of moles of $CO_2(g)$ in the equilibrium mixture? Give a reason for your answer.

(2)[37]

(1)

(10)

(19)



Solutions

- Reactants and products are in different phases. 1.
- 2. This answer takes six steps. Answers for questions 3.3 to 3.5 appear below these steps.

Step 1:

Convert the mass of the reactant to moles. ONLY moles may be used in the table.

 $M(CaCO_3) = 40 + 12 + 3(16) = 100 \text{ g} \cdot \text{mol}^{-1} \checkmark$ $n = \frac{m}{M} = \frac{5}{100} = 0.05 \text{ mol}$

Refer back to the definition of

a heterogeneous equilibrium

Solutions to Activity 7 (continued)

Step 2:

Write the expression for K_c and substitute all the known values – remember that the value of K_c was given.

 $K_c = [CO_2] \checkmark$ 0,0108 = [CO_2]

 \therefore [CO₂] = 0,0108 mol·dm⁻³ \checkmark

Step 3:

Use the calculated $CO_2(g)$ concentration and the formula for concentration (c = $\frac{n}{V}$) to calculate the number of moles of CO_2 in the equilibrium mixture. The volume of the container (500 cm³) was given. Convert the volume to dm³. Show all working.

$$c = \frac{n}{V}$$
 : 0,0108 = $\frac{n}{0.5}$: n = (0,5)(0,0108) = 0,0054 mol CO₂

Step 4:

Find the column with 2 values. Complete the mol used or produced line for this compound. (0 mol CO_2 initially + produced mol CO_2 = 0,0054 mol \checkmark ... mol CO_2 produced = 0,0054 mol)

Step 5:

From the balanced equation ratio 1 : 1 : 1 determine the ratio of the moles used and produced. Therefore 1 : 1 : 1 becomes 0,0054 (from Step 3): 0,0054 : 0,0054

Step 6:

For the reactant $CaCO_3$... initial mol – mol used = final mol at equilibrium $\therefore 0,05$ mol – 0,0054 = final mol at equilibrium = 0,0046 mol

	/			
balanced equation	CaCO ₃	CaO	CO ₂	
initial mol	0,05 (Step 1)	0 (Given)	0 (Given)	1
mol used / produced	0,0054 (Step 5)	0,0054 (Step 5)	0,0054 (Step 4)	1
final mol at equilibrium	0,05 - 0,0054 = 0,0046 (Step 6)	0,0054 (Step 3)	0,0054 (Step 3)	1
Equilibrium concentration (mol·dm ⁻³) $c = \frac{n}{V}$	not asked	not asked	$\frac{n}{V} = \frac{n}{0.5}$ = 0,0108 (Step 2)	1

 \therefore 0,0046 mol CaCO_{_3} remains unreacted at equilibrium

$$M(CaCO_3) = 40 + 12 + 3(16) = 100 \text{ g·mol}^{-1}$$

$$\boxed{n = \frac{m}{M}} \therefore 0,0046 = \frac{m}{100} \therefore \text{ m} = (0,0046)(10) = 0,46 \text{ g}$$

 \therefore 0,46g CaCO₃ remains unreacted.



- Convert cm³ to dm³:
- $500 \text{ cm}^3 = 500 \div 1000$ = 0,5 dm³. Note: cm³ = mL, dm³ = L. It's probably easier to remember e.g. that if $500 \text{ cm}^3 = 500 \text{ mL}$, it's the same as 0,5 L = 0.5 dm³
- Convert mass to mol using the formula: $n = \frac{m}{M}$



(19)

NB —

- When ∆H > 0 it means the reaction to the right (the forward reaction) is endothermic
- When △H < 0 the forward reaction is **exothermic**



These are the **initial** concentrations – **before** the new equilibrium is established. $V = 1 \text{ dm}^3$ (given)

∴ the values of the initial concentrations are equal to the initial number of moles. $c = \frac{n}{V}$ and $c = \frac{n}{1}$ ∴ n = c(1)



3. Endothermic. 🗸

 $\begin{array}{ll} \mathsf{K}_{\mathsf{c}} \text{ increases } \therefore \text{ the forward reaction or reaction to the right is} \\ \mathsf{favoured.} \checkmark \qquad \checkmark \qquad \checkmark \\ \mathsf{According to Le Châtelier's principle, an increase in temperature} \end{array}$

will favour the endothermic reaction the forward reaction or reaction to the right must be endothermic. \checkmark (5)

- 4.1 Remains the same. Only temperature affects the value of K_c.
 4.2 Increases. ✓
 - Decreasing the volume increases the pressure. According to Le Châtelier's Principle, when the pressure is increased, the reaction which decreases the pressure by producing fewer moles of gas products, is favoured.

As 0 mol (g) \therefore 1 mol (g), the reverse reaction is favoured. \checkmark

4.3 Remains the same. \checkmark

 $K_c = [CO_2]$. The temperature remains constant $\therefore K_c$ remains constant \therefore the concentration of CO_2 will remain constant. (10)

Remains the same. Adding a solid does not affect the equilibrium, it does not change the concentration of a reagent. ✓ ✓ (2)

[37]



The equation below represents an equilibrium reaction in a sealed 1dm³ container.

$$NO_2(g) + NO(g) \rightleftharpoons N_2O(g) + O_2(g)$$
 $\Delta H > 0$

Equilibrium was reached at a certain temperature and the value of K_c was 3,93. The concentration (in mol·dm⁻³) of each reactant and product in the container at equilibrium was:

 $[NO_2] = 0,06 \text{ mol} \cdot \text{dm}^{-3}$ $[NO] = 0,29 \text{ mol} \cdot \text{dm}^{-3}$ $[N_2O] = 0,18 \text{ mol} \cdot \text{dm}^{-3}$ $[O_2] = 0,38 \text{ mol} \cdot \text{dm}^{-3}$

One of the conditions affecting the equilibrium is changed and a new equilibrium is established. At the new equilibrium, the concentration of the $NO_2(g)$ is 0,12mol·dm⁻³.

- **1.** Calculate the K_c value at the new equilibrium. (11)
- **2.** Which condition, concentration or temperature, was changed? (1)
- **3.** Give an explanation for the answer to Question 4.2. (1)
 - [13]

Solutions

1. NO₂(g) + NO(g) + Energy
$$\Longrightarrow$$
 N₂O(g) + O₂(g)

 $\Delta [NO_2] = [NO_2]_{\text{final}} - [NO_2]_{\text{initial}} = (0,12 - 0,06) = 0,06 \text{ mol } NO_2 \text{ is}$ formed.

but NO_2 is the **product** of the **reverse reaction**

 \therefore the reverse reaction was favoured.

From the balanced reaction equation, $\mathbf{1} \text{ NO}_2$: $\mathbf{1} \text{ NO}$: $\mathbf{1} \text{ N}_2\text{O}$: $\mathbf{1} \text{ O}_2$ \therefore 0,06 mol N₂0 + 0,06 mol O₂ \rightarrow 0,06 mol NO₂ + 0,06 mol NO \checkmark

So at equilibrium:

	NO ₂	NO	N ₂ 0	02	
Initial number of moles (mol)	0,06 (Given)	0,29 (Given)	0,18 (Given)	0,38 (Given)	~
Number of moles used / formed (mol)	+0,06 (Step 4)	+0,06 (Step 5)	-0,06 (Step 5)	-0,06 (Step 5)	~
Number of moles at equilibrium (mol)	0,12 (Step 3)	0,35 (Step 6)	0,12 (Step 6)	0,32 (Step 6)	~
Equilibrium concentration (mol·dm ⁻³)	$\frac{n}{1} = 0,12$ (Step 2)	$\frac{0,35}{1} = 0,35$ (Step 7)	$\frac{0,12}{1} = 0,12$ (Step 7)	$\frac{0.32}{1} = 0.32$ (Step 7)	~
$K_{c} = \frac{[N_{2}O][O_{2}]}{[NO_{2}][NO]} =$	= (0,12)(0,32) (0,12)(0,35)	= 0,91 🗸	ÉcoleB	looks	(11)
2. Temperatu	re. 🗸	v			(1)



3. K_c was initially 3,93 (given) now it is 0,91. If the K_c value changed, the temperature must have changed - only a change in temperature can change the value of K $_{\rm c}$. \checkmark [13]



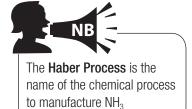
Activity 9

Consider the following reaction equation for the production of ammonia in the Haber process.

$$\mathsf{N}_2(g) + \mathsf{3H}_2(g) \leftrightarrows \mathsf{2NH}_3(g) \qquad \Delta \mathsf{H} < \mathsf{0}$$

In each of the following cases:

- a) State how K_c changes and
- b) Briefly explain your answer.
- **1**. The concentration of the nitrogen gas is increased. (1)
- 2. The pressure in the reaction system is decreased. (1)
- 3. FeO is added to the reaction system.
- 4. The reaction system is heated.



(1)

(1)

(5)[8]

Solutions

Remains constant because... ✓ (1)
 ... K_c is only affected by a change in temperature. ✓ (1)
 K_c Decreases ✓ (1)
 Heating the reaction system favours the endothermic, reverse reaction ✓ which decreases the temperature ✓ of the system ∴ the concentration of the forward product, [NH₃] ✓ decreases while the concentrations of the forward reactants, [N₂] and [H₂] increase ✓ ∴ K_c decreases. ✓ (5)



1. The reaction represented by the equation below reaches equilibrium.

 $\begin{array}{lll} \text{Co}(\text{H}_2\text{O})_6^{2+}(\text{aq}) + 4\text{C}\ell^-(\text{aq}) & \rightleftharpoons & \text{Co}\text{C}\ell_4^{2-}(\text{aq}) + 6\text{H}_2\text{O}(\ell) & \Delta\text{H} > 0 \\ \\ \text{pink} & \text{blue} \end{array}$

Which ONE of the following changes to the reaction mixture will changes its colour from blue to pink?

- A. Add a catalyst
- B. Place the reaction mixture in a container with hot water.
- **C.** Add a few drops of concentrated hydrochloric acid to the reaction mixture.
- **D.** Add water to the reaction mixture.

(2) [**2**]

So	olution		
1.	D√√		[2]

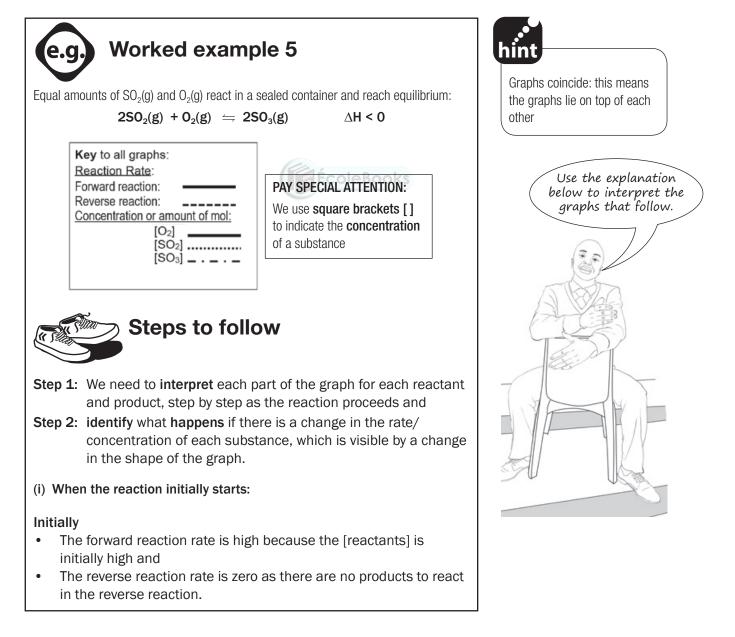
3.6 Interpretation of graphs for chemical systems in dynamic equilibrium

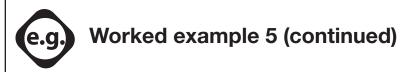
Dynamic equilibrium in a chemical system can be represented graphically by a graph of:

- reaction rate versus time
- **amount** of each reagent (number of moles / mass / volume)
- **concentration** of each reagent (in mol·dm⁻³) versus time.

For each of these graphs:

- **time** is the **independent variable** and is therefore placed on the **horizontal axis** and
- either the **concentration**, **amount** or the **reaction rate** is measured and is therefore the **dependent variable** which is placed on the **vertical axis**.

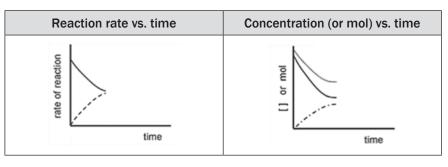




As the reaction takes place the

- concentrations of the reactants, $[SO_2]$ and $[O_2]$ decrease
- concentration of the forward product, $[SO_3]$ increases as forward reaction rate > the reverse reaction rate.

The **forward** reaction **rate** gradually **decreases** and the **reverse** reaction **rate** gradually increases.

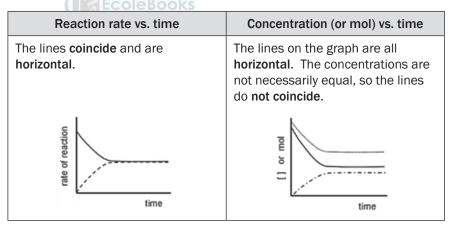


(ii) The reaction reaches a state of dynamic chemical equilibrium

The forward and reverse reactions take place at the:

- same time and
- same rate.

The concentrations of the reactants and of the products remain constant.



(iii) $O_2(g)$ is added to the system.

Adding $O_2(g)$ to the system increases the concentration of the $O_2(g)$. $O_2(g)$ is a reactant in the forward reaction, therefore the rate of the forward reaction immediately shows a sharp increase.

According to Le Châtelier's Principle:

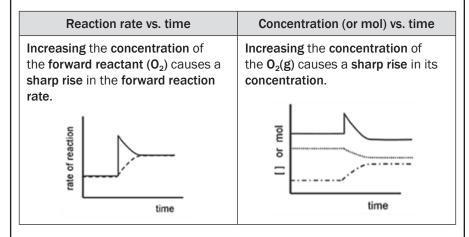
- the reaction that opposes the change and decreases the concentration of the $O_2(g)$ is favoured so the
 - forward reaction is favoured
 - concentrations of the $\mathsf{SO}_2(g)$ and $\mathsf{O}_2(g)$ (forward reactants) decrease
 - concentration of the $SO_3(g)$ (forward product) increases.



Worked example 5 (continued)

The rate of the

- forward reaction decreases as the [O₂] and [SO₂] decrease and
- reverse reaction increases as the [SO₃] increases
- until a new dynamic equilibrium is established when the
 - forward and reverse reaction rates are again equal and
 - $[O_2]$ and $[SO_2]$ as well as the $[SO_3]$ again remain constant.



(iv) $SO_3(g)$ is removed from the system.

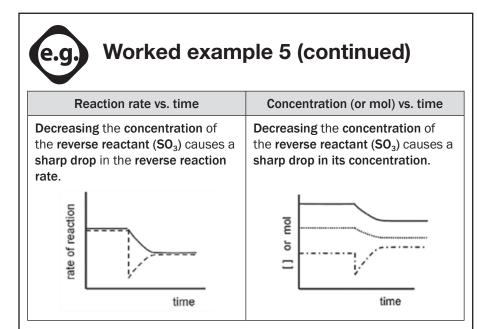
Removing $SO_3(g)$ to the system **decreases** the **concentration** of the $SO_3(g)$. $SO_3(g)$ is a reactant in the **reverse reaction**, therefore the rate of the **reverse** reaction immediately shows a **sharp decrease**.

According to Le Châtelier's Principle:

- the reaction that opposes the change and increases the concentration of the $SO_3(g)$ is favoured so the
- forward reaction is favoured
- concentrations of the $\mathsf{SO}_2(g)$ and $\mathsf{O}_2(g)$ (forward reactants) decrease
- concentration of the SO₃(g) (forward product) increases.

The rate of the

- forward reaction decreases as the [O₂] and [SO₂] decrease
- reverse reaction increases as the [SO₃] increases
 - until a new dynamic equilibrium is established when the
 - forward and reverse reaction rates are again equal
 - $[O_2]$ and $[SO_2]$ as well as the $[SO_3]$ again remain constant.



(v) The temperature of the equilibrium mixture is increased.

The heat of reaction is negative ($\Delta H < 0$) so the

- forward reaction is exothermic
- reverse reaction is endothermic.

Increasing the temperature of the system **increases both** the forward and the reverse **reaction rates**. The **rate** of the **endothermic reaction** always **increases the most** if the system's **temperature increases**, so for this reaction, the **reverse** reaction rate increases the most.

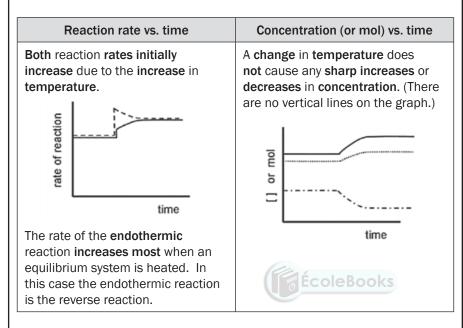
According to Le Châtelier's Principle:

- The reaction that opposes the change and decreases the temperature of the equilibrium system, is favoured so
 - the endothermic reaction is favoured and therefore the
 - reverse reaction is favoured and the
 - concentration of the $\ensuremath{\text{SO}_3(g)}$ (reverse reactant) decreases and the
 - concentrations of the $\mathsf{SO}_2(g)$ and $\mathsf{O}_2(g)$ (reverse products) increase and

Worked example 5 (continued)

The rate of the

- reverse reaction that was initially increased, decreases as the $[{\ensuremath{\mathsf{SO}}}_3]$ decreases and
- forward reaction increases as the [O₂] and [SO₂] increase
- until a new dynamic equilibrium is established when the
 - forward and reverse reaction rates are again equal and
 - [0₂] and [SO₂] as well as the [SO₃] again remain constant.



(vi) The temperature of the equilibrium mixture is decreased.

The heat of reaction is negative ($\Delta H < 0$) so the

- forward reaction is exothermic
- reverse reaction is endothermic.

Decreasing the temperature of the system **decreases both** the forward and the reverse **reaction rates**. The **rate** of the **endothermic reaction** always **decreases the most** if the system's **temperature decreases**, so for this reaction, the **reverse** reaction rate decreases the most.

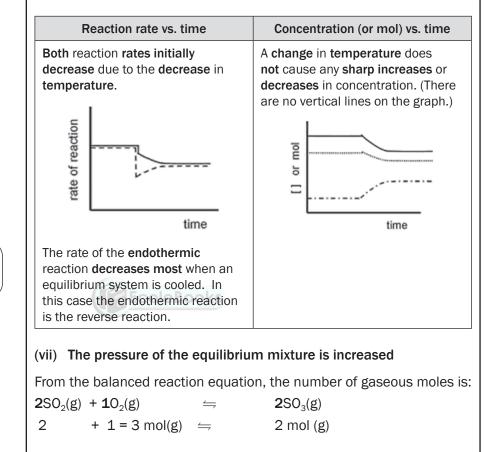
According to Le Châtelier's Principle:

- the reaction that opposes the change and increases the temperature of the equilibrium system, is favoured so the
 - exothermic reaction is favoured and therefore
 - forward reaction is favoured
 - concentrations of the SO₂(g) and O₂(g) (forward reactants) decrease and
 - concentration of the $SO_3(g)$ (forward product) increases and



The rate of the

- forward reaction decreases as the $[O_2]$ and $[SO_2]$ decrease
- reverse reaction increases as the [SO₃] increases
- until a new dynamic equilibrium is established when
 - the forward and reverse reaction rates are again equal and
 - the $[O_2]$ and $[SO_2]$ as well as the $[SO_3]$ again remain constant.



According to Le Châtelier's Principle:

- the reaction that opposes the change and decreases the pressure in the equilibrium system, is favoured so
 - the reaction that produces the least moles of gas is favoured
 - therefore the forward reaction is favoured and
 - the concentrations of the $\mathsf{SO}_2(g)$ and $\mathsf{O}_2(g)$ (forward reactants) decrease and
 - the concentration of the $\ensuremath{\text{SO}}_3(g)$ (forward product) increases and

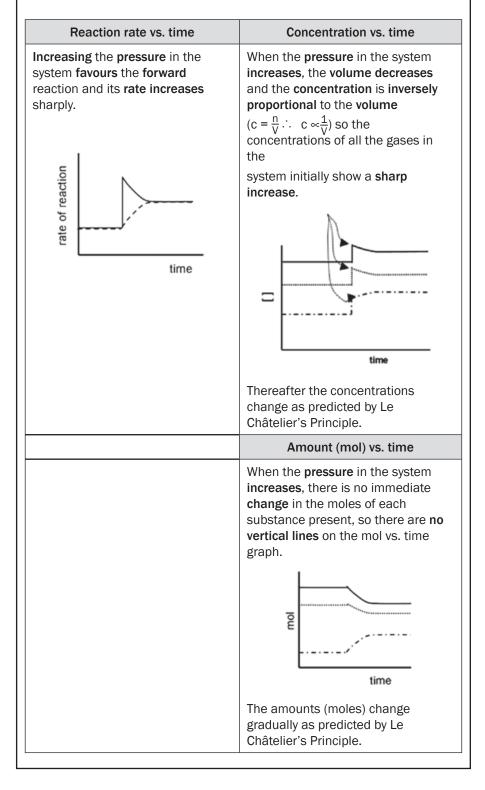
hint This applies to gases only.

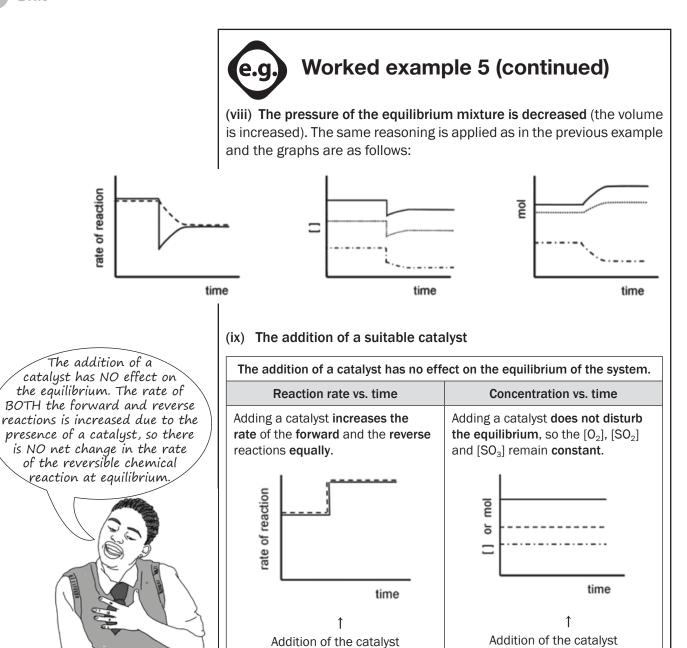


Worked example 5 (continued)

The rate of the

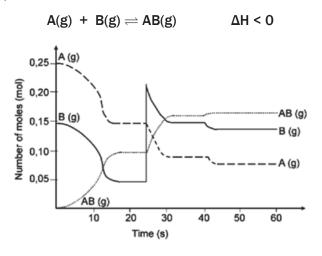
- forward reaction decreases as the $[O_2]$ and $[SO_2]$ decrease
- reverse reaction increases as the [SO₃] increases
- until a new dynamic equilibrium is established when
 - the forward and reverse reaction rates are again equal and
 - the $[O_2]$ and $[SO_2]$ as well as the $[SO_3]$ again remain constant.

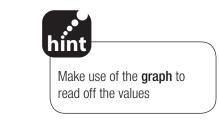






0,25 mol of A and 0,15 mol of B are introduced into a 1 dm^3 vessel. A and B react and reach an equilibrium which can be represented by the following equation:





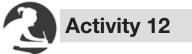
The graph shows the number of moles of A(g), B(g) and AB(g) vs time, under varying conditions.

- **1.** What are the concentrations of A(g), B(g) and AB(g) at t = 20 s? (3)
- How can we be sure that the system has reached equilibrium at t = 20 s?
- Give an explanation for the change that occurs at t = 25 s. (1)
 Explain the change in concentrations of A(g) and B(g) between
- t = 25 s and t = 35 s. (3)5. How does the equilibrium constant at t = 35 s compare with the
- equilibrium constant at t = 25 s? (No calculation is required.) (1)
 6. Assuming that the volume was kept constant, what was done at t = 40 s that produced the change as shown?
- Explain your answer.(5)7. Do any reactions occur during the interval t = 30 s and t = 40 s?
Briefly explain your answer.(4)
 - [18]



Solutions

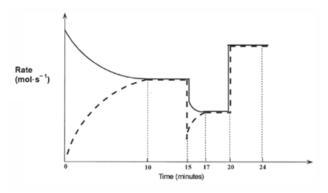
		/
1.	$[A] = 0,15 \text{ mol}\cdot\text{dm}^{-3}$ $[B] = 0,05 \text{ mol}\cdot\text{dm}^{-3}$ $[AB] = 0,1 \text{ mol}\cdot\text{dm}^{-3}$	(3)
2.	The number of mol of A, B and AB remains constant from 16 s	
	to 25 s. 🗸	(1)
3.	The amount of B is increased by adding B to the system, thus	
	increasing the [B].	(1)
4.	With the addition of B, [B] increases and the forward reaction	
	is favoured ✓ according to Le Châtelier's principle, so that	
	some of B reacts with A to form more AB. Hence the [A]	$\langle \mathbf{O} \rangle$
	and [B] 🗸 decrease and [AB] increases. 🗸	(3)
5.	K _c remains constant provided the temperature remains	(1)
	constant. V	(1)
6.	The temperature was lowered . ✓ It was not a concentration change, because there are no peaks at 25 s ✓. Therefore it must	
	be a temperature change. From the graph, it can be seen that the	
	forward reaction was favoured \checkmark because there is an increase in	,
	the number of moles of AB, and a decrease in the number of	
	moles of A and B when establishing the new equilibrium . \checkmark	
	According to the information given, the forward reaction is	
	exothermic. 🗸 According to Le Châtelier's Principle, a decrease	
	in temperature favours the exothermic reaction.	(5)
7.	Yes, but since equilibrium has been reached, 🗸 the forward	
	and reverse reactions take place at the same time \checkmark and at	
	the same	
	of A, B or AB. Je Books	(4)
		[18]



Nitrogen and oxygen gases react in a sealed container according to the following equation:

$$O_2(g) + N_2(g) \implies 2NO(g)$$

After the reaction reaches equilibrium, certain changes are made. The following graph of rate of reaction versus time represents the situation.



1. Write the equation for the reaction represented by the dashed line on this graph.

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(2)

2.	What is represented by the section of the graph between the 10th	ı
	and 15th minute? Explain your answer.	(2)
3.	A temperature change takes place at t = 15 minutes.	
	3.1 Was the temperature increased or decreased at	
	t = 15 minutes?	(1)
	3.2 Explain whether the forward reaction is exothermic or	
	endothermic.	(3)
	3.3 What effect does this temperature change have on the	
	equilibrium constant (K_c)? Explain your answer.	(3)
4.	A pressure change is introduced at t = 20 minutes.	
	4.1 Was the pressure increased or decreased?	(3)
	4.2 Explain how this change in pressure affects the amounts	
	of each gas at equilibrium.	(2)
		[16]

Solutions

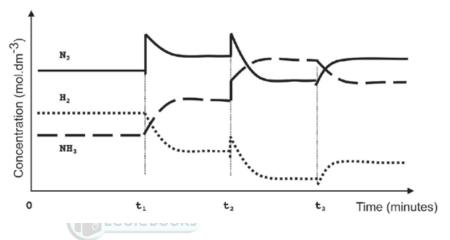
1	$2NO(g) \rightarrow N_2(g) + O_2(g) \checkmark \checkmark$	(2)
2.	The system is in equilibrium \checkmark because the rates of the forward	• •
_ .	and reverse reactions are equal. \checkmark	(2)
3.1	Decreased. 🗸	(1)
3.2	The rates of both the forward and the reverse reactions decreases \checkmark , but the rate of the reverse reaction decreases more. \checkmark The rate of the endothermic reaction will always decrease the most when a reaction mixture is cooled. Thus the reverse reaction is endothermic. That means that the forward reaction must be exothermic and was favoured by the decrease in temperature.	se
	$O_2(g) + N_2(g) \rightleftharpoons 2NO(g) + Energy$	(3)
3.3	Increases. \checkmark Since $K_c = \frac{[NO]^2}{[N_2][O_2]}$	(3)
	and the forward reaction is favoured \checkmark which causes an increase in [NO], the value of $\rm K_c$ increases. \checkmark	(3)
4.1	Increased. \checkmark The pressure is probably caused by a volume decrease. This results in the concentrations (c = $\frac{n}{V}$) of the reactants, as well as the products, to increase \checkmark , which in turn causes an equal increase in the forward and reverse reaction rates. \checkmark	(3)
4.2	The amount (n) of reactants and products does not change, \checkmark since 2 moles of gaseous reactant molecules \rightleftharpoons 2 moles of gaseous product molecules. \checkmark	(2) [16]



A fertiliser company produces ammonia on a large scale at a temperature of 450 °C. The balanced equation below represents the reaction that takes place in a sealed container.

$$N_2(g) + 3H_2(g) \iff 2NH_3(g) \qquad \Delta H < 0$$

To meet an increased demand for fertiliser, the management of the company instructs their engineer to make the necessary adjustments to increase the yield of ammonia. In a trial run on a small scale in the laboratory, the engineer makes adjustments to the TEMPERATURE, PRESSURE and CONCENTRATION of the equilibrium mixture. The graphs below represent the results obtained.



- 1. Identify the changes made to the equilibrium mixture at each of the following times:
 - **1.1** t₁ (2)
 - 1.2 t₂ (2) (2)
 - 1.3 t₃
- 2. At which of the above time(s) did the change made to the reaction mixture lead to a higher yield of ammonia? Write down only t_1 and/or t_2 and/or t_3 (2)
- **3.** The engineer now injects 5 mol N_2 and 5 mol H_2 into a 5 dm³ sealed empty container. Equilibrium is reached at 450 °C. Upon analysis of the equilibrium mixture, he finds that the mass of NH_3 is 20,4 g. Calculate the value of the equilibrium constant (K_c) at 450 °C (9)

[17]

So	Solutions			
1. 2. 3.	 1.1 The concentration of nitrogen ✓ added ✓ 1.2 The pressure ✓ on the s 1.3 The temperature ✓ is interacting t₁ ✓ and t₂ ✓ 	system is incre		Vlore (any two) (2) (2) (2) (2)
	PAY SPECIAL ATTENTION: This is how marks are allocated to Use of $n = \frac{m}{M} \checkmark$ $n(NH_3)$ at equilibrium = 1,2 mo Using ratio $n(N_2) : n(H_2) : n(NH_3)$ $n(N_2)$ at equilibrium (initial - ch $n(H_2)$ at equilibrium (initial - ch $n(H_2)$ at equilibrium (initial - ch divide by volume (calculation of K_c expression \checkmark Substitution into K_c expression Final answer \checkmark $n(NH_3) = \frac{m}{M} = \frac{20,4}{17} \checkmark = 1,2$ mo	ol \checkmark $_{3}$) = 1 : 3 : 2 \checkmark hange) \checkmark hange) \checkmark of concentration)		n: (9)
		SO ₂	02	SO ₃
	Molar ratio	1	Écola Boo	<u>ks</u> 2
	Initial quantity (mol)	5	5	0
	Change (mol)	0,6	1,8	1,2
	Quantity at equilibrium	4,4	3,2	1,2
	Concentration (mol·dm ⁻³)	0,88	0,64	0,24
	$K_{c} = \frac{[NH_{3}]^{2}}{[N_{2}][H_{2}]^{3}} = \frac{(0,24)^{2}}{(0,88)(0,64)}$) ³ = 0,25		[17]



2 mol of NO₂(g) and an unknown amount of N₂O₄(g) are sealed in a 2 dm³ container, that is fitted with a plunger, at a certain temperature. The following reaction takes place:

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

At equilibrium it is found that the NO_2 concentration is 0,4 mol·dm⁻³. The equilibrium constant at this temperature is 2.

1. Calculate the initial amount (in mol) of $N_2O_4(g)$ that was sealed in the container.

(8)

The plunger is now pushed into the container causing the pressure of the enclosed gas to increase by decreasing the volume

- How will this change influence the amount of nitrogen dioxide at equilibrium? Only write down INCREASES, DECREASES or REMAINS THE SAME. (1)
- Use Le Châtelier's principle to explain your answer to OUESTION 2.1.2.

(2)[11]

(1)

[11]

	2N0 ₂	N ₂ O ₄
Initial number of mole (mol)	2	x
Number of moles used/formed (mol)	-1,2√	+0,6 🗸
Number of moles at equilibrium(mol)	0,8√	<i>x</i> + 0,6 •
Equilibrium concentration (mol·dm ⁻³)	0,4	$\frac{(x+0,6)}{2}$

- Decreases √
- 3. When the pressure is increased the system will try to decrease the pressure. \checkmark (2)
 - The forward reaction (2 mol to 1 mol) is favoured. <

worked, please revise the "subject of formula" section at the beginning of this book.

Remember, if you struggle to see how this calculation

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3.7 Applications of equilibrium principles in the chemical industry

- Many industrial processes involve reversible chemical reactions that reach equilibrium.
- Two factors that are important from an economic point of view are the **yield (amount of products** produced relative to the amount of reactants) and the **reaction rate** (rate at which the products are formed).





The success of chemical processes in both the laboratory and the industry depends on:

- the **amount of product** that is produced and
- how **cost effective** this production is.



REMEMBER Standard atmospheric pressure (1 atm) is the

pressure (1 atm) is the atmospheric pressure at sea level.

1 atm = 101,3 kPa = 101 325 Pa (pascal)

You must understand:
 the effect of changing the reaction conditions (this implies the change in the rate of a reaction) and
 applying equilibrium principles to the Haber

principles to the Haber process and to the Contact process

Haber Process		Step 2 of the Contact Process
Nitrogen, N ₂ (g) Hydrogen, H ₂ (g)	Reactants	Sulphur dioxide, SO ₂ (g) Oxygen, O ₂ (g)
 N₂(g) : fractional distillation of liquid air H₂(g) : steam reforming of methane (CH₄) from natural gas 	Source of reactants	 S (s) : sulphur O₂ (g) : fractional distillation of liquid air S(s) + O₂(g) → SO₂(g)
Ammonia, NH ₃ (g)	Products	Sulphur trioxide, SO ₃ (g)
$N_2(g)$ + $3H_2(g) \implies 2NH_3(g)$	Reaction equation	$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$
4 mol (g) : 2 mol (g)	Gas mol ratio	3 mol (g) : 2 mol (g)
$\Delta H < 0$ forward reaction is exothermic	Heat of reaction (Enthalpy)	$\Delta H < 0$ forward reaction is exothermic
 Increasing the temperature Increasing the concentrations of the forward reactants N₂ and H₂ Adding a suitable catalyst 	Increase the reaction rate by	 Increasing the temperature Increasing the concentrations of the forward reactants SO₂ and O₂ Adding a suitable catalyst
 Decreasing the temperature (favours the forward exothermic reaction) Increasing the concentrations of the forward reactants N₂ and H₂ Increasing the pressure (favours the forward reaction that produces less gas moles) 	Increase the yield by	 Decreasing the temperature (favours the forward exothermic reaction) Increasing the concentrations of the forward reactants SO₂ and O₂ Increasing the pressure (favours the forward reaction that produces less gas moles)
Temperature: approx. 450 °C Pressure: approx. 200 atm	Optimal Reaction conditions	Temperature: approx. 450 °C Pressure: approx. 1 – 2 atm
Fe (iron) OR FeO (iron(II)oxide)	Catalyst	V_2O_5 (vanadium pentoxide)



- When the reaction system is in a state of dynamic equilibrium, **high temperatures** will **increase the reaction rates** BUT will **decrease the yield** of the products. Both the forward reactions are **exothermic**, therefore high temperature will, according to Le Châtelier's Principle, favour the reverse endothermic reactions. This makes the reactions economically less viable!
- Temperatures of \pm 450 °C are maintained in both the Haber and Contact processes.
- Industrial processes at **high pressures** require powerful compressors and strong reaction vessels which are very **expensive**. This makes the reactions economically less viable! Industrial plants that operate at high pressures also pose **safety risks** for the workers.
- It is therefore necessary to find a compromise between the reaction rates, the yield, and the higher costs.
- A pressure of 200 times that of atmospheric pressure is maintained in the Haber process to ensure that the yield is high enough.
- The yield of SO₃ in the Contact Process is however more than 90% at a pressure of 1 atm and therefore it is economically viable to keep the reaction at atmospheric pressure. It is unnecessary to maintain higher pressures and this saves unnecessary costs.

Activity 15	
Name the industrial process for the production of ammonia	(1) [1]
Solution	
Haber (Bosch) process 🗸	[1]



Sulphuric acid is an important substance used in the manufacture of fertilisers. The equation below represents one of the steps in the industrial preparation of sulphuric acid.

 $2SO_2(g) + O_2(g) \implies 2SO_3(g) \qquad \Delta H < 0$

- Write down the name of the process used to prepare sulphuric acid in industry. (1)
- Write down the NAME or FORMULA of the catalyst used in the process in question (1)
- **3.** Is the forward reaction exothermic or endothermic? Give a reason for the answer.

The reaction reaches equilibrium at a certain temperature in a 2 $\rm dm^3$ closed container.

On analysis of the equilibrium mixture, it is found that 0,6 mol of $SO_2(g)$, 0,5 mol of $O_2(g)$ and 0,4 mol of $SO_3(g)$ are present in the container. (1)

- 4. List THREE changes that can be made to this equilibrium to increase the yield of $SO_3(g)$ (3)
- 5. The temperature is NOW increased and the reaction is allowed to reach equilibrium for the second time at the new temperature. On analysis of this new equilibrium mixture, it is found that 0,2 mol of $SO_3(g)$ is present in the container. Calculate the equilibrium constant for this reaction at the new temperature. (8)

[14]



A I I
Solutions
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00					
1.	Contact process 🗸			(1)	
2.	V₂O₅ (vanadium pentoxide) ✓				
3.	Exothermic $\Delta H < 0 \checkmark$				
4. 5.	Any three: $\checkmark \checkmark \checkmark$ Decrease temperature Increase pressure Increase concentration of both/s Remove SO ₃ continuously	any one of t	he reactants	s (3)	
		SO ₂	02	SO ₃	
M	olar ratio	2	1	2	
Ini	itial quantity (mol)	0,6	0,5	0,4	
Ch	nange (mol)	0,2	0,1	0,2	
Qı	uantity at equilibrium	0,8	0,6	0,2	
Co	oncentration (mol·dm ⁻³)	0,4	0,3	0,1	
K _c	$= \frac{[SO_3]^2}{[SO_2]^2[O_2]} = \frac{(0,1)^2}{(0,4)^2(0,3)} = 0,21$			(8	
	This how marks are allocated to the answ • Change in $n(SO_3) = 0.2 \text{ mol } \checkmark$ • Ratio $n(SO_2) : n(O_2) : n(SO_3) = 2 : 1 : 2$ • $n(SO_2)$ at equilibrium = initial + chang • $n(O_2)$ at equilibrium = initial + chang • divide three equilibrium amounts by 2 • K_c expression \checkmark	2 ✓ ge ✓ ge ✓		1) 🗸	
	 Substitution into K_c expression ✓ Final answer ✓ 			(8)	



The reaction below represents the catalysed step in the contact process:

$$2SO_2(g) + O_2(g) \implies 2SO_3(g) \qquad \Delta H < 0$$

The reaction takes place in a closed container and reaches equilibrium at 427 °C. How will a HIGHER temperature affect each of the following? Write down only INCREASES, DECREASES or REMAINS THE SAME.

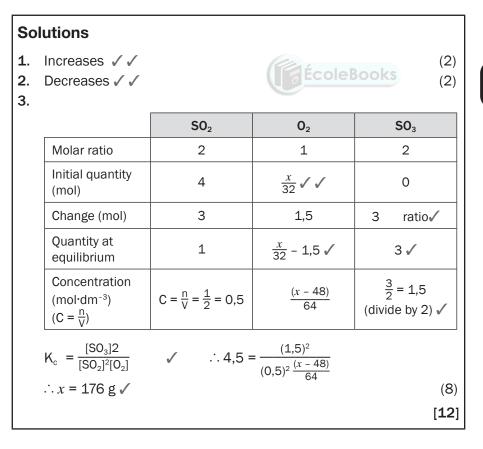
- **1.** The rate of production of $SO_3(g)$ (2)
- **2.** The yield of $SO_3(g)$
- **3.** The reaction is investigated on a small scale in the laboratory. Initially 4 mol of $SO_2(g)$ and an unknown mass, x, of $O_2(g)$ are sealed in a 2 dm⁻³ flask and allowed to reach equilibrium at a certain temperature.

At equilibrium it is found that the concentration of $SO_3(g)$ present in the flask is 1,5 mol·dm⁻³.

Calculate the mass of $O_2(g)$ initially present in the flask if the equilibrium constant (K_c) at this temperature is 4,5.

(8) [**12**]

(2)





Remember, if you struggle to see how this calculation worked, please revise the "subject of formula" section at the beginning of this book.





Acids and bases

4.1 Summary

Acid	(Arrhenius theory): is a substance that produces hydrogen ions (H ⁺) / hydronium ions (H ₃ O ⁺) when it dissolves in water (Brønsted-Lowry theory): is a proton (H ⁺ ion) donor.
Strong acid	Ionises completely in water to form a high concentration of H_3O^+ ions.
	Examples of strong acids are hydrochloric acid (HC ℓ), sulphuric acid (H ₂ SO ₄) and nitric acid (HNO ₃).
Weak acid	lonises incompletely in water to form a low concentration of $\rm H_3O^+$ ions.
	Examples of weak acids are ethanoic acid (CH $_3$ COOH) and oxalic acid (COOH) $_2$.
Concentrated acid	Concentrated acids contain a large amount (number of moles) of acid in proportion to the volume of water.
Diluted acid	Dilute acids contain a small amount (number of moles) of acid in proportion to the volume of water.
Base	(Arrhenius theory): is a substance that produces hydroxide ions (OH ⁻) when it dissolves in water.
	(Brønsted-Lowry theory): is a proton (H^+ ion) acceptor.
Strong base	Dissociates (breaks up) completely in water to form a high concentration of OH ⁻ ions. Examples of strong bases are sodium hydroxide (NaOH) and potassium hydroxide (KOH).
Weak base	Dissociates/ionises incompletely in water to form a low concentration of OH ⁻ ions. Examples of weak bases are ammonia (NH ₃), calcium carbonate (CaCO ₃), potassium carbonate (K ₂ CO ₃), and sodium hydrogen carbonate (NaHCO ₃).
Concentrated base	Concentrated bases contain a large amount (number of moles) of base in proportion to the volume of water.
Diluted base	Dilute bases contain a small amount (number of moles) of base in proportion to the volume of water.
Equivalence point	is the point at which the acid / base has completely reacted with the base/ acid .
End point	is the point where the indicator changes colour.
Ionisation	a process that takes place when a covalent compound reacts with water to form new ions OR Breaking up of a molecule into charged components (ions). In acid-base reactions this usually means dissolving in water.

Dissociation	a process that take place when an ionic compound dissolves in water allowing the ions in the compound to separate. The same as ionisation.
Hydrolysis	ionisation of a salt in water, or, more generally, splitting a molecule by reacting it with water (e.g. in organic chemistry).
Ampholyte (Amphiprotic)	is a substance that can act either as an acid or a base. example: Water (H_2O)



1. D√√

Activity 1

1.	An Arrhenius acid is a substance that						
	A. Accept a proton	Accept a proton					
	B. Donates a proton						
	C. Produces H ⁺ in an aqueous s	soluti	on				
	D. Produces OH ⁻ in an aqueous			(2)			
2.	Which of the following is an exan	nple (of the strong base				
	A. CaCO ₃	C.	K ₂ CO				
	B. KOH	D.	NaHCO ₃	(2)			
3.	An aqueous solution that contair hydroxyl ions is a(an)	ns mo	ore hydronium ions than				
	A. Acidic solution	C.	Basic solution				
	B. Neutral solution	D.	Standardised solution	(2)			
4.	A solution that has a large amou	nt of					
	proportion to the volume of wate	er					
	A. Strong solution	C.	Concentrated solution				
	B. Weak solution	D.	Diluted solution	(2)			
				[8]			
c	olutions						
13							

2. B√√ 3. A√√ 4. C√√

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[8]



NOTE:

 You must know the Arrhenius and the Brønsted-Lowry definitions for acids and bases, BUT we will ALWAYS use the Brønsted-Lowry theory for all further discussions of acids and bases.

4.2 Properties of acids and bases

	ACIDS	BASES
PROPERTIES	 Have a sour taste; Influence the colour of indictors; Are electrolytes in solution; Increase the H⁺-ion concentration in a solution; Decrease the OH⁻-ion concentration in a solution; Decrease the pH of a solution. 	 Have a bitter taste and feel soapy; Influence the colour of indictors; Are electrolytes in solution; Decrease the H⁺-ion (or H₃O⁺-ion) concentration in a solution; Increase the OH⁻-ion concentration in a solution; Increase the pH of a solution.

	ARRHENIUS						
ACID-BASE THEORIES	 An acid releases H⁺/ H₃O⁺ -ions/ in aqueous solutions. HCℓ → H⁺ + Cℓ⁻ HCℓ + H₂O → H₃O⁺ + Cℓ⁻ 	 A base releases OH⁻ -ions in aqueous solutions. NaOH → Na⁺ + OH⁻ 					
-BAS	BRØNSTED-LOWRY						
ACID-	 An acid is a proton donor. HCℓ + H₂O → H₃O⁺ + Cℓ⁻ NH₄⁺ + H₂O → H₃O⁺ + NH₃ 	 A base is a proton acceptor. OH⁻ + H⁺ → H₂O NH₃ + H₂O → OH⁻ + NH₄⁺ 					
REACTIONS WITH WATER	 Ionise in water to produce hydronium ions E.g. HCℓ + H₂O → H₃O⁺ + Cℓ⁻ 	 Ionic bases like NaOH dissociate in water to form hydroxyl ions. NaOH(s) → Na+(aq) + Cℓ⁻(aq) Ammonia (NH₃) ionises in water to form hydroxyl ions NH₃ + H₂O → OH⁻ + NH₄⁺ 					



Activity 2

- **1**. Which of the following is the property of an acid
 - A. Decreases H_3O^+ ion concentration in solution
 - B. Decreases OH- ion concentration in solution
 - C. Increases OH- ion concentration in solution
 - **D.** Increases the pH of a solution

(2) [**2**]

5	Solution	
	1 . B√√	[2]

4.3 Common acids

	ACID	FORMULA	STRONG / WEAK		EXAMPLES & USES
	Hydrochloric acid	HCℓ	Strong	y in water	 Stomach acid (to digest food) Used in swimming pools to control the pH (acidity) of the water; to clean metals for soldering.
STR	Sulphuric acid	H ₂ SO ₄	Strong	lonises almost completely in water	Used • to produce fertilisers; • to produce phosphoric acid; • as dehydrating agent; • as car battery acid and • in gold extraction.
NGTH	Nitric acid	HNO ₃	Strong	loni	Used to produce fertilisers and to produce explosives.
INCREASING STRENGTH	Oxalic acid	(COOH) ₂	Weak		Used to remove rust and stains and as bleach.
INCRE	Phosphoric acid	H ₃ PO ₄	Weak	lonises partially in water	 Used to add taste to gaseous cold drinks; in dental cement and to produce fertilisers like superphosphates.
WEAKEST	Ethanoic acid	CH₃COOH	Weak	lonises part	Vinegar • Used • to flavour food; • to produce plastics; • to neutralise hair relaxers and • to treat jellyfish stings.
	Carbonic acid	H ₂ CO ₃	Weak		Used to make gaseous cold drinks.

Unit (



Strong acid: $HC\ell$; H_2SO_4 ; HNO_3 Weak acid: CH_3COOH ; $(COOH)_2$ Strong base:NaOH; KOH; $Mg(OH)_2$ Weak base: NH_3 ; $NaHCO_3$; $CaCO_3$

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	BASE	FORMULA	STRONG / WEAK		EXAMPLES & USES
	Sodium hydroxide (Caustic soda)	NaOH	Strong		 Used in the production of soap and as drain cleaner and to relax the curl in human hair.
STRONGEST	Potassium hydroxide (Caustic potash)	КОН	Strong	ely in water	Used in the production of soap; in the production of biodiesels and as electrolytes in cells.
E	Magnesium hydroxide	Mg(OH) ₂	Strong	Dissociates completely in water	Used in antacids (Milk of Magnesia); in laxatives and to neutralise acidic waste water.
INCREASING STRENGTH	Calcium hydroxide (Slaked lime)	Ca(OH) ₂	Strong	-	 Used to clarify water by removing particles from the water; to neutralise acidic water so that water pipes are not damaged and to neutralise acidic soil.
	Sodium carbonate (Washing soda)	Na ₂ CO ₃	Weak	er	Used to manufacture glass and to soften water or laundry.
WEAKEST	Calcium carbonate (Limestone)	CaCO ₃	Weak	Dissociates / Ionises partially in wate	 Found in marble and sea shells. Used in the production of cement; in chalk to write with; as an antacid.
	Ammonia	NH ₃	Weak	Dissociates /	Used to produce nitric acid; to produce fertilizers and in cleaning materials.
	Sodium bicarbonate (Baking soda)	NaHCO ₃	Weak		Used in baking to let dough rise

4.4 Common bases

4.5 Mono- and polyprotic acids

Acids can be classified according to the number of protons $({\rm H}^{\scriptscriptstyle +})$ that they can donate.

NB: Monoprotic acids have only one proton (H^+) to donate. **Polyprotic** acids can donate two or three protons. The protons are donated in steps as shown in the examples in the table below.

Monoprotic acids Can only donate only	Polyprotic acids Can donate more than one proton (H ⁺)				
one proton (H ⁺)	Diprotic acids	Triprotic acids			
	Can donate 2 protons (H ⁺).	Can donate 3 protons (H+).			
HC <i>l</i> , HNO ₃ , CH ₃ COOH	H ₂ SO ₄ , H ₂ CO ₃	H ₃ PO ₄			
E.g. $HC\ell \rightarrow H^+ + C\ell^-$	E.g. $H_2SO_4 \rightarrow H^+ + HSO_4^-$ $HSO_4^- \rightarrow H^+ + SO_4^{2-}$	E.g. $H_3PO_4 \rightarrow H^+ + H_2PO_4^-$ $H_2PO_4^- \rightarrow H^+ + HPO_4^{2-}$ $HPO_4^{2-} \rightarrow H^+ + PO_4^{3-}$			

4.6 Conjugate acid-base pairs

4.6.1 Acid-base reactions



"Conjugate" is from Latin, it means literally "yoked together" or to be a couple.

Acid-base reactions take place **simultaneously**. The acid donates a proton to the base, while the base accepts the proton from the acid.

4.6.2 Conjugate acids and bases

CONJUGATE ACIDS

- When an acid donates a proton (H⁺), a conjugate base is produced.
- The acid and its conjugate base are called a conjugate acid-base pair.

acid	—	H⁺	+	conjugate base	
Examples:					
HCℓ	—	H⁺	+	Cℓ⁻	
acid				conjugate base	
H_2SO_4	$\stackrel{\checkmark}{\longrightarrow}$	H⁺	+	HSO₄⁻	
acid				conjugate base	



DEFINITION An acid-base (protolytic) reaction is a reaction in which a proton (H⁺) is transferred

CONJUGATE BASES

- When a base receives a proton (H⁺), a conjugate acid is produced.
- The base and its conjugate acid are called a conjugate acid-base pair.

base +	- H⁺	\leftarrow	conj	iugate acid		
Examples:						
OH-	+	H⁺	\rightleftharpoons	H ₂ O		
base				conjugate acid		
HSO₄ [−]	+	H⁺		H_2SO_4		
base				conjugate acid		



Activity 3

- In the reaction: $H_2SO_4(aq) + H_2O(\ell) \rightleftharpoons HSO_4^{-}(aq) + H_3O^{+}(aq)$, the 1. Brønsted-Lowry bases are:
 - H_2O and H_3O^+ Α
- **C** HSO_4^- and H_3O^+
- **B** H_2SO_4 and H_3O^+
- **D** H_2O and HSO_4^-

(2) [2]

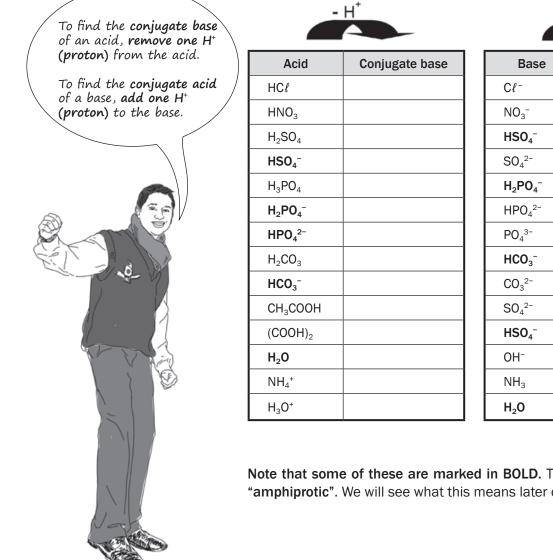
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Solution

1. D √ √

Activity 4

Find the conjugate bases and conjugate acids.





Base	Conjugate acid
Cℓ-	
NO ₃ -	
HSO₄⁻	
S042-	
$H_2PO_4^-$	
HPO42-	
PO4 ³⁻	
HCO ₃ [−]	
CO32-	
S042-	
HSO₄⁻	
OH⁻	
NH ₃	
H ₂ O	

[28]

Note that some of these are marked in BOLD. That is because they are "amphiprotic". We will see what this means later on.

Solution

1. Check your answers

Acid	Conjugate base		
HCℓ	Cℓ - ✓		
HNO ₃	NO ₃ - 🗸		
H_2SO_4	HSO₄⁻ ✓		
HSO₄⁻	SO4 ^{2−} √		
H ₃ PO ₄	$H_2PO_4^- \checkmark$		
$H_2PO_4^-$	HPO₄ ²⁻ ✓		
HP04 ²⁻	PO ₄ ^{3−} ✓		
H_2CO_3	HCO ₃ [−] ✓		
HCO₃ [−]	CO ₃ ^{2−} ✓		
CH₃COOH	CH₃COO⁻ ✓		
(COOH) ₂	C ₂ O ₄ H ⁻ ✓		
H ₂ O	OH⁻ ✓		
NH_4^+	NH ₃ 🗸		
H₃O⁺	H₂0 √		

Base	Conjugate acid		
C <i>l</i> -	HCℓ ✓		
NO_3^-	HNO3 🗸		
HSO₄ [−]	H₂SO₄ ✓		
S04 ²⁻	HSO₄⁻ ✓		
$H_2PO_4^-$	H ₃ PO ₄ ✓		
HP042-	H₂PO₄⁻ ✓		
PO ₄ ³⁻	HPO ₄ ^{2−} ✓		
HCO ₃ ⁻	H₂CO₃ ✓		
CO32-	HCO₃⁻ ✓		
S042-	HS0⁻ ✓		
HSO₄⁻	H₂SO₄ ✓		
OH⁻	H₂0 ✓		
$\rm NH_3$	$NH_4^+ \checkmark$		
H ₂ O	H ₃ O⁺ ✓		

[28]



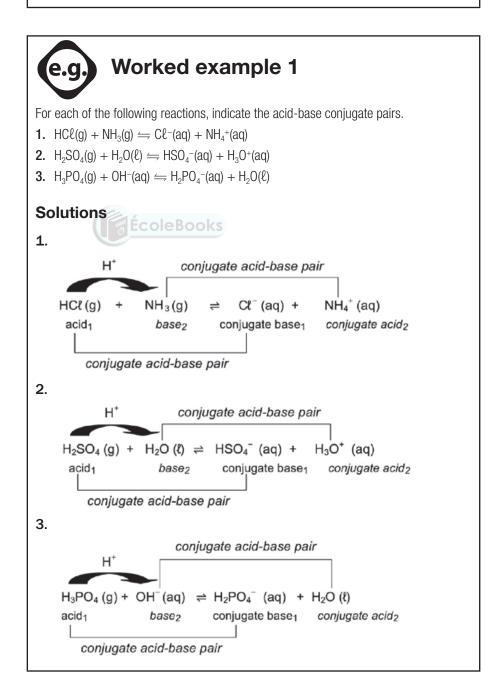
Did you know? Hydrogen carbonates are also known as bicarbonates. E.g. NaHCO₃ is known as • sodium hydrogen carbonate OR as • sodium bicarbonate

) Unit



Steps to follow when identifying conjugates

- 1. Find the acid on the left hand side of the arrow. Label it acid₁.
- 2. Find the **conjugate base** of this acid on the **right** hand side of the arrow. Label it **base**₁.
- 3. Draw a **bracket** to show that these two form an **acid-base conjugate pair**.
- 4. Find the base on the left hand side of the arrow. Label it base₂.
- 5. Find the **conjugate acid** of this base on the **right** hand side of the arrow. Label it **acid**₂.
- 6. Draw a bracket to show that these two form an acid-base conjugate pair.



4.7 Ampholyte (amphiprotic) substance

An ampholyte:

- acts as a base in the presence of an acid and
- acts as an acid in the presence of a base.

Example:

Water (H₂O) is an ampholyte:

Water as an acid $H_2O(\ell) + NH_3(g) \iff OH^-(aq) + NH_4^+(aq)$ $acid_1$ $base_2$ conjugateconjugate $base_1$ $acid_2$

Water as a base $HC\ell(g) + H_2O(g) \iff C\ell^-(aq) + H_3O^+(aq)$ $acid_1$ $base_2$ conjugateconjugate $base_1$ $acid_2$

Example:

Show that hydrogen sulphate ion (HSO_4^-) is an ampholyte.

The hydrogen sulphate ion (HSO₄ ⁻) donates a proton when it acts as an acid	The hydrogen sulphate ion (HSO₄ ⁻) accepts a proton when it acts as a base		
$HSO_4^{-}(aq) \rightleftharpoons H^+(aq) + SO_4^{2-}(aq)$	$HSO_4^{-}(aq) + H^{+}(aq) \iff H_2SO_4(aq)$		
acid conjugate base	base conjugate acid		



Activity 5

In the acid-base equilibrium formed by adding HSO_4^- and OH^- the acids are:

Α	HSO_4^- and H_2SO_4	С	SO_4^{2-} and H_2SO^{-}	
В	HSO_4^- and H_2O	D	SO_4^{2-} and H_2O	(2)

Which of the following is amphiprotic in water?

Α	SO ₂	С	HSO ₃ ⁻	
В	SO32-	D	H_2SO_3	(2)
				[4]

So	lutions			
1.	B√√	2.	C√√	[4]

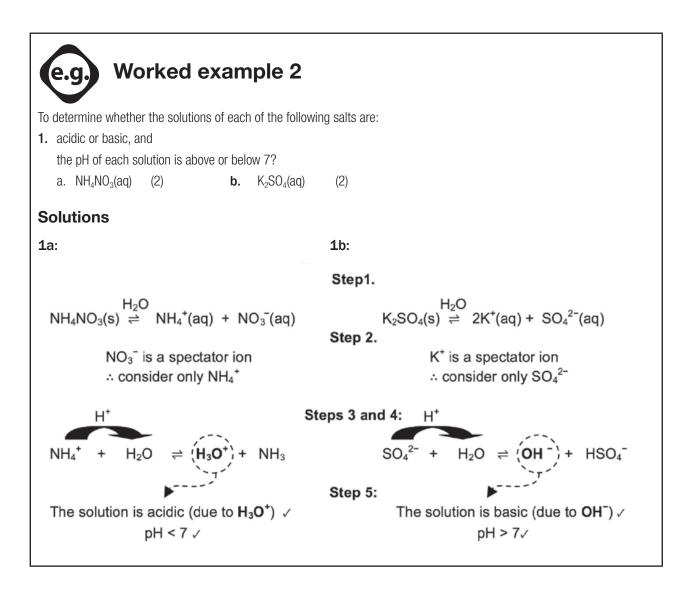
Ampholyte is a substance that can act as either a base or acid.

Unit

4.8 Salt hydrolysis

A salt is formed in the reaction between an acid and a base. When an ionic salt dissolves in water, the ions in the salt dissociate. These ions react with the water and new ions form.

NB: Hydrolysis occurs when a salt (a compound made of a metal + nonmetal portion) reacts with water. Hydrolysis, more generally, is the splitting of any compound by reacting it with water. In this chapter, we only deal with the hydrolysis of salts. (Salt is not just what you have on your table; that is just one type of salt, specifically NaC ℓ . Any metal combined with any nonmetal is a salt).



In summary:

Remember that acids and bases react with each other to form new compounds:

acid + base \rightarrow salt + water

We can determine whether the salt solution is basic or acidic by comparing the strengths of the reacting acids and bases.

- A salt formed between a strong acid and a weak base is an acidic • salt, for example $NH_4C\ell$.
- When a salt reacts with water to form hydronium ions (H_3O^+) , the ٠ solution is acidic (pH < 7).
- A salt formed between a weak acid and a strong base is a **basic salt**, for example NaCH₃COO.
- When a salt reacts with water to form hydroxyl ions (OH⁻), the solution is basic (pH > 7).
- Neutral salt is formed when a strong acid and a strong base are • neutralized in the reaction.

To determine the approximate pH of salts in salt hydrolysis

	H_2O forms H_3O^+
•	H_2O acts as a base;

- it receives a proton (H⁺) and
- H₃O⁺ ions form so
- the solution is acidic and
- pH < 7

Hydrolysis reaction:

ion + H₂O \implies H₃O⁺ + molecule / ion

REMEMBER:

- When water reacts with a salt to form hydronium ions (H_3O^+) , the solution is acidic (pH < 7).
- When a salt reacts with water to form hydroxyl ions (OH^{-}), the solution is basic (pH > 7).
- The ions that don't react are called **spectator ions**.
 - Positive spectator ions: cations from Groups I and II e.g. K⁺ and Mg²⁺
 - Negative spectator ions e.g. SO₄^{2−}; Cℓ[−]; NO₃[−].

Sal	t of	Nature of	pH in an	Example	
Acid	Base	solution	aqueous solution		
Strong	Strong	Neutral	pH = 7	NaCℓ(aq) (HCℓ + NaOH)	
Weak	Weak	Neutral	pH = 7	CH ₃ COONH ₄ (aq) (CH ₃ COOH + NH ₃)	
Strong	Weak	Acidic	pH < 7	$\begin{array}{l} NH_4C\ell(aq)\\ (HC\ell \ + \ NH_3) \end{array}$	
Weak	Strong	Basic	pH > 7	CH₃COONa(aq) (CH₃COOH + NaOH)	

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- it donates a proton (H⁺) and

Hydrolysis reaction:

ion + $H_2O \implies OH^-$ + molecule / ion

H₂O forms OH⁻ • H₂O acts as an acid;

- OH⁻ ions form so
- the solution is basic and

pH > 7 coleBooks





- **Step 1:** Write down the formula of the acid and of the base that reacted to form the salt.
- Step 2: Write down whether the acid is strong or weak.
- Step 3: Write down whether the base is strong or weak.
- Step 4: Is the salt solution acidic or basic?



Determine whether each of the following salt solutions are acidic, basic or neutral.

a) $Na_2SO_4(aq)$

```
b) NH<sub>4</sub>NO<sub>3</sub>(aq)
```

Solution

a)	Acid	+	Base	Acid	+	Base
	H_2 SO ₄	+	NaOH	HNO_3	+	NH ₃
	Strong		Strong	Strong	+	Weak
	∴ neu	tral so	olution	∴ acid	ic solu	ution

4.9 Acid-base indicators

Indicators:

- can be used to determine whether a solution is acidic or basic;
- are weak acids that are in equilibrium with their conjugate bases (or vice versa) and
- have complex structures and formulae which will simply be represented as **HIn** (**H** followed by **In** for "indicator").

Indicator in equilibrium					
HIn 👄	HIn ≒ H⁺ + In⁻				
colour 1 colour 2					
Indicator in acid	Indicator in base				
 The high [H⁺] of the acid will disturb the indicator equilibrium. 	 The low [H⁺] of the base will disturb the indicator equilibrium. 				
 According to Le Châtelier's Principle, the reverse reaction, which lowers the [H⁺], will be 	 According to Le Châtelier's principle the forward reaction, which increases the [H⁺], will be favoured. 				
favoured.	 More In⁻ is produced and the 				

- More HIn is produced and the indicator will exhibit colour **1**.
- More In⁻ is produced and the indicator will exhibit (show) colour 2.



DEFINITION

An indicator is a substance that changes colour in the presence of an acid or a base.

.g. Worked example 4

Bromothymol blue is an acid-base indicator. The colours it exhibits (shows) can be represented as follows:

 $\begin{array}{rll} \mathsf{HIn} \ \leftrightarrows \ \mathsf{H}^{\scriptscriptstyle +} & \mathsf{In}^{\scriptscriptstyle -} \\ \mathsf{yellow} & & \mathsf{blue} \end{array}$

A test tube contains a solution to which a drop of bromothymol blue has been added. The solution appears blue.

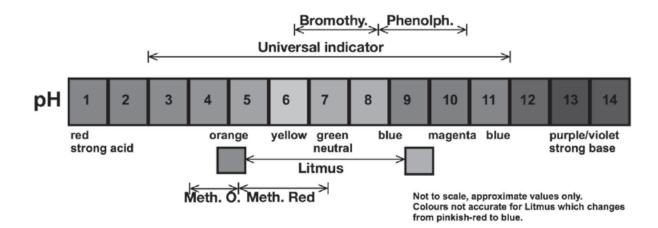
- a) What will you observe if a few drops of concentrated hydrochloric acid are added to the test tube?
- b) Explain your answer.

Solutions

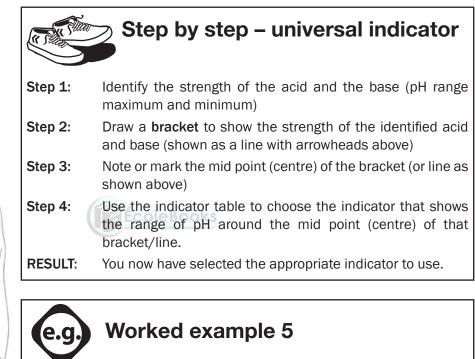
- a) The colour of the solution changes from blue to yellow.
- b) Adding hydrochloric acid increases the concentration of the H⁺ ions in solution. According to Le Châtelier's Principle the reverse reaction that opposes this change and decreases the [H⁺], will be favoured. Therefore the [HIn] increases and the colour changes to blue.

INDICATOR	pH RANGE	COLOUR CHANGE
methyl orange	3,1 - 4,4	red to orange to yellow
methyl red	4,2 - 6,2	red to yellow
litmus	4,5 - 8,3	red to blue
bromothymol blue	6,0 - 7,8	yellow to blue
phenolphthalein	8.3 - 10	pink-purple (magenta) in range, colourless outside range
universal	3-11	red (3 and below); 3-6 orange/yellow; 7 green; 8-11 blue; 11 and above, violet.

The most common indicators that are used in laboratories are:



Choose the most suitable indicator for a particular titration. If you do not have Universal Indicator available, you should follow these steps:



Which one of the indicators given below will be the most suitable to be used in the titration of ethanoic acid against sodium hydroxide?

	INDICATOR	pH COLOUR CHANGE RANGE
A	bromothymol blue	6,0 - 7,8
В	phenolphthalein	8,3 - 10
С	methyl orange	3,1 - 4,4
D	methyl red	4,2 - 6,2

Solution

Consult the table at Sections (3) and (4) above. We see Ethanoic Acid has a pH of about 2,4 (1M solution), and NaOH has a pH of about 14. The mid-point between 2,4 and 14 is about 5,8, so any indicator which changes from indicating acid to base around 5,8 would do. Answer: D; methyl red.

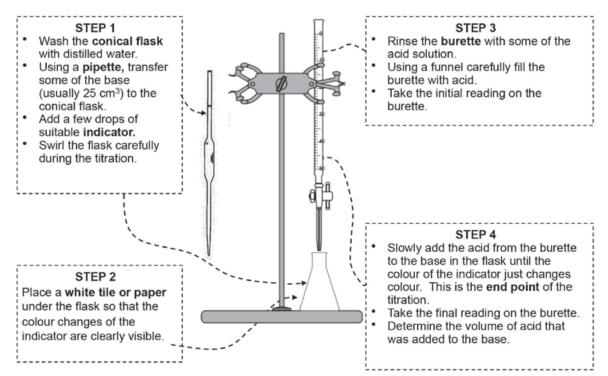


Unit

4.10 Acid-base titrations (volumetric analysis)

Titrations are used to experimentally determine the concentration of an unknown acid or base. When the titration results are used to determine the concentration of the unknown solution it is called a **volumetric analysis**.

a) Method and apparatus for an acid-base titration



4.11 Preparing a standard solution

DEFINITION

A **standard solution** has a known concentration which remains constant for a period of time.

Standard solutions are often used in laboratories and it is important to know how to prepare a standard solution.

CONCENTRATION (c =
$$\frac{n}{v}$$
)

 $+ H_2O(\ell)$

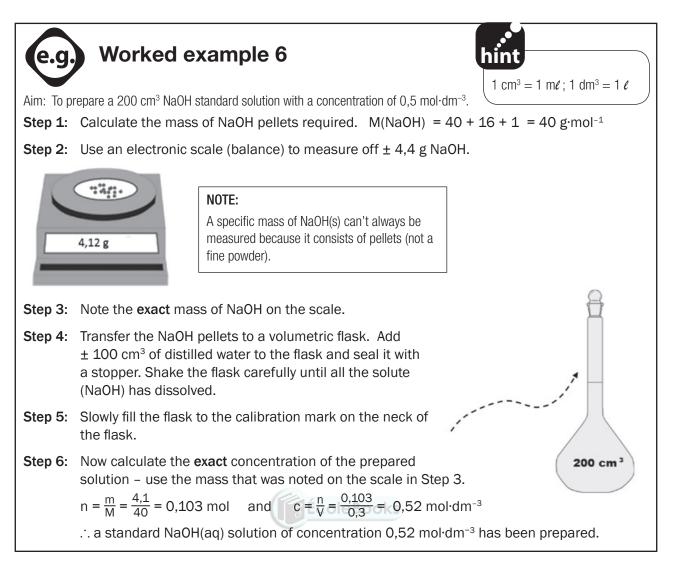
CONCENTRATED SOLUTION

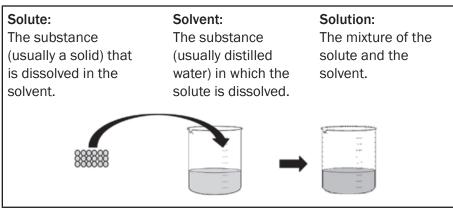
Greater number of moles of substance per unit volume.

$$c = \frac{n_{solute}}{V_4}$$

Smaller number of moles of substance per unit volume.

$$c = \frac{n_{\text{solute}}}{V_1 + V_{\text{water added}}} = \frac{n_{\text{solute}}}{V_2}$$





4.12 Dilution of solutions

We sometimes need to dilute a solution so that we can use it in a laboratory. We do this by taking a small amount of the solution and adding distilled water to it.

When diluting a solution, we need to know:

- the exact amount of distilled water that needs to added as well as
- the exact concentration of the dilute solution.

In symbols:
$$c_1V_1 = c_2V_2$$

C ₁	:	concentration 1	(mol∙dm⁻³)
V ₁	:	volume 1	(dm-3)
C ₂	:	concentration 2	(mol∙dm⁻³)
	:	volume 2	(dm ⁻³)



Worked example 7

Solution 1 has a concentration of 0,2 mol \cdot dm⁻³. Exactly 150 cm³ of solution A is transferred to a beaker 2 and 250 cm³ of distilled water is added to the beaker. Calculate the concentration of the diluted solution.

Solution

$$c_{1}V_{1} = c_{2}V_{2}$$

$$(0,2)(0,15) = c_{2}(0,4)$$

$$c_{2} = \frac{(0,2)(0,15)}{0,4}$$

$$= 0,075 \text{ mol} \cdot dm^{-3}$$
The volume of the final solution (V₂) is:

$$V_{2} = V_{1} + V_{water}$$

$$= 150 + 250 = 400 \text{ cm}^{3}$$

$$400 \text{ cm}^{3}$$

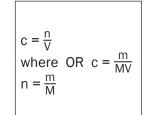
$$= 400 \div 1000 = 0.4 \text{ dm}^{3}$$

• convert to dm³

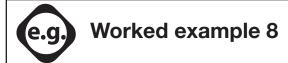


4.13 Acid-base titration calculations

 $\frac{In symbols:}{\frac{n_{a}}{n_{b}} = \frac{c_{a}V_{a}}{c_{b}V_{b}}}$



- n : mol (mol) c : concentration (mol·dm⁻³) V : volume (dm⁻³) a : acid
- b : base



During a titration 20 cm³ diluted H_2SO_4 precisely neutralises 25 cm³ of a NaOH solution. If the concentration of the H_2SO_4 solution is 0,5 mol·dm⁻³, calculate the concentration of the NaOH.

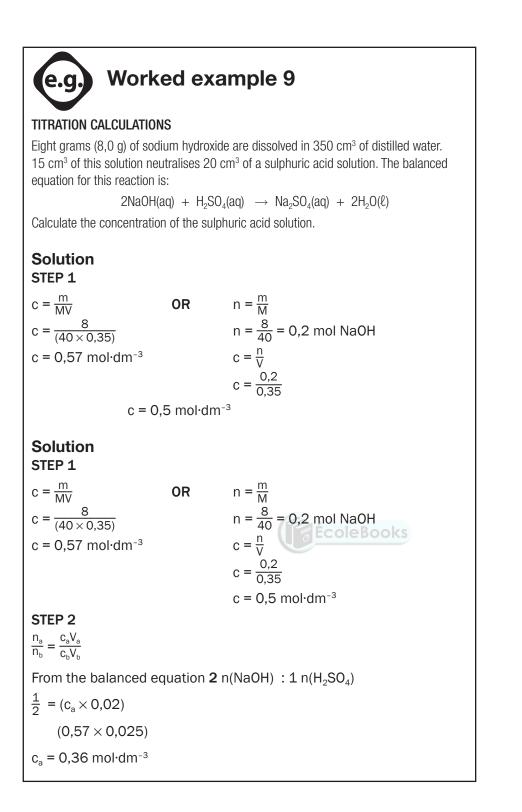
Solution

First write down the balanced reaction.

 $1 \text{ H}_2\text{SO}_4(\text{aq}) + \textbf{2} \text{ NaOH}(\text{aq}) \ \rightarrow \ \text{Na}_2\text{SO}_4(\text{aq}) + \text{H}_2\text{O}(\ell)$

Find the mol ratio of acid : base: H_2SO_4 : NaOH = 1 : 2









The titration of oxalic acid with sodium hydroxide

Part 1:

Aim: To prepare a 250 cm^3 of oxalic acid standard solution with a concentration of 0,08 mol $\cdot \text{dm}^{-3}$

Solutions

Step 1

- Measure between 2,5 and 2,7 g of pure oxalic acid hydrate crystals $(COOH)_2 \cdot 2H_2O$ into the glass beaker and weigh again.
- Add 30-60 cm³ of distilled water to the glass beaker and dissolve the crystals.
- Transfer the solution into a clean 250 cm³ volumetric flask.
- Rinse the beaker with 15-20 cm³ of distilled water and pour this solution into the volumetric flask and repeat. This will ensure that all of the oxalic acid is transferred into the volumetric flask.
- Fill the volumetric flask to within about 2 cm of the mark and allow it to sit for a minute. This will allow any water clinging to the edges of the neck to drain into the flask. Using an eyedropper, fill the flask to the calibrated mark with water.
- Stopper (close) the flask and mix the solution by repeated inversion (turning upside-down) and swirling. This requires about 30 inversions and takes close to 1 minute.

Step 2

ÉcoleBooks

• Calculate the exact concentration of the oxalic acid solution using the mass of acid used and the volume of the volumetric flask and record the concentration of your solution on the bottle.

If you have used the following

Mass oxalic acid crystals2,6 gFinal volume solution250,0 cm³

Using the above information to calculate the number of moles and concentration of oxalic acid crystals.

Part 2:

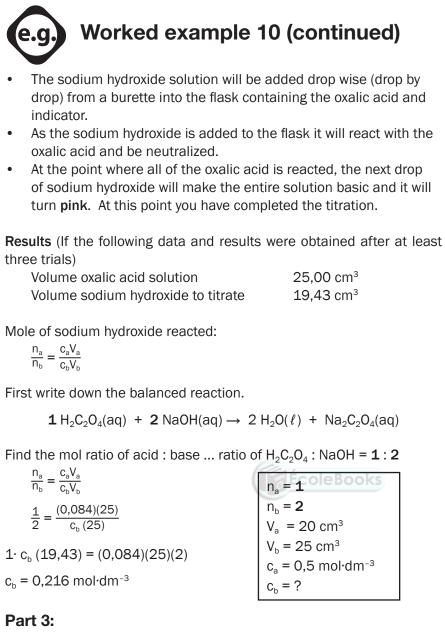
Procedure to perform (to do) a titration of sodium hydroxide with oxalic acid.

Aim: use a standard solution of oxalic acid to determine the concentration of sodium hydroxide

 $H_2C_2O_4(aq) + 2 \text{ NaOH}(aq) \rightarrow 2 H_2O(\ell) + \text{ Na}_2C_2O_4(aq)$

Solutions

- Measure exact 25,00 cm³ of the oxalic acid standard solution (c = 0,084 mol·dm⁻³) into a flask and add few drops of phenolphthalein.
- In this titration the oxalic acid solution is acidic and therefore phenolphthalein will be **colourless**.



In order to determine the concentration of acetic acid in the vinegar solution you will titrate it with the standardized sodium hydroxide solution. The equation for this reaction is

 $1 \text{ CH}_3\text{COOH}(\text{aq}) + 1 \text{ NaOH}(\text{aq}) \rightarrow \text{H}_2\text{O}(\ell) + \text{CH}_3\text{COONa}(\text{aq})$

The following data was obtained during titration

Data

Volume vinegar solution	25,00 cm ³
Volume sodium hydroxide titrated	22,84 cm ³

Calculations for determining concentration of acetic acid in vinegar

First write down the balanced reaction.

 $1 \text{ CH}_3\text{COOH}(\text{aq}) + 1 \text{ NaOH}(\text{aq}) \rightarrow \text{H}_2\text{O}(\ell) + \text{CH}_3\text{COONa}(\text{aq})$

Find the mol ratio of acid : base ... $CH_3COOH : NaOH = 1:1$



Solids and pure liquids are omitted from the $K_{\rm c}$ expression as their concentration is [1], as multiplying by 1 has no effect.



K_c: equilibrium constant (no unit)

[substance]: concentration of reactant or product (in mol·dm⁻³)

mol: number of moles of each compound in the balanced reaction equation.

From a balanced equation 2 n(NaOH) : **1** n(H₂SO₄)

 $\frac{n_{a}}{n_{b}} = \frac{c_{a}V_{a}}{c_{b}V_{b}}$ $\frac{1}{1} = \frac{(c_{a})(25)}{(0,216)(22,84)}$ $1 \cdot (0,216) (22,84) = c_{a} (25)(2)$

 $c_a = 0,197 \text{ mol} \cdot \text{dm}^{-3}$

 $\begin{array}{l} n_{a} = \mathbf{1} \\ n_{b} = \mathbf{1} \\ V_{a} = 25 \text{ cm}^{3} \\ V_{b} = 22,84 \text{ cm}^{3} \\ c_{b} = 0,216 \text{ mol} \cdot \text{dm}^{-3} \\ c_{a} = ? \end{array}$

In order to get the best precision possible, you should repeat each titration until you get 3 trials that are within 1% of each other.

4.14 The Equilibrium Constant (K_c) (The Law of Mass Action)

The concentrations of all the compounds (solutions and gases) in a closed system in dynamic chemical equilibrium are related by a mathematical equation. The numerical value of this equation is called the **equilibrium constant** (K_c).

In the hypothetical equation below the equilibrium expression for this reaction is:

 $2P + 3R \rightleftharpoons 2S + 4T$

$$\mathsf{K}_{c} = \frac{[\mathsf{S}]^{2} \times [\mathsf{T}]^{4}}{[\mathsf{P}]^{2} \times [\mathsf{R}]^{3}}$$



- This is the correct way of writing the K_c expression
- The coefficients are the moles of each reactant and product in the balanced equation
- The product of the concentration of **reactants** (not to be added, but **multiplied**!!), **raised to the power** of the number of moles is the **numerator**
- The product of the concentration of products (not to be added, but multiplied!!), raised to the power of the number of moles is the denominator
- The concentrations used in the Law of Mass Action is the [reactant]_{equilibrium} and [product]_{equilibrium} (NOT initial concentrations!! i.e. the concentrations of reactants and products at equilibrium)

4.15 K_a and K_b values

Since the ionisation of a weak acid is an equilibrium, a chemical equation and an equilibrium constant expression can be written as follows. Remember that square brackets means "concentration", or moles per dm³.

$$HA + H_2O \rightleftharpoons H_3O^+ + A^ K_a = \frac{[H_3O^+][A^-]}{[HA]}$$

The equilibrium constant for the ionisation of an acid is called the *acid* ionisation constant (K_a).

A similar expression can be written for bases:

 $A + H_2 O \Longrightarrow HA^+ + OH^- \quad Kb = \frac{[OH^-][HA^+]}{[A^-]}$

The equilibrium constant for the ionisation of a base is called the base ionisation constant (K_b)

ACIDS	BASES		
Ionisation of acid (HA):	lonisation of base (B):		
$HA + H_2O \rightleftharpoons H_3O^+ + A^-$	$B + H_2 O \rightleftharpoons OH^- + BH^+ (aq)$		
$K_{a} = \frac{[H_{3}O^+][A^-]}{[HA]}$	$K_{b} = \frac{[OH^{-}][BH^{+}]}{[B]}$		
	(NB: here we substituted in values from the line above!)		
Strong acid \rightarrow high K _a -value (>1)	Strong base \rightarrow high K _b -value (>1)		
Weak acid \rightarrow low K _a -value (<1)	Weak base \rightarrow low K _b -value (<1)		
Examples: ÉcoleBooks			

 $\begin{array}{|c|c|c|c|c|} HC\ell(g) \ + \ H_2O(\ell) \rightleftharpoons H_3O^*(aq) \ + \\ C\ell^-(aq) \end{array}$

Activity 6

Do you think a strong acid will have larger or smaller $\rm K_{a}$ value? Explain your answer.

(3) [**3**]

Solution	
The strong acid will have a larger K_a value. \checkmark	
A strong acid is a better proton donor, resulting in more products. Since the concentration of the products is in the numerator of	[3]
the ${\bf K}_{\rm a} {\rm expression},$ the stronger the acid, the larger the ${\bf K}_{\rm a}.$ \checkmark	[3]



An acid or base's strength refers to its degree of ionisation. A strong acid will completely ionise in water while a weak acid will only partially ionise. Since there are different degrees of ionisation, there are different levels of weakness. Fortunately, there is a simple quantitative way of expressing this.

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

Dissociation of base:

NaOH (s) \rightarrow Na⁺ (aq) + OH⁻ (aq) $K_{b} = [Na^{+}][OH^{-}]$

 $H_2O(\ell)$

NH4⁺(aq)



Activity 7

Choose the strongest base in the list below by comparing their K_b values.

	Base	K _b	
А	Ammonia, NH ₃	$1,8 imes 10^{-5}$	
В	Hydroxylamine, HONH ₂	$9,1 imes 10^{-9}$	
С	Ethylamine, $C_2H_5NH_2$	$4,3 imes 10^{-4}$	(2)
			[2]



Solution

 $C \checkmark \checkmark$ [The larger the K_b , the stronger the base]

[2]

4.16 The relationship between K_a and K_b for a substance

We know that the strength of a conjugate base is inversely proportional to the strength of the conjugate acid; i.e. weak acids produce strong conjugate bases, and vice versa.

ACID	CONJUGATE BASE			
$HA(aq) + H_2O(\ell) \rightleftharpoons H_3O^{+}(aq) + A^{-}(aq)$ $K_a = \frac{[H_3O^{+}][A^{-}]}{[HA]}$	$A^{-}(aq) + H_2O(\ell) \Longrightarrow HA(aq) + OH^{-}(aq)$ $K_{b} = \frac{[OH^{-}][HA^{+}]}{[A^{-}]}$			
Then follows:				
$K_{a}K_{b} = \frac{[H_{3}O^{+}][A^{-}]}{[HA]} \times \frac{[HA][OH^{-}]}{[A^{-}]} = [H_{3}O^{+}][OH^{-}]$				
But:				
$[H_3O^+][OH^-] = K_w = 1 \times 10^{-14}$				



You are aware that the pH scale runs from 1 to 14... now look at the values above again.

4.17 Auto-ionisation of water

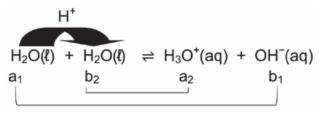
Water is an ampholyte and can react as an acid (donates a H⁺) or a base (accepts a H⁺).

Two water molecules can undergo autoprotolysis or auto-ionisation. One water molecule can act as an acid and donate a H⁺ to the other water molecule, the base.

An acid : $H_2O \rightleftharpoons H^+ + OH^-$

- A base : $H_2O + H^+ \rightleftharpoons H_3O^+$
- Water is a weak acid and a weak base.
- Low % auto-ionisation occurs.
- Pure water is a weak electrical conductor.

Net reaction showing the conjugate acid-base pairs:



4.18 Equilibrium constant for water (K_w)

From the acid-base reaction for water the equilibrium expression for water can be written.

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

 $K_{c} = [H_{3}O^{+}][OH^{-}]$ $K_w = [H_3O^+][OH^-]$

	COLEBOOKS
K _w : equilibrium constant	At 25°C:
for water	$K_w = 1 \times 10^{-14}$

Water has a low percentage of ionisation with a low concentration of products. The K_w-value will be low.

Due to the symbol H⁺ often being used instead of H_3O^+ , the ionisation constant (ion product) for water can also be written as:

 $K_{w} = [H^{+}][OH^{-}]$

Therefore:

Ion product for water $K_w = [H_30^+][OH^-] = [H^+][OH^-] = 1 \times 10^{-14} \text{ at } 25 \text{ °C}$

4.19 The pH scale

We know $K_w = [H_3O^+][OH^-] = [H^+][OH^-] = 1 \times 10^{-14}$

therefore

 $[H_3O^+] = [OH^-] = 10^{-7}$ or $[H^+] = [OH^-] = 10^{-7}$

Acid solution	Neutral solution	Base solution
$[H_3O^+] > [OH^-]$	$[H_3O^+] = [OH^-]$	[H ₃ 0⁺] < [OH⁻]
OR	OR	OR
[H⁺] > [OH⁻]	[H⁺] = [OH⁻]	[H⁺] < [OH⁻]
$[H_30^+] > 10^{-7} \text{ mol} \cdot \text{dm}^{-3}$	$[H_3O^+] = 10^{-7} \text{ mol} \cdot \text{dm}^{-3}$	$[H_30^+] < 10^{-7} \text{ mol} \cdot \text{dm}^{-3}$



 $\begin{array}{l} \textbf{DEFINITION} \\ \textbf{pH} \text{ of a solution is the} \\ \textbf{negative logarithm} \\ \textbf{of the hydronium ion} \\ \textbf{concentration} \text{ in a solution.} \\ \textbf{pH} = \log \left[H_3 0^+ \right] \end{array}$



Determine whether the following solutions are acidic, basic or neutral:

1. A solution with $[H_3O^+] = 10^{-3} \text{ mol} \cdot \text{dm}^{-3}$ $10^{-3} \text{ mol} \cdot \text{dm}^{-3} > 10^{-7} \text{ mol} \cdot \text{dm}^{-3}$ \therefore Solution is acidic
2. A solution with $[H_30^+] = 10^{-12} \text{ mol·dm}^{-3}$ 10 ⁻¹² mol·dm ⁻³ < 10 ⁻⁷ mol·dm ⁻³ ∴ Solution is basic
3. A solution with $[OH^-] = 10^{-7} \text{ mol} \cdot \text{dm}^{-3}$ $[H_3O^+][OH^-] = 10^{-14}$
$\begin{array}{ccc} \ddots & [H_3O^+] (10^{-7}) &= 10^{-14} \\ \ddots & [H_3O^+] &= 10^{-14} \div 10^{-7} = 10^{-7} \\ \ddots \text{ Solution is neutral} \end{array}$
4. A solution with $[OH^-] = 10^{-4} \text{ mol} \cdot \text{dm}^{-3}$ $[H_3O^+][OH^-] = 10^{-14}$
$ \begin{array}{ll} \ddots & [H_3 0^+] (10^{-4}) & = 10^{-14} \\ \ddots & [H_3 0^+] & = 10^{-14} \div 10^{-4} = 10^{-10} \\ 10^{-10} \text{mol} \cdot \text{dm}^{-3} & < 10^{-7} \text{mol} \cdot \text{dm}^{-3} \\ \ddots \text{Solution is basic} \end{array} $

It is complicated to continually refer to the hydronium ion concentration. The pH scale is therefore used as a simplified method of indicating the degree of acidity of a solution.

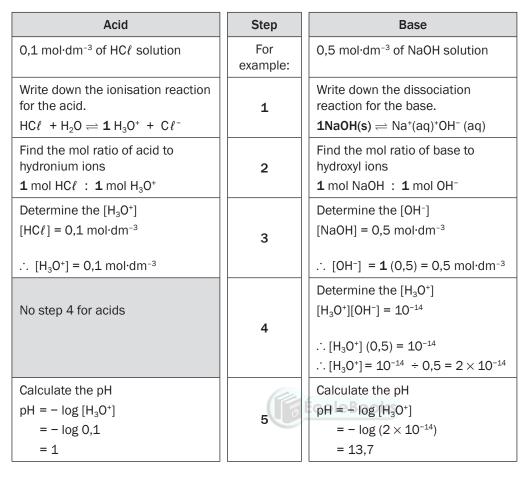
0.0 ◄	▶ 7.0 ◄	▶ 14.0
pH < 7	pH = 7	pH > 7
acid	neutral	base
$[H_3O^+] > 10^{-7} \text{ mol} \cdot \text{dm}^{-3}$	$[H_3O^+] = 10^{-7} \text{ mol} \cdot \text{dm}^{-3}$	$[H_3O^+] < 10^{-7} \text{ mol} \cdot \text{dm}^{-3}$

pН	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0
[H]	1×10 ⁰	1×10 -1	1×10 -2	1×10 ⁻³	1×10 -4	1×10 ⁻⁵	1×10 -8	1×10 -7	1×10 -8	1×10 ⁻⁹	1 × 10 ⁻¹⁰	1×10 ⁻¹¹	1×10 ⁻¹²	1 × 10 ⁻¹³	1×10 ⁻¹⁴
[OH [_]]	1× 10 ⁻¹⁴	1× 10 ⁻¹³	1× 10 ⁻¹²	1× 10 ⁻¹¹	1× 10 ⁻¹⁰	1× 10 ⁻⁹	1× 10 ⁻⁸	1× 10 ⁻⁷	1× 10 ⁻⁶	1× 10 ⁻⁵	1× 10 -4	1× 10 ⁻³	1× 10 ⁻²	1× 10 ⁻¹	1× 10 ⁰
	Concentrated lab acids	Gastric (Stomach) acid	Lemon juice	Vinegar, Gas cold drinks	Wine	Tomatoes Bananas	Black coffee Rain water	Saliva Milk	Blood Ecomption Securator	Baking powder	•	Lime water	Ammonia	Bleaching agents	0,1 M NaOH
3	$\langle -$		Мо	re Ac	dic							More	Basic		\Rightarrow

4.20 pH Calculations for strong acids and bases

To calculate the pH of a strong acid or base, these steps should be followed:

Unit



e.g. Worked example 12

Calculate the pH of a H_2SO_4 solution of concentration 0,6 mol·dm⁻³.

Solutions

4.21 Summary: Strong and weak acids and bases

Acids ionise in water to form ions:

Examples:

 $HC\ell(g) + H_2O(\ell) \rightleftharpoons H_3O^{+}(aq) + C\ell^{-}(aq)$

 $CH_{3}COOH(g) + H_{2}O(\ell) \rightleftharpoons H_{3}O^{+}(aq) + CH_{3}COO^{-}(aq)$

STRONG AND	WEAK ACIDS		
Strong acids	Weak acids		
 High % ionisation Donate many protons (H⁺) High [H₃O⁺] or [H⁺] Low pH Good electric conductors High reaction rates 	 Low % ionisation Donate few protons (H⁺) Low [H₃O⁺] or [H⁺] Relatively low pH Poor electric conductors Low reaction rates 		
Examples: $HC\ell$ (hydrochloric acid) H_2SO_4 (sulphuric acid) HNO_3 (nitric acid)	Examples: CH_3COOH (acetic acid) $(COOH)_2$ (oxalic acid) $C_6H_8O_7$ (citric acid) H_2CO_3 (carbonic acid)		
Strong acid \rightleftharpoons weak conjugate base + H ⁺ HC $\ell \rightleftharpoons$ C ℓ^- + H ⁺	Weak acid \leftrightarrows strong conjugatebase + H*CH_3COOH \Leftarrow CH_3COO ⁻ + H*		

The electrical conductivity of

REMEMBER:

any electrolyte is determined by the number of ions in solution. The greater the ion concentration, the higher the conductivity.

Reaction rate is determined by the concentration of a reactant. The higher the concentration of the ions in a solution, the higher the rate of reaction.

Bases like: ÉcoleBooks

- NaOH are ionic and dissociate in water while
- NH₃ consists of covalent molecules which ionise in water forming NH₄⁺.

STRONG AND WEAK BASES					
Strong bases	Weak bases				
 High % dissociation Accept many protons (H⁺) High [OH⁻] Very high pH 	 Low % dissociation or ionisation Accept few protons (H⁺) Low [OH⁻] Relatively high pH 				
NaOHSodium hydroxideKOHPotassium hydroxide	NH ₃ Ammonia CaCO ₃ Calcium carbonate				
strong base + $H^+ \Longrightarrow$ weak conjugate acid $OH^- + H^+ \leftrightarrows H20$	weak base + $H^+ \rightleftharpoons$ strong conjugate acid NH_3 + $H^+ \leftrightarrows NH_4^+$				

REMEMBER:

The pH of an acid is dependent on the relative concentrations of the H_3O^+ and OH^- ions in the solution.

In general:

pH1-2 : strong acid pH3-6 : weak acid pH 12 - 14 : strong base pH 8 - 11 : weak base

pH 7: neutral

4.22 Summary: Concentrated and dilute acids and bases

Concentration of an acid or a base is an indication of the number of moles of solute per unit volume. Both strong and weak acids and bases can be either concentrated or diluted.

Examples:

- **1** mol·dm⁻³ HCl(aq) : concentrated solution of a strong acid
- **0,01 mol·dm**⁻³ $HC\ell(aq)$: **diluted** solution of a strong acid
- **1 mol·dm**⁻³ CH₃COOH(aq) : concentrated solution of a weak acid
- 0,01 mol·dm⁻³ CH₃COOH(aq) : diluted solution of a weak acid
- **1** mol·dm⁻³ NaOH(aq) : concentrated solution of a strong base
- 0,01 mol·dm⁻³ NaOH(aq) : diluted solution of a strong base
- **1** mol·dm⁻³ $NH_3(aq)$: concentrated solution of a weak base
- **0,01 mol·dm**⁻³ $NH_3(aq)$: **diluted** solution of a weak base



- 1. A standard solution is a solution ...
 - A. at 25°C
 - B of an acid or a base
 - **C** of which the volume is known
 - D of which the concentration is known EcoleBooks

(2)

2. Consider the following ionisation equilibrium:

$$H_2O(\ell) \rightleftharpoons H^+(aq) + OH^-(aq)$$

The ionisation constant of water (K_w) in the above reaction increases from 1×10^{-14} at 25 °C to 9.6×10^{-14} at 60 °C. Which one of the following statements is therefore correct

- A [H⁺] > [OH⁻] at 60°C
- **B** The ionisation reaction is exothermic
- C The pH increases with an increase in temperature
- **D** The pH decreases with an increase in temperature
- 3. Consider the reaction:

$$CH_3COOH(g) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + CH_3COO^-(aq)$$

The ionisation constant for this reaction at 25 °C is 1.8×10^{-5} . The equilibrium constant for this reaction at 60 °C, is 3.6×10^{-7} . From this information we can deduce that forward reaction ... (Explain your choice).

- A is endothermic
- B is exothermic
- **C** is a redox reaction
- D is a precipitation reaction

(2)

(2)



4. Two beakers, A and B, contain solutions of the same concentration with a pH of 2 and 4,5 respectively. Which of the following combinations is correct?

	Beaker A	Beaker B	
Α	Weak Acid	Strong Acid	
В	Strong Acid	Weak Acid	
С	Strong base	Weak base	
D	Weak base	Strong base	(2)

- **5.** Andile rinses the apparatus before starting an acid-base titration experiment. Which rinsing method is likely to cause inaccurate results?
 - A The Erlenmeyer (conical) flask is rinsed with distilled water
 - **B** The burette is rinsed with the acids it is to be filled with
 - **C** The pipette is rinsed with the base it is to be used for
 - **D** The volumetric (measuring) flask, which is used to make up the standard solution of the base, is rinsed with distilled water.
- 6. If base X is titrated against acid Y, the pH of the solution at the end point is 8. The base X and acid Y are respectively:

	Х	Y
Α	NaOH	CH₃COOH
В	Na ₂ CO ₃	HCℓ
С	NaOH	H_2SO_4
D	Na ₂ CO ₃	CH ₃ COOH

Solutions

30	utions		
1. 2.	D √. D		(2)
		C: $[H^+] = [OH^-] = \sqrt{9.6 \times 10^{-14}} = 3.1 \times 10^{-7} \text{ mol} \cdot \text{dm}^{-3} \checkmark$ $\log[H^+] = -\log(3.1 \times 10^{-7}) = 6.5 \checkmark$	(2)
3.	B√√	K_c at 25 °C is greater than K_c at 60 °C	
		$K_c = [CH_3COO^-][H_3O^+]$. If the mixture is heated, the K_c decreases	(2)
4.	B√√	Beaker A has a low pH which indicates that it contains more H ⁺ , therefore it has ionised completely. Whilst beaker B has a high pH which indicates few H ⁺ ions, the	ıs
		it has partially ionised.	(2)
5.	A√√	The Erlenmeyer (conical) flask must be rinsed with distivater. Only the number of moles of base which was	lled
		measured in the pipette must be neutralised.	(2)
6.	AVV		(2)
			[12]

(2)

(2) [**12**]

Activity 9

1.	Write down:	
	1.1 The meaning of the term diprotic acid.	(2)
	1.2 The formula of a diprotic acid.	(1)
2.	Magnesium hydroxide $(Mg(OH)_2)$ is often used as medicine to relieve an upset stomach. The pH of the HC ℓ (aq) in a person's stomach is 1.	
	2.1 Calculate the concentration of the hydrochloric acid in the person's stomach.	(3)
	2.2 Will the pH in the stomach INCREASE, DECREASE or STAY THE SAME after taking in a dose of Mg(OH) ₂ ?	(2)
	2.3 A person takes in a dose of Mg(OH) ₂ . Write down the balanced equation for the reaction that takes place in	
	the stomach.	(3)
3.	A textbook states that calcium sulphate (CaSO ₄) is slightly soluble in water.	

Two learners decided to test the dam water from a local municipality for calcium sulphate. They took a 0,5 dm³ sample of the dam water and treated it with sodium carbonate solution to precipitate the calcium ions present according to the following equation:

 $CaSO_4(aq) + Na_2CO_3(aq) \rightarrow Na_2SO_4(aq) + CaCO_3(s)$

The precipitate is then dissolved in 30 cm³ of 0,1 mol·dm⁻³ HC ℓ solution which converts the precipitate to aqueous calcium chloride, water and carbon dioxide according to the following equation:

 $CaCO_3 + 2HC\ell \rightarrow CaC\ell_2 + CO_2 + H_2O$

The HC ℓ was in excess. They neutralised the excess HC ℓ by adding 15,8 cm³ of a 0,1 mol·dm⁻³ NaOH solution. The equation for the reaction is:

 $\mathrm{HC}\ell \ + \ \mathrm{NaOH} \ \rightarrow \ \mathrm{NaC}\ell \ + \ \mathrm{H_2O}$

Calculate the mass of calcium sulphate that was present in the sample of dam water.

(10)

Solutions

1. An acid that can <u>release</u>/donate \checkmark two protons (H⁺) \checkmark (2)**2**. H₂SO₄✓ $(H_2S; H_2SO_3; H_2CO_3; (COOH)_2)$ (1)**2.1** pH = $-\log [H_3O^+] = 1\sqrt{}$ \therefore [H₃O⁺] = 10⁻¹ = 0,1 \checkmark \therefore [HC ℓ] = 0,1 mol·dm⁻³ (3) 2.2 INCREASE (2)**2.3** Mg(OH)₂(s) + 2HC ℓ (aq) \rightarrow MgC ℓ ₂(aq) + 2H₂O(ℓ) (3) \checkmark 3. $= 15,8 \text{ cm}^{3}$ $\frac{n_{a}}{n_{b}} = \frac{c_{a}V_{a}}{c_{b}V_{b}} \checkmark$ $V_{\text{HC}\ell}$ (reacted with NaOH) $n_{a} = n_{b} = 1$ $V_{\text{HC\ell}\ (reacted\ with\ CaCO_3)}\ = 30-15,8\ cm^3$ 🗸 $n(CaCO_3) = 0.5 \times n(HC\ell)$ $= 14.2 \text{ cm}^{3}$ $= 0.5 \times 1.42 \times 10^{-3}$ $\therefore n_{\text{HCl (reacted with CaCO_3)}} = 0,0142 \times 0,1$ $= 7.1 \times 10^{-4} \text{ mol } \checkmark$ $= 1,42 \times 10^{-3}$ mol \checkmark $V = c_b V_b = 0.1 \times 15.8 \times 1 = 15.8 \text{ cm}^3$ \therefore n(CaSO₄) = 0,5 × n(HC ℓ) \checkmark $= 0.5 \times 1.42 \times 10^{-3}$ $= 7,1 \times 10^{-4}$ mol ∴ m(CaSO₄) = nM ✓ $= 7.1 \times 10^{-4} \times 136$ = 0,097 g oleBooks (10)[21]





Just remember,
 the two half reactions

are added together to

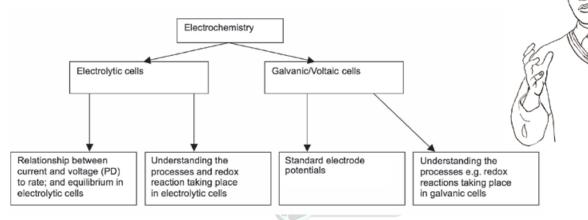
produce the overall or

net redox reaction.

Electrochemistry

Electrochemistry refers to chemical reactions during which chemical energy is converted to electric energy, or electric energy is converted to chemical energy. During these chemical reactions oxidation and reduction take place. These are called redox reactions.

5.1 Summary



Redox (reduction - oxidation) reactions:

- Electron transfers take place.
- can be represented by two half-reactions:
 - an oxidation half-reaction and
 - a reduction half-reaction.

5.2 Key concepts: Definitions and terminology



Electrolysis is the chemical process in which electrical energy is converted to chemical energy. Electrolysis is the process where electrical energy is used to produce a chemical change.

REMEMBER

You must remember these basic **definitions** for electrochemistry:

- Galvanic cells
- Reduction
- Anode

•

- Electrolysis
- Electrolytic cells
- Oxidising agent
- Cathode
- OxidationReducing agent
- Reducing age
- Electrolyte

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Another name for a galvanic cell is a voltaic cell. A galvanic cell has self-sustaining electrode reactions.

A galvanic cell is a cell in which chemical energy is converted into electrical energy.

An electrolytic cell is a cell in which electrical energy is converted into chemical energy.

> Reduction **Reduction** is the gain of electrons by a substance (i.e. by an atom, a

Gain of Electrons is Reduction. (because gaining electrons is gaining minuses, so reducing) A substance that is reduced (i.e. gains electrons) is called an

decreases (becomes more negative,

	Oxidation	Reduction
REMEMBER	Oxidation is the loss of electrons by a substance (i.e. by an atom, a molecule or an ion).	Reduction is the gain of electro by a substance (i.e. by an atom molecule or an ion).
We define oxidation and reduction in terms of electron (e ⁻) transfer	<i>Learn: LEO</i> for <i>L</i> oss of <i>E</i> lectrons is O xidation.	Learn: GER for Gain of Electrons is Reduction. (because gaining electrons is gaining minuses, so reducing)
RED CAT: REDuction – CAThode	A substance that is oxidised (i.e. loses electrons) is called a reducing agent.	A substance that is reduced (i.e. gains electrons) is called a oxidising agent .
AN OX : ANode - OXidation	The oxidation number of a compound that is oxidised , increases (becomes less negative, or becomes more positive).	The oxidation number of a compound that is reduced , decreases (becomes more neg or becomes less positive).
	The anode (-) is the electrode whe	re oxidation (+) takes place
	The cathode (+) is the electrode wh	nere reduction (–) takes place.

The electrodes:

- conduct electricity Books
- are placed in electrolytes which are solutions consisting of ions.

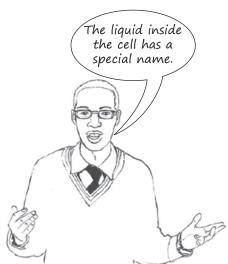
The electrolyte is the solution/liquid/dissolved substance that conducts electricity through the movement of ions.



Activity 1

Give one word for the following statements:

- **1.** The chemical process when an electric current is passed through an ionic compound in solution or in molten state. (1)
- 2. An ionic solution that conducts electricity.
- 3. The reactant that donates electrons during a redox reaction. (1)
- 4. The electrode in an electrochemical cell where reduction takes place.
- 5. **TRUE OR FALSE?** The reactions $C(s) + O_2(g) \rightarrow CO_2(g)$ and $2\text{KC}\ell O_3(s) \rightarrow 2\text{KC}\ell(s) + 3O_2(g)$ are examples of redox reactions. (1)
- The electrode in an electrochemical cell where oxidation occurs. 6. (1)
 - A substance that shows a decrease in oxidation number during chemical reactions. (1)



(1)

(1)

- 8. Which of the following substances can be used as an electrolyte?
 - A. Mercury
 - B. Molten copper
 - C. Sugar dissolved in distilled water
 - D. Table salt dissolved in distilled water. (1)

Solutions

- 1. Electrolysis√
- 2. Electrolyte√
- 3. Reducing agent√
- 4. Cathode√
- 5. TRUE statement √
- 6. Anode√
- 7. Oxidising agent√
- 8. D√

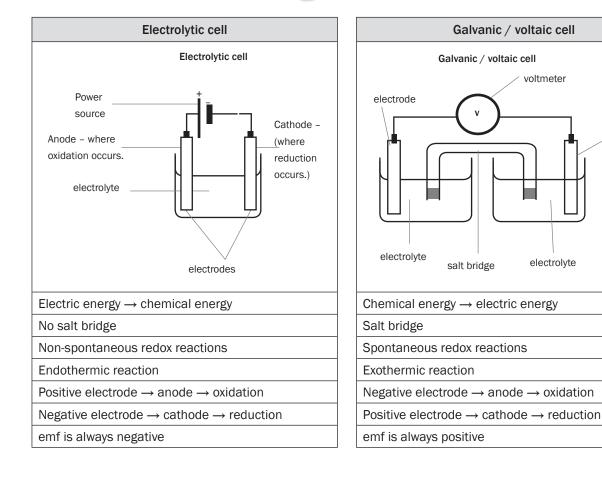
5.3 **Electrochemical cells**

Electrochemical cells allow conversion between electrical and chemical energy.

There are two types of electrochemical cells:

- Galvanic (voltaic) cells
- Electrolytic cells.







voltmeter

electrolvte

electrode

[8]

(1)

(1)

(1)

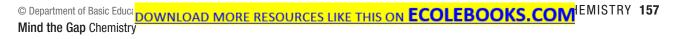
(1)

(1)

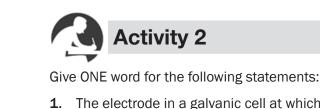
(1)

(1)

(1)[8]







1.	The electrode in a galvanic cell at which reduction occurs.	(1)
2.	Anode in an electrolytic cell.	(1)
3. 4.	The type of electrochemical cell in which electrical energy is converted to chemical energy. TRUE or FALSE ?	(1)
- .	An electrolytic cell converts mechanical energy to electrical energy.	(1)
5.	Which ONE of the following half-reactions occurs at the cathode during the electrolysis of an aqueous $CuC\ell_2$ solution? A. $C\ell_2 + 2e^- \rightarrow 2C\ell^-$ B. $Cu^+ + e^- \rightarrow Cu$ C. $2C\ell^- \rightarrow C\ell_2 + 2e^-$ D. $Cu^{2+} + 2e^- \rightarrow Cu$	(2)
6.	 The gain of electrons by a substance in a chemical reaction is known as A. Oxidation B. Reduction C. Electrolysis D. Oxidation and reduction 	(2) [8]
Sc	olutions ÉcoleBooks	
1. 2. 3.	Cathode / Positive electrode /	(1) (1) (1)



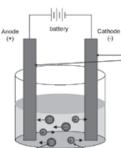
3.	Electrolytic 🗸	(1)
4.	This statement is FALSE. This cell converts electrical energy to	
	chemical energy.√	(1)
5.	$D\checkmark\checkmark$	(2)

- 5. D √
- **6**. B √

(2)

[8]

5.4 Electrolytic cells



Electrodes are made from unreactive substances (platinum, Pt or graphite, C) and are placed in the same ionic solution or molten ionic compound

Negative ions (anions) move (migrate) to the anode where they are oxidised Positive ions (cations) move (migrate to the cathode where they are reduced The electrons flow in the **external circuit** from the negative pole of the battery to the cathode (-)

a) Electrolysis of molten ionic compounds:

- The negative ions migrate (move) to the anode where they are **oxidised**.
- The positive ions migrate to the cathode where they are reduced.

b) Electrolysis of ionic solutions:

The **anions** (negative ions) from the ionic compound **and** the hydroxyl ions (OH^{-}) from the water migrate to the anode (positive electrode). The anions from the ionic compound compete with the hydroxide ions (OH^{-}) from the solution, to be oxidised.

Rules:

If the ionic compound contains:

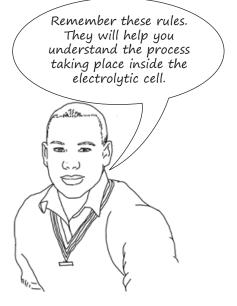
- halide ions (Cl⁻; Br⁻ or I⁻), the halide ion will be oxidised and NOT the hydroxide ion. The product will therefore be the corresponding halogen.
- sulphate (SO₄²⁻) or nitrate (NO₃⁻) ions, the hydroxide ion (OH⁻) will be oxidised to produce oxygen, O₂(g).

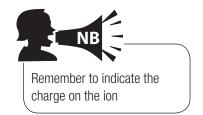
The cations (positive ions) from the ionic compound and the H^+ ions from the water migrate to the **cathode** (negative electrode). The cations from the ionic compound compete with the H^+ ions to be reduced.

Rules:

If the ionic compound contains:

- cations of metals with a positive electrode potential, these cations will be reduced to form the corresponding metal e.g. Cu. See the table on electrode potentials provided in introduction to this book.
- cations of metals with a negative electrode potential (e.g. Zn^{2+}), the H⁺ ions will be reduced to form hydrogen, H₂(g). See the table on electrode potentials provided in this book.







1. Explain how the electrolysis of a copper (II) chloride solution $CuC\ell_2(aq)$ takes place.

Solution

1. The anions $C\ell^-$ and OH^- migrate to the positive anode. The $C\ell^$ ions are oxidised.

oxidation half-reaction: $2C\ell^{-}(aq) \rightarrow C\ell_{2}(g) + 2e^{-}$

The cations (Cu^{2+} and H^+) migrate to the cathode. The Cu^{2+} ions are reduced.

reduction half-reaction:

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

The net reaction:

 $Cu^{2+}(aq) + 2C\ell^{-}(aq) \rightarrow Cu(s) + C\ell_{2}(g)$

The solution is initially blue due to the presence of the Cu²⁺ ions, but as they are reduced to Cu(s), the solution turns colourless and red-brown Cu(s) is deposited on the cathode.

Worked example 2 e.q

2. Predict the products of the electrolysis of a copper (II) sulphate solution CuSO₄(aq)

Solution

2.

- At the anode: $O_2(g)$
- At the cathode: Cu(s)



3. Predict the products of the electrolysis of a zinc chloride solution $ZnC\ell_2(aq)$

Solution

3.

- At the anode: $C\ell_2(g)$
- At the cathode: Zn(s)

c) Electrolysis of water:

Water is a weak electrolyte (weak electric conductor). A small amount of dilute sulphuric acid (H_2SO_4) is added to water to increase its conductivity. When an electric current is passed through the acidified water, oxidation and reduction reactions take place.

At the anode:

oxidation half-reaction: $2H_2O \rightarrow O_2(g) + 4H^+ + 4e^- E^0 = +1,23 V$

At the cathode:

reduction half-reaction: $2H^+ + 2e^- \rightarrow H_2(g)$ $E^0 = 0,00 \text{ V}$

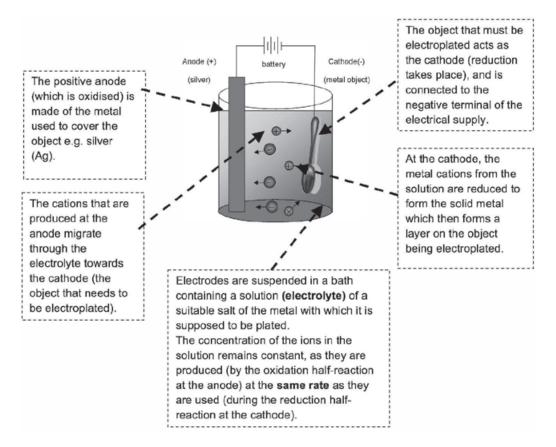
The net reaction: $2H_2O(\ell) \rightarrow 2H_2(g) + O_2(g)$

5.5 Application of electrolysis

- Electroplating
- Production of chemicals e.g. chlorine gas, hydrogen gas and sodium hydroxide (membrane cell, chlor-alkali industry)
- Extraction of metals e.g. aluminium
- Refining (purifying) of metals e.g. copper.

a) Electroplating

Electroplating is the process of putting a metallic coating on an object using electrolytic reactions.

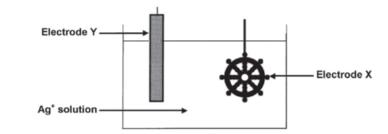


Electroplating is used to protect metals that oxidise easily, by covering them with a thin layer of a metal that does not oxidise easily e.g. chromium, silver or gold. A relatively cheap metal is covered by an expensive metal. Silver is used to cover cutlery — it is too expensive to make a spoon of pure silver, and it is too weak to use — while chromium can be used to cover car parts like bumpers.



Worked example 4

An attractive silver appearance can be created by electroplating artefacts (objects) made from cheaper metals, such as nickel, with silver. The simplified diagram here represents an arrangement that can be used to electroplate a nickel artefact with silver.



- 1. Which electrode (cathode or anode) does the nickel artefact represent?
- 2. Name the metal represented by electrode Y.
- **3.** Write down the half-reaction responsible for the change that occurs at the surface of the artefact.
- **4.** Give a reason why the concentration of the electrolyte remains constant during electroplating.
- **5.** In industry some plastic articles are sometimes electroplated. Explain why plastic must be coated with graphite before electroplating.
- **6.** Give a reason why, from a business point of view, it is not advisable to plate platinum with silver.

Solutions

coleBook

- 1. Cathode
- 2. Silver
- 3. $Ag^{+} + e^{-} \rightarrow Ag$
- 4. The rate of oxidation of silver at the anode is equal to the rate of reduction of silver ions at the cathode.
- 5. Plastic is a non-conductor. It must be covered with a conducting layer so that it can act as the cathode. Graphite is a conductor.
- 6. Platinum is expensive and is more durable than other metals. You would normally electroplate a cheap metal with an expensive, durable metal and not the other way round.

[2]

[2]



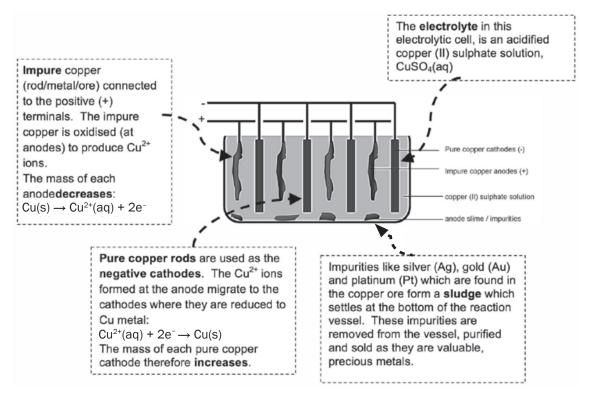
1. TRUE or FALSE? During electroplating of a steel teaspoon with silver, the teaspoon is the cathode and the electrolyte is a solution of any soluble compound

Solution

FALSE. ✓... the electrolyte is a solution of a soluble <u>silver</u> compound. ✓

b) Refining of copper

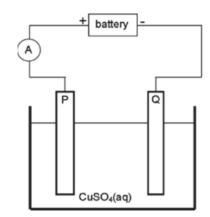
Copper which is mined is impure and the copper ore can be refined as follows by means of electrolysis:





Worked example 5

Impure copper can be purified by the process of electrolysis. The simplified diagram represents an electrolytic cell used to purify copper.



- **1.** Define the term electrolysis.
- **2.** Which electrode, P or Q, consists of the impure copper? Explain how you arrived at your answer.
- 3. Write down the half-reactions that take place at electrodes P and Q.
- **4.** During purification, metals such as silver and platinum form sludge at the bottom of the container. Refer to the relative strengths of reducing agents to explain why these two metals do not form ions during the purification process.
- **5.** Explain why the concentration of the copper (II) sulphate solution remains constant. Assume that the only impurities in the copper are silver and platinum.
- 6. Why is the sludge of economic importance?

Solutions

- **1**. Electrolysis is a process during which electrical energy is converted to chemical energy. It is the process in which electricity is used to bring about a chemical change / decompose / break compounds into components.
- 2. P: P is the positive electrode / anode. The impure Cu is oxidised at the positive electrode / anode.
- 3. P: Anode: $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^{-}$ oxidation impure

Q: Cathode:
$$Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s)$$
 reduction pure

- **4.** Platinum and silver are both weaker reducing agents than copper and will not be oxidised to form ions.
- **5.** The rate at which copper is oxidised (at the anode) is equal to the rate at which copper ions are reduced (at the cathode).
- 6. Silver and platinum are valuable and expensive metals and can therefore be sold at a profit.



- **1.** Refer to the diagram in the worked example above. One of the electrodes consists of impure copper and the other one of pure copper.
 - **1.** What type of power source is used to drive the reaction in this cell? Write down only AC or DC.
 - Give a reason why the copper(II) sulphate is dissolved in water before it is used in this cell. (1)

When an electric current passes through the solution, electrode **P** becomes coated with copper.

- **3.** Is electrode **P** the cathode or the anode? Support your answer by writing the half-reaction that takes place at electrode **P**.
- 4. Write down the half-reaction that takes place at electrode Q. (2)

It is found that the impure copper plate contains platinum. The platinum forms a residue at the bottom of the container during electrolysis.

- **5.** Refer to the relative strengths of reducing agents to explain why platinum forms a residue at the bottom of the container. (2)
- How will the concentration of the copper(II) sulphate solution change during electrolysis? Write down only INCREASES, DECREASES or REMAINS THE SAME.
 (3)
 - [11]

(1)

(2)

Solutions 1. DC 🗸 (1)2. Free ions needed to conduct electricity 🗸 (1)3. Cathode. \checkmark Cu²⁺ + 2e⁻ \rightarrow Cu \checkmark (2)4. $Cu \rightarrow Cu^{2+} + 2e^{-} \checkmark \checkmark$ (2)5. Pt is a weaker reducing agent than Cu √and will not be oxidised 🗸 (2)OR Cu is a stronger reducing agent than Pt and will be oxidised 6. Remains the same. anode \checkmark equals the rate at which Cu²⁺(aq) is reduced at the cathode 🗸 (3)[11]

c) The recovery or extraction of aluminium metal from bauxite

Aluminium:

- is one of the most abundant metals on earth, yet it is expensive largely because of the amount of electricity needed to extract it.
- has the following properties: a low density; the ability to resist corrosion; is very ductile; can be rolled out in thin layers; is lightweight and is a good electrical conductor.

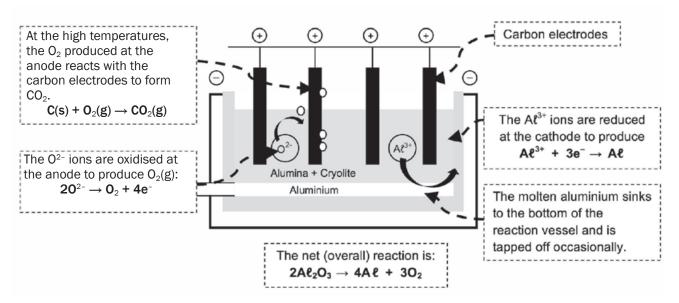


A very important application of electrolysis is the recovery of **aluminium**. South Africa imports bauxite, an aluminium ore.



The process involves:

- Aluminium oxide $(A \ell_2 O_3)$ is extracted from the bauxite and it is then heated.
- The melting point of $A\ell_2O_3$ is higher than 2 000 °C. Cryolite $(Na_3A\ell F_6)$ is added to the ore before it is heated. Cryolite does not lower the melting point of $A\ell_2O_3$ but dissolves it. $A\ell_2O_3$ dissolved in a molten cryolite can be electrolysed easily. This means that less electricity is required to extract the aluminium, thereby decreasing the extraction cost.
- The ions, $A \ell^{3+}$ and O^{2-} , are formed during the extraction.
- The mass of the anode therefore gradually decreases. The cost of replacing the anode when it is depleted adds to the high cost of the aluminium extraction.



- The ecological impact of Al extraction: Loss of landscape due to the size of the chemical plant needed; disposal of red mud (iron (III) oxide) formed during extraction of aluminium oxide from bauxite, into rivers and lagoons and into ground water.
- Environmental impact of A*l* extraction: Carbon dioxide from the burning of the anodes contributes to the greenhouse effect, causing global warming. Fluorine and its compounds lost from the cryolite during the electrolysis process are poisonous. Chemicals in the red mud dams drain into the soil and contaminate groundwater.
 Pollution caused by power generation (for electrolytic process) using coal fired plants leads to acid rain and adds to the greenhouse effect. Noise pollution from the extraction plant.



Give ONE word for the following phrase:

- **1.** The main ore from which aluminium is extracted. (1)
- 2. The name of the chemical substance in which $A\ell_2O_3$ is dissolved to lower its melting point during the industrial extraction of aluminium.

(1) [**2**]

Solutions				
1.	Bauxite 🗸			
2	Cryolite 🗸 [2	!]		



Activity 6

- **1.** In an aluminium smelter, aluminium metal is extracted from bauxite, a hydrated aluminium oxide, via an electrolytic process.
 - 1.1 Write down the energy conversion that takes place in an electrolytic cell. (2)
 1.2 Write down the equation for the half reaction responsible for the formation of aluminium metal in a smelter. (2)
 - **1.3** Explain in terms of the relative strength of oxidizing agents why the electrolytic production of aluminum requires more electrical energy than that of iron or copper. (2)
 - 1.4 Name TWO advantages that the use of aluminium has over that of iron. (2)
- A huge aluminium smelter is planned for Coega in the Eastern Cape. When operational, it will consume 1350 MW of electricity, or 4% of the nation's total electrical energy. It is estimated that 5200 jobs will be created at the peak of construction. About 1000 workers will be employed on a full-time permanent basis, and between 200 and 300 full-time subcontractors will also be directly associated with the smelter.
 - (Source: www.engineeringnews.co.za; www.groundwork.org.za).**2.1** Taking the present South African socio-economic
 - realities into account, give ONE reason why the aluminium smelter should:
 - (a) Not be built
 (b) Be built
 (1)
 (1)
 (1)
 (1)
 (1)
 (1)
 (1)
 (1)
 (1)
 (1)

Solutions

1.1	Electrical energy \rightarrow chemical energy $\checkmark \checkmark$	(2)
1.2	$A\ell^{3^{+}} + 3e^{-} \to A\ell \checkmark \checkmark$	(2)
1.3	Aluminium has a lower reduction potential (-1,66 V) √/ Weaker oxidizing agent compared to that of iron (-0,44 V) [and copper (+0,34 V)]. The aluminium ions therefore require a large amount of energy to be reduced/ will reduce more difficultly than iron (and copper). √	(2)
1.4	It is much lighter for the same strength (or stronger for the same mass). \checkmark	(2)
	It is corrosion free. \checkmark	(2)
2.1	 (a) It will consume huge amount of electricity. √/ Will cause power failures √ (any 2) 	(1)
	 (b) It will create jobs √/Create foreign investment. √ Contribute to GDP √ (any 3) 	(1)
2.2	The production of the large amount of electricity used \checkmark enhances the greenhouse effect (or climate change) \checkmark OR	
	The process is responsible for toxic fluoride waste OR pollution. (any one)	(1)
		[11]
L		



As the oxidation and

reduction reactions take

place in two different beakers, we refer to

indirect or external

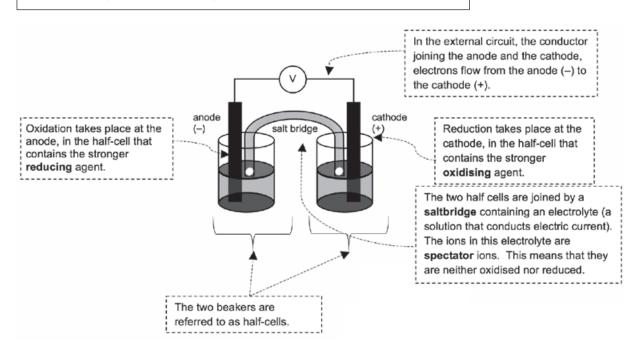
electron transfer.

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5.6 Voltaic (Galvanic) cells

REMEMBER:

• A **Galvanic** or **voltaic cell** is a cell in which chemical energy is converted to electrical energy spontaneously. We therefore use a chemical reaction to produce electricity. E.g. standard AA / penlight batteries.

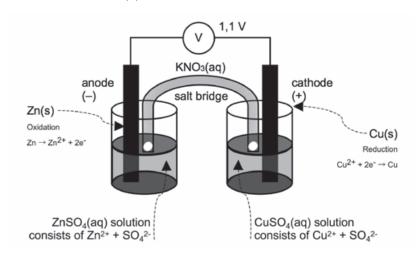


Consider a copper-zinc cell:

A strip of zinc metal is placed in a zinc ion solution. A strip of copper is placed in a separate beaker in an aqueous copper (II) ion solution. These solutions are the **electrolytes**. As they contain ions which dissociated when the salts were dissolved in water, they are good electric conductors.

• The half reactions that occur in each half cell: $Zn(s) \rightarrow Zn^{2+} + 2e^{-}$

 $Cu^{2+} + 2e^- \rightarrow Cu(s)$



REMEMBER

When redox half-reactions are to be written, the correct single arrow should be used.



- In redox reactions, most learners struggle to understand the difference between the name of the process, such as oxidation and the substance, for example the reducing agent.
- Be very careful not to write <u>reduction</u> agent instead write <u>reducing</u> agent.
- Be able to clearly distinguish between the oxidising and the reducing agent.



Potassium chloride is not suitable for a silver half-cell, because AgC ℓ is formed and this compound is insoluble, thus a precipitate will form.



The nitrate salts of ionic compounds are very suitable as an electrolyte, since the salts are soluble in water.

Zn half-cell	Cu half-cell
Oxidation half-reaction at the anode which is always the negative electrode (e ⁻ are given off).	Reduction half-reaction at the cathode which is always the positive electrode.
The stronger reducing agent is oxidised (gives off electrons)	The stronger oxidising agent is reduced (receives electrons)
$Zn(s) \rightarrow Zn^{2+} + 2e^{-}$ (read from right to left)	$Cu^{2+} + 2e^- \rightarrow Cu(s)$ (read from left to right)
Zn is the stronger reducing agent	Cu ²⁺ is the stronger oxidising agent
The anode always decreases in mass if the reducing agent is a solid (The Zn rod is corroding).	The cathode always increases in mass if the reduced product is a solid (copper deposits on rod).
Net cell reaction:	
Add the two half reactions together, sides.	eliminating the electrons from both
	tion with suitable coefficients to ensure uals the number of electrons gained.
Oxidation half-reaction: Z	$in(s) \rightarrow Zn^{2+} + 2e^{-}$
Reduction half-reaction: C	$Cu^{2+} + 2e^{-} \rightarrow Cu(s)$
Net cell reaction: Z	$n(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

a) Salt bridge – part of electrochemical cell (usually a tube) containing electrolyte providing electrical contact between two solution.

The salt bridge: oleBooks

- Completes the circuit.
- Keeps the two electrolytes in the two half-cells separate so that they do not mix.
- Allows movement of ions between the electrolytes, so as to ensure electrical neutrality i.e. it acts as an ion **exchanger**.
- Contains a saturated salt solution (not 1 mol·dm⁻³) of either KNO_3 or $KC\ell$.
- The electrolyte in the salt bridge must contain ions which are weak reducing agents and weak oxidising agents. This will ensure that these ions are not oxidised or reduced, but act as spectator ions.

b) Electrolyte:

- The salt of the compounds need to be soluble.
- Suitable soluble salts of zinc and copper are zinc nitrate and copper nitrate.
- The electrolyte solutions in this cell is $Zn(NO_3)_2(aq)$ and $Cu(NO_3)_2(aq)$.
- As the Zn(s) is oxidised to Zn²⁺(aq), the concentration of the Zn²⁺ ions increases in the diagram above. This means that the Zn halfcell will start building up a positive charge. As the electrons will only move away from a negative potential, the function of the cell would become impaired.
- In the same way as the Cu²⁺ ions are reduced to Cu(s), the concentration of the Cu²⁺ ions decreases. This leads to the copper

The migration of the NO₃⁻ anions in the salt bridge to the anode (the Zn half-cell) and of the K⁺ ions in the salt bridge to the cathode (the Cu half-cell), cancel this build-up of undesired charge and maintain the cell's electric neutrality. The cell therefore continues to function properly.

c) Electron current:

- Electrons always flow from the anode, through the external circuit, to the cathode.
- In the Cu/Zn cell, electrons therefore flow from the zinc (Zn) to the copper (Cu).

5.7 Cell notation

The structure of the galvanic cell may also be represented in symbols.

Rules:

- Always start with the anode on the left and end with the cathode on the right.
- Use a / to separate the anode or cathode from its electrolyte.
- Represent the salt bridge with the symbol //.
- Inert electrodes (usually Pt or C) and phases are usually included: $Zn(s)\ /\ Zn^{2+}(aq)\ //\ Cu^{2+}(aq)\ /\ Cu(s)$

electrode / electrolyte // electrolyte / electrode

anode (-) salt bridge cathode (+)

e.g. Pt/reducing agent/oxidised species//oxidising agent/reduced species/Pt

Pt / C ℓ -(aq) / C $\ell_2(g)$ // F $_2(g)$ / F-(aq) / Pt



Give ONE word for the following phrase:

- **1.** The electrode in a galvanic cell at which reduction occurs. (1)
- **2.** The component of a galvanic cell that allows for the movement of ions between the half-cells.
- **3.** Which statement is CORRECT for a Zn-Cu galvanic cell that operates under standard conditions? (Standard Conditions are defined in the tables at the beginning of this book)
 - A The concentration of the Zn²⁺ ions in the zinc half-cell gradually decreases.
 - **B** The concentration of the Cu²⁺ ions in the copper half-cell gradually increases.
 - **C** Negative ions migrate from the zinc half-cell to the copper half-cell.
 - **D** The intensity of the colour of the electrolyte in the copper half-cell gradually decreases.

(2)

(1)

4. The reactions below occur in two different electrochemical cells X and Y.

Cell X: $CuC\ell_2(aq) \rightarrow Cu(s) + C\ell_2(g)$ Cell Y: Zn(s) + CuSO₄(aq) \rightarrow Cu(s) + ZnSO₄(aq)

Which ONE of the following correctly describes the substance that forms at the CATHODE of each of these cells?

	Cell X	Cell Y
А	C ₂ (g)	Cu(s)
В	Cu(s)	Cu(s)
С	Cℓ ₂ (g)	ZnSO ₄ (aq)
D	Cu(s)	ZnSO₄(aq)

(2)

- 5. Which one of the following statements regarding a copper-silver galvanic cell is TRUE?
 - A Silver is formed at the anode
 - **B** Copper is formed at the anode
 - **C** Silver is formed at the cathode
 - **D** Copper is formed at the cathode

(2) [**8**]

(1)

(2)

(2) [**8**]

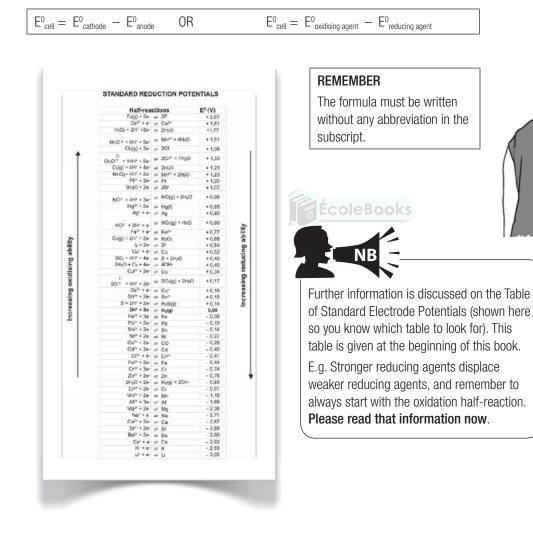
- 1. Cathode 🗸
- 2. Salt bridge ✓ (1)
- **3.** D √√ (2)
- **4**. B √√
- 5. C √ √

5.8 Standard electrode potentials

The **Reactivity Series** is a list of substances which are arranged in order of their ability to act as **reducing agents** or as **oxidising agents**.

The Table of Standard Reduction Potentials lists the standard electrode potentials (E^{o} values) for various compounds. There are two tables, they are similar, but the entries are arranged in opposite directions.

- The tables of Standard Reduction Potentials can be used to:
 - identify oxidising and reducing agents
 - write balanced redox reaction equations
 - predict whether a redox reaction takes place spontaneously or not
 - calculate the emf of a voltaic cell by using one of the following formulae (formulas):





You will notice that all ionic compounds, for example, H_2SO_4 , HNO_3 and $HC\ell$ must be dissociated into ions, before we can use the information in the Table of Standard Reduction Potentials.





Worked example 6

A piece of zinc metal (Zn) is placed in a beaker containing a copper (II) sulphate solution and a piece of copper metal (Cu) is placed in a beaker containing a zinc (II) sulphate solution.

- 1. Predict which redox reaction will take place spontaneously.
- 2. Motivate your answer.
- **3.** Write the oxidation half-reaction, the reduction half-reaction and the net cell reaction for the spontaneous redox reaction.

Solutions

- **1.** Zn is oxidised to Zn²⁺ and Cu²⁺ is reduced to Cu. The redox reaction in the beaker containing the piece of zinc (Zn) and the copper (II) sulphate solution with Cu²⁺ ions is spontaneous.
- 2. Zn is a stronger reducing agent than Cu (see reducing ability on table), i.e. Zn will be oxidised more readily than Cu and Cu²⁺ is a stronger oxidising agent than Zn²⁺ (see oxidising ability on table) i.e. Cu²⁺ will be reduced more readily than Zn²⁺. Therefore Zn will displace Cu from CuSO₄(aq).
- **3.** oxidation half-reaction : reduction half-reaction: $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^{-}$ $Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s)$

Overall or net ionic reaction is: $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$



Worked example 7

- **1.** Use the Table of Standard Reduction Potentials to determine whether Ag will spontaneously displace Zn²⁺ ions from a zinc sulphate (ZnSO₄) solution. Motivate your answer.
- **2.** Write the oxidation half-reaction, the reduction half-reaction and the net ionic reaction which takes place when a piece of copper (Cu) is dipped in a silver nitrate (AgNO₃) solution.

Solutions

- No, the reaction will not take place. Ag is a weaker reducing agent than Zn, therefore it will not be able to displace Zn from the zinc sulphate solution.
- **2.** oxidation half-reaction: $Cu \rightarrow Cu^{2+} + 2e^{-}$ reduction half-reaction: $Ag^+ + e^- \rightarrow Ag^+$

Multiply this reaction by 2, so that the number of electrons released by the copper atom equals the number of electrons gained.

$$\frac{2Ag^{*} + 2e^{-} \rightarrow 2Ag^{*}}{Cu + 2Ag^{*} \rightarrow Cu^{2*} + 2Ag^{*}}$$

net ionic reaction:



1. Which one of the following solutions can be stored in an aluminium container?

(Use the Table of Standard Reduction Potentials.)

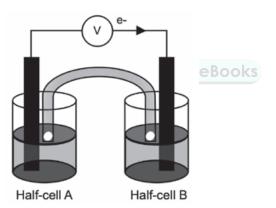
- $\textbf{A} \quad CuSO_4(aq)$
- B ZnSO₄(aq)
- C NaCℓ(aq)
- **D** $Pb(NO_3)_2(aq)$

	[2]
Solution	
1 . C √√	[2]

(2)



The galvanic cell represented in the diagram consists of a Mg electrode dipped into a Mg(NO₃)₂ solution, and a Pb electrode dipped into a Pb(NO₃)₂ solution. Assume that the cell operates under standard conditions.



- State TWO standard conditions under which this cell operates. (2)
 Write down the half-reaction that takes place in half-cell A. (2)
- 3. Write down the cell notation for this cell. (2)
- Calculate the emf of this cell. (3)
 How will each of the following changes influence the value of
- the cell's emf calculated in QUESTION 2.4? Write down onlyINCREASES, DECREASES or REMAINS THE SAME**5.1** An increase in [Mg²⁺(aq)]**5.2** An increase in [Pb²⁺(aq)]
- 6. In which direction, from half-cell A to B or from half-cell B to A, do cations move within the salt bridge to maintain electrical neutrality? Explain how you arrived at your answer.
 (3)
 [14]



Solutions

- Temperature: 298 K (25 °C) √√
- 2. $Mg(s) \rightarrow Mg^{2+}(aq) + 2e^{-} \checkmark \checkmark$ (2)
- **3.** Mg(s)/Mg²⁺(1 mol·dm⁻³) \checkmark // Pb²⁺(aq)(1 mol·dm⁻³)/Pb(s) \checkmark (2)
- 4. $E^{o}_{cell} = E^{o}_{cathode} E^{o}_{anode} \checkmark$ = -0,13 - (-2,36) \checkmark = 2,23 V \checkmark
- 5.
 - 5.1 DECREASES ✓ (1) 5.2 INCREASES ✓ (1)
- Half-cell A to half-cell B ✓
 Concentration of positive ions/cations √/ Pb²⁺ ions decreases in half-cell B. ✓

OR

Concentration of positive ions/cations/Mg^{2+} ions increases in half-cell A

To prevent a build-up of positive ions in half-cell A and negative ions in half-cell B /for electrical neutrality.

Positive ions migrate from/through the salt bridge (3)

[14]

(2)

(1)

(2)

(3)



Learners conduct an investigation to determine which combination of two half-cells will provide the largest emf under standard conditions.

Three half-cells, represented as A, B and C in the table below, are available.

Half-cell A	Half-cell B	Half-cell C	
Mg/Mg ²⁺	Pb/Pb ²⁺	Aℓ/Aℓ ³⁺	

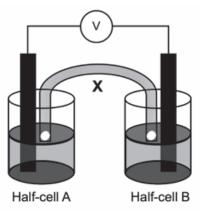
The learners set up galvanic cells using different combinations of the above half-cells.

- **1.** Write down the standard conditions under which these cells operate.
- 2. Write down the dependent variable in this investigation. If you can't remember what the dependent (and independent) variables are, please see the introductory materials at the beginning of this book.
- **3.** Use the Table of Standard Reduction Potentials to determine which one of the three half-cells (**A**, **B** or **C**) contains the:
 - **3.1** Strongest reducing agent. (1)
 - **3.2** strogest oxidizing agent. (1)

 Without any calculation, write down the combination of two half-cells which will produce the highest emf. Write down only AB, BC or AC.

(1)

5. One group of learners set up a galvanic cell using half-cells A and **B**, as shown below. X is one of the components of the galvanic cell.

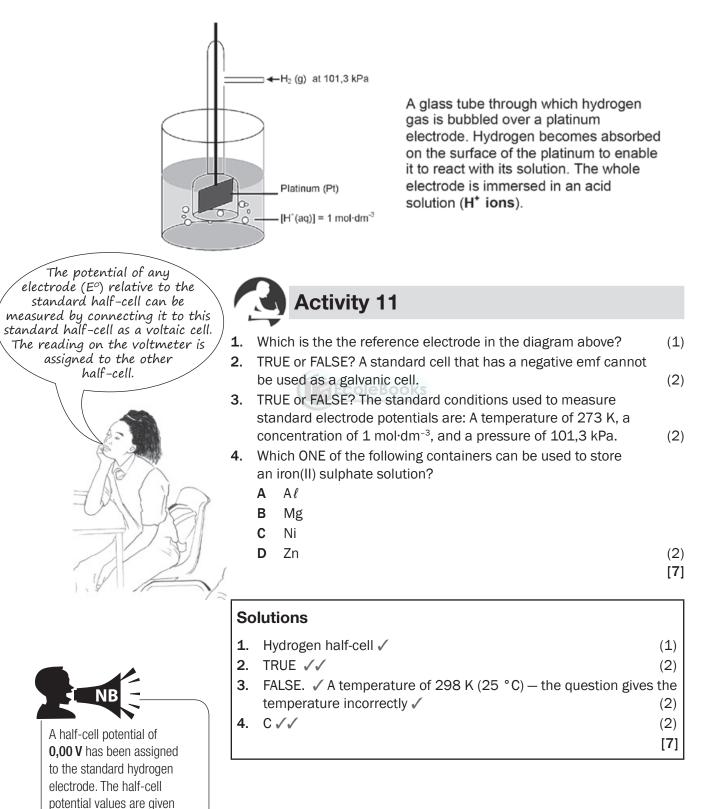


5.1 Write down the NAME or SYMBOL of the substance that will act as the anode in this cell. Give a reason for the	
answer.	(2)
5.2 Calculate the initial emf of this cell.	(3)
5.3 How will an increase in the concentration of the electrolyte in half-cell B affect the initial emf of this cell? Write down only INCREASES, DECREASES or REMAINS	
THE SAME.	(1)
5.4 Briefly explain how component X ensures electrical	
neutrality while the cell is functioning.	(1)
	[13]

1.	Temperature 25 °C / 298 K 🗸	
	Concentration of electrolytes = 1 mol·dm ⁻³ \checkmark	(2)
2.	emf/potential difference 🗸	(1)
	3.1 Half-cell A ✓	(1)
	3.2 Half-cell B √	(1)
4.	Combination AB 🗸	(1)
	5.1 Magnesium/Mg. √Is oxidised/loses electrons/increase in	
	oxidation number/stronger reducing agent 🗸	(2)
	5.2 $E_{cell}^0 = E_{cathode}^0 - E_{anode}^0 \checkmark$	
	= - 0,13 - (-2,36) 🗸	
	= 2,23 V 🗸	(3)
	5.3 Increases 🗸	(1)
	5.4 Allows for the migration of positive ions to the cathode	
	half-cell 🗸	(1)
	OR	
	Allows for the migration of negative ions to the anode half-cell	
		[13]

5.9 The standard hydrogen electrode

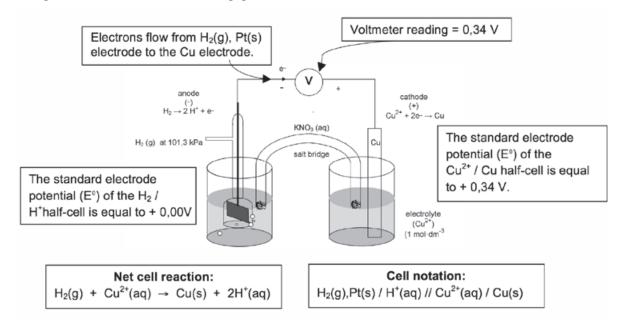
The hydrogen gas/hydronium ion electrode has been chosen as **standard** half-cell.



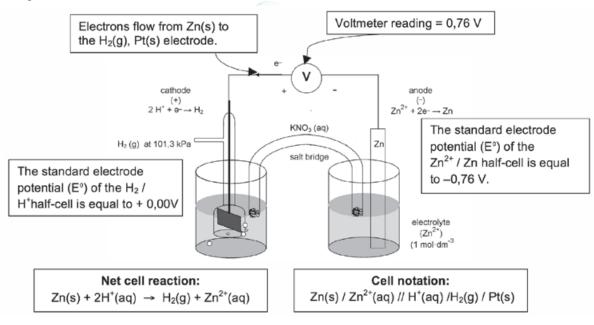
on the right hand side of the

table.

a) To determine the standard electrode potential of the copper half-cell



b) To determine the standard electrode potential of the zinc half-cell



5.10 The emf of an electrochemical cell

- A **voltmeter** connected to the zinc / copper cell has a reading of 1,1 V. It reads the **difference** between the electric potentials of the two separate electrodes.
- This reading of 1,1 V can also be referred to as the **potential difference** or **cell potential** or **emf** of the cell.



Always use the values exactly as they stand on the table; do not round off.





Using the Cu / Zn cell as an example: $E_{cell}^{0} = E_{cathode}^{0} - E_{anode}^{0}$ = +0.34 - (-0.76) = +0.34 + 0.76

= +1,1 V

- The cell potential (voltage) does not depend on the surface area of the electrode.
- The **bigger the surface area** of the electrode, the **bigger the current** produced by the cell.
- In general the cell potential increases slightly with an increase in temperature.
- The reaction in the cell reaches **equilibrium** when the cell is completely discharged (flat or dead). This usually means that the concentration of the cations in the reduction half-cell (i.e. at the cathode) has **decreased** to zero.

Using the Table of Standard Reduction Potentials to predict whether a redox reaction will be spontaneous or not:

- Assume that the reaction will take place as suggested in the question.
- Identify the reducing agent and the oxidising agent according to the given equation.
- Calculate the cell potential for this reaction.
- If the cell potential is **positive**, the reaction will be **spontaneous** i.e. it will take place without the addition of any other form of energy. If it is **negative**, the reaction will **not** occur spontaneously.
- If the two half reactions are very close to each other on the Table of Standard Reduction Potentials, heating the reaction mixture may supply enough additional energy for the reaction to take place.



- **Step 1.** Use the Reduction Potentials to determine whether a reaction will take place spontaneously.
- **Step 2.** If the calculated cell potential is a positive value the redox reaction will take place spontaneously.



 $H_2S \longrightarrow S + 2H^+ + 2e^-$

OR

 $\mathsf{S} + 2\mathsf{H}^{\scriptscriptstyle +} + 2\mathsf{e}^{\scriptscriptstyle -} \longleftarrow \mathsf{H}_2\mathsf{S}$

is the \boldsymbol{only} correct way of writing a half-reaction

- Note the direction of the single arrow changes, depending on whether the reaction is an oxidation or reduction half reaction.
- Please do NOT include the double arrow in the half reaction.
- Always remember to include the charges on the ions in the half-cell reactions.

NB -

When you have to explain the relative strength of oxidizing and reducing agents, write the explanations as follows:

- Cu is a stronger oxidising agent than Mg. Do NOT state the position of a substance in terms of its position in the Reduction Table (e.g. Cu is above Mg)
- Do NOT state the relative strength in terms of relative reactivity only, for example, Mg is more reactive than Cu.

Your correct answer would read as follows:

Mg is a stronger reducing agent than Cu and therefore Mg will be able to reduce $\rm Cu^{2+}$ ions to Cu.

OR

e.g

Explain the relative strength of the oxidizing and reducing agents in terms of their relative strength as electron acceptor and donors.

Mg is a stronger reducing agent than Cu because Cu has a stronger tendency to accept electrons than Mg. OR: Mg has a stronger tendency to donate electrons to Cu than Cu has to donate electrons to Mg.

Worked example 9

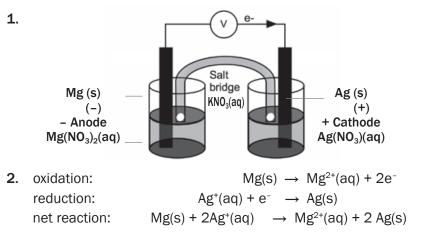
Batteries consist of one or more galvanic cells. A galvanic cell is a combination of two half-cells. John wants to determine which one of Options A or B, shown below, can be used to assemble a galvanic cell with the highest potential difference.

Option	Combination of half-cells
А	Ag(s) in AgNO ₃ (aq) & Ni(s) in Ni(NO ₃) ₂ (aq)
В	Mg(s) in Mg(NO ₃) ₂ (aq) & Ag(s) in AgNO ₃ (aq)

 Draw a fully labelled diagram of the galvanic cell that John can use to measure the potential difference for the cell in Option B. Use a positive (+) and negative (-) sign to indicate the positive and negative electrodes respectively.



- **2.** Write down the oxidation and reduction half reactions as well as a balanced chemical equation, excluding spectator ions, for the net (overall) cell reaction for the galvanic cell in Option B.
- **3.** Calculate the initial potential difference that can be obtained under standard conditions for the galvanic cell in Option B.
- **4.** State TWO standard conditions that John must adhere to during the experiment, to ensure that the measured potential difference is the same as the calculated potential difference.
- 5. Write down the cell notation for the galvanic cell in Option A.
- **6.** Without doing any calculations, determine which one of Option A or Option B should result in the galvanic cell with the highest potential difference. Refer to the relative strengths of the two reducing agents, as well as the two oxidising agents involved, to explain your answer.
- **7.** How will each of the following changes influence the value of the cell's emf calculated in Question 3?
 - 7.1 An increase in [Mg²⁺(aq)].
 - 7.2 An increase in [Ag+(aq)].
- 8. In which direction, from half-cell Mg²⁺ / Mg to Ag ⁺ / Ag, or from half-cell Ag ⁺ / Ag to Mg²⁺ / Mg, do cations move within the salt bridge to maintain electrical neutrality? Explain how you arrived at your answer.
- **9.** Give two functions of the salt bridge.
- 10. Name the cathode and the anode for the galvanic cell in option B.
- **11.** Which electrode will show an increase in mass for the galvanic cell in option B?
- **12.** Distilled water is added to the Ag⁺ solution for the galvanic cell in Option B. How will the emf of the cell be influenced? Explain your answer.
- **13.** Consider the galvanic cell in Option B. If 0,6 moles of electrons flow from the anode to the cathode, what will the decrease in mass of the anode be?
- **14.** A 2 V bulb is connected to the cell in option B instead of the voltmeter. Will the bulb light up? Justify your answer.
- 15. Consider the galvanic cell in Option B. It is observed that after a while, the reading on the voltmeter drops to zero. We say the cell is 'flat' or 'dead'. Explain this observation in terms of the concentrations of the solutions in the cell.
- 16. Give two uses of galvanic cells.



3.	$E^{0}_{cell} = E^{0}_{cathode} - E^{0}_{anode} = 0,80 - (-2,36) = 3,16 V$
4.	Ensure a temperature of 25 $^\circ\text{C}$ and Mg^{2+}, Ni^{2+} and Ag^+ solutions of concentration 1 mol·dm^3.
5.	Ni(s) / Ni ²⁺ (aq) (1 mol·dm ⁻³) // Ag(s) ⁺ (aq) (1 mol·dm ⁻³) /Ag(s)
6.	Option B. The reaction leading to the highest emf (or potential difference) will be between the strongest reducing agent (Mg) and the strongest oxidising agent (Ag ⁺).
7.	 An increase in the rate of the forward reaction will increase the emf of a galvanic cell. 7.1 decreases; the reverse reaction is favoured 7.2 increases; the forward reaction is favoured
8.	Half-cell Mg ²⁺ / Mg to Ag ⁺ / Ag Concentration of positive ions or cations; [Ag ⁺] ions decreases in half-cell Ag ⁺ / Ag. OR Concentration of positive ions or cations; [Mg ²⁺] ions increases in half-cell Mg ²⁺ / Mg. To prevent a build-up of positive ions in half-cell Mg ²⁺ / Mg and negative ions in half-cell Ag ⁺ / Ag. For electrical neutrality, positive ions migrate from/through the salt bridge to the cathode.
9.	Any two: It completes the circuit. It ensures electrical neutrality by allowing the migration of ions through the salt bridge. It separates the electrolytes.
10.	cathode = Ag anode = Mg
11.	cathode = Ag
12.	By adding water to the solution, the [Ag ⁺] will decrease. Thus the reverse reaction is favoured and emf decreases.
14. 15.	$\begin{array}{llllllllllllllllllllllllllllllllllll$

) Unit



Rusting is an unwanted redox reaction. Iron rusts when exposed to oxygen and moisture. The unbalanced ionic equation for one reaction that occurs during rusting is represented below.

 $Fe(s) + O_2(g) + H_2O(\ell) \rightarrow Fe^{2+}(aq) + OH^{-}(aq)$

Use the Table of Standard Reduction Potentials to answer the following questions for this reaction:

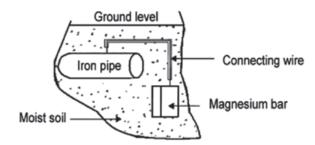
- 1. Write down the oxidation and the reduction half-reactions.
- **2.** Write down the NAME of the substance that is reduced.
- **3.** Perform a calculation to verify that this reaction is spontaneous.

Solutions

- 1. oxidation: $Fe \rightarrow Fe^{2+} + 2e^{-}$ reduction: $2H_2O + O_2 + 4e^{-} \rightarrow 4OH^{-}$ 2. oxygen 3. oxidation: $Fe \rightarrow Fe^{2+} + 2e^{-}$
- 3. oxidation: $Fe \rightarrow Fe^{2+} + 2e^{-}$ reduction: $2H_2O + O_2 + 4e^{-} \rightarrow 4OH^{-}$ $E^{0}_{anode} = -0,44 V$ $E^{0}_{cell} = E^{0}_{cathode} - E^{0}_{anode} = 0,4 - (-0,44) = 0,84 V$ Because E^{0}_{cell} is positive, the reaction is spontaneous.



Magnesium is used to protect underground iron pipes against rusting (cathodic protection). The diagram here shows an iron pipe connected to a magnesium bar.



- 1. Use the Table of Standard Reduction Potentials to explain why magnesium can be used to protect an iron pipe against rusting.
- 2. The iron pipe in contact with the magnesium bar forms an electrochemical cell. What serves as the salt bridge of this cell?
- 3. Give a reason why the magnesium bar must be replaced after some time.
- 4. Write down a half-reaction to support your answer to Question 3.3.
- 5. Name TWO other methods that can be used to protect iron pipes against rust.
- 6. State ONE advantage and ONE disadvantage of using plastic pipes instead of iron pipes.

Solutions

- 1. Mg is a stronger reducing agent (than Fe) and will be oxidised more readily than Fe which is a weaker reducing agent.
- 2. The salts which are dissolved in the moist soil.
- **3.** Mg is continuously oxidised to Mg²⁺ and therefore its mass decreases i.e. it is used up.
- 4. Mg \rightarrow Mg²⁺ + 2e⁻
- **5.** Any two: Paint; electroplating e.g. galvanising; oil or waterproofing; plastic coating.
- <u>Advantages</u>: Plastic is cheaper; plastic does not rust.
 <u>Disadvantages</u>: Plastic not biodegradable; plastic is not as strong as iron.



Activity 12

Give ONE word for the following phrase:

The process taking place in a cell when an electric current passing through its electrolyte, results in chemical reactions at its electrodes. (1)
 TRUE or FALSE? A battery labelled as 3 000 mA·h can deliver a current of 500 mA for 6 hours. (2)
 [3]

Solutions

- 1. Electrolysis 🗸
- 2. True. √√



- The most common filling for tooth cavities is 'dental amalgam' a solid solution of tin and silver in mercury. If you bite on a piece of aluminium foil that is in contact with a dental filling in your mouth, you may feel a painful sensation because
 - **A** the aluminium foil is hard.
 - **B** a temporary galvanic cell has been set up whilst the aluminium and filling are in contact.
 - **C** electrons are being transferred to the aluminium.
 - **D** a temporary electrolytic cell has been set up whilst the aluminium and filling are in contact.

(1)

(2) [**3**]

(2)

- 2. Which one of the following can be classified as a redox reaction?
 - A $NH_3(g) + HNO_3(g) \rightarrow NH_4NO_3(s)$
 - **B** FeS(aq)+ 2HC ℓ (aq) \rightarrow FeC ℓ_2 (aq) + H₂S(g)
 - $\mathbf{C} \quad \mathsf{A}\ell(s) + \mathsf{C}\ell_2(g) \longrightarrow \mathsf{A}\ell\mathsf{C}\ell_3(s)$
 - **D** Mg(NO₃)₂(s) \rightarrow Mg²⁺(aq) + 2NO³⁻(aq) [with H₂O catalyst] (2)
- **3.** A silver (Ag) spoon is left in a beaker containing copper nitrate, $Cu(NO_3)_2$, solution. What will be observed after some time?
 - A The spoon will be covered with a thin layer of copper.
 - **B** The nitrate will form NO_2 gas and copper will form in the beaker.
 - **C** The spoon will start to erode and its mass will decrease.
 - **D** There will be no reaction.

(2) [**6**]

(2)

(2)

[16]

Solutions

 1. $B. \sqrt{4}$ (2)

 2. $C. \sqrt{4}$ (2)

 3. $D. \sqrt{4}$ (2)

 [6]



Activity 14

- 1. A group of learners set up an electrochemical cell using lead and copper half cells.
 - **1.1** Which ONE of copper or lead will be the negative electrode? Give a reason for your answer.
 - **1.2** Use the Table of Standard Reduction Potentials and write down the reduction half-reaction that will take place in this cell.
 - **1.3** A 2V bulb is connected to the cell. Will the bulb light up?Justify your answer with a calculation.(5)
 - A voltmeter is now connected to the cell instead of the bulb. It is observed that after a while the reading on the voltmeter drops to zero. We say the cell is 'flat' or 'dead'. Explain this observation in terms of the concentrations of the solutions in the cell. (3)
- A cell such as the one described above is not much useful. However, the principle is used in batteries for cars, torches, computers, et cetera. These batteries are called secondary cells. One such battery is the mercury cell. The half reactions occurring in this cell are shown below.

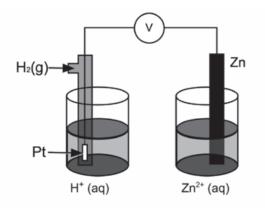
Zn(s) + 20H⁻(aq) → ZnO(s) + H₂O + 2e⁻...... (i) HgO(s) + H₂O + 2e⁻ → Hg(ℓ) + 2OH⁻(aq)...... (ii)

- **2.1** Write down the overall cell reaction. (3)
- 2.2 Why does the use of this battery pose an environmental hazard? (1)

Solu	tions	
1.1	Lead. 🗸 Stronger reducing agent 🗸 OR Is oxidised preferably	(2)
1.2	$Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s) \checkmark \checkmark$	(2)
1.3	$E^{o}_{cell} = E^{o}_{cathode} - E^{o}_{anode} \checkmark$ $= 0,34- (-0,13) \checkmark$	
	= 0,47 V 🗸	(5)
	Bulb will not light, 🗸 energy from cell not sufficient 🗸 OR	
1.4.	emf of cell is much less than 2 V needed for the bulb \checkmark While the cell is in operation, the concentration of the reactar (Cu ²⁺ (aq)) decreases. \checkmark At the same time the concentration of the products (Pb ²⁺ (aq)) increases. \checkmark The result is a graduat decrease in the cell potential until there is no further change in concentration and equilibrium is reached where the cell potential will be zero. \checkmark	al
2.1 2.2	Zn(s) + HgO(s) → ZnO(s) + Hg(ℓ) $\checkmark \checkmark \checkmark$ Mercury is poisonous \checkmark	(3) (1) [16]



The discovery of electrochemical cells has revolutionised our way of life. The diagram below represents an electrochemical cell.



- **1.** Name the type of electrochemical cell that converts chemical energy to electrical energy.
- If the electrochemical cell is set up as illustrated, there will be no reading on the voltmeter. Give a reason for this observation. (1)
- **3.** Write down the value of the standard emf of the electrochemical cell when it is functioning. (1)
- Write down the voltmeter reading when the net cell reaction in the above electrochemical cell reaches equilibrium. (1)

(1)

- **5.** Write down the equation for the reaction that occurs at the anode.
- 6. Another electrochemical cell is set up under standard conditions by replacing the standard hydrogen half-cell with a standard magnesium half-cell.
 - 6.1 Which electrode will undergo a decrease in mass? Give a reason for your answer. (2)
 - 6.2 Calculate the initial emf of this electrochemical cell under standard conditions. (3)
 - 6.3 After a while the emf of this electrochemical cell decreases. Explain this observation by referring to the concentration of the electrolytes. (2)
- Electrochemical cells such as motor car batteries with plastic casings can harm the environment if not disposed of safely. Suggest TWO ways how motor car batteries can be safely disposed of.
 - [14]

(2)

(1)

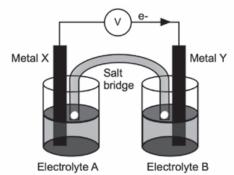
Solutions

1.	Galvanic/voltaic cell 🗸	(1)
2.	Incomplete circuit/No salt bridge 🗸	(1)
3.	0,76 V 🗸	(1)
4.	Zero 🗸	(1)
5.	$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^{-} \checkmark$	(1)
6.1	Mg. 🗸 Mg is oxidised 🗸	(2)
6.2	$E^{o}_{cell} = E^{o}_{cathode} - E^{o}_{anode} \checkmark = 0,76 - (-2,36) \checkmark = 1,6 V \checkmark$	(3)
6.3	As the cell functions, the concentration of zinc ions (reactants) decreases \checkmark relative to the standard conditions and the concentration of magnesium ions (products) increases relative to standard conditions. The reverse reaction starts opposing the forward reaction causing the emf to decrease relative to standard conditions. \checkmark	
7.	Neutralise acid before disposal. 🗸	
	Recycle plastic casing and lead electrodes \checkmark	(2)
		[14]



In 1780, Luigi Galvani discovered that when copper and zinc metal were connected to each other and if each free end touched different parts of the same nerve of a frog leg at the same time, the frog's leg contracted. He called this "animal electricity".

 Briefly explain what this "animal electricity" really was. (1) The diagram shows an electrochemical cell setup under standard conditions using aluminium (Al) and nickel (Ni) electrodes. AlCl₃(aq) and NiCl₂(aq) are used as the electrolytes, and a solution of sodium nitrate (NaNO₃(aq)) is used in the salt bridge. Answer each of the following questions on this electrochemical cell:



Unit

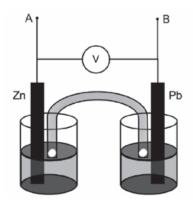
2. The diagram indicates that electrons flow from metal X to metal Y. Identify:

	2.1	Metal X	(1)
	2.2	Electrolyte B	(1)
3.	What i	s the concentration of electrolyte B?	(1)
4.		down the FORMULA of the substance that moves towards Y in the salt bridge.	(1)
5.	Write of this ce	lown the half-reaction that occurs at the cathode of II.	(2)
6.	Calcula	ate the reading on the voltmeter.	(3)
7.		what happens to the concentration of metal ions in the on containing electrolyte as time goes by?	(1)
8.			
	8.1	Consider 5.7 again and recall your answer. What effect	(4)
		does this have on the voltmeter reading?	(1)
	8.2	Briefly explain your answer to 5.8.1.	(2)
			[14]

	Condions	
1.	The chemical reaction between the zinc and the copper r	
	eleased electrical energy 🗸	(1)
2.1	Metal X: A l 🗸	(1)
2.2	Electrolyte B: NiC ℓ_2 🗸	(1)
3.	1mol·dm ⁻³ ✓	(1)
4.	NO ₃ - ✓	(1)
	Ni ²⁺ + 2e ⁻ → Ni \checkmark \checkmark	(2)
6.	$E^{0}_{cell} = E^{0}_{oxidising agent} - E^{0}_{reducing agent} \checkmark$ $= -0.25V - (-1.66V) \checkmark$	
	= 1,41 V 🗸	(3)
7.	Increase 🗸	(1)
8.1	The voltmeter reading decreases \checkmark	(1)
8.2	As the $[A\ell^{3+}]$ increases, \checkmark the reverse reaction in the $A\ell A\ell^{3+}$ half-cell:	
	$A\ell := A\ell^{3+} + 3e^{-}$ is favoured.	(2)
	OR	
	The tendency of the net reaction A ℓ + Ni^{2+} \rightarrow A ℓ^{3+} + Ni	
	to proceed from left to right is reduced. This lowers the elect potential of this half-cell, resulting in a lower cell potential.	rode [14]



Tina wants to investigate the effect of the area of the metal plates used as electrodes in a galvanic cell on the emf of the cell. She sets up the following Zn/Pb cell under standard conditions and measures the emf.



1.	Which functio	electrode will show an increase in mass when this cell is ning?	(1)
2.	Write c anode.	lown the equation for the half-reaction occurring at the	(2)
3.	Calculate the emf that you would expect Tina to read on the voltmeter.		
4.	Name investi	TWO variables that should be controlled for during this gation.	(2)
5.		by replaces the two metal plates with ones of larger e area, and takes the readings again. How would you expect the new emf to compare with the one calculated in Question 6.3? (Only write SMALLER THAN, LARGER THAN or EQUAL TO) Explain your answer to Question 5.1	(1) (1)
6.		ow connects a resistor of low resistance across terminals A She notes that the reading on the voltmeter immediately	
	6.1	Give a reason for this observation.	(1)
	6.2	After some time she observes a further drop in the reading	S
		on the voltmeter. Give a reason for this observation.	(2)
]	13]

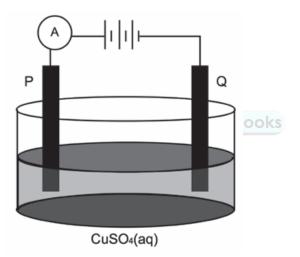
1.	Pb ✓	(1)
2.	Zn → Zn ²⁺ + 2e ⁻ ✓✓	(2)
3.	$E^{o}_{cell} = E^{o}_{oxidising agent} - E^{o}_{reducing agent} \checkmark$ $= -0.13 - (-0.76) \checkmark$ $= 0.63 V \checkmark$	(3)

4.	Temperature, \checkmark (initial) concentration of electrolytes \checkmark	(2)
5.1	Equal to 🗸	(1)
5.2	Area/size of electrodes has no effect on the emf of a	
	cell. It is still a standard cell 🗸	(1)
6.1	the cell has internal resistance \checkmark	(1)
6.2	The emf decreases as the concentration of Pb ²⁺ (aq) decreases.	(2) [13]



Electrolysis is an important industrial process used to decompose compounds, extract metals from their ores and to purify metals like gold or copper.

The simplified diagram below represents an electrolytic cell used to purify copper.



1.	Define the term electrolysis.	(2)
2.	Which electrode, P or Q, consists of the impure copper? Explain how you arrived at your answer.	(2)
3.	Write down the half-reaction that takes place at electrode Q.	(2)
4.	During purification, metals such as silver and platinum form sludge at the bottom of the container. Refer to the relative strengths of reducing agents to explain why these two metals do not form ions during the purification process.	(2)
5.	Explain why the concentration of the copper(II) sulphate solution remains constant. Assume that the only impurities in the copper are silver and platinum.	(2)
6.	Why is the sludge of economic importance?	(1)
		[11]



1.	The process in which electricity is used to bring about a chemical change / decompose / break compounds into components $\checkmark\checkmark$ OR A process in which electrical energy is converted to chemical	(2
	energy.	
2.	P. ✓	
	P is the positive electrode /anode ✓ OR	(2
	Oxidation takes place at the positive electrode/anode	
3.	$Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s) \checkmark \checkmark$	(2
4.	Pt and Ag are both weaker reducing agents 🗸 (than copper) an will not be oxidised 🗸 OR	d (:
	Cu is a stronger reducing agent (than Pt and Ag) and will be oxidised	
5.	The rate at which copper is oxidised at the anode, \checkmark is equal to the rate at which copper ions are reduced at the cathode. \checkmark	(2
6.	Contains platinum and silver that are valuable/expensive metals \checkmark	(
		[1:

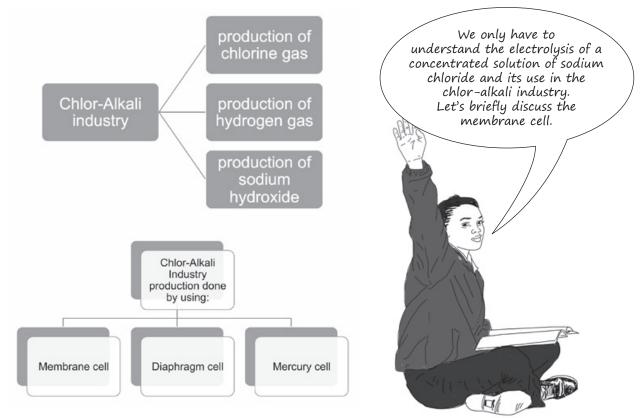




The chlor-alkali industry

The chlor-alkali industry is a large worldwide multimillion industry which produces compounds that are essential to human existence. The industry is based on the **electrolysis of sodium chloride** solutions.

6.1 Summary



Chlor-Alkali industry involves the **electrolysis** of a sodium chloride solution which produces:

- chlorine gas;
- hydrogen gas and
- sodium hydroxide (aq).

6.2 Definitions and terminology

The processes involved are electrolysis, oxidation and reduction.

Electrolysis:

- is an **endothermic reaction**
- involves a process during which electric energy is converted to chemical energy or brings about a chemical change
- involves a non-spontaneous redox reaction.

Oxidation:

- takes place when electrons are given off
- at the **anode**.

Reduction:

- takes place when electrons are received
- at the cathode.

Terminology:

Corrosive: Substance that damages and destroys substances (including living matter) it comes into contact with (touches).

Leaching: Movement of a substance (like NaOH (aq), pesticides or fertilisers) that are carried by water, down through soil (ground) to the underground water table. The water table is the level below which the ground is saturated with water.

Carbon footprint: The amount of carbon dioxide and other greenhouse gases released into the atmosphere due to the activities of a person, organisation or process.

Brine: A concentrated solution of NaCl(aq)





sign for corrosive substances

how to: • Identify the processes involved • Give a description of the concept or term • Give the correct definition • Describe the process and chemicals involved/ produced • State uses of the products • State the environmental issues

You must know

6.3 The Chlor-alkali industry – reactants and products

REACTANTS

- Sodium chloride solution, NaC ℓ (aq)
- Produced by evaporation from sea water, salt lakes

PRODUCTS						
	Chlorine gas Cℓ₂(g)	Hydrogen gas H ₂ (g)	Sodium hydroxide (caustic soda) NaOH(aq)			
PROPERTIES & PRECAUTIONS	 Yellow-green gas Poisonous: Do not inhale. 	 Colourless gas Explosive: No open flames or electronic sparks nearby. 	 Colourless solution Highly corrosive Prevent leaching into the ground Prevent skin and eye contact. 			
USES	 Reactant for production of: hydrochloric acid, HCl(aq); extraction of Cu, Au, Ti; paint; PVC plastics; insecticides and weed killers; bleaching agents. 	 Reactant for production of: hydrochloric acid, HCℓ(aq); ammonia, NH₃(g), H₂O₂(g) (hydrogen peroxide); nylon; rocket fuel; margarine from plant oils (hydrogenation of unsaturated hydrocarbons). 	Reactant for production of: • soap and bleaching agents; • paper; • textiles; • oven cleaners. Used to: • treat waste water (sewage water).			



Learn this table. The table summarises the products of the electrolysis of a concentrated solution of sodium chloride and the uses of these products





The **membrane cell** is preferred because the:

- components of the cell are non-toxic;
- products are more pure and
- production costs are relatively low.
- Sodium chloride (table sale) NaCl(s) is an ionic compound and is very soluble in water (a polar solvent).
- NaCl (s) dissociates in an aqueous solution – the ions in the ionic crystal lattice separate.
- NaC ℓ (s) $\xrightarrow{H_2O(\ell)}$ Na⁺ (aq) + C ℓ^- (aq)
- A sodium chloride solution, NaCl (aq), is known as brine.

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Unit

6.4 The chlor-alkali industry – industrial process

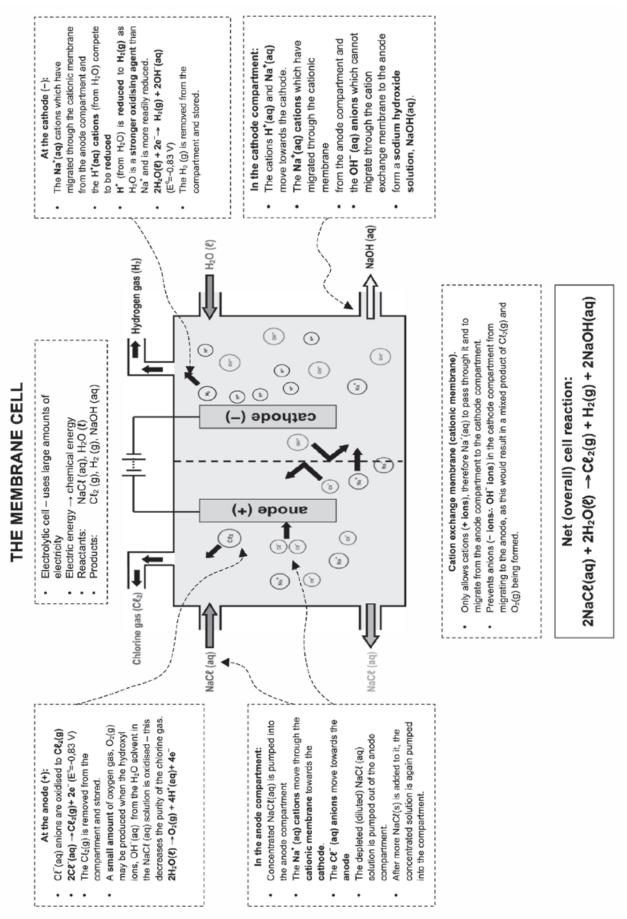
The chlor-alkali industry products can be produced by using a:

- membrane cell
- mercury cell
- diaphragm cell

	Membrane Cell	Diaphragm Cell	Mercury Cell
Purity and yield of Cℓ₂ (g) produced	• Produces relatively pure $C\ell_2(g)$ that is mixed with very small amount of $O_2(g)$.	• Produces $C\ell_2(g)$ that is mixed with $O_2(g)$ so the product is less pure.	 Low yield of Cℓ₂(g) and of NaOH(aq).
Purity of NaOH (aq) produced	• High	 Medium NaOH (aq) is mixed with NaCℓ (aq) 	• Low
Energy consumption (Affects costs)	Lowest	Relatively low	Very high
Environmental impact	 Lowest Non-toxic, reusable components low setup costs. Lowest energy consumption therefore small carbon footprint. 	 High Diaphragm is made from asbestos. 	 Highest Mercury reacts with the NaCl (aq) and leaches into the groundwater.
Health risks	 No potential health risks / environmental risks due to components. H₂(g) is explosive and Cl₂(g) is poisonous. 	 Diaphragm is made from asbestos – health risk for workers – asbestosis and cancer. H₂(g) is explosive and Cl₂(g) is poisonous. 	 Mercury is toxic. Risks due to contamination of groundwater. (Fish, animals and humans use the water. H₂(g) is explosive and Cl₂(g) is poisonous.



• Very few companies still use mercury cells but many still use diaphragm cells. When new industrial sites are set up today, **membrane cells** are mostly used. CHEMICAL CHANGE: ELECTROCHEMICAL REACTIONS: THE CHLOR-ALKALI INDUSTRY





Worked example 1

1. Chlorine is produced industrially by electrolysis in an electrolytic cell and can be represented as follows:

 $2NaC\ell(aq) + 2H_2O(\ell) \rightarrow H_2(g) + C\ell_2(g) + 2NaOH(aq)$

	2H ₂ 0	+	2e⁻	\rightarrow	H ₂	+	20H⁻
	Cl ₂	+	2e⁻	\rightarrow	 2Cℓ -		
	2C <i>l</i> -			\rightarrow	Cl ₂	+	2e⁻
IV	H ₂	+	20H-	\rightarrow	2H ₂ 0	+	2e⁻

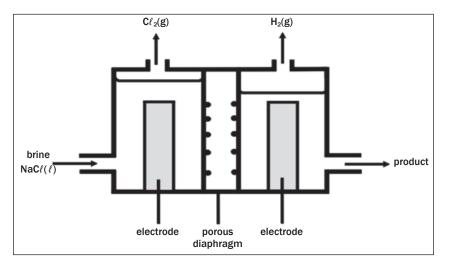
The correct statement(s) is/are:

- A I and III
- B I only
- C II and IV
- D III only
- 2. Chlorine is a poisonous gas commonly used as a bleaching agent. Chlorine is produced in industry by _____.

- EcoleBoo
- **1**. A
- 2. Electrolysis of brine

Activity 1

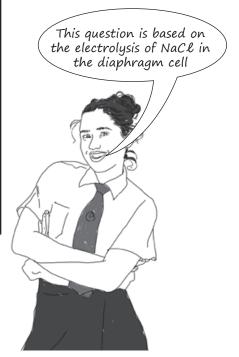
The electrolysis of saturated sodium chloride can be illustrated as follows: Hydrogen and chlorine bubble off at the electrodes.



- 1. Give an equation to show how chlorine bubbles are formed at the electrode. (2)
- 2. At which electrode are the chlorine bubbles formed? (1)(1)
- 3. At which electrode does hydrogen gas form?
- 4. What is the name of the product which leaves the cell? (1)
- 5. Give TWO applications of the product formed in 2.4.
- 6. What purpose does the porous diaphragm serve? Books (2)
- The chlorine gas produced, dissolves in water to form chlorine 7. water. Write down a balanced equation for the reaction that takes place.

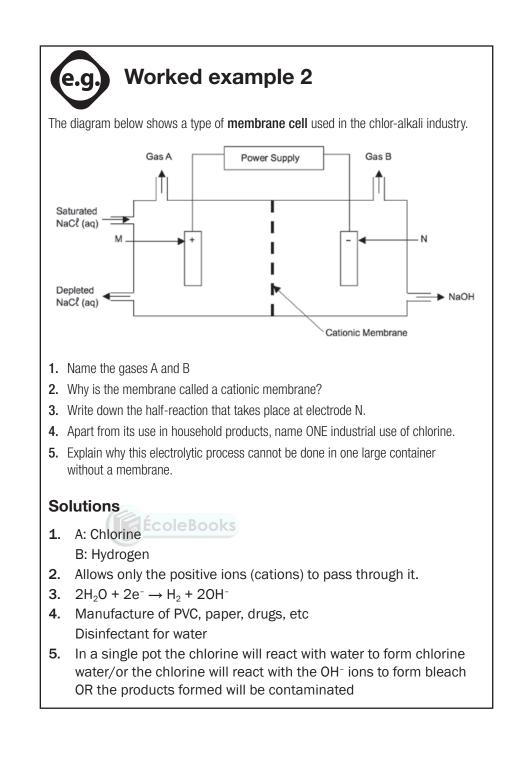
Solutions

1.	$2C\ell^{-}(aq) \rightarrow C\ell_{2}(g) + 2e^{-\ell}$	(2)
2.	Anode 🗸	(1)
3.	Cathode 🗸	(1)
4.	Sodium hydroxide 🗸	(1)
5.	Making soap and detergents; paper; rayon and other fibres;	
	dyeing textiles 🖌 (any 2)	(2)
6.	Stops chlorine passing through; helps to separate sodium	
	hydroxide from NaCl (aq). 🗸 🔍	(2)
7.	$C\ell_2 + H_2 O \rightarrow HC\ell + HOC\ell$	(2)
	\checkmark \checkmark	[11]



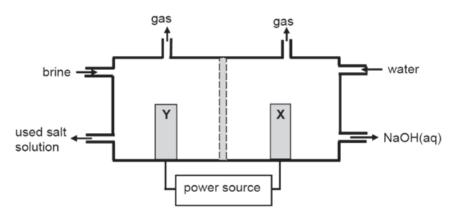
(2)

(2)[11]





The simplified diagram of a cell used in the chlor-alkali industry is shown below.



1.	Write down the CHEMICAL FORMULA of brine.	(1)
		(-)

- 2. At which electrode, X or Y is chlorine gas formed?
- **3.** Write down a half-reaction that explains the formation of hydrogen gas at one of the electrodes. (4)
- The purity of the sodium hydroxide produced in the chlor-alkali industry depends on the extent to which it is separated from the chlorine gas produced by this cell. Briefly describe how chlorine gas and sodium hydroxide are prevented from mixing in this cell.
 Apart from the advantages and disadvantages of products
- produced, write down for this process:
 - **5.1** ONE positive impact on humans.(1)**5.2** ONE negative impact on humans(1)
 - [10]

(1)

	iudons	
1.	NaCℓ (aq) ✓	(1)
2.	Y	(1)
3.	$2H_20 + 2e^- \rightarrow H_2 + 20H^-$	(4)
4.	The membrane prevents chloride ions from moving to the	
	cathode, only allows positive ions through. 🗸	(2)
5.1	. Job creation resulting in more people having a better life. \checkmark	(1)
5.2	Uses huge amounts of electricity resulting in load shedding.	
	Chemical plant uses a lot of space that could have been used	
	for housing/gardens, etc. 🗸 (any one)	(1)
		[10]



The fertiliser industry

The need for fertilisers is increasing due to:

- the growth in the world population more people means more food is necessary and
- the decrease in available agricultural land less land means the available land must produce a lot of high quality food at a high rate (fast).

Nutrients in the soil are used by the plants that grow and these nutrients must be replaced.

Inorganic fertilisers are produced industrially in the Haber, Contact & Ostwald processes at chemical plants like SASOL.

7.1 Nutrients required by plants

		MACRO NUTRIENT	S	MICRONUTRIENTS
	Primary non- mineral nutrients	Primary mineral nutrients	Secondary nutrients	Trace elements
Elements	 C carbon H hydrogen O oxygen 	 N nitrogen P phosphorus K potassium 	 Ca calcium Mg magnesium S sulphur 	 Cu copper Fe iron Mn manganese Zn zinc I iodine
Sources	 From the air as CO₂(g) and in rainwater as H₂O(ℓ) 	 Absorbed from the soil by the roots as water- soluble salts. 	 Absorbed from the soil by the roots as water-soluble salts. 	 Absorbed from the soil by the roots as water-soluble salts.
Availability	Sufficient available in the air	 Used up and must be replaced by using fertilisers 	Sufficient available in the soil	 Sufficient available in the soil

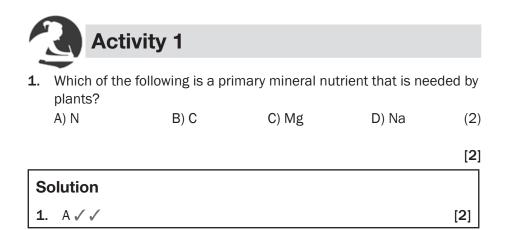
DID YOU KNOW?

- Bone meal is produced when the bones of dead animals are ground into powder.
- Kelp meal is dried seaweed.
- **Granite meal** is finely ground granite rock.



DEFINITIONS

Promote: to help or encourage Essential: absolutely necessary Inorganic: not produced by a living organism; not containing carbon Mineral: an inorganic solid substance that occurs naturally (not man-made) Inert: unreactive Sufficient: enough



7.2 Functions and sources of the primary mineral nutrients

	PRIMARY MINERAL NUTRIENTS				
Nuti	rient	(N)	Phosphorous (P)	Potassium (K)	
Function		 Promotes growth of leaves; gives a healthy green colour to the plant; is part of chlorophyll which is needed for photosynthesis. 	 Promotes development of roots and stems; is essential for good growth; is necessary for photosynthesis; is active during production of oils, sugar and starch. 	 Ensures high quality and colourful flowers, fruit and vegetables; promotes resistance against diseases. 	
Sou Pre- Wor War	ld	 Guano (Sea bird excrement) Plant Compost 	Bone meal	Wood ashMined in Germany	
r II	Organic	 Animal manure Fish emulsion Dried animal blood Guano (bat excrement) Compost 	Bone meal	 Kelp meal (ground seaweed) 	
Sources Post World War II	Inorganic	 Nitrate (NO₃⁻) salts and ammonium (NH₄⁺) salts from ammonia (NH₃) produced in the Haber process E.g. NH₄NO₃ ammonium nitrate KNO₃ potassium nitrate (NH₄)₂SO₄ ammonium sulphate 	 Superphosphates CaH₄(PO₄)₂·H₂O Monoammonium phosphate (MAP) NH₄H₂PO₄ Diammonium phosphate (DAP): (NH₄)₂HPO₄ 	 KCl, potassium chloride is imported to South Africa. Also: KNO₃ potassium nitrate K₂SO₄ potassium sulphate 	



Atmospheric nitrogen is fixed into compounds containing nitrates (NO₃⁻) or ammonium ions (NH₄⁺) so that the nitrogen can be taken in by plants and used as nutrient.

- Atmospheric fixation: fixation by lightning;
- Biological fixation: fixation by bacteria in the ground and by the roots of legumes;
- Industrial fixation: fixation by industrial processes like the Haber process.

		Haber Process	Contact Process	Ostwald Process
Product	$NH_3(g)$	Ammonia	H ₂ SO ₄ (t) Sulphuric acid	HNO ₃ (aq) Nitric acid
Reactants	 N₂(g) H₂(g) 	Nitrogen Hydrogen	 S(s) Sulphur O₂(g) Oxygen 	 NH₃(g) Ammonia O₂(g) Oxygen
Source of reactants	 N₂(g) H₂(g) 	fractional distillation of liquid air steam reforming of methane (CH _a) from natural earth gas	 S(s) sulphur O₂(g) fractional distillation of liquid air 	 NH₃(g) Haber process O₂ (g) fractional distillation of liquid air
	C + \~/ W	Fe Fe	Step 1: S(s) + $O_2(g) \rightarrow SO_2(g)$	Step 1: Catalytic oxidation of ammonia:
	• forward r	יד סרום (קוד איז איז איז) איז	Step 2: SO ₂ (g) is dried and purified, then:	$\begin{array}{l} 4NH_3(g) + 5O_2(g) \xrightarrow{Pt} 4NO(g) + 6H_2O(g) \\ \DeltaH < 0 \end{array}$
			V_2O_5 2SO ₂ (g) + O ₂ (g) \rightleftharpoons 2SO ₃ (g) $\Delta H < 0$	Step 2:
			.: forward reaction is exothermic	$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$
Reaction (c)			Step 3: SO /ot is discoluted in concentrated	Step 3:
equalion(s)			Solid) is discoved in concernated sulphuric acid to form pyrosulphuric acid (also known as oleum):	$3NO_2(g) + H_2O(t) \rightarrow 2HNO_3(aq) + NO(g)$
			$SO_3(g) + H_2SO_4(\ell) \rightarrow H_2S_2O_7(\ell)$	
			Step 4: $H_2S_2O_7(t)$ is mixed with water to produce sulphuric acid:	
			$H_2S_2O_7(\mathfrak{k}) + H_2O(\mathfrak{k}) \rightarrow 2H_2SO_4(\mathfrak{k})$	
Optimal Reaction	Temperatu	Temperature: + 450 °C	Step 2: Temperature: + 450 °C	Temperature: + 900 °C
conditions	Pressure:	± 200 atm	Pressure: ±1-2 atm	Pressure: ± 1 atm
Catalyst	Fe (iron)		Step 2: V ₂ O ₆ (vanadium pentoxide)	Step 1: Pt / Rh (platinum / rhodium)

INDUSTRIAL PRODUCTION OF NH₃(g), H₂SO₄(ℓ) and HNO₃(aq)

1.	In the Haber process:		
	Steam reforming of methane (natural gas) in the presence of a platinum catalyst form a mixture of carbon monoxide (CO) and hydrogen (H_2) gases (synthesis gas).		
	$CH_4(g) + \underbrace{H_2O(g) \rightarrow CO(g)}_{synthesis gas} + 3H_2(g)$		
2.	In the Con	tact process:	
	2.1	If $SO_2(g)$ is not dried before step 2, it reacts with water to form sulphurous acid, $H_2SO_3(aq)$ which forms acid rain, a type of rain which is produced as a side-effect of human industrial activities, which is corrosive to structures and harmful to living things.	
		$SO_2(g) + H_2O(\ell) \longrightarrow H_2SO_3(aq)$	
	2.2	SO_3 (g) reacts with water to form gaseous sulphuric acid, H_2SO_4 (g) which escapes into the atmosphere and forms acid rain.	
		$SO_3(g) + H_2O(\ell) \longrightarrow H_2SO_4(g)$	
3.	In the Con	tact process:	
	3.1	The 1st step is known as the catalytic oxidation of ammonia . Pt	
		$4NH_3(g) + 5O_2(\ell) \longrightarrow 4NO(g) + 6H_2O(g)$	
	3.2	NO_2 (nitrogen dioxide) is a brown gas which reacts with water to form $HNO_3(g)$ which escapes into the atmosphere and forms acid rain.	

Fluorapatite, Ca₅(PO₄)₃F

- 1. is mined at Phalaborwa;
- 2. is insoluble in water and can't be absorbed by plant roots;
- 3. reacts with sulphuric acid, $H_2SO_4(\ell)$ to produce phosphoric acid, $H_3PO_4(aq)$.

Superphosphate

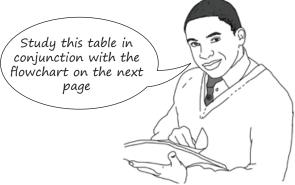
1. is produced when fluorapatite reacts with sulphuric acid H_2SO_4 and is a mixture of $Ca(H_2PO_4)_2$: H_2O and $CaSO_4$ (gypsum)

Triple Superphosphate

2. is produced when fluorapatite reacts with phosphoric acid H_3PO_4 to form $Ca(H_2PO_4)_2$ ·H20 (no CaSO₄ is formed).

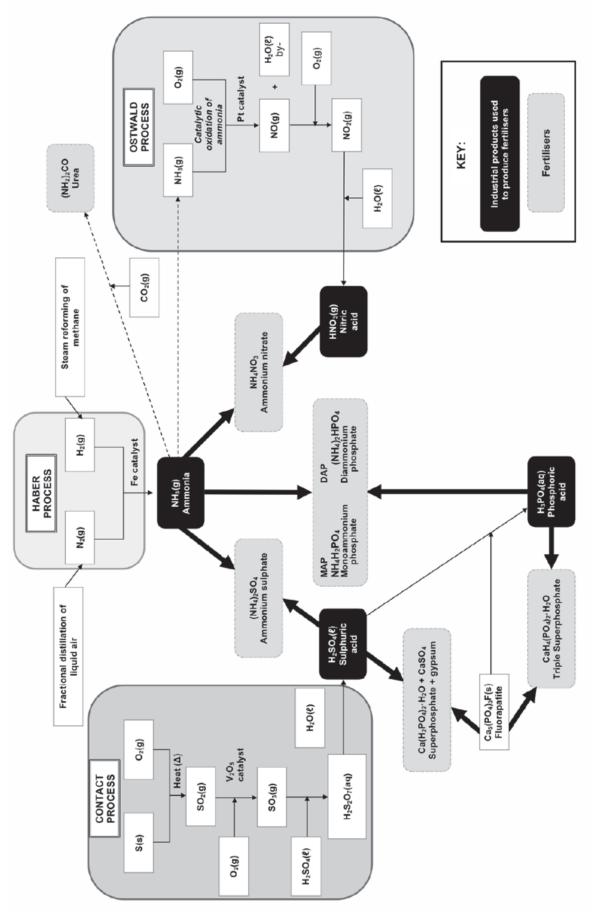
Unit

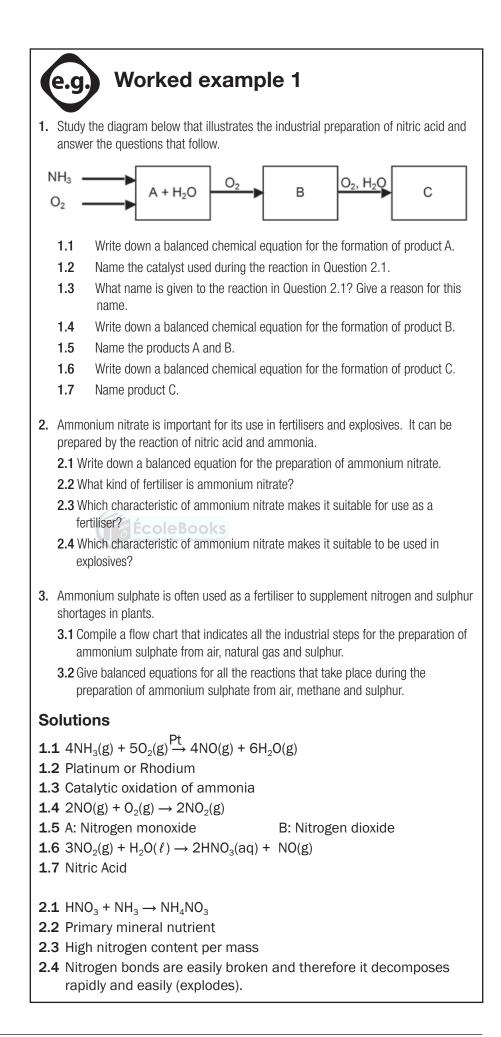
7.3 The industrial production of fertilisers

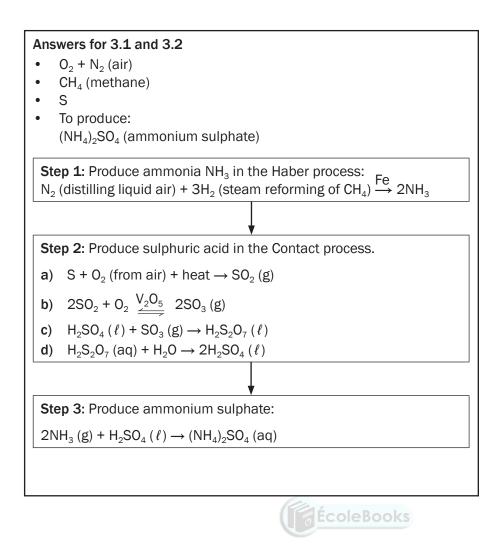


					ORGANIC
Fertiliser	Ammonium sulphate (NH ₄) ₂ SO ₄	Ammonium nitrate NH ₄ NO ₃	Monoammonium phosphate (MAP) NH ₄ H ₂ PO ₄ Diammonium phosphate (DAP) (NH ₄) ₂ HPO ₄	Superphosphate $Ca(H_2PO_4)_2 \cdot H_2O +$ $CaSO_4$ Triple Superphosphate $Ca(H_2PO_4)_2 \cdot H_2O$	Urea (NH ₂) ₂ CO
Reactants	$NH_3(g)$ Ammonia (Haber process) $H_2SO_4(\ell)$ Sulphuric acid (Contact process)	NH ₃ (g) Ammonia (Haber process) HNO ₃ (aq) Nitric acid (Ostwald process)	NH ₃ (g) Ammonia (Haber process) H ₃ PO ₄ (aq) Phosphoric acid	$Ca_5(PO_4)_3F$ fluorapatite H_2SO_4 sulphuric acid (Contact process) OR H_3PO_4 Phosphoric acid	NH ₃ (g) Ammonia (Haber process) CO ₂ (g) Carbon dioxide (by-product of the Haber process)
Reaction equation	$2NH_{3}(g) + H_{2}SO_{4}(\ell) \rightarrow (NH_{4})_{2}SO_{4}(aq)$ memorise!	$NH_3(g) + HNO_3(aq)$ $\rightarrow NH_4NO_3(aq)$ memorise!	$\begin{array}{l} NH_3(g) + H_3PO_4(aq) \\ \rightarrow \\ NH_4H_2PO_4(aq) \\ \\ 2NH_3(g) + \\ H_3PO_4(aq) \rightarrow \\ (NH_4)_2HPO_4(aq) \end{array}$	Not required	$2NH_{3}(g) + CO_{2}(g)$ \rightarrow $(NH_{2})_{2}CO(g) +$ $H_{2}O(g)$
Properties	 Very soluble in water; easily absorbed by plant roots; provides plants with both nitrogen (N) and sulphur (S). 	 Very soluble in water; easily absorbed by plant roots; provides plants with nitrogen (N). 	 Very soluble in water; easily absorbed by plant roots; provides plants with both nitrogen (N) and phosphorous (P). 	 Soluble in water; superphosphate also supplies the secondary nutrient S, sulphur; widely used. 	 Very soluble in water; easily absorbed by plant roots; provides plants with nitrogen (N).

7.4 Flowchart: The industrial production of fertilisers

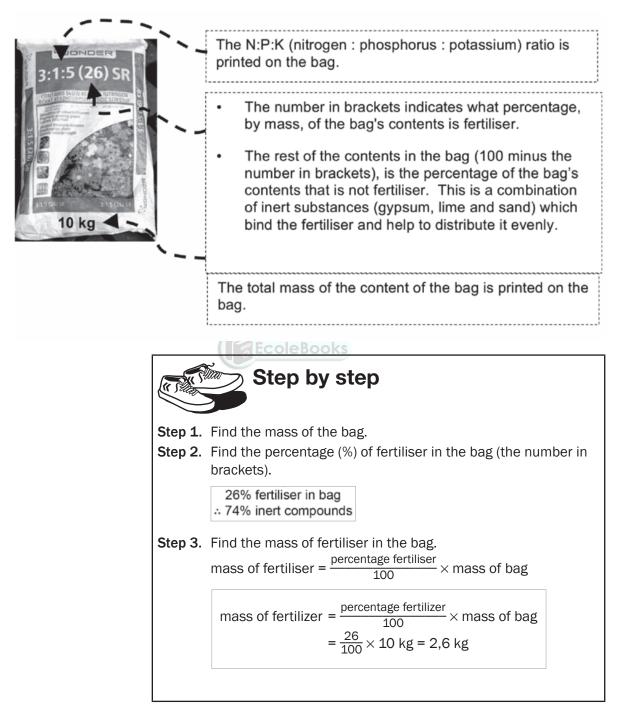




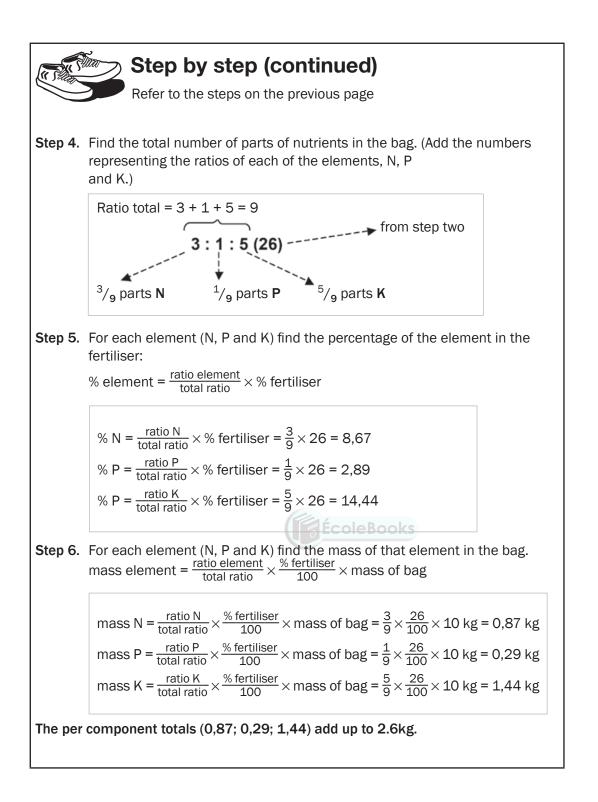


7.5 N:P:K fertilisers

As plants need a large amount of the primary mineral nutrients (nitrogen, phosphorus and potassium) and these need to be replenished (replaced) in the soil to make sure that crops grow well to provide enough food, NPK fertilisers that contain a mix of these nutrients, are usually used. They are produced by mixing a nitrogen fertiliser, a phosphorus fertiliser and potassium chloride (KC ℓ).



Unit





A bag of fertiliser has the following information on it: 3:2:3 (26).

- 1. What information can you deduce from these numbers?
- 2. Calculate the percentage composition of the fertiliser in the bag.

Solutions

- **1**. It shows the ratio N : P : K.
 - 3 + 2 + 3 = 8 therefore the fertiliser mixture consists of: $\frac{3}{8}$ parts N; $\frac{2}{8}$ parts P and $\frac{3}{8}$ parts K These nutrients make up 26% of the mass of the bag content.

The other 74% is made up of gypsum, lime and sand.

2. % N = $\frac{\text{ratio N}}{\text{total ratio}} \times \%$ fertiliser = $\frac{3}{8} \times 26 = 9,75$ % P = $\frac{\text{ratio P}}{\text{total ratio}} \times \%$ fertiliser = $\frac{2}{8} \times 26 = 6,5$ % K = $\frac{\text{ratio K}}{\text{total ratio}} \times \%$ fertiliser = $\frac{3}{8} \times 26 = 9,75$



7.6 **Excessive use of fertiliser and** the environment

The correct application of fertiliser to crops is essential for high quality, fast growing crops but using too much or unnecessary fertiliser has a negative effect on the environment.

- Groundwater is contaminated by fertiliser leaching (spreading by • water) into the ground.
- Soil becomes acidic (pH decreases). Many plants do not grow in • acidic soil.
- Invasive plants grow excessively while indigenous plants die. Invasive • plants are undesirable non-indigenous (foreign) plants that grow too fast and out-compete local plants.
- Fertiliser in dams and rivers leads to "eutrophication", defined below. •
- High nitrate concentrations in drinking water decreases the ability • of haemoglobin in the blood to carry oxygen and leads to 'blue baby syndrome'.

7.6.1 **Eutrophication**

	In water (dams and rivers)	On land
	 Poor (bad) control of waste products. Excessive / unnecessary application of fertilisers. 	
Causes	 Waste products (urine and faeces) and excessive fertiliser nutrients leach into ground water and run into rivers and dams. 	 Poor (bad) farming practises: Excessive / unnecessary use of fertilisers Animal waste in feeding and milking stalls contains urea and ammonia and leaches into ground water.
Ellects	 Excessive growth of algae; Algae die; Bacteria feed on the algae and use oxygen; Oxygen levels in the water drop; Fish and other living organisms die. 	 Invasive plants grow excessively, indigenous plants die; Bird and insect species move away disturbing the ecosystems; Soil erosion increases due to absence of indigenous plants with strong root systems.
	 Strict control over all waste and sewage must be enforced. Waste products: must be treated and not allowed to leach into groundwater or run into rivers and dams. 	 Test soil to determine need for fertiliser – apply correct amount and type; Plant indigenous plants along rivers to prevent erosion and prevent inflow of contaminated water; Conserve natural swamps which break down excess nitrogen nutrients naturally; Control animal waste in feeding and milking stalls.



ER

oundance (excess,) of nutrients (N and er leads to:

- st and excessive th of and other water s (this is called 'algal 1') acteria
- ng a drop in the n concentration in ater and
- eath of fish and other organisms in the



VOCABULARY	
Overabundance / excess:	more than is needed
Shortage:	not enough
Invasive plants:	plants that do not naturally grow in a certain area
Indigenous plants:	plants that grow naturally in (are native to) a certain area
Swamps:	ground that is uncultivated but is usually covered with water
Erosion:	soil and rock is removed from the Earth's surface by wind, rain or water
Stunted growth:	reduced growth leading to smaller, underdeveloped plants



Which ONE of the following is NOT associated with eutrophication in water?

- A Dead zones
- B Algal bloom
- C Depletion of oxygen
- D Increased aquatic life

(2) [**2**]



7.6.2 The effect of a shortage or excess of the primary nutrients (N, P and K) on plants

	N (nitrogen)	P (phosphorus)	K (potassium)
Shortage	Little growthWeak stemsYellow leaves	Stunted growthSlow growthPurple leaves	 Poor quality flowers and fruit (colour and taste) Leaves have brown or yellow edges
Excess	 Dark green leaves Poor production of seed and fruit 	Causes shortage of micro nutrients Fe and Zn	 Causes shortage of micro nutrients Mg and Ca Stunted growth Poor quality flowers and fruit

7.7 Alternatives to inorganic fertilisers

Although fertilisers are essential for the fast growth of high quality crops, the negative effects of inorganic compounds on the environment must be taken into account. Alternative sources of organic nutrients that can be used to ensure good crops are:

- Bone meal;
- Animal manure;
- Natural plant compost;
- Bat guano (faeces);
- Fish emulsions;
- Kelp meal

Advantages of organic fertilisers:

- Break down and release nutrients more slowly than inorganic fertilisers, so there is less chance of the fertiliser leaching into the soil and causing contamination of groundwater;
- Usually cost less and
- Are often available for free.

Disadvantages of organic fertilisers:

- Not enough is available for large scale usage;
- Provide less nutrients more has to be used;
- Slow release of nutrients sometimes harms plants;
- Slow release may cause nutrients to be available too late in the plant's growth cycle.



Fertilisers allow farmers to grow crops in the same soil year after year. However, environmental problems, such as eutrophication, are associated with the application of fertilisers.

1. State ONE PRECAUTION that a maize farmer can take to prevent eutrophication.

Nitric acid is an important reactant in the production of ammonium nitrate, a nitrogen-based fertiliser.

- Write down the name of the industrial process for the production of nitric acid. (1)
- Write down a balanced equation for the preparation of ammonium nitrate from nitric acid. (3)

Learn the advantages and disadvantages of organic fertilisers.



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(1)

[5]



Solutions

1.	Use fertilisers sparingly 🗸 / Do not over-fertilise 🗸	
	Make use of precision (computerised) application of fertilisers	
	Ensure that water from fields does not run into rivers/dams \checkmark	
	Redirect water from fields into reservoirs/away from	
	rivers/dams 🗸 (any one)	(1)
2.	Ostwald process 🗸	(1)

(3) [**5**]

3. $HNO_3 \checkmark + NH_3 \checkmark \rightarrow NH_4NO_3 \checkmark$



The rapidly increasing human population is resulting in an ever-increasing demand for food. To meet this demand, farmers apply fertiliser to the same cultivated land EACH YEAR.

- Explain why farmers have to apply fertilisers to their land each year. (1)
- Write down one negative impact that over-fertilisation can have on humans. (1)
- **3.** Sulphuric acid is an important substance used in the manufacture of fertilisers.

The equation below represents one of the steps in the industrial preparation of sulphuric acid.

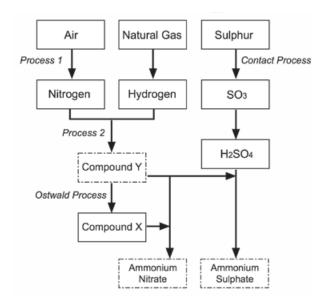
	$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ $\Delta H < 0$	
3.1	L Write down the name of the process used to pre sulphuric acid in industry	oare (1)
3.2	2 Write down the name or the formula if the cataly in 2.3.1	()
3.3	Is the forward reaction endothermic or exotherm reason for your answer.	ic? Give a (1)
3.4	Write down the name or formula of the fertiliser	formed
	when sulphuric acid reacts with ammonia.	(2)
		[7]

Solutions			
1.	Fertilisers replenish nutrients depleted by the growing of crops \checkmark	(1)	
2.	Damage to crops/soil 🗸 resulting in small or no harvest/ less income. Excessive fertiliser seeps into groundwater and contaminates drinking water 🗸 or runs into rivers and/or dams and causes eutrophication 🗸 which may result in less income //poor quality drinking water //fewer recreation areas/		
	animals 🗸 (any one)	(1)	
3.1	. Contact process 🗸	(1)	
3.2	2 V₂O₅ 🗸 vanadium pentoxide 🖌 (any one)	(1)	
3.3	Exothermic as $\Delta H < 0 \checkmark$	(1)	
3.4	\cdot (NH ₄) ₂ SO ₄ \checkmark \checkmark OR / Ammonium \checkmark sulphate \checkmark	(2)	
		[7]	



Activity 5

Ammonia, ammonium nitrate and ammonium sulphate are three important nitrogen-containing fertilisers. The flow diagram below shows how these fertilisers are produced in industry.



- 1. Use the information in the flow diagram above and write down the following:
 - 1.1 Name Process 1 (1)1.2 Balanced equation for Process 2 (3) 1.3 Name or Formula for compound X (1)
 - 1.4 Balanced equation for the preparation of ammonium sulphate using sulphuric acid and compound Y (3)
 - 1.5 Name or Symbol of the primary nutrient in ammonium sulphate (1)

- 2. Write down one positive impact of fertilisers on humans
- Write down two negative impacts of the use of ammonium nitrate as fertiliser, on humans. (2)

[12]

(1)

Solutions

- 1.1Fractional distillation of liquid air (1)1.2 $N_2 + 3H_2 \rightarrow 2NH_3$ (reactants products balance (3)
- **1.3** Nitric acid / $HNO_3 \checkmark$ (1)
- **1.4** $H_2SO_4 + 2NH_3 \rightarrow (NH_4)_2SO_4$ (reactants \checkmark products \checkmark balance \checkmark) (3)
- 1.5 Nitrogen / N ✓ (1)
 2. Enhance growth of crops/plants ✓ to produce more food for humans ✓ food security for humans ✓ production / application of fertiliser ✓ results in job creation selling of fertilisers ✓ stimulates the economy ✓ (any one) (1)
 3. (Excessive) nitrates in water (eutrophication) ✓ can result in blue
- 3. (Excessive) intrates in water (eutrophication) ✓ can result in blue baby syndrome or cancer ✓ (Excessive) nitrates/ammonium ions in water can result in poor quality drinking water ✓ or death of fish ✓ or less food ✓ or fewer recreational facilities ✓ or famine due to killing plants / crops from the excess ✓ or excessively changing the pH of the soil and thereby reducing the food production ✓ (any two)
 [12]



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