

GRADE 12

PHYSICAL SCIENCES

TEACHER'S GUIDE

WRITTEN BY VOLUNTEERS



basic education

Department:
Basic Education
REPUBLIC OF SOUTH AFRICA



EVERYTHING SCIENCE

**GRADE 12 PHYSICAL SCIENCES
TEACHER'S GUIDE**

VERSION 1 CAPS

WRITTEN BY VOLUNTEERS

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EVERYTHING SCIENCE

When we look outside at everything in nature, look around us at everything manufactured or look up at everything in space we cannot but be struck by the incredible diversity and complexity of life; so many things, that look so different, operating in such unique ways. The physical universe really contains incredible complexity.

Yet, what is even more remarkable than this seeming complexity is the fact that things in the physical universe are knowable. We can investigate them, analyse them and understand them. It is this ability to understand the physical universe that allows us to transform elements and make technological progress possible.

If we look back at some of the things that developed over the last century – space travel, advances in medicine, wireless communication (from television to mobile phones) and materials a thousand times stronger than steel we see they are not the consequence of magic or some inexplicable phenomena. They were all developed through the study and systematic application of the physical sciences. So as we look forward at the 21st century and some of the problems of poverty, disease and pollution that face us, it is partly to the physical sciences we need to turn.

For however great these challenges seem, we know that the physical universe is knowable and that the dedicated study thereof can lead to the most remarkable advances. There can hardly be a more exciting challenge than laying bare the seeming complexity of the physical universe and working with the incredible diversity therein to develop products and services that add real quality to people's lives.

Physical sciences is far more wonderful, exciting and beautiful than magic! It is everywhere.

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momentum

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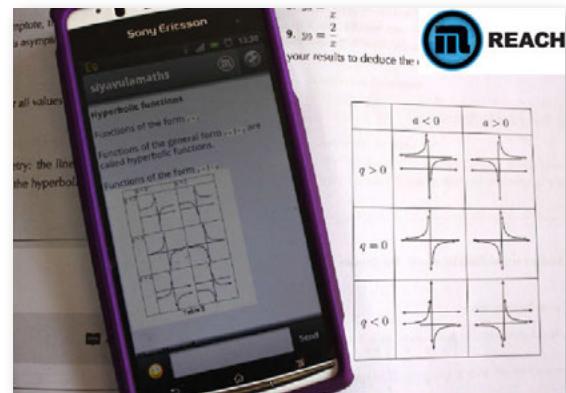
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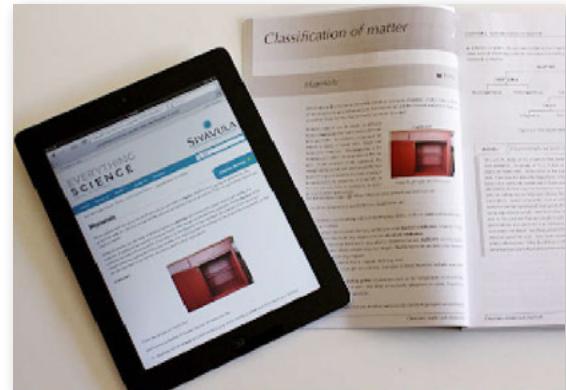
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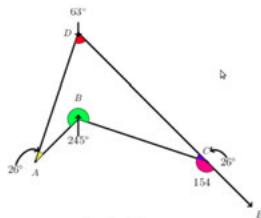
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Angles in quadrilaterals

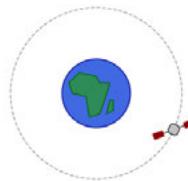
The diagram below represents quadrilateral ABCD with extended line \overline{CE} . Quadrilateral ABCD is a polygon with four sides and four angles. The sum of the interior angles in a quadrilateral is 360° . Angles on a straight line like $\overline{CE} = 180^\circ$.



Effect of mass on gravitational force

The International Space Station (ISS) has a mass M , as it orbits the Earth, it experiences a gravitational force of F . A space shuttle docks onto the ISS. The gravitational force the ISS experiences once the mass of the shuttle is added increases by a factor of 3.

By what factor does the mass of the ISS increase for it to experience this increase of gravitational force? Write your answer as a fraction of the original mass M_{ISS} of the ISS.



Answer: M_{ISS} [2 points]

[Help! How should I type my answer?](#)

Wavelength and diffraction

Two diffraction patterns are presented, determine which one has the longer wavelength based on the features of the diffraction pattern. The first pattern is for green light and the second pattern is for violet light:

green



violet



The same diffraction grating is used to generate both diffraction patterns.

Answer: [2 points]

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Classification of matter	22 / 34	★★★	<div style="width: 64.7%;"></div>
States of matter and the kinetic molecular theory	66 / 77	★★★★	<div style="width: 86.8%;"></div>
The atom	395 / 526	★★★★	<div style="width: 75.1%;"></div>
The periodic table	71 / 128	★★★★	<div style="width: 55.3%;"></div>
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Transverse pulses		★★★	<div style="width: 0%;"></div>
Transverse waves		★★★	<div style="width: 0%;"></div>
Longitudinal waves		★★★	<div style="width: 0%;"></div>
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Physical Sciences - Teachers guide

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0.1 On the Web, Everyone can be a Scientist

Did you know that you can fold protein molecules, hunt for new planets around distant suns or simulate how malaria spreads in Africa, all from an ordinary PC or laptop connected to the Internet? And you don't need to be a certified scientist to do this. In fact some of the most talented contributors are teenagers. The reason this is possible is that scientists are learning how to turn simple scientific tasks into competitive online games.

This is the story of how a simple idea of sharing scientific challenges on the Web turned into a global trend, called citizen cyberscience. And how you can be a scientist on the Web, too.

Looking for Little Green Men

A long time ago, in 1999, when the World Wide Web was barely ten years old and no one had heard of Google, Facebook or Twitter, a researcher at the University of California at Berkeley, David Anderson, launched an online project called SETI@home. SETI stands for Search for Extraterrestrial Intelligence. Looking for life in outer space.

Although this sounds like science fiction, it is a real and quite reasonable scientific project. The idea is simple enough. If there are aliens out there on other planets, and they are as smart or even smarter than us, then they almost certainly have invented the radio already. So if we listen very carefully for radio signals from outer space, we may pick up the faint signals of intelligent life.

Exactly what radio broadcasts aliens would produce is a matter of some debate. But the idea is that if they do, it would sound quite different from the normal hiss of background radio noise produced by stars and galaxies. So if you search long enough and hard enough, maybe you'll find a sign of life.

It was clear to David and his colleagues that the search was going to require a lot of computers. More than scientists could afford. So he wrote a simple computer program which broke the problem down into smaller parts, sending bits of radio data collected by a giant radio-telescope to volunteers around the world. The volunteers agreed to download a programme onto their home computers that would sift through the bit of data they received, looking for signals of life, and send back a short summary of the result to a central server in California.

The biggest surprise of this project was not that they discovered a message from outer space. In fact, after over a decade of searching, no sign of extraterrestrial life has been found, although there are still vast regions of space that have not been looked at. The biggest surprise was the number of people willing to help such an endeavour. Over a million people have downloaded the software, making the total computing power of SETI@home rival that of even the biggest supercomputers in the world.

David was deeply impressed by the enthusiasm of people to help this project. And he realized that searching for aliens was probably not the only task that people would be willing to help with by using the spare time on their computers. So he set about building a software platform that would allow many other scientists to set up similar projects. You can read more about this platform, called BOINC, and the many different kinds of volunteer computing projects it supports today, at <http://boinc.berkeley.edu/>.

There's something for everyone, from searching for new prime numbers (PrimeGrid) to simulating the future of the Earth's climate (ClimatePrediction.net). One of the projects, Malaria-Control.net, involved researchers from the University of Cape Town as well as from universities in Mali and Senegal.

Another feature of BOINC is that it lets people who share a common interest in a scientific topic share their passion, and learn from each other. BOINC even supports teams – groups of people who put their computer power together, in a virtual way on the Web, to get a higher score than their rivals. So BOINC is a bit like Facebook and World of Warcraft combined – part social network, part online multiplayer game.

Here's a thought: spend some time searching around BOINC for a project you'd like to participate in, or tell your class about.

You are a Computer, too

Before computers were machines, they were people. Vast rooms full of hundreds of government employees used to calculate the sort of mathematical tables that a laptop can produce nowadays in a fraction of a second. They used to do those calculations laboriously, by hand. And because it was easy to make mistakes, a lot of the effort was involved in double-checking the work done by others.

Well, that was a long time ago. Since electronic computers emerged over 50 years ago, there has been no need to assemble large groups of humans to do boring, repetitive mathematical tasks. Silicon chips can solve those problems today far faster and more accurately. But there are still some mathematical problems where the human brain excels.

Volunteer computing is a good name for what BOINC does: it enables volunteers to contribute computing power of their PCs and laptops. But in recent years, a new trend has emerged in citizen cyberscience that is best described as volunteer thinking. Here the computers are replaced people, connected via the Web. Because for some complex problems – especially those that involve recognizing complex patterns or three-dimensional objects – the human brain is still a lot quicker and more accurate than a computer.

Volunteer thinking projects come in many shapes and sizes. For example, you can help to classify millions of images of distant galaxies (GalaxyZoo), or digitize hand-written information associated with museum archive data of various plant species (Herbaria@home). This is laborious work, which if left to experts would take years or decades to complete. But thanks to the Web, it's possible to distribute images so that hundreds of thousands of people can contribute to the search.

Not only is there strength in numbers, there is accuracy, too. Because by using a technique called validation – which does the same sort of double-checking that used to be done by humans making mathematical tables – it is possible to practically eliminate the effects of human error. This is true even though each volunteer may make quite a few mistakes. So projects like Planet Hunters have already helped astronomers pinpoint new planets circling distant stars. The game FoldIt invites people to compete in folding protein molecules via a simple mouse-driven interface. By finding the most likely way a protein will fold, volunteers can help understand illnesses like Alzheimer's disease, that depend on how proteins fold.

Volunteer thinking is exciting. But perhaps even more ambitious is the emerging idea of volunteer sensing: using your laptop or even your mobile phone to collect data – sounds, images, text you type in – from any point on the planet, helping scientists to create global networks of sensors that can pick up the first signs of an outbreak of a new disease (EpiCollect), or the initial tremors associated with an earthquake (QuakeCatcher.net), or the noise levels around a new airport (NoiseTube).

There are about 2 billion PCs and laptops on the planet, but already 5 billion mobile phones. The rapid advance of computing technology, means that citizen cyberscience has a bright future in mobile phones. And this means that more and more of the world's population can be part of citizen cyberscience projects. Today there are probably a few million participants in a few hundred citizen cyberscience initiatives. But there are more than seven billion brains on the planet. That is a lot of potential citizen cyberscientists.

You can explore much more about citizen cyberscience on the Web. There's a great list of all sorts of projects, with brief summaries of their objectives, at <http://distributedcomputing.info/>. BBC Radio 4 produced a short series on citizen science <http://www.bbc.co.uk/radio4/science/citizensciences.html> and you can subscribe to a newsletter about the latest trends in this field at <http://scienceforcitizens.net/>.

The Citizen Cyberscience Centre, www.citizenrycyberscience.net which is sponsored by the South African Shuttleworth Foundation, is promoting citizen cyberscience in Africa and other developing regions.

0.2 Blog posts and other interesting online content

General blog posts

- Educator's Monthly - Education News and Resources (<http://www.teachersmonthly.com>)
 - "We eat, breathe and live education! "
 - "Perhaps the most remarkable yet overlooked aspect of the South African teaching community is its enthusiastic, passionate spirit. Every day, thousands of talented, hard-working educators gain new insight from their work and come up with brilliant, inventive and exciting ideas. Educator's Monthly aims to bring educators closer and help them share knowledge and resources.
 - Our aim is twofold:
 - * To keep South African educators updated and informed.
 - * To give educators the opportunity to express their views and cultivate their interests."
- Head Thoughts – Personal Reflections of a School Headmaster (<http://headthoughts.co.za/>)
 - blog by Arthur Preston
 - "Arthur is currently the headmaster of a growing independent school in Worcester, in the Western Cape province of South Africa. His approach to primary education is progressive and is leading the school through an era of new development and change."
- Reflections of a Science Teacher - Scientist, Educator, Life-Long Learner (<http://sanmccarron.blogspot.com/>)
 - blog by Sandra McCarron
 - "After 18 years as an Environmental Consultant, I began teaching high school science and love it. My writings here reflect some of my thoughts about teaching, as they occur. I look forward to conversations with other thoughtful teachers."
- René Toerien – Resources for science teachers (<http://renetoerien.net/>)
 - blog by René Toerien
 - "I am the coordinator of the UCT Chemical Engineering Schools Project. We develop resource materials for the South African Physical Sciences curriculum."
- The Naked Scientists - Science Radio and Naked Science Podcasts (<http://www.thenakedscientists.com/>)
 - "The Naked Scientists" are a media-savvy group of physicians and researchers from Cambridge University who use radio, live lectures, and the Internet to strip science down to its bare essentials, and promote it to the general public. Their award winning BBC weekly radio programme, The Naked Scientists, reaches a potential audience of 6 million listeners across the east of England, and also has an international following on the web."
- Wired Science - News for your neurons (<http://www.wired.com/wiredscience/>)
 - Blog posts and interesting pictures about science as it happens.

Chemistry blog posts

- Chemical Heritage Foundation – We Tell the Story of Chemistry (<http://www.chemheritage.org/>)
 - "The Chemical Heritage Foundation (CHF) fosters an understanding of chemistry's impact on society. An independent, nonprofit organization, CHF maintains major collections of instruments, fine art, photographs, papers, and books. We host conferences and lectures, support research, offer fellowships, and produce educational materials. Our museum and public programs explore subjects ranging from alchemy to nanotechnology."

- ChemBark – A Blog About Chemistry and Chemical Research (<http://blog.chembark.com/>)
 - blog maintained by Paul Bracher
 - “The scope of this blog is the world of chemistry and chemical research. Common subjects of discussion include ideas, experiments, data, publications, writing, education, current events, lab safety, scientific policy, academic politics, history, and trivia.”
- Chemistry World Blog (<http://www.rscweb.org/blogs/cw/>)
 - “This blog provides a forum for news, opinions and discussion about the chemical sciences. Chemistry World is the monthly magazine of the UK’s Royal Society of Chemistry.”
- Chemistry Blog (<http://www.chemistryblog.net/>)
 - “A brand new site for chemists and the home of the international chemistry societies’ electronic network. The site provides interesting features and useful services for the chemistry community. The information you find has been made available by various national chemistry societies for dissemination on a single site. Currently around 30 such societies are providing varying levels of information.”
- About.com Chemistry (<http://chemistry.about.com/>)
 - This website is full of great chemistry information, including Chem 101, science projects, elements, plus many interesting articles, including a daily “This Day in Science History”

Physics blog posts

- dotphysics (<http://scienceblogs.com/dotphysics/>)
 - blog by Rhett Allain
 - “This blog is about physics. Not crazy hard physics, but nice physics. You know, like physics you would take home to your mom. I try to aim most of the posts at the physics level an advanced high school student could understand.”
- Think Thnk Thunk – Dealing with the Fear of Being a Boring Teacher (<http://101studiestreet.com/wordpress/>)
 - blog by Shawn Cornally
 - “I am Mr. Cornally. I desperately want to be a good teacher. I teach Physics, Calculus, Programming, Geology, and Bioethics. Warning: I have problem with using colons. I proof read, albeit poorly.”

Interesting online content

- XKCD What if?
Answering your hypothetical questions with physics, every Tuesday.
<http://what-if.xkcd.com/>
- MinutePhysics
Cool videos and other sweet science - all in a minute!
<http://www.youtube.com/user/minutephysics>
- AsapScience
Short videos about various scientific questions.
http://www.youtube.com/channel/UCC552Sd-3nyi_tk2BudLUzA
- Veritasium
Great teaching videos about everyday physics questions.
<http://www.youtube.com/channel/UCHnyfMqiRRG1u-2MsSQLbXA>
- Science Alert
We connect, engage and inspire science enthusiasts worldwide by sharing reputable science news, information and entertainment. (On facebook.)
<https://www.facebook.com/ScienceAlert?ref=stream>

0.3 Overview

Dear educator, welcome to the force of educators that make a difference by unlocking the marvels of the Physical Sciences to learners. What a privilege you have to guide the learners in becoming critical thinkers!

To improve curriculum implementation and to meet the vision for our nation, the National Curriculum Statement Grades R - 12 (NCS) was revised, changed and is replaced by a national policy document developed for each subject. All Physical Sciences educators in the country have to use the National Curriculum and Assessment Policy Statement for Physical Sciences. This policy document replaces all old Subject Statements, Learning Programme Guidelines and Subject Assessment Guidelines in Grades R - 12. These changed curriculum and assessment requirements come into effect in January 2012. As a Physical Sciences educator for Grade 12, you need to have a sound understanding of the National Curriculum and Assessment Policy Statement for Physical Sciences.

This teachers' guide is divided into two main parts:

- Part 1 deals with the policy document; and
- Part 2 with the learners' textbook.

Part 1

The National Curriculum and Assessment Policy Statement for Physical Sciences has four sections:

Section 1: Curriculum overview

Section 2: Physical Sciences

Section 3: Physical Sciences Content (Grades 10 - 12)

Section 4: Assessment

This part will assist you in getting to grips with the objectives and requirements laid down for the Physical Sciences at national level, and how to implement the prescribed policy document.

Part 2

Each chapter in the textbook addresses prescribed content, concepts and skills. The range of activities includes practical activities, experiments, and informal and formal assessment tasks.

0.4 Curriculum overview

From the beginning of January 2012, all learning and teaching in public and independent schools in South Africa is laid down in the National Curriculum and Assessment Policy Statements (January 2012) (CAPS) document. National Curriculum and Assessment Policy Statements were developed for each subject and replace all previous policy statements including:

1. National Senior Certificate: a qualification at Level 4 on the National Qualifications Framework (NQF);
2. An addendum to the policy document, the National Senior Certificate: a qualification at Level 4 on the National Qualifications Framework (NQF), regarding learners with special needs, published in the Government Gazette, No. 29466 of 11 December 2006;
3. The Subject Statements, Learning Programme Guidelines and Subject Assessment Guidelines for Grades R - 9 and Grades 10 - 12.

The following sections in this document set out the expected norms and standards and minimum outcomes, as well as processes and procedures for the assessment of learner achievement in public and independent schools.

The national agenda and how the curriculum can serve this agenda:

1. The knowledge, skills and values worth learning for learners in South Africa are clearly set out in the National Curriculum and Assessment Policy Statement for Physical Sciences. The content links to the environment of the learners and is presented within local context, with awareness of global trends.
2. The National Curriculum Statement Grades R - 12 undertakes to:
 - equip all learners, irrespective of their socio-economic background, race, gender, physical ability or intellectual ability, with the knowledge, skills and values necessary for self-fulfilment to participate meaningfully in society as citizens of a free country;
 - provide access to higher education;
 - facilitate the transition of learners from education institutions to the workplace; and
 - provide employers with a sufficient profile of a learner's competencies.
3. The key principles (fuller described in the document) of the National Curriculum Statement for Grades R - 12 are:
 - social transformation: making sure that the educational differences of the past are put right, by providing equal educational opportunities to all;
 - active and critical learning: encouraging an active and critical approach to learning, not only rote learning of given facts;
 - high knowledge and high skills: specified minimum standards of knowledge and skills are set to be achieved at each grade;
 - progression: content and context of each grade shows progression from simple to complex;
 - human rights, inclusivity, environmental and social justice: being sensitive to issues such as poverty, inequality, race, gender, language, age, disability and other factors;
 - valuing indigenous knowledge systems: acknowledging the rich history and heritage of this country; and
 - credibility, quality and efficiency: providing an education that is comparable in quality, breadth and depth to those of other countries.
4. The aims as listed in the National Curriculum Statement Grades R - 12 interpret the kind of citizen the education system tries to develop. It aims to produce learners that are able to:
 - identify and solve problems and make decisions using critical and creative thinking;
 - work effectively as individuals and with others as members of a team;
 - organise and manage themselves and their activities responsibly and effectively;
 - collect, analyse, organise and critically evaluate information;
 - communicate effectively using visual, symbolic and/or language skills in various modes;
 - use science and technology effectively and critically showing responsibility towards the environment and the health of others; and
 - demonstrate an understanding of the world as a set of related systems by recognising that problem solving contexts do not exist in isolation.
5. Inclusivity is one of the key principles of the National Curriculum Statement Grades R - 12 and should become a central part of the organisation, planning and teaching at each school. Educators need to:
 - have a sound understanding of how to recognise and address barriers to learning;
 - know how to plan for diversity;
 - address barriers in the classroom;
 - use various curriculum differentiation strategies; (Consult the Department of Basic Education's Guidelines for Inclusive Teaching and Learning (2010))
 - address barriers to learning using the support structures within the community; District-Based Support Teams, Institutional-Level Support Teams, parents and Special Schools as Resource Centres.

As economic growth is stimulated by innovation and research which is embedded in the Physical Sciences, this subject plays an increasingly important role to meet the country's needs. The nature of the Physical Sciences and the needs of the country are reflected in the curriculum. The specific aims direct the classroom activities that intend to develop higher order cognitive skills of learners, needed for higher education.

The nature of the Physical Sciences is to:

- investigate physical and chemical phenomena through scientific inquiry, application of scientific models, theories and laws in order to explain and predict events in the physical environment;
- deal with society's need to understand how the physical environment works in order to benefit from it and responsibly care for it;
- use all scientific and technological knowledge, including Indigenous Knowledge Systems (IKS) to address challenges facing society.

The specific aims of Physical Sciences

The specific aims provide guidelines on how to prepare learners to meet the challenges of society and the future during teaching, learning and assessment. The Specific Aims of the Physical Sciences (CAPS document, stated below) are aligned to the three Learning Outcomes (NCS document) with which you are familiar. Developing language skills as such is not a specific aim for the Physical Sciences, but we know that cognitive skills are rooted in language; therefore language support is crucial for success in this subject.

The specific aims for the Physical Sciences are:

- to promote knowledge and skills in scientific inquiry and problem solving; the construction and application of scientific and technological knowledge; an understanding of the nature of science and its relationships to technology, society and the environment.
- to equip learners with investigating skills relating to physical and chemical phenomena. These skills are: classifying, communicating, measuring, designing an investigation, drawing and evaluating conclusions, formulating models, hypothesising, identifying and controlling variables, inferring, observing and comparing, interpreting, predicting, problem solving and reflective skills.
- to prepare learners for future learning (including academic courses in Higher Education), specialist learning, employment, citizenship, holistic development, socio-economic development, and environmental management. Learners choosing Physical Sciences as a subject in Grades 10 - 12, including those with barriers to learning, can have improved access to professional career paths related to applied science courses and vocational career paths.

Within each of these aims, specific skills or competences have been identified. It is not advisable to try to assess each of the skills separately, nor is it possible to report on individual skills separately. However, well designed assessments must show evidence that, by the end of the year, all of the skills have been assessed at a grade-appropriate level. Study the next section that deals with assessment.

Developing language skills: reading and writing

As a Physical Sciences educator you need to engage in the teaching of language. This is particularly important for learners for whom the Language of Learning and Teaching (LoLT) is not their home language. It is important to provide learners with opportunities to develop and improve their language skills in the context of learning Physical Sciences. It will therefore be critical to afford learners opportunities to read scientific texts, to write reports, paragraphs and short essays as part of the assessment, especially (but not only) in the informal assessments for learning.

Six main knowledge areas inform the Physical Sciences. These are:

- Matter and Materials
- Chemical Systems
- Chemical Change
- Mechanics
- Waves, Sound and Light
- Electricity and Magnetism

Time Allocation of the Physical Sciences in the Curriculum

The teaching time for Physical Sciences is 4 hours per week, with 40 weeks in total per grade. The time allocated for the teaching of content, concepts and skills includes the practical work. These are an integral part of the teaching and learning process.

Grade	No. of weeks allocated	Content, concepts and skills (Weeks)	Formal assessment
10	40	30	10
11	40	30	10
12	40	28	12

Topics and Content to be Dealt with in Grade 12

(Consult the National Curriculum and Assessment Policy Statement for Physical Sciences for an overview of Grades 10 - 12)

Topic	Content
Mechanics	Momentum and Impulse (momentum, Newton's second law expressed in terms of momentum, conservation of momentum and elastic and inelastic collisions, Impulse), Vertical projectile motion in one dimension (1D) (vertical projectile motion represented in words, diagrams, equations and graphs), Work, Energy and Power (work, work-energy theorem, conservation of energy with non-conservative forces present, power). 28 hours
Waves, sound and light	Doppler Effect (either moving source or moving observer) (with sound and ultrasound, with light - red shifts in the universe). 6 hours
Electricity and magnetism	Electric circuits (internal resistance and series-parallel networks), Electrodynamics (electrical machines (generators, motors), alternating current). 12 hours
Matter and materials	Optical phenomena and properties of materials (photo-electric effect, emission and absorption spectra) (6 hours for physics). Organic chemistry (functional groups; saturated and unsaturated structures; isomers; naming and formulae; physical properties; chemical reactions (substitution, addition and elimination; plastics and polymers)). 22 hours
Chemical systems	Chemical industry (fertilizer industry). 6 hours
Chemical change	Reaction rate (factors affecting rate; measuring rate; mechanism of reaction and of catalysis). Chemical equilibrium (factors affecting equilibrium; equilibrium constant; application of equilibrium principles). Acids and bases (reactions; titrations, pH, salt hydrolysis). Electrochemical reactions (electrolytic and galvanic cells; relation of current and potential to rate and equilibrium; standard electrode potentials; oxidation and reduction half reaction and cell reactions; oxidation numbers; application of redox reactions). 28 hours
Skills for practical investigations	Skills for practical investigations in physics and chemistry. 4 hours

An overview of practical work

Educators now have clarity regarding the role and assessment of practical work. This document specifies that practical work must be integrated with theory to strengthen the concepts being taught. Practical work can be: simple practical demonstrations; an experiment or practical investigation. In Section 3 practical activities are outlined alongside the content, concepts and skills column. The table below lists prescribed practical activities for formal assessment as well as recommended practical activities for informal assessment in Grade 12.

Term	Formal Assessment	Informal Assessment
Term 1	Experiment (Chemistry): Preparation of esters	Experiment (Physics): Draw a graph of position vs. time and velocity vs. time for a free falling object. and Use the data to determine the acceleration due to gravity. or Experiment (Chemistry): Reaction of alkanes and alkenes with bromine and potassium permanganate. or Making a polymer like <i>slime</i> or <i>silly putty</i> .
Term 2	Experiment (Chemistry): How do you use the titration of oxalic acid against sodium hydroxide to determine the concentration of the sodium hydroxide? or Experiment (Physics): Conservation of linear momentum.	Investigation (Physics): Perform simple experiments to determine the work done in walking up (or running up a flight of stairs). By timing the run and walk (same flight of stairs) one can enrich the concept of power. or Investigate Conservation of linear Momentum. or Experiment (Chemistry): Rate of chemical reactions with sodium sulphite and hydrochloric acid. or Chemical equilibrium.
Term 3	Experiment (Physics): <i>Part 1:</i> Determine the internal resistance of a battery. <i>Part 2:</i> Set up a series-parallel network with known resistor. Determine the equivalent resistance using an ammeter and a voltmeter and compare with the theoretical value.	Investigation (Physics): Set up a series-parallel network with an ammeter in each branch and external circuit and voltmeters across each resistor, branch and battery, position switches in each branch and external circuit. Use this circuit to investigate short circuits and open circuits. or Experiment (Chemistry): Investigate electrolytic and galvanic cells.
Term 4	Final examinations.	

Weighting of topics [40 week programme]:

	Grade 12	Time
Mechanics	17,50%	28 hours
Waves, Sound and Light	3,75%	6 hours
Electricity and Magnetism	7,50%	12 hours
Matter and Materials	15,25%	22 hours
Chemical Change	17,50%	28 hours
Chemical Systems	3,75%	6 hours
Skills for practical investigations	2,50%	4 hours
Teaching time (theory and practical work)	66,25%	106 hours
Time for examinations and control tests	33,75%	54 hours

Total time = 4 hours per week × 40 weeks = 160 hours per year

0.5 Physical Sciences content (Grade 12)

This section of the CAPS document provides a complete plan for: time, topics, content, concepts and skills, practical activities, resource material and guidelines for educators. You need to consult this section of the document regularly to check whether your classroom activities fall within the requirements and objectives of the prescribed curriculum. Use the condensed work schedule below which is aligned with Section 3 and the learner's book as a pacesetter to check your progress.

Term 1: 38 hours or 10 weeks			
Weeks	Topics	Informal assessment	Formal assessment
Week 1 (4 h)	<i>Skills for practical investigations</i> Skills needed for practical investigations (observation, precautions, data collection, data handling, tables, general types of graphs, analysis, writing conclusions, writing a hypothesis, identifying variables, for example independent, dependent and control variables).		
Physics (Mechanics)			
Week 2 (4 h)	<i>Momentum and Impulse</i> Momentum (2 h) Newton's second law expressed in terms of momentum (2 h)		
Week 3 (5 h)	<i>Momentum and Impulse</i> Conservation of momentum and Elastic and Inelastic collisions.	Investigate the conservation of momentum and energy using Newton's cradle (qualitative).	Verify the conservation of linear momentum.
Week 4 (4 h)	<i>Momentum and Impulse</i> Impulse.		
Weeks 5 and half of week 6 (5 h)	<i>Vertical projectile motion in 1D</i> Vertical projectile motion (1D) represented in words, diagrams, equations and graphs (near the surface of the Earth and in the absence of air friction).	Investigate the motion of a falling body. Draw a graph of position vs. time and velocity vs. time for a free falling object. AND Use the data to determine the acceleration due to gravity.	

Chemistry (Matter and Materials)			
Half of week 6 (3 h)	<i>Organic molecules</i> Organic molecular structures - functional groups, saturated and unsaturated structures, isomers.	1. Use the reactions of alkanes and alkenes with bromine water and potassium permanganate to indicate saturated and unsaturated molecules. 2. Prepare alkynes and investigate the reactions with bromine water and potassium permanganate.	
Week 7 (4 h)	<i>Organic molecules</i> IUPAC naming and formulae (3 h) Structure physical property relationships (1 h)		
Weeks 8 and 9 (5 h)	<i>Organic molecules</i> Applications of organic chemistry (1 h) Substitution, addition and eliminations (only alkanes, alkenes, alkynes, alcohols, haloalkanes, carboxylic acids, and esters) (4 h).		Prepare different esters and identify the esters by smell.
Week 10 (4 h)	<i>Organic molecules</i> Plastics and polymers (only basic polymerisation as application for organic chemistry).	1. Cross-linking polymers - polyvinyl alcohol and sodium borate to make slime. 2. Cross-linking polymers - white wood glue and borax to make silly putty.	

Term 2: 36 hours or 10 weeks			
Physics (Mechanics)			
Weeks	Topics	Informal assessment	Formal assessment
Week 1 (4 h)	<i>Work, Energy and Power</i> Definition of work (2 h) Work-Energy theorem (2 h)		
Week 2 and half of week 3 (6 h)	<i>Work, Energy and Power</i> Conservation of energy with non-conservative forces present (3 h) Power (3 h)	Perform simple experiments to determine the work done in walking up (or running up) a flight of stairs. By timing the run and walk (same flight of stairs) one can enrich the concept of power.	

Physics (Waves, Sound and Light)			
Half of week 3 and week 4 (6 h)	<p><i>Doppler Effect (relative motion between source and observer)</i></p> <p>With sound and ultrasound (4 h)</p> <p>With light - red shifts in the universe (evidence for the expanding universe). (2 h)</p>		
Chemie (Chemiese Verandering)			
Week 5 (4 h)	<p><i>Rate and Extent of Reaction</i></p> <p>Rates of reaction and factors affecting rate (nature of reacting substances, concentration [pressure for gases], temperature and presence of a catalyst) (2 h)</p> <p>Measuring rates of reaction (1 h)</p> <p>Mechanism of reaction and of catalysis (1 h)</p>	<p>Determine the quantitative reaction rate and draw graphs in the reaction between $\text{Na}_2\text{S}_2\text{O}_3$ and HCl. Turbidity is seldom quantitatively accurate, but it is useful.</p>	
Weeks 6 and 7 (8 h)	<p><i>Chemical Equilibrium</i></p> <p>Chemical equilibrium and factors affecting equilibrium (2 h)</p> <p>Equilibrium constant (4 h)</p> <p>Application of equilibrium principles (2 h)</p>	<p>1. Investigate equilibrium and the factors influencing equilibrium on the equilibrium of CoCl_2 and H_2O.</p> <p>2. Designing and performing an experiment to investigate effects of pH on equilibrium systems such as $\text{Br}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HOBr}(\text{aq}) + \text{H}^+(\text{aq}) + \text{Br}^-(\text{aq})$ and $\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons 2\text{CrO}_4^{2-}(\text{aq}) + 2\text{H}^+(\text{aq})$</p>	

Weeks 8 and 9 (8 h)	<i>Acids and Bases</i> Acid-base reactions		<ol style="list-style-type: none"> 1. Preparing a standard solution for volumetric analysis. 2. Performing acid-base titrations using suitable indicators e.g. oxalic acid against sodium hydroxide with phenolphthalein as indicator. 3. Using a titration experiment to determine the concentration of acetic acid in vinegar or the concentration of sodium hydroxide in drain cleaner. 4. Do acid-base titration experiments to determine presence of acid in a compound (% of ethanoic acid in vinegar etc).
Week 10	Mid year examinations.		<p>Chemistry How do you use the titration of oxalic acid against sodium hydroxide to determine the concentration of the sodium hydroxide.</p> <p>OR</p> <p>Physics Conservation of linear momentum (this experiment should be conducted when teaching the section on momentum but formally assessed in term 2).</p>

The learners are asked to design an experiment investigating pH during the section on Chemical Equilibrium. However, pH is only covered in detail in the next chapter (Acids and Bases).

Term 3: 36 hours or 9 weeks			
Physics (Electricity and Magnetism)			
Weeks	Topics	Informal assessment	Formal assessment
Week 1 (4 h)	<i>Electric circuits</i> Internal resistance and series- and parallel networks.	Set up a series parallel network with an ammeter in each branch and external circuit and voltmeters across each resistor, branch and battery, position switches in each branch and external circuit. Use this circuit to investigate short circuits and open circuits.	1. Determine the internal resistance of a battery. 2. Set up a series parallel network with known resistor. Determine the equivalent resistance using an ammeter and a voltmeter and compare with the theoretical value.
Weeks 2 and 3 (8 h)	<i>Electrodynamics</i> Electrical machines (generators, motors) (4 h) Alternating current (4 h)		
Physics (Matter and Materials)			
Weeks 4 and half of 5 (6 h)	<i>Optical phenomena and properties of materials</i> Photoelectric effect (4 h) Emission and absorption spectra (2 h)		
Chemistry (Chemical change)			
Half of week 5 (2 h)	<i>Electrochemical reactions</i> Electrolytic cells and galvanic cells (2 h)	1. Investigate the electrolysis of water and sodium iodide. 2. Find the galvanic cell with the highest potential. 3. Investigate the reduction of metal ions and halogens.	
Weeks 6 and half of 7 (6 h)	<i>Electrochemical reactions</i> Relation of current and potential to rate and equilibrium (1 h) Understanding of the processes and redox reactions taking place in cells (1 h) Standard electrode potentials (1 h) Writing of equations representing oxidation and reduction half-reactions and redox reactions (2 h) Oxidation numbers and application of oxidation numbers (1 h)		
Chemistry (Chemical systems)			
Half of week 7 and week 8 (6 h)	<i>Chemical industry</i> The fertiliser industry (N, P, K)		
Week 9 (4 h)	Assessment.		Physics Determine internal resistance of a battery. AND Trial examinations.

Term 4: 8 hours or 2 weeks			
Physics			
Weeks	Topics	Practical activities	Assessment
Week 1 (4 h)	Mechanics, Electricity and Magnetism, Waves, Sound and Light	1. At least two problem-solving exercises as homework and/or class work (every day, if possible cover all cognitive levels) 2. One practical activity per term. 3. At least one informal test per term.	Final examinations.
Chemistry			
Week 2 (4 h)	Organic chemistry (2 h) Rate and Equilibrium (1 h) Acids and Bases and Electrochemistry (1 h)	1. At least two problem-solving exercises as homework and/or class work (every day, if possible cover all cognitive levels) 2. One practical activity per term. 3. At least one informal test per term.	Final examinations.

0.6 Assessment

Dear Educator, as the Programme of Assessment (PoA) is the driving force of teaching and learning in the classroom, you need to familiarise yourself with the requirements specified in the National Curriculum and Assessment Policy Statement for Physical Sciences (CAPS) document. It is important that you take notice of the significant role of practical work in the Physical Sciences.

Assessment is a continuous planned process of identifying, gathering and interpreting information about the performance of learners, using various forms of assessment

It involves four steps:

- generating and collecting evidence of achievement;
- evaluating this evidence;
- recording the findings; and
- using this information to understand and assist the learner's development to improve the process of learning and teaching.

Assessment should be both informal (Assessment for Learning) and formal (Assessment of Learning). To enhance the learning experience, learners need regular feedback from both informal and formal assessment.

Assessment is a process that measures individual learners' attainment of knowledge (content, concepts and skills) in a subject by collecting, analysing and interpreting the data and information obtained from this process to:

- enable the educator to make reliable judgements about a learner's progress;
- inform learners about their strengths, weaknesses and progress;
- assist educators, parents and other stakeholders in making decisions about the learning process and the progress of the learners.

Assessment should be mapped against the content, concepts and skills and the aims specified for Physical Sciences and in both informal and formal assessments. It is important to ensure that in the course of a school year:

- all of the subject content is covered;
- the full range of skills is included;

- a variety of different forms of assessment are used.

Informal or daily assessment

Assessment for learning has the purpose of continuously collecting information on a learner's achievement, that can be used to improve their learning. Informal assessment is a daily monitoring of learners' progress. This is done through observations, discussions, practical demonstrations, learner-educator conferences, informal classroom interactions, etc.

Informal assessment may be as simple as stopping during the lesson to observe learners, or to discuss with them how learning is progressing. Informal assessment should be used to provide feedback to the learners and to inform planning for teaching, but need not be recorded. It should not be seen as separate from learning activities taking place in the classroom.

Informal assessment tasks can consist of:

- homework, class work, practical investigations, experiments and informal tests.

Informal assessment tasks will assess:

- structured problem solving involving calculations, include problem-solving exercises that do not involve calculations, practical investigations, experiments, projects, scientific arguments, ability to predict, observe and explain.

Learners or educators can mark these assessment tasks.

Self-assessment and peer assessment actively involves learners in assessment. This is important as it allows learners to learn from and reflect on their own performance. The results of the informal daily assessment tasks are not formally recorded unless the educator wishes to do so. The results of daily assessment tasks are not taken into account for promotion and certification purposes. Informal, on-going assessments should be used to structure the gaining of knowledge and skills, and should precede formal tasks in the Programme of Assessment.

Formal assessment

Formal assessment tasks form part of a year-long formal Programme of Assessment in each grade and subject. Examples of formal assessments include tests, examinations, practical tasks, projects, oral presentations, demonstrations, performances, etc. Formal assessment tasks are marked and formally recorded by the educator for progression and certification purposes. All Formal Assessment tasks are subject to moderation for the purpose of quality assurance and to ensure that appropriate standards are maintained. Formal assessment provides educators with a systematic way of evaluating how well learners are progressing in a grade and in a particular subject.

Control Tests and Examinations

Control tests and examinations are written under controlled conditions within a specified period of time. Questions in tests and examinations should assess performance at different cognitive levels with an emphasis on process skills, critical thinking, scientific reasoning and strategies to investigate and solve problems in a variety of scientific, technological, environmental and everyday contexts. The table below shows recommended weighting of cognitive levels for formal assessment.

Cognitive level	Description	Paper 1 (Physics)	Paper 2 (Chemistry)
1	Recall	15%	15%
2	Comprehension	35%	40%
3	Analysis, application	40%	35%
4	Evaluation, synthesis	10%	10%

The recommended weighting of cognitive levels for examinations and control tests in the Physical Sciences in Grades 10 - 12. See Appendix 1 of the CAPS document for a detailed description of the cognitive levels.

Practical Investigations and Experiments

Practical investigations and experiments should focus on the practical aspects and the process skills required for scientific inquiry and problem solving. Assessment activities should be designed so that learners are assessed on their use of scientific inquiry skills, like planning, observing and gathering information, comprehending, synthesising, generalising, hypothesising and communicating results and conclusions.

Practical investigations should assess performance at different cognitive levels and focus on process skills, critical thinking, scientific reasoning and strategies to investigate and solve problems in a variety of scientific, technological, environmental and everyday contexts. The CAPS document distinguishes between a practical investigation and an experiment: an experiment is conducted to verify or test a known theory; an investigation is an experiment that is conducted to test a hypothesis i.e. the result or outcome is not known beforehand.

Requirements for grade 12 practical work

Three prescribed experiments for formal assessment (**one or two** Chemistry and **one or two** Physics experiment). This gives a total of **three** formal assessments in practical work in Physical Sciences. It is recommended that Grade 12 learners also do **three** experiments for informal assessment (**one or two** Chemistry and **one or two** Physics experiments).

A summary to use as a checklist for practical work in Grade 12:

Practical work	Chemistry	Physics
Prescribed experiments (Formal assessment)	1/2	2/1
Experiments (Informal assessment)	1/2	2/1
Total	6 practical activities, 3 Chemistry and 3 Physics	

Programme of formal assessment for Grade 12

Assessment consists of two components: a Programme of Assessment which makes up 25% of the total mark for Physical Sciences and an external examination which makes up the remaining 75%. The Programme of Assessment for Physical Sciences comprises six tasks that are internally assessed. Together the Programme of Assessment and external assessment make up the annual assessment plan for Grade 12. Table 7 illustrates the assessment plan and weighting of tasks in the programme of assessment for Physical Sciences Grade 12.

Programme of assessment for Grade 12 (SBA)						External assessment
Assessment tasks (25%)						End-of-year assessment (75%)
Term 1		Term 2		Term 3		Term 4
Type	Mark	Type	Mark	Type	Mark	Final examination (2 x 150 marks giving a total of 300 marks for papers 1 and 2)
Experiment	15	Experiment	15	Experiment	15	
Control test	10	Control test	20	Control test	25	
Total: 25 marks		Total: 35 marks		Total 40 marks		Total: 300 marks
Total = 400 marks						
Final mark = 25% (assessment tasks) + 75% (final exam) = 100%						

Assessment Tools

You use an assessment tool to record information during an assessment. Assessment tools can be:

- Check lists
- Assessment grids/sheets
- Rubrics
- Observation books or notebooks
- Completed tasks, assignments of worksheets

- Conferencing or interviews
- Self or Peer Assessment Sheets
- Recordings, photographs, written descriptions
- Portfolios

Before you use the tool the learners must know:

- When he/she is to be assessed
- When he/she is to be assessed
- How she/he will be assessed
- The consequences of the assessment
- The expected mode for response (written, spoken, practical)

After using the tool, the educator needs to answer the following question:

- Were the criteria used adequate to assess the outcome, and were the levels appropriate?
- Is appropriate feedback given to learners?
- Are learning difficulties identified and action planned?
- What happens to the product?
- What feedback follow-up action is needed?
- Has the integrating function been addressed?
- What learner appeal process exists?
- How will assessment inform further teaching/learning?

Rubrics

A rubric is an assessment tool which defines different levels of performance. It can be used for assessing concepts and process skills during informal and formal assessment, and for practical work. Rubrics aim to make assessment more objective and consistent. Some of the advantages of using rubrics are:

- Learners become aware of the expectations of educators
- Educators become aware of learners' progress and potential
- Enhance greater learner involvement
- Learners are more focused and self-directed

Examples of rubrics:

Assessment of Practical Work

Planning and organising experimental investigations to test hypotheses

Criteria	High (3)	Medium (2)	Low (1)
Plan should reflect process of identification of variables, control of variables, range of conditions, ways in which the experiment could be improved, awareness of inaccuracies, offering of a conclusion.	Able to plan independently an experiment in which all variables are identified and controlled as necessary. Able to suggest ways in which the experiment could be improved.	Able to plan independently an experiment to test a hypothesis in which most of the variables are identified and controlled as necessary.	Able to plan a one-step experiment to test the hypothesis.

Following instructions and manipulations

Criteria	High (3)	Medium (2)	Low (1)
Accurately following a sequence of written/verbal instructions.	FOLLOWING A SEQUENCE OF INSTRUCTIONS INCLUDING BRANCHED INSTRUCTIONS.	CAN COMPLETE AN EXPERIMENT BY FOLLOWING A SEQUENCE OF INSTRUCTIONS.	ABLE TO FOLLOW A SINGLE WRITTEN, DIAGRAMMATIC OR VERBAL INSTRUCTION.
SELECTING/USING THE APPROPRIATE APPARATUS.	SELECT IN ADVANCE ALL THE APPARATUS NEEDED TO EXECUTE A PARTICULAR EXPERIMENT AND BE ABLE TO USE IT.	ABLE TO SELECT/USE MOST OF THE APPARATUS NECESSARY; SOME MORE SPECIALIZED EQUIPMENT MAY STILL BE NEEDED.	ABLE TO SELECT/USE ONLY THE MOST BASIC APPARATUS.
MANIPULATIVE SKILLS INCLUDE CORRECT AND SAFE HANDLING OF APPARATUS AND MATERIAL.	ABLE TO USE ALL APPARATUS AND MATERIAL CORRECTLY AND SAFELY.	USE MOST OF THE APPARATUS AND MATERIAL SAFELY.	ABLE TO USE ONLY THE MOST BASIC EQUIPMENT.

Making accurate observations and measurements, being aware of possible sources of error.

Criteria	High (3)	Medium (2)	Low (1)
ACCURACY, COMPLETENESS AND RELEVANCE OF OBSERVATIONS.	ABLE TO MAKE A COMPLETE SEQUENCE OF OBSERVATIONS IN A GIVEN SITUATION AND IS AWARE OF A NUMBER OF SOURCES OF ERROR.	ABLE TO MAKE A RANGE OF OBSERVATIONS IN A GIVEN SITUATION AND IS ABLE TO SUGGEST ONE POSSIBLE SOURCE OF ERROR.	ABLE TO MAKE A SINGLE OBSERVATION AND MORE IF PROMPTED, E.G.: WHAT DID YOU OBTAIN REGARDING COLOUR AND SMELL OR TEMPERATURE IN TEST TUBE?
SELECTION OF MEASUREMENT INSTRUMENT, PERFORMANCE OF MEASURING OPERATION AND READING SCALES.	ABLE TO READ A VARIETY OF SCALES AS ACCURATELY AS THE SCALE PERMITS.	ABLE TO READ A SCALE TO THE NEAREST DIVISION.	ABLE TO READ SCALES WITHIN \pm ONE NUMBERED SCALE DIVISION.

Criteria for check lists could be more differentiated when directed towards specific experiments in Chemistry or Physics.

Regarding the scope of observations properties, similarities and differences taking place in colour, hardness, mass, relative speed, size, smell, sound, state, temperature, texture, volume, voltages could be listed.

The performance of measuring which might be used for assessment could be listed as:

1. Is the instrument capable of measuring the correct amount?
2. Was the correct range of the instrument selected?
3. Were the necessary precautions taken to ensure that the measurements will be valid?
4. Are measurements repeated or checked?
5. Are readings made with due regard for parallax?
6. Is the scale reading translated to the correct magnitude and are the correct units assigned?

Recording accurately and clearly the results of experiments

Criteria	High (3)	Medium (2)	Low (1)
ALL THE OBSERVATIONS ARE DESCRIBED ACCURATELY AND COMPLETELY. APPROPRIATE METHODS (WRITTEN, TABLES, DIAGRAMS) USED TO RECORD OBSERVATIONS AND MEASUREMENTS.	ABLE TO DRAW FULLY LABELLED DIAGRAMS TO RECORD OBSERVATIONS. ABLE TO RECORD RESULTS IN NEAT TABLES WITH APPROPRIATE HEADINGS AND UNITS, WITH ALL MEASUREMENTS RECORDED AS WELL AS DERIVED QUANTITIES.	DATA RECORDED AS AN ORDERED SET OF STATEMENTS, OR IN A TABLE SOME DATA AND UNITS OMITTED.	INFORMATION RECORDED AS A PROSE ACCOUNT, AS A SEQUENCE OF STATEMENTS. ABLE TO RECORD DATA IN A PRE-PREPARED TABLE.

Presentation of data in graphic form

Criteria	High (3)	Medium (2)	Low (1)
Acceptable scale. X-axis correctly labelled. Units on X-axis. Y-axis correctly labelled. Units on Y-axis. Points correctly marked. Points correctly linked. Contradictory results "normalised". Appropriate subtitle.	All the criteria could be met without assistance.	All the criteria could be met with help.	Graphs could only be drawn with pre-prepared axes, with a lot of assistance.

Drawing conclusions and making generalisations from experiments

Criteria	High (3)	Medium (2)	Low (1)
Valid deductions from results.	Able to identify patterns or relationships and explain fundamental principles, verbal or in mathematical terms.	Able to identify a pattern, simple or trend in the relationship between two variables. Perform simple calculations of a derived quantity.	Classifications of observations and recognition of similarities and differences. Able to explain a simple observation.

End-of-year external Grade 12 examination

The external examinations are set externally, administered at schools under conditions specified in the *National policy on the conduct, administration and management of the National Senior Certificate: A qualification at Level 4 on the National Qualifications Framework (NQF) and marked externally*.

The core content outlined in the Physical Sciences Curriculum and Assessment Policy (CAPS) document is compulsory and will be examined through Papers 1 and 2. Note that all the topics in the grade 12 curriculum are examinable in the end of year examination plus selected topics from grades 10 and 11. Below is a list of selected content, outlined for Grade 10 and 11 in the CAPS document that is also examinable in the Grade 12 final examination.

Examinable topics from grades 10 and 11

Selected Examinable Grades 10 and 11 Topics	
Physics from Grade 11	Chemistry from Grades 10 and 11
1. Newtons' Laws (Newton 1, 2, 3 and Newton's Law of Universal Gravitation) and Application of Newton's Laws 2. Electrostatics (Coulomb's Law and Electric field) 3. Electric circuits (Ohm's Law, Power and Energy)	1. Representing chemical change (grade 10) 2. Intermolecular forces (grade 11) 3. Stoichiometry (grade 11) 4. Energy and Change (grade 11)

Multiple-choice questions could be set in examination papers. However, such questions should have a maximum weighting of 10%. The examination paper may also consist of conceptual type questions.

The final end-of-year examination is nationally set, marked and moderated.

The nationally set, marked and moderated examination will consist of two papers:

- Paper 1: Physics focus (3 hours, 150 marks)

- Paper 2: Chemistry focus (3 hours, 150 marks)
- All of the questions will focus on content as stated in the National Curriculum Statement.
- Questions will reflect the different levels of the Physical Sciences Assessment Taxonomy (APPENDIX 1 of CAPS) appropriate to the paper.

Grade 12								
Paper	Content	Marks	Total marks per paper	Duration (hours)	Weighting of questions across cognitive levels			
					Level 1	Level 2	Level 3	Level 4
Paper 1: Physics focus	Mechanics	63	150	3	15%	35%	40%	10%
	Waves, Sound and Light	17						
	Electricity and Magnetism	55						
	Matter and Materials	15						
Paper 2: Chemistry focus	Chemical Change	84	150	3	15%	40%	35%	10%
	Chemical Systems	18						
	Matter and Materials	48						

Recording and Reporting

Recording is a process in which the educator documents the level of a learner's performance in a specific assessment task. It shows learner progress towards the achievement of the knowledge and skills as prescribed in the Curriculum and Assessment Policy Statements. Records of learner performance should provide evidence of the learner's conceptual progression within a grade and her / his readiness to progress or be promoted to the next grade. Records of learner performance should also be used to verify the progress made by educators and learners in the teaching and learning process.

Reporting is a process of communicating learner performance to learners, parents, schools, and other stakeholders. Learner performance can be reported through report cards, parents' meetings, school visitation days, parent-educator conferences, phone calls, letters, class or school newsletters, etc. Educators in all grades report in percentages against the subject. The various achievement levels and their corresponding percentage bands are as shown in the table below.

Note: The seven point scale should have clear descriptions that give detailed information for each level. Educators will record actual marks against the task by using a record sheet, and report percentages against the subject on the learners' report card.

Codes and Percentages for Reporting in Grades R - 12:

Rating Code	Description of Competence	Percentage
7	Outstanding Achievement	80% - 100%
6	Meritorious Achievement	70% - 79%
5	Substantial Achievement	60% - 69%
4	Adequate Achievement	50% - 59%
3	Moderate Achievement	40% - 49%
2	Elementary Achievement	30% - 39%
1	Not Achieved	0% - 29%

Schools are required to provide quarterly feedback to parents on the Programme of Assessment using a formal reporting tool such as a report card. The schedule and the report card should indicate the overall level of performance of a learner.

This section requires you to reference Appendix 2 of the CAPS document, as it recommends that the skills it covers be incorporated in lessons in Grade 12, in order to sharpen the skills necessary for successful teaching and learning. Skills covered are scientific notation, conversion of units, changing the subject of the formula, rate and its applications in physics and chemistry, direct and inverse proportions, fractions and ratios, the use and meaning of constants in equations, skills needed for practical investigations (observation, precautions, data collection, data handling, tables, general types of graphs, analysis, writing conclusions, writing a hypothesis, identifying variables - for example independent, dependent and control variable), models in science, safety data, and basic trigonometry skills, etc.

CHAPTER



Skills for science

1.2	<i>Scientific method</i>	30
1.3	<i>Data and data analysis</i>	32

1 Skills for science

In this chapter learners will look at some basic skills required for practical investigations in the physical sciences. A lot of these skills were introduced to the learners in Grade 10, and while doing practical investigations in Grade 11. Four hours are allocated to this chapter in CAPS.

The following topics are covered in this chapter.

- **The development of a scientific theory.**

This section should be used to show learners how scientific theories come from the studies of many different people using the information of those who came before them. They should understand that science is ever changing, as more of the world is understood.

- **The scientific method**

In this section learners should generate their own experiment from a question they are interested in. This includes doing background research, and following the scientific method. Before designing their own experiment they should study the flow diagram of the scientific method provided in the activity.

A brief reminder of how to measure distances, temperature, mass and volumes is covered in this section before the learners are required to complete an experiment. The experiment is broken up into sections. In this first section they perform the experiment.

- **Data and data analysis**

Learners are given an overview of how to present data in graphs, they are then required to analyse the data they obtained in the experiment and determine whether their data is qualitative or quantitative. In the third part of this experiment they have to draw a conclusion based on their results and decide if the results are biased in any way. They need to understand how to design a model based on their experimental data.

- **Laboratory safety procedures**

These skills are not part of the CAPS statement for this chapter. However, it is advisable that you go through these rules with the learners before they perform their first experiments. It would be useful to refer them back to this section throughout the year.

There is one experiment in this chapter that is split into three parts. This is to help the learners understand the scientific method better. The learners are also required to write up their own experiment. This can be on a topic of their choice, but should follow the scientific method. More information is provided in the relevant section.

The skills for science section should be taught while the learners do an investigation themselves. Numerous activities have been provided and the skills for practical investigations should also be discussed and practiced as a class at regular intervals throughout the year. Any support material that develops these skills can be used.

1.2 Scientific method

In the analysis of the scientific method activity:

1. The question may already be answered in the literature, or there may be background research that you can build upon. It is also best to make a hypothesis, prediction and an experiment with as good an understanding of the topic as possible.
2. A controlled variable is one which you keep constant (controlled) so that it does not have an effect between readings. The independent variable is the one you change between collecting data points, while the dependent variable is the variable that changes as a result of a change in the independent variable.
 - It is important to identify all the variables that you think will have an effect on your investigation.
 - Firstly think of all the relevant variables you can change.
 - Secondly think of all the variables you can measure or observe.
 - Thirdly choose one variable to change (independent variable) which will have an effect on the one variable you can measure or observe (dependent variable).
 - All the other variables you need to keep constant (fixed/controlled variable).

3.
 - Identifying a problem involves thinking about the world around you and a specific part of it that you don't understand.
 - A hypothesis is more formal, it is a prediction about that problem based on your current understanding and background research.
 - A scientific theory comes from an experimentally tested and proven hypothesis. It is repeatable and current data fits the theory.
4. Data may fit a hypothesis in a specific instance. That does not mean that the hypothesis is generally true. It is important to repeat the experiment to make sure that the experiment was not an anomaly. Before something becomes a scientific theory it must be tested repeatedly and be repeatable by different people.

When the learners design their own experiment:

1. An example of a question that the learner might ask would be why do rainbows form?
2. Before beginning an investigation background research needs to be undertaken. Background research should always be referenced.
In this example the type of background research might include the particles found in the atmosphere, the diffraction of light through water and the different wavelengths of light.
3. Learners must write down a statement that answers their question. This is the hypothesis and should be specific, relating directly to the question they are asking.
In this example their hypothesis might be: *Rainbows form because of the diffraction of light through water droplets in the atmosphere. If light is shone through water at the right angle a rainbow will form.* Their hypothesis should be testable.
4. The learners should identify variables that are important in their specific experiment. For example, the temperature of the water, the type of light they use, the purity of the water, the angle of the light could all be variables in their experiment.
5. The learners should understand the difference between independent, dependent and controlled variables and be able to identify them in their experiment.

For example, the type of light might be controlled (sunlight). The temperature could be an independent variable (perform the experiment on different days with different temperatures). With the temperature as an independent variable then the angle the light comes out at could be a dependent variable, to see if there is a link. If the temperature is made a controlled variable on that day, then the angle could be the independent variable, and the shape and size of the rainbow would be the dependent variable.

6. The learner must design an experiment that accurately tests their hypothesis. The experiment is the most important part of the scientific method. These are all important concepts to know when designing an experiment:

- The method should be written so that a complete stranger will be able to carry out the same procedure in the exact same way and get almost identical results.
- The method must be clear and precise instructions including the labelling of apparatus, giving exact measurements or quantities of chemicals or substances to be used and making sure that all the apparatus used is listed.
- The method must give clear instructions about/describing how the results should be recorded (table, graph, etc.)
- The method should include safety precautions where possible.

7. The learner should present a one page experimental write up with an aim, the apparatus necessary, the method that will be followed. An example experiment is given here. Note that this is just an example, the learners could perform their experiment on anything.

• Aim

The aim of this experiment is to determine what happens when sunlight is shone through a glass of water.

• Apparatus

- A clear 500 ml glass, three A4 pieces of white paper, a tape measure, sticky tape, a pencil, a thermometer
- At least 400 ml of water, sunlight.

- **Method**

- Use the sticky tape to stick an A4 piece of a paper to a sunny wall exactly 1 m from the ground.
- Use the sticky tape to stick an A4 piece of paper above the first one, and the last A4 piece of paper below the first one.
- Fill the glass with 400 ml water and measure the temperature (be careful to keep the thermometer out of direct sunlight between measuring the temperatures).
- Hold the glass (near the bottom) level with the bottom of the middle piece of paper in the sunlight. If a rainbow forms on the sheets of paper, mark where it forms on the paper.
- Measure the temperature of the water in the glass, then move the glass upwards 5 cm and repeat.
- Repeat step 5 until you reach the top of the uppermost A4 piece of paper.

- **Results**

- Your results should be presented in the form of a table (Result? should be answered with a yes or a no depending on whether a rainbow formed):

Temperature (°C)	Height of glass (m)	Result?	Height of rainbow

From this data the angle of refraction of the water can be measured, as well as what angle is required for the sunlight to create a rainbow through the water.

Performing experiments

The boiling points and rate of evaporation experiment is a very simple one meant to introduce the learners to the concept of the scientific method in a practical way. It has been broken up into three parts: performing the practical investigation, analysis of results, drawing conclusions.

The learners should be as accurate as possible when measuring the drop in volume as they will be required to plot a graph of their data.

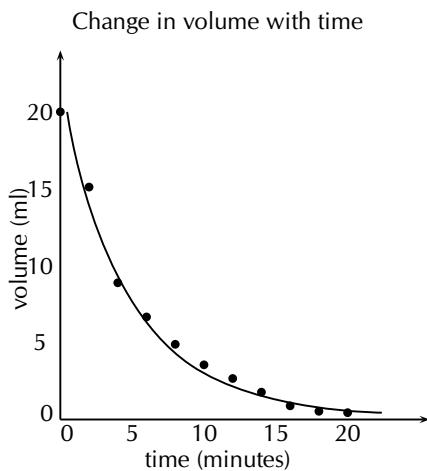
1.3 Data and data analysis

Qualitative and quantitative analysis

This is the second part of the boiling points and rate of evaporation experiment.

Results

Learners should record their results in a table like the one given. They should then plot a graph of all four liquids on the same set of axes. An example of how the drop in nail polish remover might look is given below.



Discussion and conclusion

Learners should find that water takes the longest time to evaporate and so has the shallowest drop on their graph. Water has strong intermolecular forces (hydrogen bonds). Ethanol ($\text{CH}_3\text{CH}_2\text{OH}$) and methylated spirits (mainly ethanol ($\text{CH}_3\text{CH}_2\text{OH}$) with some methanol (CH_3OH)) both have hydrogen bonds but these are slightly weaker than the hydrogen bonds in water. Nail polish remover (acetone (CH_3COCH_3)) has dipole-dipole forces only and so evaporates quickly and will have the sharpest decrease on their graph.

The graph should be exponential and as time increases the dependent variable (volume) decreases.

Conclusions based on scientific evidence

In this activity, learners could mention topics such as more direct sunlight on one container, higher volatility (though that is related to intermolecular forces), a breeze speeding up the rate of evaporation over one or more of the containers, and water vapour in the air slowing down the rate of evaporation for water.

The main point of this activity is that they understand that there can be more than one explanation for a set of data, which why repeating an experiment, doing thorough background research, and not having their ideas fixed before analysing data is so important.

- Many natural medicines were used by people long before any studies were performed. These plants were tried and tested by people, and were known to help with many different ailments. Many people seek alternative forms of treatment. In South Africa, individuals commonly use traditional medicines like African Potato (*Hypoxis hemerocallidea*) and "Cancer bush" (*Sutherlandia frutescens*), to boost the immune system while undergoing conventional treatments.

The cancer bush (*Sutherlandia frutescens*, uNwele) is an indigenous medicinal plant which the Khoi and Nama people used to wash wounds and to reduce high fevers. The early settlers also used this bush to treat chicken pox, eye problems and internal cancers. Cancer patients often lose weight and suffer muscle wastage and a tonic made from this bush may improve appetite, decreases anxiety and slows down the weight loss.

- A reliable way of navigating is by using the stars. The stars move so slowly you would only notice a change in about 50 000 years, and only in 100 000 years would the constellations look different enough to need a new star map. So we can say the constellations are made up of *fixed stars*.

The Earth, on the other hand, spins at $1674,4 \text{ km.h}^{-1}$ causing the *fixed stars* to rise and set (including the Sun) every day, and depending on your latitude they will rise and set at specific coordinates, hence you can calculate your latitude if you know the coordinates of the stars you can see.

In the Southern hemisphere we use the Southern Cross to find South. In the northern hemisphere the Pole star can be used to find North.

Determining your longitude is a bit more complicated, unless you have an accurate clock. This is why one of the essential tasks a sailor had in the past was to reset the ship clock before continuing the voyage, and why all major sea ports had observatories, to provide sailors with reliable times.

The stars tell you the time and the direction, so you know when and where you are on Earth. Until very recently in our history, before satellites and digital technology, stars were the most reliable way to navigate at sea, where there are no landmarks.

Similarly to every culture across the world, the peoples of Africa, and more locally Southern Africa used the stars as a canvas for their mythologies. The stars were also used as agricultural calendars. A few brief examples include:

- the people living along the Nile in ancient Egypt knew that when Sirius was seen just before sunrise the Nile would flood,
- all over Africa, the IsiLimela or the Pleiades, a star cluster in Taurus, were used to indicate the start of the growing season. They are also called the 'digging stars', and
- the Venda people saw the Southern Cross and Pointers as giraffes, and in October when the 'giraffes' were just above the trees in the evening they knew it was time to finish planting.

CHAPTER



Momentum and impulse

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2.1 Introduction

The following must be covered by the end of this chapter:

Momentum:

- The definition of momentum.
- The calculations done on momentum using $p = mv$ and the change in momentum under the influence of a resultant force.
- The understanding of the vector nature of momentum and the applications concerning momentum.
- Representing momentum using vector diagrams.

Newton's second law expressed in terms of momentum:

- State Newton's second law in terms of momentum.
- Expression of Newton's second law in terms of symbols.
- Emphasis on the vector nature of momentum
- The relationship between the net force and change in momentum for a variety of motions by using different examples.
- Do calculations on the change in momentum when a resultant force acts on an object to change the velocity.

Conservation of momentum:

- Definition of :
 - A system
 - Internal forces
 - External forces
 - Isolated system
- State the law of conservation of momentum.
- Explain the difference between elastic and inelastic collisions by using the concept of kinetic energy before and after a collision.
- Do calculations on the principle of conservation of momentum.
- Do practical demonstrations on the principle of conservation of momentum.
- Applications of the principle of conservation of momentum.

Impulse:

- Definition of impulse.
- The understanding of the vector nature of impulse.
- The change in momentum and impulse are equal to each other (impulse-momentum theorem).
- Calculations done by using the impulse-momentum theorem.

Key Mathematics Concepts

- Units and unit conversions — Physical Sciences, Grade 10, Science skills
- Equations — Mathematics, Grade 10, Equations and inequalities
- Techniques of vector addition — Physical Sciences, Grade 10, Vectors and scalars
- Newton's laws — Physical Sciences, Grade 11, Forces

2.2 Momentum

Change in momentum

Exercise 2 – 1:

1. a) The fastest recorded delivery for a cricket ball is $161,3 \text{ km}\cdot\text{hr}^{-1}$, bowled by Shoaib Akhtar of Pakistan during a match against England in the 2003 Cricket World Cup, held in South Africa. Calculate the ball's momentum if it has a mass of 160 g.

$$p = mv \quad v = 161,3 \text{ km} \cdot \text{hr}^{-1}$$

and $m = 160 \text{ g}$.

Converting the velocity to the correct S.I units:

$$v = 161,3 \text{ km} \cdot \text{hr}^{-1} \cdot \frac{1000 \text{ m}}{3600 \text{ s}} \\ = 44,81 \text{ m} \cdot \text{s}^{-1}$$

Converting the mass to the correct S.I units:

$$m = 160 \text{ g} \cdot \frac{\text{kg}}{1000 \text{ g}} = 0,16 \text{ kg}$$

Therefore, computing the momentum:

$$p = 0,16 \text{ kg} \cdot 44,81 \text{ m} \cdot \text{s}^{-1} = 7,17 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$$

- b) The fastest tennis service by a man is $246,2 \text{ km}\cdot\text{hr}^{-1}$ by Andy Roddick of the United States of America during a match in London in 2004. Calculate the ball's momentum if it has a mass of 58 g.

We convert the mass and velocity to S.I. units.

$$p = mv = 0,058 \text{ kg} \cdot 68,39 \text{ m} \cdot \text{s}^{-1} = 3,97 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$$

- c) The fastest server in the women's game is Venus Williams of the United States of America, who recorded a serve of $205 \text{ km}\cdot\text{hr}^{-1}$ during a match in Switzerland in 1998. Calculate the ball's momentum if it has a mass of 58 g.

We convert the mass and velocity to S.I. units.

$$p = mv = 0,058 \text{ kg} \cdot 56,94 \text{ m} \cdot \text{s}^{-1} = 3,30 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$$

- d) If you had a choice of facing Shoaib, Andy or Venus and didn't want to get hurt, who would you choose based on the momentum of each ball?

The ball with the smallest momentum gives you the least chance of being hurt and so you would choose to face Venus.

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1. 27HP



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2.3 Newton's Second Law revisited

Exercise 2 – 2:

1. Which expression accurately describes the change of momentum of an object?

- a) $\frac{\vec{F}}{m}$
- b) $\frac{\vec{F}}{\Delta t}$
- c) $\vec{F} \cdot m$
- d) $\vec{F} \cdot \Delta t$

$$\vec{F} \cdot \Delta t$$

2. A child drops a ball of mass 100 g. The ball strikes the ground with a velocity of $5 \text{ m}\cdot\text{s}^{-1}$ and rebounds with a velocity of $4 \text{ m}\cdot\text{s}^{-1}$. Calculate the change of momentum of the ball. Choose down as positive.

We convert the mass to kilograms: $\frac{100}{1000} = 0,1 \text{ kg}$

$$\Delta p = mv_f - mv_i$$

$$\Delta p = (0,1)(-4) - (0,1)(5)$$

$$\Delta p = 0,9 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1} \text{ upwards}$$

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1. 27HQ 2. 27HR



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2.4 Conservation of momentum

Conservation of momentum

Exercise 2 – 3:

1. Two golf balls roll towards each other. They each have a mass of 100 g. Ball 1 is moving at $\vec{v}_1 = 2,4 \text{ m}\cdot\text{s}^{-1}$ to the right, while ball 2 is moving at $\vec{v}_2 = 3 \text{ m}\cdot\text{s}^{-1}$ to the left. Calculate the total momentum of the system.

$$m_1 = 100\text{g} = 0,1\text{kg}$$

$$m_2 = 100\text{g} = 0,1\text{kg}$$

$$v_1 = 2,4\text{m/s}$$

$$v_2 = -3\text{m/s}$$

Therefore the total momentum of the system is:

$$p = m_1 v_1 + m_2 v_2$$

$$p = (0,1\text{kg} \times 2,4\text{m/s}) + (0,1\text{kg} \times -3\text{m/s})$$

$$p = -0,06\text{kg}\cdot\text{m/s}$$

2. Two motorcycles are involved in a head on collision. Motorcycle A has a mass of 200 kg and was travelling at $120 \text{ km}\cdot\text{hr}^{-1}$ south. Motor cycle B has a mass of 250 kg and was travelling north at $100 \text{ km}\cdot\text{hr}^{-1}$. A and B are about to collide. Calculate the momentum of the system before the collision takes place.

First convert the velocities to the correct units:

$$\text{motorcycle 1: } \frac{(120)(1000)}{3600} = 33,33 \text{ m}\cdot\text{s}^{-1}$$

$$\text{motorcycle 2: } \frac{(100)(1000)}{3600} = 27,78 \text{ m}\cdot\text{s}^{-1}$$

Taking south as positive:

$$p_{\text{total}} = m_1 v_1 + m_2 v_2$$

$$p_{\text{total}} = (200)(33,33) + (250)(-27,78)$$

$$p_{\text{total}} = -279 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1}$$

3. A 700 kg truck is travelling north at a velocity of $40 \text{ km}\cdot\text{hr}^{-1}$ when it is approached by a 500 kg car travelling south at a velocity of $100 \text{ km}\cdot\text{hr}^{-1}$. Calculate the total momentum of the system.

We need to convert the velocities to the correct units:

$$\frac{(40)(1000)}{3600} = 11,11 \text{ m}\cdot\text{s}^{-1}$$

$$\frac{(100)(1000)}{3600} = 27,78 \text{ m}\cdot\text{s}^{-1}$$

Take north to be positive.

$$p_{\text{total}} = mv_1 + mv_2$$

$$p_{\text{total}} = (700)(11,11) + (500)(-27,78)$$

$$p_{\text{total}} = -6113 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1}$$

$$p_{\text{total}} = 6113 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1} \text{ to the south}$$

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1. 27HS 2. 27HT 3. 27HV



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Collisions

Exercise 2 – 4: Collisions

1. A truck of mass 4500 kg travelling at $20 \text{ m}\cdot\text{s}^{-1}$ hits a car from behind. The car (mass 1000 kg) was travelling at $15 \text{ m}\cdot\text{s}^{-1}$. The two vehicles, now connected carry on moving in the same direction.

- a) Calculate the final velocity of the truck-car combination after the collision.

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v$$

$$v = \frac{(4500)(20) + (1000)(15)}{4500 + 1000}$$

$$v = 19,09 \text{ m}\cdot\text{s}^{-1}$$

- b) Determine the kinetic energy of the system before and after the collision.

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

$$KE_{1i} = \frac{1}{2}(4500)(20)^2 = 900\,000 \text{ J}$$

$$KE_{2i} = \frac{1}{2}(1000)(15)^2 = 112\ 500\ J$$

$$KE_{Ti} = KE_{1i} + KE_{2i} = 900\ 000 + 112\ 500 = 1\ 012\ 500\ J$$

$$KE_{Tf} = \frac{1}{2}mv_f^2 = \frac{1}{2}(5500)(19,09)^2 = 1\ 002\ 177\ J$$

$$KE_{Ti} = 1\ 012\ 500\ J$$

$$KE_{Tf} = 1\ 002\ 177\ J$$

- c) Explain the difference in your answers for b).

The energy difference is permanently transferred into non-elastic deformation during the collision.

- d) Was this an example of an elastic or inelastic collision? Give reasons for your answer.

Inelastic. Kinetic energy was not conserved in the collision.

2. Two cars of mass 900 kg each collide head-on and stick together. Determine the final velocity of the cars if car 1 was travelling at $15\text{ m}\cdot\text{s}^{-1}$ and car 2 was travelling at $20\text{ m}\cdot\text{s}^{-1}$.

$$m_1\vec{v}_1 + m_2\vec{v}_2 = (m_1 + m_2)\vec{v}$$

$$(900)(15) + (900)(-20) = (900 + 900)\vec{v}$$

$$\vec{v} = -2,5\text{ m}\cdot\text{s}^{-1}$$

$\vec{v} = 2,5\text{ m}\cdot\text{s}^{-1}$ in the same direction as the car that was originally travelling at $20\text{ m}\cdot\text{s}^{-1}$

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1. 27HW 2. 27HX



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2.5 Impulse

Exercise 2 – 5:

1. Which one of the following is **not** a unit of impulse?

- a) $\text{N}\cdot\text{s}$
- b) $\text{kg}\cdot\text{m}\cdot\text{s}^{-1}$
- c) $\text{J}\cdot\text{m}\cdot\text{s}^{-1}$
- d) $\text{J}\cdot\text{m}^{-1}\cdot\text{s}$

$$\text{J}\cdot\text{m}\cdot\text{s}^{-1}$$

2. A toy car of mass 1 kg moves eastwards with a speed of $2\text{ m}\cdot\text{s}^{-1}$. It collides head-on with a toy train. The train has a mass of 2 kg and is moving at a speed of $1,5\text{ m}\cdot\text{s}^{-1}$ westwards. The car rebounds (bounces back) at $3,4\text{ m}\cdot\text{s}^{-1}$ and the train rebounds at $1,2\text{ m}\cdot\text{s}^{-1}$.

- a) Calculate the change in momentum for each toy.

Take Eastwards as positive.

For the car:

$$\Delta p = mv_f - mv_i$$

$$\Delta p = (1)(-3,4) - (1)(2) = -5,4\text{ kg}\cdot\text{m}\cdot\text{s}^{-1}$$

For the train:

$$\Delta p = mv_f - mv_i$$

$$\Delta p = (2)(1.2) - (2)(-1.5) = 5.4 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$$

- b) Determine the impulse for each toy.

For the car:

$$\text{Impulse} = -5.4 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$$

For the train:

$$\text{Impulse} = 5.4 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$$

- c) Determine the duration of the collision if the magnitude of the force exerted by each toy is 8 N.

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

$$\Delta t = \frac{5.4}{8} = 0.675 \text{ s}$$

3. A bullet of mass 20 g strikes a target at $300 \text{ m} \cdot \text{s}^{-1}$ and exits at $200 \text{ m} \cdot \text{s}^{-1}$. The tip of the bullet takes 0,0001 s to pass through the target. Determine:

- a) the change of momentum of the bullet.

$$\Delta p = mv_f - mv_i$$

$$\Delta p = (0.02)(200) - (0.02)(300) = -2 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$$

- b) the impulse of the bullet.

$$\text{Impulse} = -2 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$$

- c) the magnitude of the force experienced by the bullet.

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

$$F_{\text{net}} = \frac{2}{0.0001} = 20000 \text{ N}$$

4. A bullet of mass 20 g strikes a target at $300 \text{ m} \cdot \text{s}^{-1}$. Determine under which circumstances the bullet experiences the greatest change in momentum, and hence impulse:

- a) When the bullet exits the target at $200 \text{ m} \cdot \text{s}^{-1}$.

If the bullet leaves the target its total momentum is: $\Delta \vec{p} = (0,02)(200) - (0,02)(300) = -2 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$

- b) When the bullet stops in the target.

If the bullet remains in the target its total momentum is: $\Delta \vec{p} = (0,02)(0) - (0,02)(300) = -6 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$

- c) When the bullet rebounds at $200 \text{ m} \cdot \text{s}^{-1}$.

If the bullet rebounds from the target its total momentum is: $\Delta \vec{p} = (0,02)(-200) - (0,02)(300) = -10 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$

So the bullet experiences the greatest change in momentum and hence impulse, when it rebounds from the target.

5. A ball with a mass of 200 g strikes a wall perpendicularly at a velocity of $12 \text{ m} \cdot \text{s}^{-1}$ and rebounds at a velocity of $9 \text{ m} \cdot \text{s}^{-1}$.

- a) Calculate the change in the momentum of the ball.

Take the direction towards the wall as positive.

$$\Delta p = mv_f - mv_i = (0.2)(-9) - (0.2)(12) = -4.2 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$$

- b) What is the impulse of the wall on the ball?

$$-4.2 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$$

- c) Calculate the magnitude of the force exerted by the wall on the ball if the collision takes 0,02 s.

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

$$F_{\text{net}} = \frac{-4.2}{0.02} = -210 \text{ N}$$

6. If the ball in the previous problem is replaced with a piece of clay of 200 g which is thrown against the wall with the same velocity, but then sticks to the wall, calculate:

- a) The impulse of the clay on the wall.
 Calculate the change in momentum of the clay:

$$\begin{aligned}\Delta \vec{p} &= m\vec{v}_f - m\vec{v}_i \\ &= (0,2)(0) - (0,2)(12) \\ &= -(0,2)(12) \\ &= -2,4 \\ &= 2,4 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1} \text{ away from the wall}\end{aligned}$$

The change in momentum of the wall is equal and opposite to the change in momentum of the clay, therefore:

$$\Delta \vec{p}_{wall} = 2,4 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1} \text{ into the wall}$$

The impulse on the wall is equivalent to its change in momentum, therefore

$$\text{impulse} = 2,4 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1} \text{ into the wall}$$

$$\text{impulse} = 2,4 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1} \text{ into the wall}$$

- b) The force exerted by the clay on the wall if it is in contact with the wall for 0,5 s before it comes to rest.

$$\begin{aligned}F &= \frac{\Delta \vec{p}}{\Delta t} \\ F &= \frac{2,4}{0,5} \\ &= 4,8 \text{ N into the wall}\end{aligned}$$

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1. 27HY 2. 27HZ 3. 27J2 4. 27J3 5. 27J4 6. 27J5



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2.6 Physics in action: Impulse

Exercise 2 – 6:

1. A cannon, mass 500 kg, fires a shell, mass 1 kg, horizontally to the right at 500 $\text{m}\cdot\text{s}^{-1}$. What is the magnitude and direction of the initial recoil velocity of the canon?

We treat the system as an isolated system and conserve momentum. We choose to the right to be the positive direction. The initial velocity of the system is zero.

Momentum conservation means that $\vec{p}_{Ti} = \vec{p}_{Tf}$:

$$\begin{aligned}
\vec{p}_{Ti} &= \vec{p}_{Tf} \\
0 &= m_{cannon}\vec{v}_{cf} + m_{shell}\vec{v}_{sf} \\
0 &= (500)\vec{v}_{cf} + (1)(+500) \\
-(500)\vec{v}_{cf} &= (1)(+500) \\
\vec{v}_{cf} &= \frac{500}{-500} \\
\vec{v}_{cf} &= -1 \\
\vec{v}_{cf} &= 1 \text{ m}\cdot\text{s}^{-1} \text{ towards the left}
\end{aligned}$$

The canon recoils at $1 \text{ m}\cdot\text{s}^{-1}$ towards the left.

2. A trolley of mass 1 kg is moving with a speed of $3 \text{ m}\cdot\text{s}^{-1}$. A block of wood, mass 0,5 kg, is dropped vertically into the trolley. Immediately after the collision, the speed of the trolley and block is $2 \text{ m}\cdot\text{s}^{-1}$. By way of calculation, show whether momentum is conserved in the collision.

We calculate the momentum of the system before and after the collision.

Before the collision the velocity of the block is 0. The momentum is:

$$\vec{p}_i = m_1\vec{v}_1 + m_2\vec{v}_2 = 0 + (1)(3) = 3 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1}$$

After the collision the momentum is:

$$\vec{p}_f = (m_1 + m_2)\vec{v} = (1 + 0,5)(2) = 3 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1}$$

Since the momentum before the collision is the same as the momentum after the collision, momentum is conserved.

3. A 7200 kg empty railway truck is stationary. A fertiliser firm loads 10 800 kg fertiliser into the truck. A second, identical, empty truck is moving at $10 \text{ m}\cdot\text{s}^{-1}$ when it collides with the loaded truck.

- a) If the empty truck stops completely immediately after the collision, use a conservation law to calculate the velocity of the loaded truck immediately after the collision.

We will take to the left as positive.

1. We can use the law of conservation of momentum.

$$\begin{aligned}
m_1v_{i1} + m_2v_{i2} &= m_1v_{f1} + m_2v_{f2} \\
(18000)(0) + (7200)(10) &= (18000)(v_{f1}) + (7200)(0) \\
v_{f1} &= 4 \text{ m}\cdot\text{s}^{-1} \text{ to the left}
\end{aligned}$$

- b) Calculate the distance that the loaded truck moves after collision, if a constant frictional force of 24 kN acts on the truck.

2. From the force we can get the acceleration:

$$F = ma$$

$$24 \times 10^3 = 18000a$$

$$a = 1,33 \text{ m}\cdot\text{s}^{-2}$$

Now we can use the equations of motion to find the distance.

$$\begin{aligned}
\vec{v}_f^2 &= \vec{v}_i^2 + 2a\Delta x \\
0 &= 4^2 + 2(1,33)(\Delta x)
\end{aligned}$$

$$\Delta x = 6,02 \text{ m} \text{ to the left}$$

4. A child drops a squash ball of mass 0,05 kg. The ball strikes the ground with a velocity of $4 \text{ m}\cdot\text{s}^{-1}$ and rebounds with a velocity of $3 \text{ m}\cdot\text{s}^{-1}$. Considering only the squash ball, does the law of conservation of momentum apply to this situation? Explain.

The principle of conservation of linear momentum states:

"The total linear momentum of an isolated system is constant. An isolated system has no forces acting on it from the outside."

This means that in an isolated system the total momentum before a collision or explosion is equal to the total momentum after the collision or explosion. Taking downwards as positive.

The momentum before the ball hits the floor is:

$$\begin{aligned}\vec{p}_{down} &= m\vec{v}_i \\ &= (0,05)(+4) \\ &= (0,2) \\ &= 0,2 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1} \text{ downwards}\end{aligned}$$

The momentum after the ball hits the floor is:

$$\begin{aligned}\vec{p}_{up} &= m\vec{v}_f \\ &= (0,05)(-3) \\ &= (0,15) \\ &= 0,15 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1} \text{ upwards}\end{aligned}$$

Since the momentum before the ball hits the floor is not equal to the momentum after the ball hits the floor the law of conservation of momentum does not apply to this situation.

We say that the system is not isolated and that there is a force acting on the ball from outside the system.

5. A bullet of mass 50 g travelling horizontally at $600 \text{ m}\cdot\text{s}^{-1}$ strikes a stationary wooden block of mass 2 kg resting on a smooth horizontal surface. The bullet gets stuck in the block.

- a) Name and state the principle which can be applied to find the speed of the block-and-bullet system after the bullet entered the block.

Conservation of momentum

- b) Calculate the speed of the bullet-and-block system immediately after impact.

$$\begin{aligned}m_1 v_{i1} + m_2 v_{i2} &= (m_1 + m_2) v_f \\ (0,05)(600) + (2)(0) &= (0,05 + 2)(v_f) \\ v_f &= 14,63 \text{ m}\cdot\text{s}^{-1} \\ \vec{v}_f &= 14,63 \text{ m}\cdot\text{s}^{-1}\end{aligned}$$

- c) If the time of impact was $5 \times 10^{-4} \text{ s}$, calculate the force that the bullet exerts on the block during impact.

Calculate the change in momentum of the bullet:

$$\begin{aligned}\Delta \vec{p}_{bullet} &= m(\vec{v}_f - \vec{v}_i) \\ &= 0,05(14,63 - 600) \\ &= -29,27 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1}\end{aligned}$$

The bullet's change in momentum is equal and opposite to the impulse on the block:

$$\begin{aligned}\text{impulse} &= \vec{F} \Delta t \\ \vec{F} &= \frac{29,27}{5 \times 10^{-4}} \\ \vec{F} &= 58\,540 \text{ N}\end{aligned}$$

$$\vec{F} = 58\,540 \text{ N}$$

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1. 27J6 2. 27J7 3. 27J8 4. 27J9 5. 27JB



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Chapter summary

Exercise 2 – 7: Momentum

1. [SC 2003/11] A projectile is fired vertically upwards from the ground. At the highest point of its motion, the projectile explodes and separates into two pieces of equal mass. If one of the pieces is projected vertically upwards after the explosion, the second piece will...

- a) drop to the ground at zero initial speed.
- b) be projected downwards at the same initial speed as the first piece.
- c) be projected upwards at the same initial speed as the first piece.
- d) be projected downwards at twice the initial speed as the first piece.

be projected downwards at the same initial speed as the first piece.

2. [IEB 2004/11 HG1] A ball hits a wall horizontally with a speed of $15 \text{ m}\cdot\text{s}^{-1}$. It rebounds horizontally with a speed of $8 \text{ m}\cdot\text{s}^{-1}$. Which of the following statements about the system of the ball and the wall is **true**?

- a) The total linear momentum of the system is not conserved during this collision.
- b) The law of conservation of energy does not apply to this system.
- c) The change in momentum of the wall is equal to the change in momentum of the ball.
- d) Energy is transferred from the ball to the wall.

The change in momentum of the wall is equal to the change in momentum of the ball.

3. [IEB 2001/11 HG1] A block of mass M collides with a stationary block of mass $2M$. The two blocks move off together with a velocity of \vec{v} . What is the velocity of the block of mass M immediately **before** it collides with the block of $2M$?

- a) \vec{v}
- b) $2\vec{v}$
- c) $3\vec{v}$
- d) $4\vec{v}$

$$M\vec{v}_{1i} + 2M\vec{v}_{2i} = (M + 2M)\vec{v}$$

$$M\vec{v}_{1i} = 3M\vec{v}$$

$$\vec{v}_{1i} = 3\vec{v}$$

$$3\vec{v}$$

4. [IEB 2003/11 HG1] A cricket ball and a tennis ball move horizontally towards you with the same momentum. A cricket ball has greater mass than a tennis ball. You apply the same force in stopping each ball.

How does the time taken to stop each ball compare?

- a) It will take longer to stop the cricket ball.
- b) It will take longer to stop the tennis ball.
- c) It will take the same time to stop each of the balls.
- d) One cannot say how long without knowing the kind of collision the ball has when stopping.

Since their momenta are the same, and the stopping force applied to them is the same, it will take the same time to stop each of the balls.

5. [IEB 2004/11 HG1] Two identical billiard balls collide head-on with each other. The first ball hits the second ball with a speed of V , and the second ball hits the first ball with a speed of $2V$. After the collision, the first ball moves off in the opposite direction with a speed of $2V$. Which expression correctly gives the speed of the second ball after the collision?

- a) V
- b) $2V$
- c) $3V$
- d) $4V$

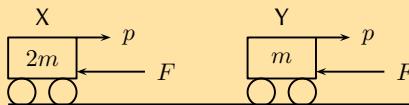
V

6. [SC 2002/11 HG1] Which one of the following physical quantities is the same as the rate of change of momentum?

- a) resultant force
- b) work
- c) power
- d) impulse

resultant force

7. [IEB 2005/11 HG] Cart X moves along a smooth track with momentum p . A resultant force F applied to the cart stops it in time t . Another cart Y has only half the mass of X, but it has the same momentum p .



In what time will cart Y be brought to rest when the same resultant force F acts on it?

- a) $\frac{1}{2}t$
- b) t
- c) $2t$
- d) $4t$

t

8. [SC 2002/03 HG1] A ball with mass m strikes a wall perpendicularly with a speed, v . If it rebounds in the opposite direction with the same speed, v , the magnitude of the change in momentum will be ...

- a) $2mv$
- b) mv
- c) $\frac{1}{2}mv$
- d) $0mv$

$2mv$

9. Show that impulse and momentum have the same units.

The units of momentum are: $mv = \text{kg} \cdot \text{m} \cdot \text{s}^{-1}$

Impulse can be defined as force over total time:

$$F\Delta t = \text{N} \cdot \text{s} = \text{kg} \cdot \text{m} \cdot \text{s}^{-1}$$

This is the same as the units for momentum.

10. A golf club exerts an average force of 3 kN on a ball of mass 0,06 kg. If the golf club is in contact with the golf ball for 5×10^{-4} seconds, calculate

- a) the change in the momentum of the golf ball.

$$\Delta p = F_{\text{net}}\Delta t = (3 \times 10^3) (5 \times 10^{-4}) = 1.5 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$$

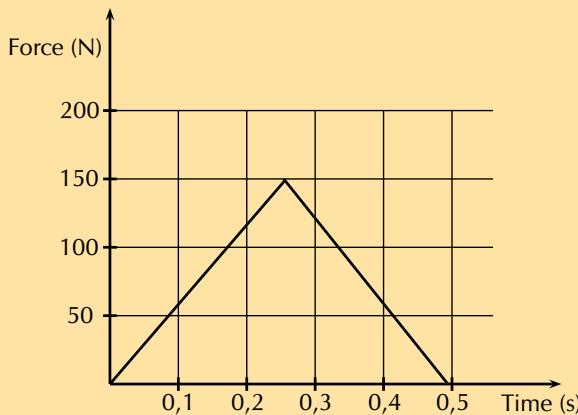
- b) the velocity of the golf ball as it leaves the club.

$$\Delta p = mv$$

$$1.5 = 0.06v$$

$$v = 25 \text{ m} \cdot \text{s}^{-1}$$

11. During a game of hockey, a player strikes a stationary ball of mass 150 g. The graph below shows how the force of the ball varies with the time.



- a) What does the area under this graph represent?

Impulse

- b) Calculate the speed at which the ball leaves the hockey stick.

$$\text{Impulse} = F\Delta t = \Delta p = m\Delta v$$

The impulse is the area under the graph $\text{Impulse} = (0, 5) (150) (0, 5) = 37,5 \text{ N} \cdot \text{s}$

$$\Delta v = \frac{37,5}{0,150} = 250 \text{ m} \cdot \text{s}^{-1}$$

$$250 \text{ m} \cdot \text{s}^{-1}$$

- c) The same player hits a practice ball of the same mass, but which is made from a softer material. The hit is such that the ball moves off with the same speed as before. How will the **area**, the **height** and the **base** of the triangle that forms the graph, compare with that of the original ball?

The area will remain the same because the final velocity and the mass are the same. The duration of the contact between the bat and the ball will be longer as the ball is soft, so the base will be wider. In order for the area to be the same, the height must be lower. Therefore, the player can hit the softer ball with less force to impart the same velocity on the ball.

12. The fronts of modern cars are deliberately designed in such a way that in case of a head-on collision, the front would crumple. Why is it desirable that the front of the car should crumple?

If the front crumples then the force of the collision is reduced. The energy of the collision would go into making the front of the car crumple and so the passengers in the car would feel less force.

13. [SC 2002/11 HG1] In a railway shunting yard, a locomotive of mass 4000 kg, travelling due east at a velocity of $1,5 \text{ m}\cdot\text{s}^{-1}$, collides with a stationary goods wagon of mass 3000 kg in an attempt to couple with it. The coupling fails and instead the goods wagon moves due east with a velocity of $2,8 \text{ m}\cdot\text{s}^{-1}$.

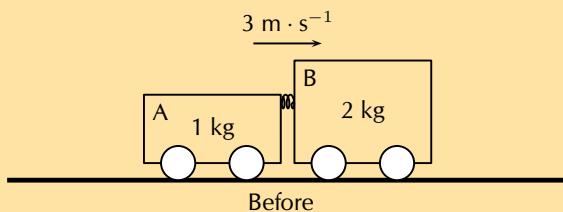
- a) Calculate the magnitude and direction of the velocity of the locomotive immediately after collision.

$$\begin{aligned}m_1 v_{i1} + m_2 v_{i2} &= m_1 v_{f1} + m_2 v_{f2} \\(4000)(1,5) &= (3000)(2,8) + (4000)v_{f2} \\v_{f2} &= -0,6 \text{ m}\cdot\text{s}^{-1} = 0,6 \text{ m}\cdot\text{s}^{-1} \text{ west}\end{aligned}$$

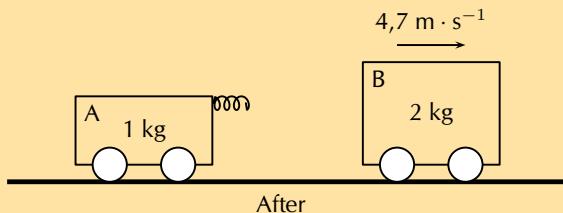
- b) Name and state in words the law you used to answer the previous question

The principle of conservation of linear momentum. The total linear momentum of an isolated system is constant.

14. [SC 2005/11 SG1] A combination of trolley A (fitted with a spring) of mass 1 kg, and trolley B of mass 2 kg, moves to the right at $3 \text{ m}\cdot\text{s}^{-1}$ along a frictionless, horizontal surface. The spring is kept compressed between the two trolleys.



While the combination of the two trolleys is moving at $3 \text{ m}\cdot\text{s}^{-1}$, the spring is released and when it has expanded completely, the 2 kg trolley is then moving to the right at $4,7 \text{ m}\cdot\text{s}^{-1}$ as shown below.



- a) State, in words, the principle of *conservation of linear momentum*.

The total linear momentum of an isolated system is constant.

- b) Calculate the magnitude and direction of the velocity of the 1 kg trolley immediately after the spring has expanded completely.

$$\begin{aligned}(m_1 + m_2)\vec{v}_i &= m_1 \vec{v}_{f1} + m_2 \vec{v}_{f2} \\(2 + 1)(3) &= (2,7)(2) + (1)\vec{v}_{f2} \\\vec{v}_{f2} &= -0,4 \text{ m}\cdot\text{s}^{-1}\end{aligned}$$

$\vec{v}_{f2} = 0,4 \text{ m}\cdot\text{s}^{-1}$ to the left
 $0,4 \text{ m}\cdot\text{s}^{-1}$ to the left

15. [IEB 2002/11 HG1] A ball bounces back from the ground. Which of the following statements is true of this event?

- a) The magnitude of the change in momentum of the ball is equal to the magnitude of the change in momentum of the Earth.
- b) The magnitude of the impulse experienced by the ball is greater than the magnitude of the impulse experienced by the Earth.
- c) The speed of the ball before the collision will always be equal to the speed of the ball after the collision.

- d) Only the ball experiences a change in momentum during this event.

The magnitude of the change in momentum of the ball is equal to the magnitude of the change in momentum of the Earth.

16. [SC 2002/11 SG] A boy is standing in a small stationary boat. He throws his schoolbag, mass 2 kg, horizontally towards the jetty with a velocity of $5 \text{ m}\cdot\text{s}^{-1}$. The *combined mass* of the boy and the boat is 50 kg.

- a) Calculate the magnitude of the horizontal momentum of the bag immediately after the boy has thrown it.

$$p = mv = (2)(5) = 10 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1}$$

- b) Calculate the velocity (magnitude and direction) of the *boat-and-boy* immediately after the bag is thrown.

$$\begin{aligned}0 &= m_1 \vec{v}_{1f} + m_2 \vec{v}_{2f} \\-10 &= (50) \vec{v}_{2f} \\\vec{v}_{2f} &= \frac{-10}{50} \\&= -0,2 \text{ m}\cdot\text{s}^{-1}\end{aligned}$$

$0,2 \text{ m}\cdot\text{s}^{-1}$ in the opposite direction to the jetty

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1. 27JD 2. 27JF 3. 27JG 4. 27JH 5. 27JJ 6. 27JK
7. 27JM 8. 27JN 9. 27JP 10. 27JQ 11. 27JR 12. 27JS
13. 27JT 14. 27JV 15. 27JW 16. 27JX



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CHAPTER

3

Vertical projectile motion in one dimension

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3.1 Introduction

- Understand the principle of free falling under gravity with a constant acceleration for an upwards and downwards motion.
- Know that it's only vertical displacement no horizontal displacement.
- Always move only under the influence of only gravity.
- The meaning of time symmetry and the magnitude of velocity.
- Do an experiment to measure the position and time during a motion.
- Calculations done on projectiles by knowing how to use a single set of equations.
- Graphical representations of the equations of motion - Draw graphs for the projectiles motions.
- Deduct equations and determine the position, displacement, velocity or acceleration from the graphs.
- Describe the motion of the object from the graphs.

Key Mathematics Concepts

- Units and unit conversions — Physical Sciences, Grade 10, Science skills
- Rectilinear motion — Physical Sciences, Grade 10, Todo
- Linear equations — Mathematics, Grade 10, Todo
- Quadratic equations — Mathematics, Grade 10, Todo

3.2 Vertical projectile motion

Equations of motion

Exercise 3 – 1: Equations of motion

1. A cricketer hits a cricket ball straight up into the air. The cricket ball has an initial velocity of $20 \text{ m}\cdot\text{s}^{-1}$ vertically upwards.
 - a) What height does the ball reach before it stops to fall back to the ground.
 - b) How long has the ball been in the air for?
 - a) Note that the final velocity is 0 at the maximum height that the ball reaches. (Take upwards as +ve direction.)

$$\begin{aligned}\vec{v}_f^2 &= \vec{v}_i^2 + 2\vec{g}\Delta\vec{x} \\ \Delta\vec{x} &= \frac{\vec{v}_i^2}{2\vec{g}} \\ &= \frac{-(20^2)}{(2)(-9,8)} \\ &= 20,41 \text{ m}\end{aligned}$$

b)

$$\begin{aligned}\vec{v}_f &= \vec{v}_i + \vec{g}t \\ t &= \frac{\vec{v}_f - \vec{v}_i}{\vec{g}} \\ &= \frac{0 - 20}{-9,8} \\ &= 2,04 \text{ s}\end{aligned}$$

a) 20,41 m

b) 2,04 s

2. Zingi throws a tennis ball straight up into the air. It reaches a height of 80 cm.

a) Determine the initial velocity of the tennis ball.

b) How long does the ball take to reach its maximum height?

a) We first convert the height given to m:

$$\frac{80}{100} = 0,8 \text{ m}$$

$$\begin{aligned}\vec{v}_f^2 &= \vec{v}_i^2 + 2\vec{g}\Delta\vec{x} \\ 0 &= \vec{v}_i^2 + 2(-9,8)(0,8) \\ \vec{v}_i^2 &= 15,68 \\ \vec{v}_i &= 3,96 \text{ m}\cdot\text{s}^{-1}\end{aligned}$$

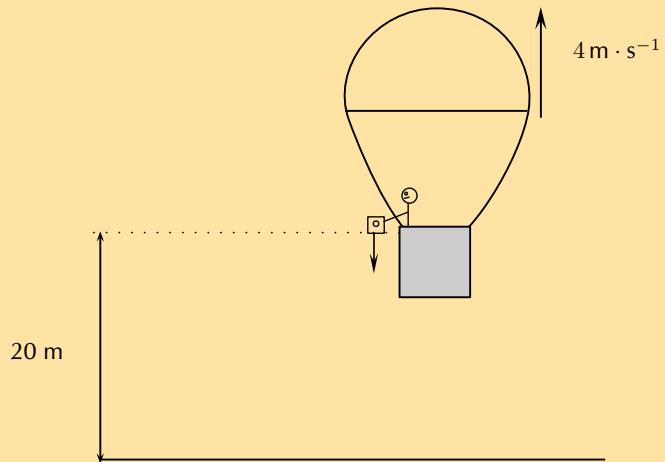
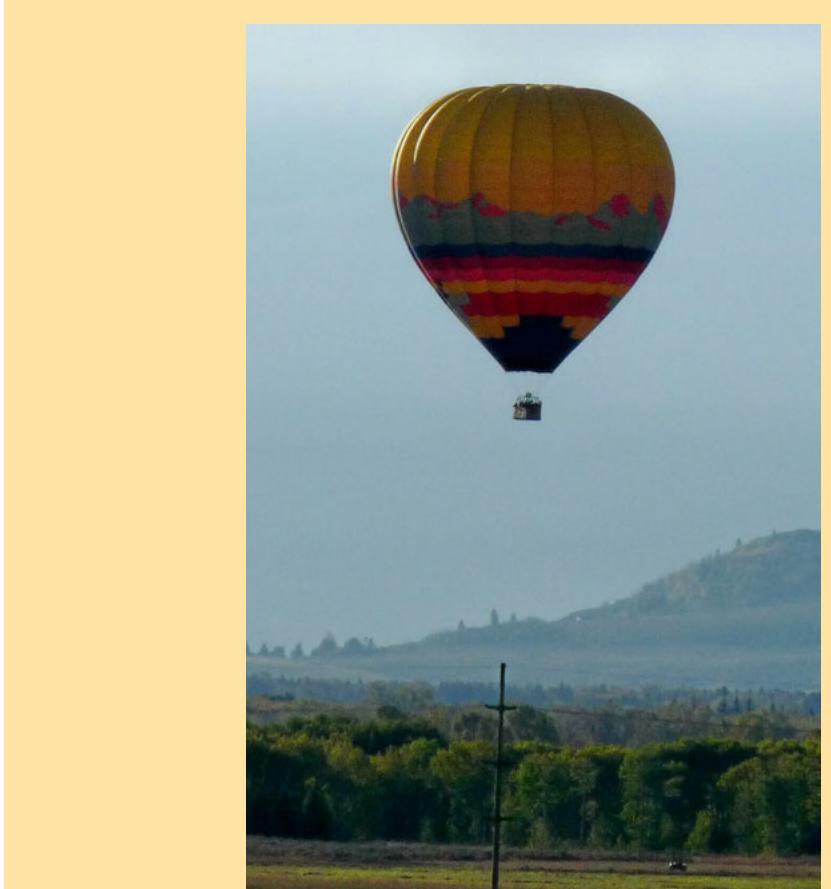
b)

$$\begin{aligned}\vec{v}_f &= \vec{v}_i + \vec{g}t \\ 0 &= 3,96 + (-9,8)(t) \\ 9,8t &= 3,96 \\ t &= 0,4 \text{ s}\end{aligned}$$

a) $3,96 \text{ m}\cdot\text{s}^{-1}$ upwards

b) 0,4 s

3. A tourist takes a trip in a hot air balloon. The hot air balloon is ascending (moving up) at a velocity of $4 \text{ m}\cdot\text{s}^{-1}$ vertically upwards. He accidentally drops his camera over the side of the balloon's basket, at a height of 20 m. Calculate the velocity with which the camera hits the ground.



Draw a rough sketch:

We now calculate the additional height above the ground that the camera reaches:

$$\begin{aligned}\vec{v}_f^2 &= \vec{v}_i^2 + 2\vec{g}\Delta\vec{x} \\ \Delta\vec{x} &= \frac{14^2}{2(9,8)} \\ &= 0,82 \text{ m}\end{aligned}$$

So the total height above the ground is 20,82 m.

$$\vec{v}_f^2 = \vec{v}_i^2 + 2\vec{g}\Delta\vec{x}$$

$$\vec{v}_f^2 = 2(9,8)(20,82) = 408,072$$

$$\vec{v}_f = 20,2 \text{ m}\cdot\text{s}^{-1}$$

$$20,2 \text{ m}\cdot\text{s}^{-1}$$

4. A ball is dropped vertically from a tower. If the vertical distance covered in the last second is equal to the distance covered in first three seconds, find the height of the tower.

Let us consider that the ball covers the height y_n in n^{th} second. Then, the distance covered in the n^{th} second is given as :

$$y_n = u + \frac{g}{2} x (2n - 1) = 0 + \frac{10}{2} x (2n - 1) = 10n - 5$$

On the other hand, the distance covered in first 3 seconds is :

$$y_3 = ut + \frac{1}{2}gt^2 = 0 + \frac{1}{2} x 10 x 3^2 = 45 \text{ m}$$

According to question,

$$y_n = y_3$$

$$10n - 5 = 45$$

$$n = 5 \text{ s}$$

Therefore, the height of the tower is :

$$y = \frac{1}{2} x 10 x 5^2 = 125 \text{ m}$$

$$125 \text{ m}$$

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1. 27K3 2. 27K4 3. 27K5 4. 27K6



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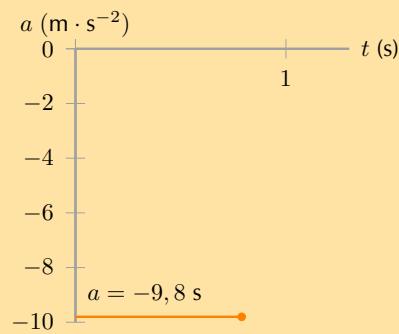
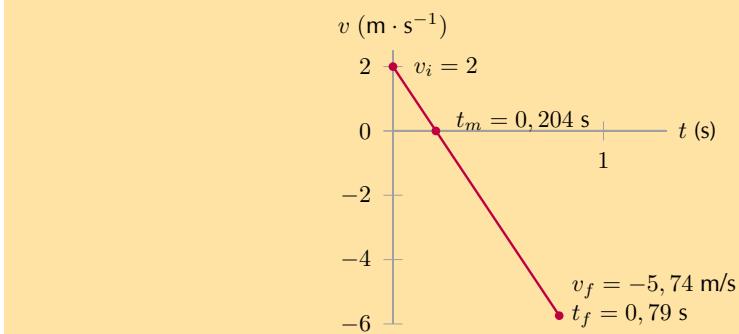
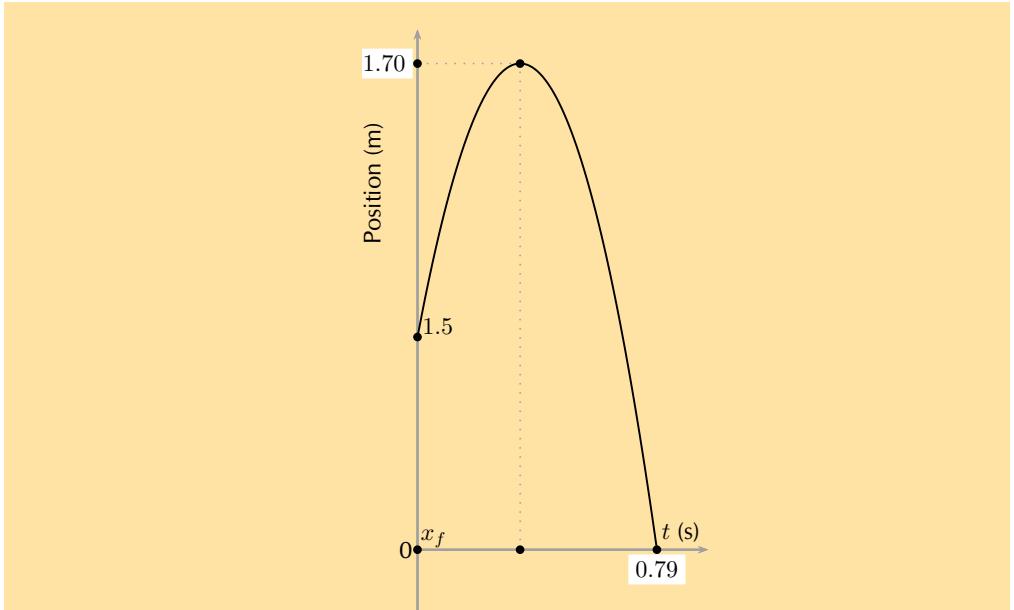


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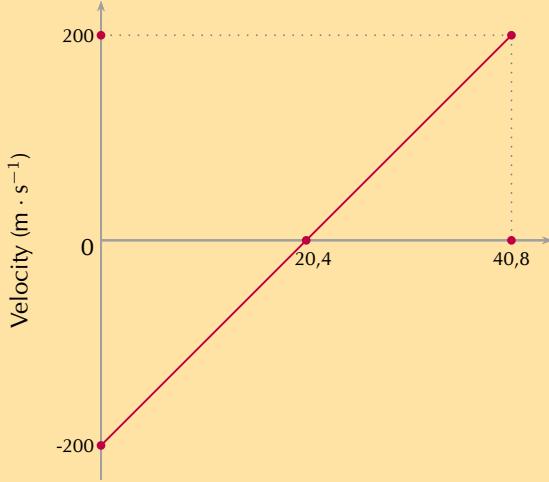
Graphs of vertical projectile motion

Exercise 3 – 2: Graphs of vertical projectile motion

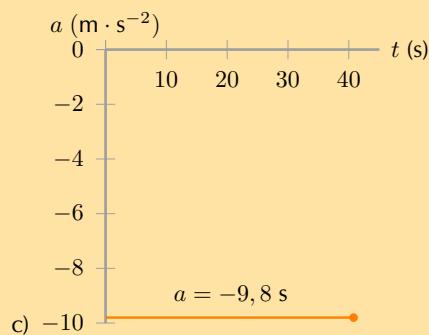
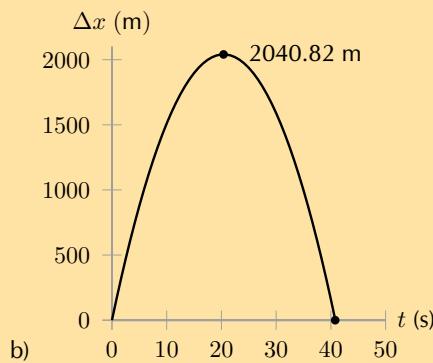
1. Amanda throws a tennis ball from a height of 1,5 m straight up into the air and then lets it fall to the ground. Draw graphs of x vs t ; v vs t and a vs t for the motion of the ball. The initial velocity of the tennis ball is $2\text{m}\cdot\text{s}^{-1}$. Choose upwards as positive.



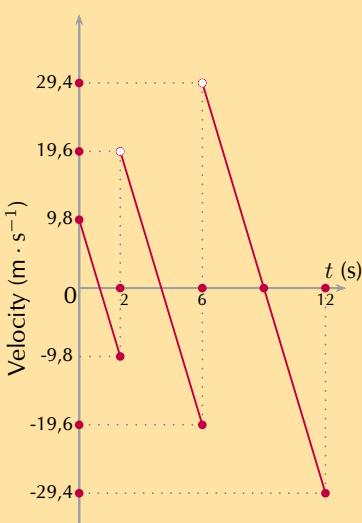
2. A bullet is shot straight upwards from a gun. The following graph is drawn. Downwards was chosen as positive
- Describe the motion of the bullet.
 - Draw a displacement - time graph.
 - Draw an acceleration - time graph.



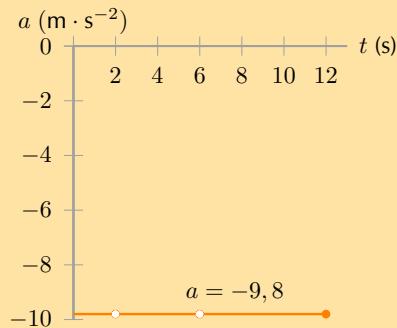
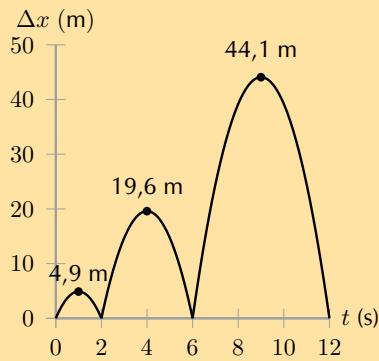
- a) The bullet moves at a decreasing velocity upwards for 20,4 s. It then stops and drops back down for another 20,4 s until it reaches a speed of $200 \text{ m} \cdot \text{s}^{-1}$ which is the same speed with which it started.



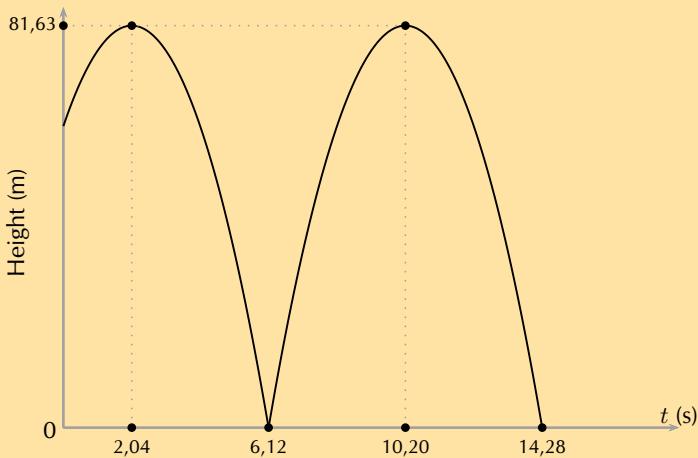
3. Describe the motion resulting from the velocity vs time graph shown below, assuming an initial height of 0 m, and draw a displacement vs time graph and an acceleration vs time graph:



The object starts with an initial height of 0 m, moves upwards for 1 s, then slows and falls back to its starting position where it bounces upwards at a higher velocity, and travels upwards (higher than before) for 2 s, then stops and falls back to its starting position where it bounces upwards again at an even higher velocity, travelling over 3 s to an even higher position, before finally falling back to the ground and stopping.



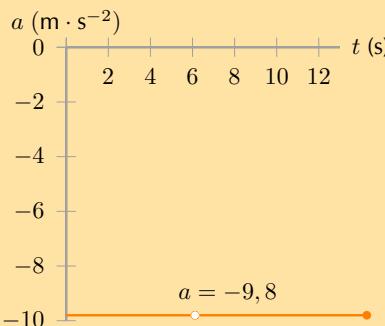
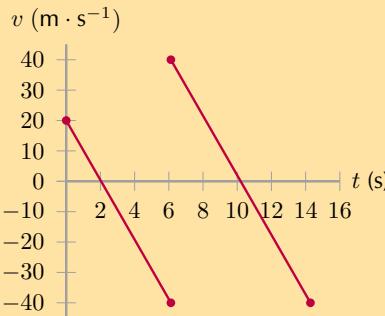
4. What is the initial height? Draw a velocity vs time graph and an acceleration vs time graph that would result in this displacement vs time graph:



Calculate starting height, we can use time symmetry. The initial height is at time zero and the max is at time 2,04 s. The ball will fall back to the same height as the initial height in 2,04 s, therefore:

$$\begin{aligned}s &= \frac{1}{2}\vec{g}t^2 \\&= \frac{1}{2}(9,8)(2,04)^2 \\&= 20,39 \text{ downwards}\end{aligned}$$

Therefore initial height is $81.63 - 20.39 = 61.24$ m.



5. A ball that always bounces off the floor with the same magnitude of the velocity as it hit the floor is dropped from 3 m above a stack of 4 crates. Each crate is 30 cm high. After the ball bounces off a crate it is quickly removed so that the next time the ball bounces it bounces off the next crate in the pile. This is repeated until all the crates have been removed. Draw the following graphs for the situation:

- Displacement vs time
- Velocity vs time
- Acceleration vs time

The time in each case for the ball to fall from maximum to the crate can be calculated from the distance:

$$s = ut + \frac{1}{2}gt^2$$

$$(u = 0)$$

$$s = \frac{1}{2}gt^2$$

$$\frac{2s}{g} = t^2$$

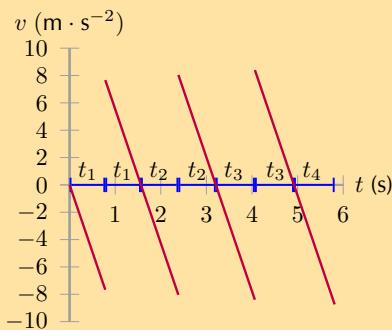
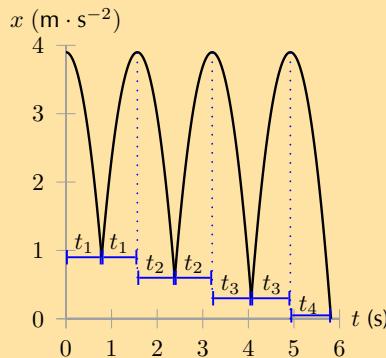
$$t = \sqrt{\frac{2s}{g}}$$

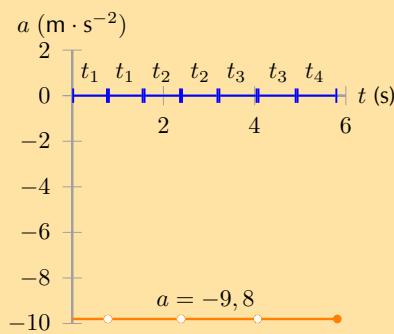
The ball bounces perfectly which means it always bounces back to the original height. The distances for each bounce are then:

- $x_1 = 3 \text{ m}$
- $x_2 = 3,3 \text{ m}$
- $x_3 = 3,6 \text{ m}$
- $x_4 = 3,9 \text{ m}$

The times to drop these distances under gravitational acceleration from rest are then:

- $x_1 = 3 \text{ m} ; t_1 = 0,782460 \text{ s}$
- $x_2 = 3,3 \text{ m} ; t_2 = 0,820651 \text{ s}$
- $x_3 = 3,6 \text{ m} ; t_3 = 0,857142 \text{ s}$
- $x_4 = 3,9 \text{ m} ; t_4 = 0,892142 \text{ s}$
- $x_1 = 3 \text{ m} ; t_1 = 0,782460 \text{ s}$
- $x_2 = 3,3 \text{ m} ; t_2 = 0,820651 \text{ s}$
- $x_3 = 3,6 \text{ m} ; t_3 = 0,857142 \text{ s}$
- $x_4 = 3,9 \text{ m} ; t_4 = 0,892142 \text{ s}$





6. A ball is dropped from 4 m above a cushioned mat. Each time the ball bounces the magnitude of the velocity in the upwards direction is half the magnitude of the velocity with which it hit the floor. The ball is allowed to bounce 2 times, draw the following graphs for the situation and the equation describing each section of the graph:

- Displacement vs time
- Velocity vs time
- Acceleration vs time

The time in each case for the ball to fall from maximum to the mat can be calculated from the distance:

$$\begin{aligned}
 s &= ut + \frac{1}{2}gt^2 \\
 (u = 0) \\
 s &= \frac{1}{2}gt^2 \\
 \frac{2s}{g} &= t^2 \\
 t &= \sqrt{\frac{2s}{g}}
 \end{aligned}$$

We calculate the velocity with which it hits the mat from:

$$v^2 = u^2 + 2gs$$

After the bounce it has an initial velocity upwards of 1/2 the magnitude that it hit with. We use this reduced initial velocity to calculate the new height.

$$v^2 = u^2 + 2gs$$

a) First motion:

$$\begin{aligned}
 v_{1f}^2 &= 2gs \\
 v_{1f}^2 &= 2(9,8)(4) \\
 v_{1f} &= \sqrt{2(9,8)(4)} \\
 v_{f1} &= 8,854377 \text{ m}\cdot\text{s}^{-1}
 \end{aligned}$$

Time to fall from max:

$$\begin{aligned}
 s_1 &= ut + \frac{1}{2}gt_1^2 \\
 (u = 0) \\
 s_1 &= \frac{1}{2}gt_1^2 \\
 \frac{2s_1}{g} &= t_1^2 \\
 t_1 &= \sqrt{\frac{2s_1}{g}} \\
 t_1 &= \sqrt{\frac{2(4)}{9,8}} \\
 &= 0,9035079 \text{ s}
 \end{aligned}$$

b) First bounce, height attained:

$$\begin{aligned}
 v_{max}^2 &= v_{i2}^2 + 2gs \\
 (v_{max} = 0) \\
 -(0.5 * 8.854377)^2 &= 2(-9,8)s \\
 s_2 &= \frac{-(0.5 * 8.854377)^2}{2(-9,8)} \\
 s_2 &= 1,00000 \text{ m}
 \end{aligned}$$

Time to fall from max:

$$\begin{aligned}
 s_2 &= \frac{1}{2}gt_2^2 \\
 (v_i = 0) \\
 s_2 &= \frac{1}{2}gt_2^2 \\
 \frac{2s_2}{g} &= t_2^2 \\
 t_2 &= \sqrt{\frac{2s_2}{g}} \\
 t_2 &= \sqrt{\frac{2(1)}{9,8}} \\
 &= 0,45175395 \text{ s}
 \end{aligned}$$

c) Second bounce, height attained:

$$\begin{aligned}
 v_{max}^2 &= v_{i3}^2 + 2gs \\
 (v_{max} = 0) \\
 -(0.5 * 0.5 * 8.854377)^2 &= 2(-9,8)s_3 \\
 s_3 &= \frac{-(0.5 * 0.5 * 8.854377)^2}{2(-9,8)} \\
 s_3 &= 0,25000 \text{ m}
 \end{aligned}$$

Time to fall from max:

$$s_3 = \frac{1}{2}gt_3^2$$

$$(u = 0)$$

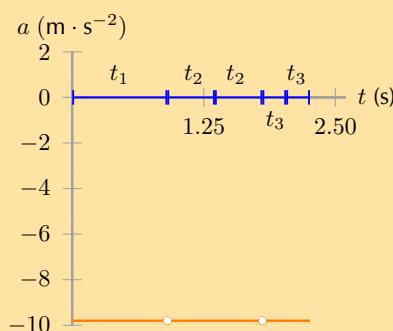
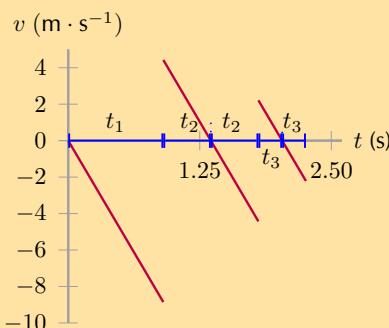
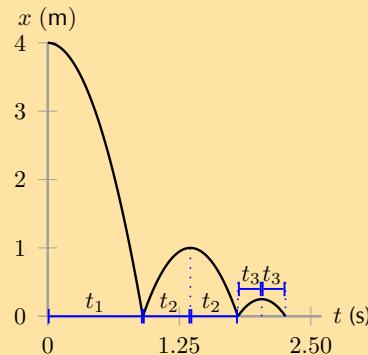
$$s_3 = \frac{1}{2}gt_3^2$$

$$\frac{2s_3}{g} = t_3^2$$

$$t_3 = \sqrt{\frac{2s_3}{g}}$$

$$t_3 = \sqrt{\frac{2(0.25000)}{9.8}}$$

$$= 0.225877$$



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1. 27K7 2. 27K8 3. 27K9 4. 27KB 5. 27KC 6. 27KD



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3.3 Chapter summary

Exercise 3 – 3:

1. [SC 2001/11 HG1] A bullet fired vertically upwards reaches a maximum height and falls back to the ground.

Which **one** of the following statements is **true** with reference to the acceleration of the bullet during its motion, if air resistance is ignored? The acceleration:

- a) is always downwards
- b) is first upwards and then downwards
- c) is first downwards and then upwards
- d) decreases first and then increases

is always downwards

2. [IIEB 2002/11 HG1] Two balls, P and Q, are simultaneously thrown into the air from the same height above the ground. P is thrown vertically upwards and Q vertically downwards with the same initial speed. Which of the following is true of both balls just before they hit the ground? (Ignore any air resistance. Take downwards as the positive direction.)

	Velocity	Acceleration
A	The same	The same
B	P has a greater velocity than Q	P has a negative acceleration; Q has a positive acceleration
C	P has a greater velocity than Q	The same
D	The same	P has a negative acceleration; Q has a positive acceleration

A. The same velocity and the same acceleration.

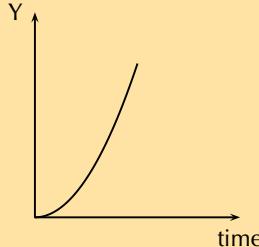
3. [SC 2003/11] A ball X of mass m is projected vertically upwards at a speed u_x from a bridge 20 m high. A ball Y of mass $2m$ is projected vertically downwards from the same bridge at a speed of u_y . The two balls reach the water at the same speed. Air friction can be ignored.

Which of the following is true with reference to the speeds with which the balls are projected?

- a) $u_x = \frac{1}{2}u_y$
- b) $u_x = u_y$
- c) $u_x = 2u_y$
- d) $u_x = 4u_y$

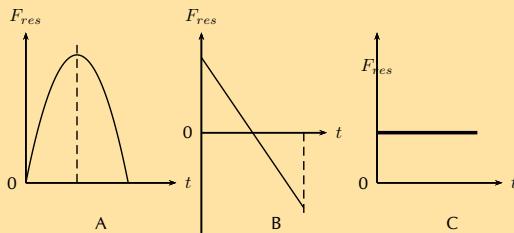
- b) $u_x = u_y$

4. [SC 2002/03 HG1] A stone falls freely from rest from a certain height. Which one of the following quantities could be represented on the y-axis of the graph below?



- a) velocity
 b) acceleration
 c) momentum
 d) displacement
- d) displacement
5. A stone is thrown vertically upwards and it returns to the ground. If friction is ignored, its acceleration as it reaches the highest point of its motion is
- greater than just after it left the thrower's hand.
 - less than just before it hits the ground.
 - the same as when it left the thrower's hand.
 - less than it will be when it strikes the ground.
- c) the same as when it left the thrower's hand.

6. [IEB 2004/11 HG1] A stone is thrown vertically up into the air. Which of the following graphs best shows the resultant force exerted on the stone against time while it is in the air? (Air resistance is negligible.)



C - the force is constant since the acceleration is constant.

7. What is the velocity of a ball just as it hits the ground if it is thrown upward at $10 \text{ m}\cdot\text{s}^{-1}$ from a height 5 meters above the ground?

The ball will travel upwards, stop at its highest point, and then fall back down to the ground. As it reaches the initial position of 5 metres above the ground, it will be travelling once again at $10 \text{ m}\cdot\text{s}^{-1}$ but this time in the downwards direction. Taking downwards as the +ve direction:

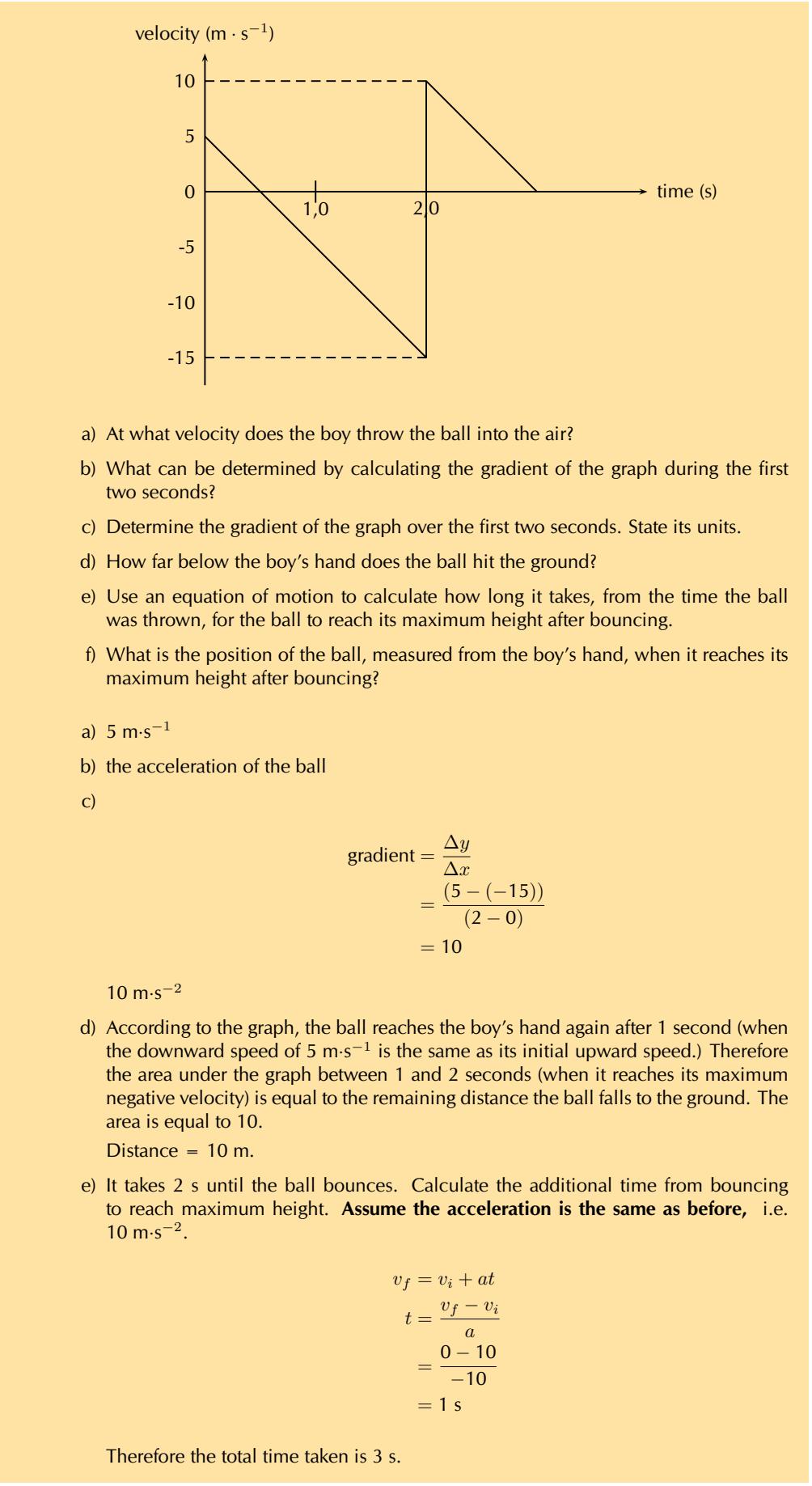
$$\begin{aligned}
 v_f^2 &= v_i^2 + 2a\Delta x \\
 &= (10)^2 + 2(9,8)(5) \\
 &= 198 \\
 v_f &= \sqrt{198} = 14,07 \text{ m}\cdot\text{s}^{-1}
 \end{aligned}$$

8. [IEB 2002/11 HG1 - Bouncing Ball]

A ball bounces vertically on a hard surface after being thrown vertically up into the air by a boy standing on the ledge of a building.

Just before the ball hits the ground for the first time, it has a velocity of magnitude $15 \text{ m}\cdot\text{s}^{-1}$. Immediately, after bouncing, it has a velocity of magnitude $10 \text{ m}\cdot\text{s}^{-1}$.

The graph below shows the velocity of the ball as a function of time from the moment it is thrown upwards into the air until it reaches its maximum height after bouncing once.



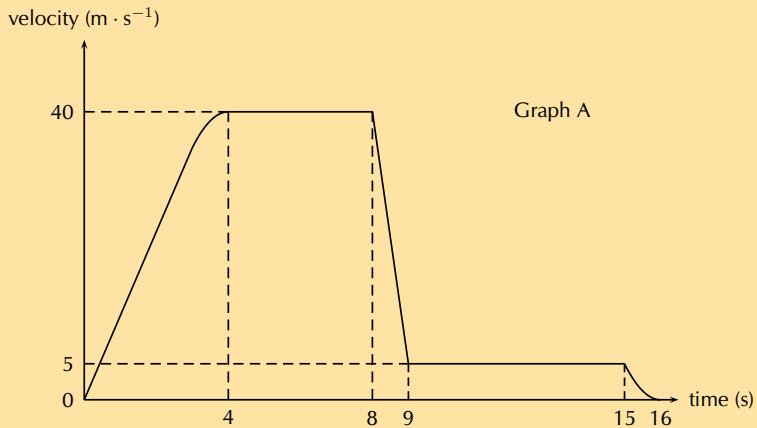
- f) Calculate the area under the graph for the final 1 second or use equation of motion to find maximum height after the bounce:

$$\begin{aligned}\Delta x &= v_i t + \frac{1}{2} a t^2 \\ &= (10)(1) + \frac{1}{2}(-10)(1)^2 \\ &= 5 \text{ m}\end{aligned}$$

Therefore the position of the ball, measured from the boy's hand is $5 \text{ m} - 5 \text{ m} = 0 \text{ m}$. In other words, it is the same height as the boy's hand.

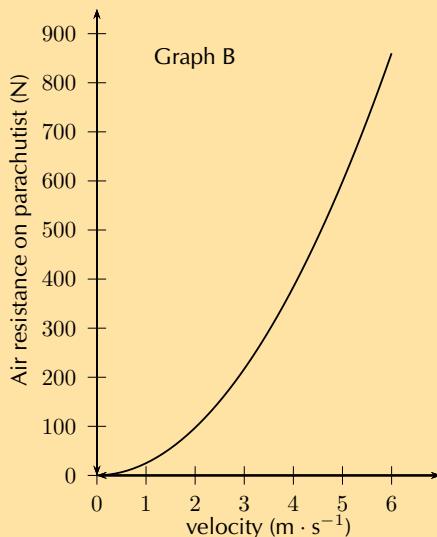
9. [IEB 2001/11 HG1] - Free Falling?

A parachutist steps out of an aircraft, flying high above the ground. She falls for the first 8 seconds before opening her parachute. A graph of her velocity is shown in Graph A below.



- Use the information from the graph to calculate an approximate height of the aircraft when she stepped out of it (to the nearest 10 m).
- What is the magnitude of her velocity during her descent with the parachute fully open?

The air resistance acting on the parachutist is related to the speed at which the parachutist descends. Graph B shows the relationship between air resistance and velocity of the parachutist descending with the parachute open.



- Use Graph B to find the magnitude of the air resistance on her parachute when she was descending with the parachute open.

d) Assume that the mass of the parachute is negligible. Calculate the mass of the parachutist showing your reasoning clearly.

a) Calculate the area under the graph to find the total height she falls. For the first 4 s, approximate area with a triangle:

$$\begin{aligned}\Delta x_1 &= \frac{1}{2} \text{base} \times \text{height} \\ &= \frac{1}{2}(4)(40) \\ &= 80 \text{ m}\end{aligned}$$

For the time 4-8 s:

$$\begin{aligned}\Delta x_2 &= \text{base} \times \text{height} \\ &= (4)(40) \\ &= 160 \text{ m}\end{aligned}$$

For the time 8-9 s, approximate area with a triangle plus a square:

$$\begin{aligned}\Delta x_3 &= \frac{1}{2} \text{base} \times \text{height} + \text{base} \times \text{height}_2 \\ &= \frac{1}{2}(1)(35) + (1)(5) \\ &= 22,5 \text{ m}\end{aligned}$$

For the time 9-15 s, approximate area with a rectangle:

$$\begin{aligned}\Delta x_4 &= (6)(5) \\ &= 30 \text{ m}\end{aligned}$$

For the time 15-16 s, approximate area with a triangle:

$$\begin{aligned}\Delta x_5 &= \frac{1}{2}(1)(5) \\ &= 2,5 \text{ m}\end{aligned}$$

Total distance fallen = 80 m + 160 m + 22,5 m + 30 m + 2,5 m = 295 m .

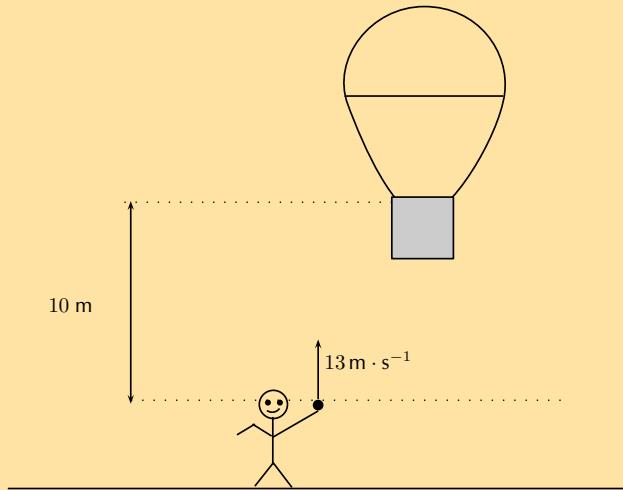
Rounded to the nearest 10 m is 300 m

- b) $5 \text{ m} \cdot \text{s}^{-1}$
c) 600 N
d) Once the parachute is open, the parachutist falls at constant speed, implying that her net acceleration is zero. Therefore the force on her due to gravity and the force on her due to air resistance are equal and opposite:

$$\begin{aligned}\vec{F}_g &= \vec{F}_{\text{air}} \\ mg &= 600 \text{ N} \\ m(9,8) &= 600 \text{ N} \\ m &= 61,22 \text{ kg}\end{aligned}$$

- a) 300 m
b) $5 \text{ m} \cdot \text{s}^{-1}$
c) 600 N
d) 61,22 kg

10. Niko, in the basket of a hot-air balloon, is stationary at a height of 10 m above the level from where his friend, Bongi, will throw a ball. Bongi intends throwing the ball upwards and Niko, in the basket, needs to **descend** (move downwards) to catch the ball at its maximum height.



Bongi throws the ball upwards with a velocity of $13 \text{ m} \cdot \text{s}^{-1}$. Niko starts his descent at the same instant the ball is thrown upwards, by letting air escape from the balloon, causing it to accelerate downwards. Ignore the effect of air friction on the ball.

- Calculate the maximum height reached by the ball.
- Calculate the magnitude of the minimum average acceleration the balloon must have in order for Niko to catch the ball at its maximum height.

a)

$$\begin{aligned} v_f^2 &= v_i^2 + 2a\Delta x \\ \Delta x &= \frac{v_f^2 - v_i^2}{2a} \\ &= \frac{(0)^2 - (13)^2}{2(-9,8)} \\ &= 8,62 \text{ m} \end{aligned}$$

- Calculate the time taken for the ball to reach its maximum height:

$$\begin{aligned} v_f &= v_i + at \\ t &= \frac{v_f - v_i}{a} \\ &= \frac{0 - 13}{-9,8} \\ &= 1,33 \text{ s} \end{aligned}$$

Now calculate the acceleration needed:

$$\begin{aligned} \Delta x &= v_i t + \frac{1}{2} a t^2 \\ &= (0)t + \frac{1}{2} a t^2 \\ a &= \frac{2\Delta x}{t^2} \\ &= \frac{2(10 - 8,62)}{(1,33)^2} = 1,63 \text{ m} \cdot \text{s}^{-2} \end{aligned}$$

- a) 8,62 m
- b) $1,63 \text{ m}\cdot\text{s}^{-2}$

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- 1. 27KG
- 2. 27KH
- 3. 27KJ
- 4. 27KK
- 5. 27KM
- 6. 27KN
- 7. 27KP
- 8. 27KQ
- 9. 27KR
- 10. 27KS



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CHAPTER

4

Organic molecules

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4.1 What are organic molecules?

This section studies simple organic molecules, functional groups and the physical properties associated with these functional groups. Only molecules with one type of functional group, and no more than three of the same functional group, should be studied. This section is a basis for any organic chemistry they may study beyond school so it is important that learners have a thorough understanding of this chapter. Some common polymers are also covered in this chapter, learners should understand the environmental impacts of these polymers as well as their connection with simple organic molecules through the monomers they are formed from.

This section of work is the first chemistry chapter of the Grade 12 year. Learners should have an understanding of intermolecular forces and chemical bonds from Grade 11. These will be particularly important in the physical properties section. Only 12 hours are allocated in CAPS for this section. If possible more time could be given here to ensure a thorough understanding, as there is a lot of work to cover.

Emphasis should be placed on the different representations of organic compounds: macroscopic, sub-microscopic, symbolic representations and the links between all three. Where possible, use atomic model kits to help explain reactions, physical properties and the structure of molecules.

The following topics are covered in this chapter.

- **What makes a molecule organic, and organic molecular structures**

This chapter starts with a brief introduction to what makes a molecule organic (containing carbon atoms). This then leads in to the properties of carbon that make it so unique. Learners are introduced to structural, semi-structural, condensed and molecular formula representations for molecules. It is important that they have a thorough understanding of this before moving on as they will use these representations throughout the chapter. It is also important that learners understand that molecules are not two-dimensional, if possible do some demonstrations with atomic model kits so they can get a better feel for the shape of an organic molecule. Semi-structural representations are not required by CAPS, but will be shown in many textbooks and so it would be good for the student to understand them.

- **Functional groups**

Understanding functional groups is essential to understanding organic molecules. An introduction to each of the required basic functional groups, the homologous series to which they belong, and their general formulas are covered in this section: hydrocarbons (alkanes, alkenes, alkynes), alcohols, alkyl halides (specifically haloalkanes), aldehydes, ketones, carboxylic acids and esters. The concept of saturated and unsaturated compounds is also covered, this will become more important later in the chapter when studying reactions. Isomers of compounds with the same functional groups, and compounds with different functional groups are also covered.

- **IUPAC naming**

A good knowledge of IUPAC naming is very important in organic chemistry. This section walks the learners through the naming of the functional groups, with many worked examples. Going through those worked examples and the associated exercises will help the learners understand this section. There are a number of in-class activities provided that will also help with understanding. The naming of compounds with more than three of the same functional group, or more than one functional group, is not required by CAPS. Chain lengths of no more than eight carbon atoms are allowed, and esters may not have branched groups.

- **Physical properties and structure**

A revision of Grade 11 intermolecular forces would be useful before starting this section. The important IMF this year are hydrogen bonds and van der Waals forces. The physical properties covered include: viscosity, density, melting and boiling points, flammability and vapour pressure, volatility, physical state, smell. It would be good for learners to

revise molecular shape from Grade 11 as well. The changes in physical properties are linked to the intermolecular forces of the molecule, which is in turn linked to functional groups, chain length and chain branching. Although these are separated into sections the learner should understand that they are linked (different intermolecular forces are due to functional groups, chain length, etc.).

- **Applications of organic chemistry**

In this section learners will explore the applications of organic molecules. Specifically the cracking of hydrocarbons, and the (complete) combustion of alkanes. Esters are also covered in more detail in this section, with industrial uses.

- **Addition, elimination and substitution reactions**

The learners need to know the addition, elimination and substitution reactions mentioned in this section, including reaction conditions and the major and minor products that will be formed. They should understand the difference between an addition reaction, an elimination reaction and a substitution reaction and the reactants required in each specific reaction.

No mechanisms of reactions are required, only the reaction equations.

- **Plastics and polymers**

The polymers covered in this section are: polyethene, polypropene, polyvinyl chloride, polyvinyl acetate, polystyrene, polyethylene terephthalate and polylactic acid. Learners should understand what makes a compound a polymer, the difference between an addition and a condensation reaction, and how to determine the polymer from the monomer and the monomer from the polymer.

There are several experiments in this chapter. The learners will be using dangerous chemicals and should be properly instructed on the correct use of safety equipment, including safety goggles, gloves and protective clothing. They should also be reminded not to sniff any chemicals as the fumes can be dangerous as well. More information on laboratory procedures as well as safety precautions is provided in Chapter 1 (Science skills).

These experiments are also an excellent opportunity to get the learners to research organic molecules. Before any experiment the hazards of the chemicals being worked with should be studied. Have the learners do the research for at least some of the experiments before completing them as a way of better understanding the molecules. More information for each experiment is provided in the relevant sections.

4.2 Organic molecular structures

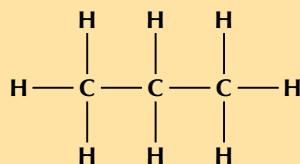
Representing organic molecules

Exercise 4 – 1: Representing organic compounds

1. For each of the following, give the **structural formula** and the **molecular formula**.



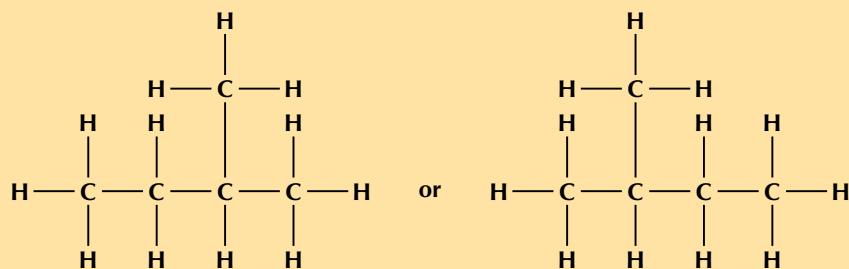
Structural formula:



Molecular formula: C_3H_8

b) $\text{CH}_3\text{CH}_2\text{CH}(\text{CH}_3)\text{CH}_3$

Structural formula:

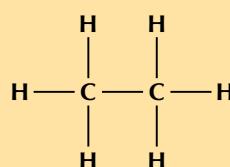


Although the condensed formula was written with the methyl group attached to the third carbon, if we look at the formula from right to left you will see that it is attached to the second carbon and so either of the representations given above are acceptable.

Molecular formula: C₅H₁₂

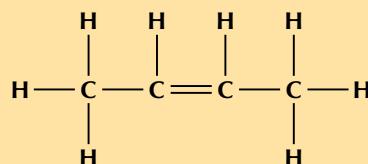
c) CH_3CH_3

Structural formula:



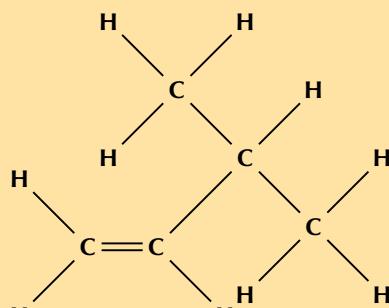
Molecular formula: C₂H₆

2. For each of the following organic compounds, give the **condensed structural formula** and the **molecular formula**.



a) Condensed Structural: $\text{CH}_3\text{CHCHCH}_3$

Molecular: C₄H₈

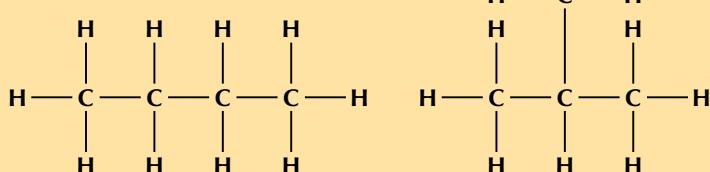


b) $\text{H}_3\text{CCH}(\text{CH}_3)\text{CH}_2\text{CH}_3$

Molecular: C₅H₁₀

3. Give two possible structural formulae for the compound with a molecular formula of C_4H_{10} .

The only two possible options are:



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1. 27KT 2. 27KV 3. 27KW



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The hydrocarbons

For the experiment on saturated and unsaturated compounds, if cyclohexane and cyclohexene are not available any alkanes/alkenes that are liquids at room temperature are acceptable. These should be relatively easy to source.

Liquid bromine is corrosive and toxic, including the fumes. If you have to prepare your own bromine water from liquid bromine do not let the learners handle the liquid bromine. Wear full safety gear and do not breath in the fumes. Work in a well ventilated area (preferably a fume hood) and be careful.

To make 50 ml bromine water:

- Take a bottle with a capacity of at least 100 ml and a lid that closes securely (screw top).
- Label the bottle and place 50 ml of water into the bottle.
- Decant the vapours from a bottle of liquid bromine (with appropriate precautions) into the labelled bottle until the airspace above the water is completely full of the reddish-brown gas.
- Cap both bottles and gently swirl the bromine water bottle so that the bromine gas dissolves in the water.
- Repeat the process at least one more time, until the water retains an orange colour.

Exercise 4 – 2: The hydrocarbons

1. Answer these questions on the hydrocarbons.

- a) What is the difference between the alkanes, alkenes and alkynes?

Alkanes have only single bonds between carbon atoms, alkenes have at least one double bond between carbon atoms and alkynes have at least one triple bond between carbon atoms.

- b) Give the general formula for the alkynes



- c) Of the alkanes, alkenes and alkynes which is:

i. saturated

the alkanes

ii. unsaturated

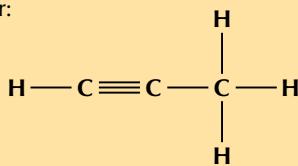
the alkenes and alkynes

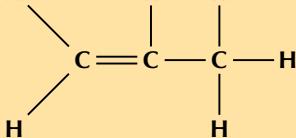
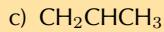
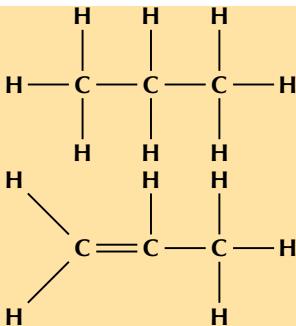
- d) Which series is the least reactive? Explain why.

The alkanes are the least reactive. The saturated bonds are more reactive than the unsaturated double or triple bonds found in alkenes and alkynes.

2. Draw the structural formulae for:

- a) CHCCH_3





3. Fill in the table below:

Compound	Saturated or unsaturated?
$\text{CH}_3\text{CH}_2\text{CH}_3$	
$\text{H} - \text{C} \equiv \text{C} - \text{H}$	
$\text{CH}_3\text{CH}_2\text{CHCHCH}_2\text{CH}_2\text{CH}_2\text{CH}_3$ heptane	
$\text{CH}_2 \equiv \text{CH} - \text{CH}_2 - \text{CH}_3$	

Compound	Saturated or unsaturated?
$\text{CH}_3\text{CH}_2\text{CH}_3$	saturated
$\text{H} - \text{C} \equiv \text{C} - \text{H}$	unsaturated
$\text{CH}_3\text{CH}_2\text{CHCHCH}_2\text{CH}_2\text{CH}_2\text{CH}_3$ heptane	unsaturated
$\text{CH}_2 \equiv \text{CH} - \text{CH}_2 - \text{CH}_3$	unsaturated

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The alcohols

Make sure the learners understand the difference between primary, secondary and tertiary carbons:

- **Primary**

A primary carbon is a carbon atom bonded to one other carbon atom.

- **Secondary**

A secondary carbon is a carbon atom bonded to two other carbon atoms.

- **Tertiary**

A tertiary carbon is a carbon atom bonded to three other carbon atoms.

For example:

$\text{CH}_3\text{CH}_2\text{CH}_3$, carbon 1 and carbon 3 are primary carbon atoms because they are only bonded to one other carbon atom. Carbon 2 is a secondary carbon atom because it is bonded to two other carbon atoms.

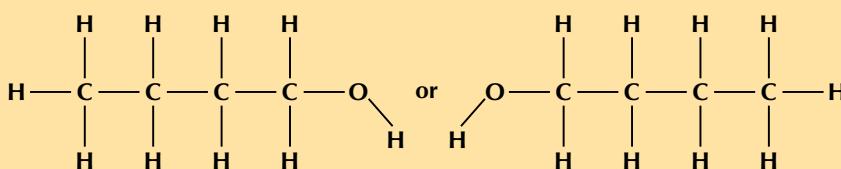
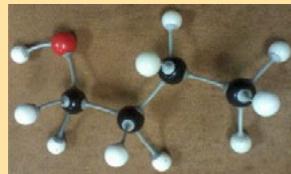
$\text{C}(\text{CH}_3)_3\text{X}$, The central carbon atom in this compound is a tertiary carbon atom because it is bonded to three other carbon atoms.

A primary alcohol has the hydroxyl ($-OH$) group bonded to a primary carbon atom. Similarly, a secondary alcohol has the hydroxyl bonded to a secondary carbon atom and a tertiary alcohol has the hydroxyl bonded to a tertiary carbon atom.

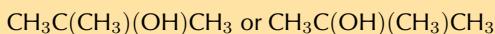
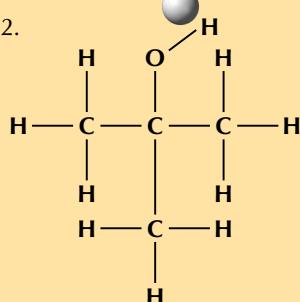
Exercise 4 – 3: The alcohols

Give the structural and condensed structural formula for the following alcohols. State, with reasons, whether the compound is a primary, secondary, or tertiary alcohol.

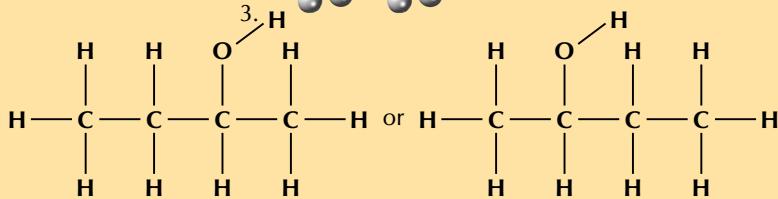
(Note: a black ball represents a carbon atom, a white ball represents a hydrogen atom, and a red ball represents an oxygen atom)



This is a primary alcohol. The hydroxyl ($-OH$) group is bonded to a carbon atom that is bonded to only one other carbon atom.



This is a tertiary alcohol. The hydroxyl ($-OH$) group is bonded to a carbon atom that is bonded to three other carbon atoms.



$$\text{CH}_3\text{CH}_2\text{CH(OH)CH}_3 \text{ or } \text{CH}_3\text{CH(OH)CH}_2\text{CH}_3$$

This is a secondary alcohol. The hydroxyl ($-OH$) group is bonded to a carbon atom that is bonded to two other carbon atoms.

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1. 27M3 2. 27M4 3. 27M5



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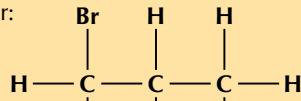
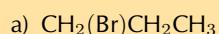
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Alkyl halides

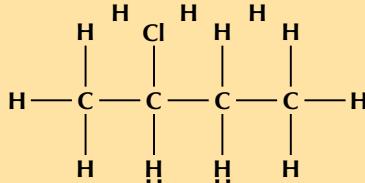
Exercise 4 – 4: Haloalkanes

1. Answer these questions on the haloalkanes.
 - a) Give the general formula for the haloalkanes with only one halogen atom
 $C_nH_{2n+1}X$ where X is any halogen atom
 - b) Are haloalkanes saturated compounds?
Yes
 2. Draw the structural formulae for:
Br **H** **H**

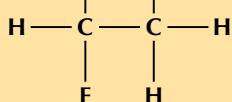
2. Draw the structural formulae for:



b) $\text{CH}_3\text{CH}(\text{Cl})\text{CH}_2\text{CH}_3$



c) $\text{CH}_2(\text{F})\text{CH}_3$



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Carbonyl-containing compounds

Exercise 4 – 5: Carbonyl compounds

1. Answer these questions on carbonyl compounds.
 - a) What other functional group does a carboxylic acid have in addition to a carbonyl group?

hydroxyl group

- b) What is the main difference between aldehydes and ketones

An aldehyde **must** have the carbonyl group at the **end** of the carbon chain (carbonyl carbon atom bonded to a hydrogen atom). A ketone **must** have the carbonyl group in the **middle** of the chain (carbonyl carbon atom not bonded to a hydrogen atom).

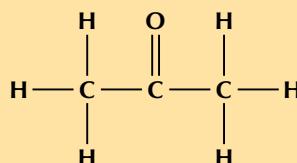
- c) What two reactants are required to make an ester?

alcohol and carboxylic acid

- d) How is ethanoic acid produced?

Through the oxidation of ethanol.

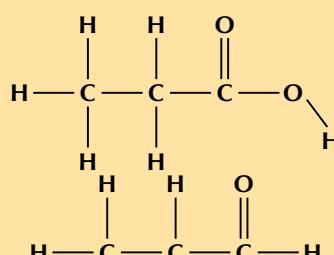
2. Draw the structural formulae for each of the following compounds. What series does each compound belong to?



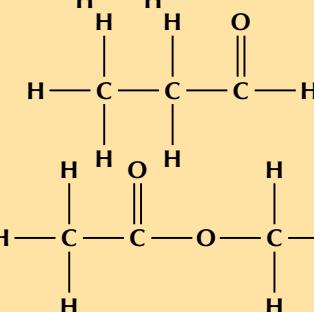
ketone



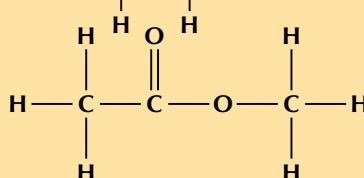
carboxylic acid



aldehyde



ester



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1. 27M9 2. 27MB



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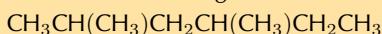


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Exercise 4 – 6: Functional groups

1. Write down the:

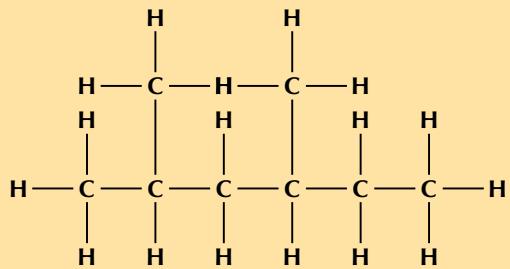
- a) name of the homologous series of:



All the carbon atoms are bonded to the maximum number of other atoms (four) and there are only hydrogen and carbon atoms in the molecule. Therefore this is an alkane.

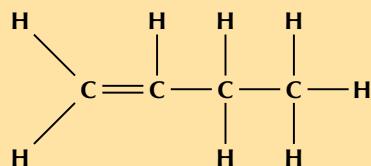
OR

Draw the structural formula:

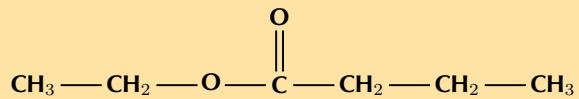


There are only single carbon-carbon bonds, and all the atoms are carbon or hydrogen atoms. This compound belongs to the alkane homologous series.

b) general formula of:

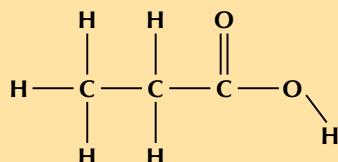
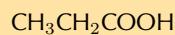


c) name of the homologous series of:



esters

d) structural formula of:



Look at the list of organic compounds in the table below:

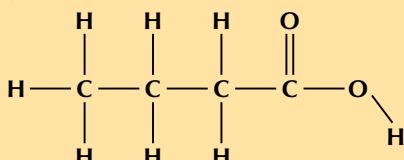
	Organic compound	Homologous series
	$\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$	
	<pre> H O H—C—C—O—C—C—C—H H H H </pre>	
2.	CH_3CHO	
	<pre> H H H H—C—C—C—H H H H </pre>	
	$\text{CH}_3\text{CCCH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	

a) Complete the table by identifying the functional group of each compound.

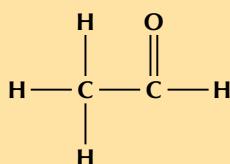
	Organic compound	Homologous series
	$\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$	carboxylic acid
	<pre> H O H—C—C—O—C—C—C—H H H H </pre>	ester
	CH_3CHO	aldehyde
	<pre> H H H H—C—C—C—H H H H </pre>	alkane
	$\text{CH}_3\text{CCCH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	alkyne

b) Give the structural representation of the compounds represented by condensed structural formulae.

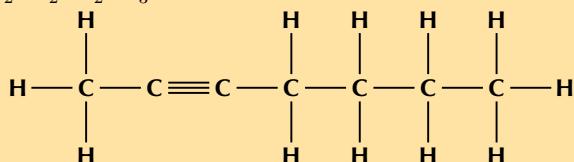
- $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$



- CH_3CHO



- $\text{CH}_3\text{CCCH}_2\text{CH}_2\text{CH}_2\text{CH}_3$



3. A chemical reaction takes place and ethyl methanoate is formed.

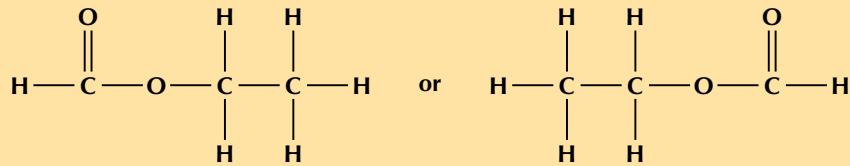
a) Identify the homologous series to which ethyl methanoate belongs?

Esters

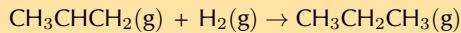
b) Name the two types of reactants used to produce this compound in a chemical reaction.

alcohol and carboxylic acid

c) Give the structural formula of ethyl methanoate ($\text{HCOOCH}_2\text{CH}_3$).

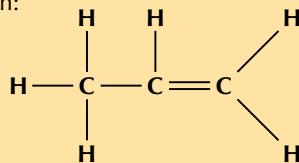


4. The following reaction takes place:



a) Give the name of the homologous series of the organic compound in the reactants.

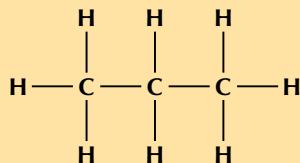
Draw the structural representation:



The organic compound in the reactants has a double carbon-carbon bond, therefore it is an alkene.

b) What is the name of the homologous series of the product?

Draw the structural representation:



The organic compound in the reactants has only single carbon-carbon bonds and no other functional group. Therefore it is an alkane.

c) Which compound in the reaction is a saturated hydrocarbon?

The product (the alkane), propane.

5. More questions. Sign in at Everything Science online and click 'Practise Science'.

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1. 27MC 2. 27MD 3. 27MF 4. 27MG



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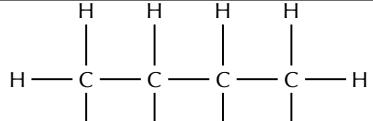
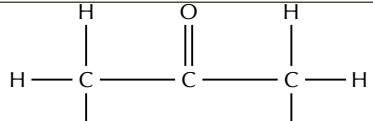


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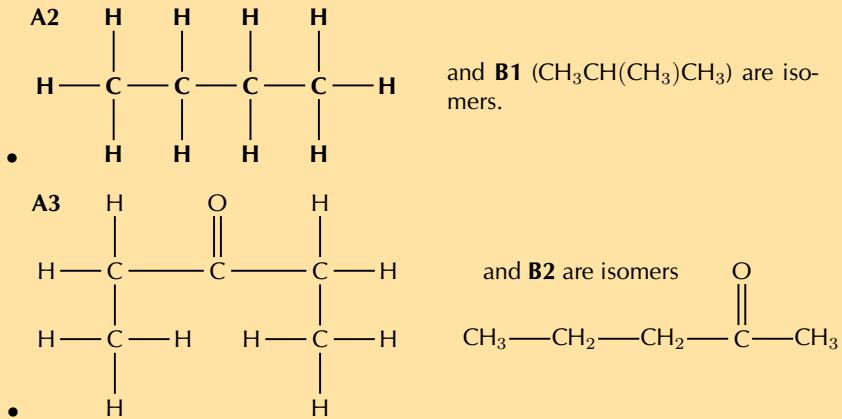
Isomers

Exercise 4 – 7: Isomers

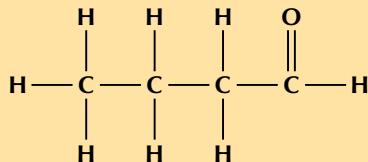
1. Match the organic compound in Column A with its isomer in Column B:

	Column A	Column B
1	$\text{CH}_3\text{CH}_2\text{CH}_2(\text{OH})$ 	$\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_3$ 
2		$\text{CH}_3\text{CH}_2\text{CH}_2\text{C}(=\text{O})\text{CH}_3$ 
3		$\text{CH}_3\text{CH}(\text{OH})\text{CH}_3$

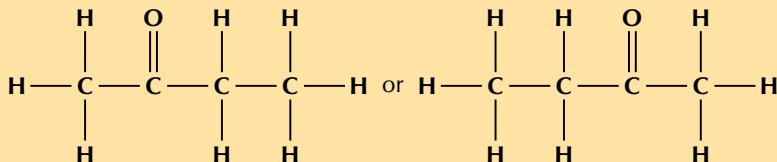
- A1 ($\text{CH}_3\text{CH}_2\text{CH}_2(\text{OH})$) and B3 ($\text{CH}_3\text{CH}(\text{OH})\text{CH}_3$) are isomers.



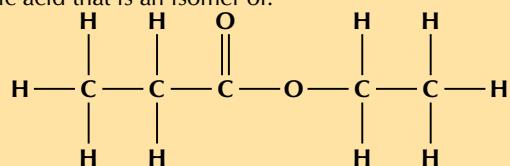
2. a) Give the ketone isomer of butanal:



A ketone requires that the carbonyl group is **not** at the end of the chain. Therefore it must be on carbon 2. The isomer must have the same number of each type of atom: $\text{C}_4\text{H}_8\text{O}$

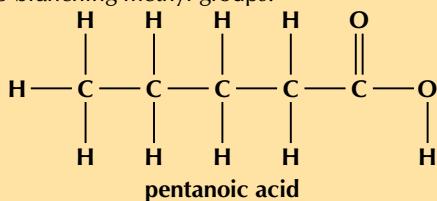


b) Give a carboxylic acid that is an isomer of:

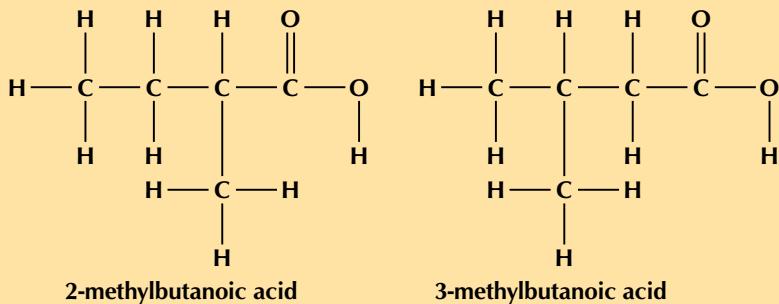


The molecule is an ester. A carboxylic acid must have the –COOH functional group. The isomer must have the same number of each type of atom: C₅H₁₀O₂. So there are four options (names not required):

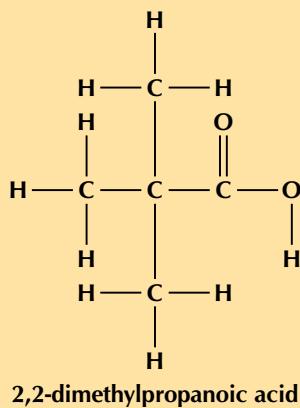
One isomer with no branching methyl groups:



Two isomers that have one branching methyl group:



One isomer that has two branching methyl groups:



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1. 27MH 2a. 27MJ 2b. 27MK



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4.3 IUPAC naming and formulae

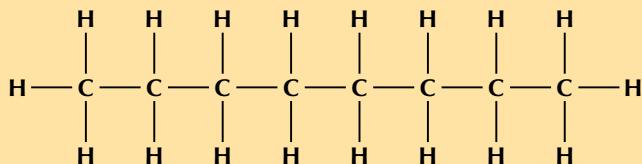
Naming hydrocarbons

Exercise 4 – 8: Naming alkanes

- Give the structural formula for each of the following alkanes

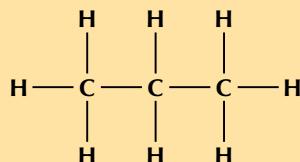
a) Octane

The suffix -ane tells us that this is an alkane. The prefix oct- tells us that there are eight carbon atoms in the longest chain.



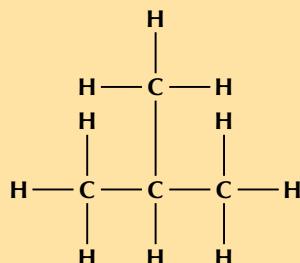
b) Propane

The suffix -ane tells us that this is an alkane. The prefix prop- tells us that there are three carbon atoms in the longest chain.



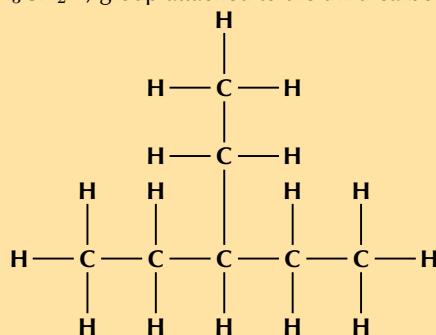
c) 2-methylpropane

The suffix -ane tells us that this is an alkane. The prefix prop- tells us that there are three carbon atoms in the longest chain. 2-methyl tells us that there is a methyl (CH_3-) branched group attached to the second carbon atom.



d) 3-ethylpentane

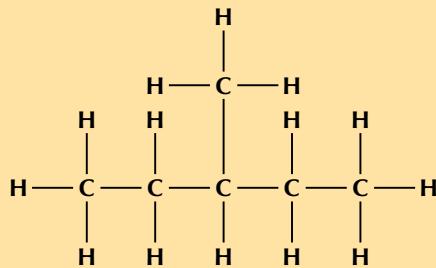
The suffix -ane tells us that this is an alkane. The prefix pent- tells us that there are five carbon atoms in the longest chain. 3-ethyl tells us that there is an ethyl branched group (CH_3CH_2-) group attached to the third carbon atom.



2. Give the IUPAC name for each of the following alkanes:



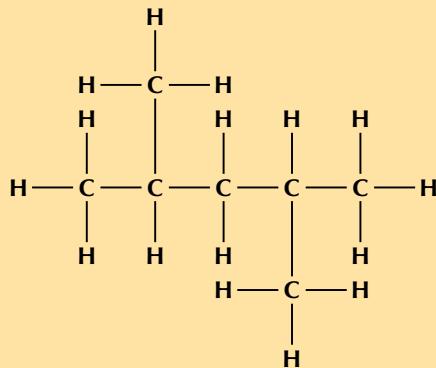
This is hard to do unless you draw the structural formula of the molecule out. It is recommended that you do this in exams.



There are five carbons in the longest chain so the prefix is pent-. There are only single carbon-carbon bonds and no other functional group so the compound is an alkane and the suffix is -ane. There is one methyl group at position 3 (you can number from either end of the chain for this example). So the compound is **3-methylpentane**.

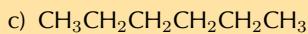


This is hard to do unless you draw the structural formula of the molecule out. It is recommended that you do this in exams.

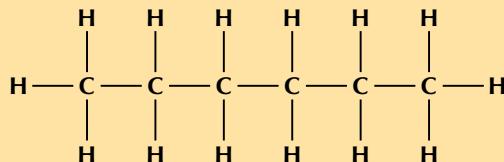


There are five carbons in the longest chain, so the prefix is pent-. There are only single carbon-carbon bonds so the compound is an alkane and the suffix is -ane. There is one methyl group at position 2 and one at position 4 (once again you can number from either end). So the compound is

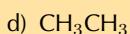
2,4-dimethylpentane.



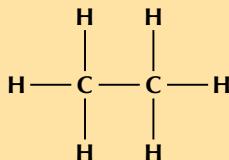
This is hard to do unless you draw the structural formula of the molecule out. It is recommended that you do this in exams.



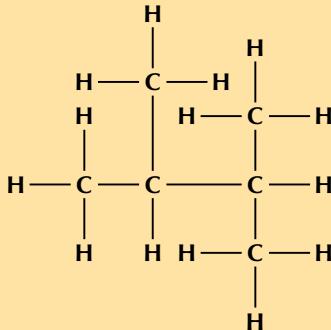
There are six carbon atoms in the longest chain so the prefix is hex-. There are only single carbon-carbon bonds and no other functional group so the compound is an alkane and the suffix is -ane. There are no branched groups, so the molecule is **hexane**.



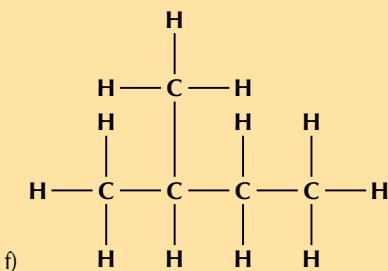
This is hard to do unless you draw the structural formula of the molecule out. It is recommended that you do this in exams.



There are two carbon atoms in the longest chain so the prefix is eth-. There are only single carbon-carbon bonds and no other functional group so the compound is an alkane and the suffix is -ane. There are no branched groups, so the molecule is **ethane**.



There are four carbon atoms in the longest chain, so the prefix is but-. There are two methyl branches at positions 2 and 3. The functional group is an alkane, so the suffix is -ane. Combining all this information we get: **2,3-dimethylbutane**. Note that in this example it does not matter which end you start numbering from.



There are four carbon atoms in the longest chain so the prefix is but-. The functional group is an alkane, so the suffix is -ane. There is one branched group which is a methyl group and this is at position 2. The molecule is **2-methylbutane**.

Note that in this example it **does** matter which way you number the chain as the branched group needs to have the lowest number possible and so the compound is **not** 3-methylbutane.

3. More questions. Sign in at Everything Science online and click 'Practise Science'.

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1. 27MM 2. 27MN



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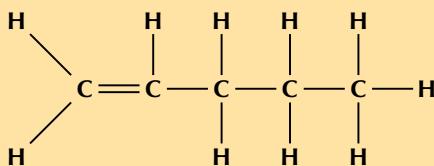
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Exercise 4 – 9: Naming alkenes

1. Give the IUPAC name for each of the following alkenes:

a) $\text{CH}_2\text{CHCH}_2\text{CH}_2\text{CH}_3$

Draw the structural representation:

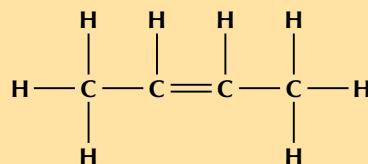


The molecule contains a double carbon-carbon bond. It is an alkene and so the suffix is -ene. There are five carbons in the longest chain, so the prefix is pent-. There are no branched groups. The double bond occurs between carbons 1 and 2. So the molecule is *1-pentene* or *pent-1-ene*.

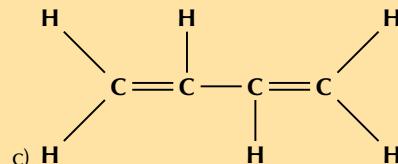
Note that the way you number the carbon atoms matters here, the molecule is **not** *pent-4-ene*.

b) $\text{CH}_3\text{CHCHCH}_3$

Draw the structural representation:



The molecule contains a double carbon-carbon bond. It is an alkene and so the suffix is -ene. There are four carbons in the longest chain so the prefix is but-. There are no branched groups. The double bond occurs between carbons 2 and 3. The molecule is *2-butene* or *but-2-ene*.

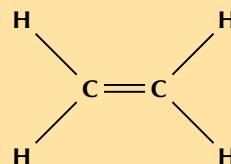


The compound contains two double carbon-carbon bonds. It is an alkene and so the suffix is -diene. There are four carbons in the longest chain containing the double bonds, so the prefix is but-. There are no branched chains. The first double bond occurs between carbons 1 and 2. The second double bond occurs between carbons 3 and 4. The compound is *but-1,3-diene*.

2. Give the structural formula for each of the following alkenes:

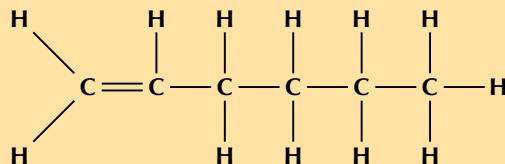
a) ethene

The prefix eth- tells us there are two carbon atoms in the chain. The suffix -ene tells us there is a double bond between these carbon atoms.



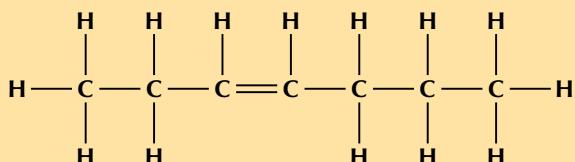
b) hex-1-ene

The prefix hex- tells us there are six carbon atoms in the chain. The suffix -1-ene tells us there is a double bond between the first and second carbon atoms.



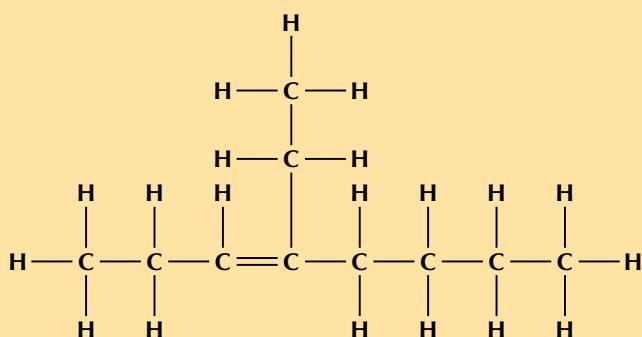
c) hept-3-ene

The prefix hept- tells us there are seven carbon atoms in the chain. The suffix -3-ene tells us there is a double bond between the third and fourth carbon atoms.



d) 4-ethyloct-3-ene

The prefix oct- tells us there are eight carbon atoms in the longest chain containing the functional group. The suffix -3-ene tells us there is a double bond between the third and fourth carbon atoms. 4-ethyl tells us that there is an ethyl (CH_3CH_2-) branched group attached to the fourth carbon atom.



3. More questions. Sign in at Everything Science online and click 'Practise Science'.

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1. 27MP 2. 27MQ



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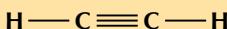
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Exercise 4 – 10: Naming alkynes

1. Give the structural formula for each of the following alkynes:

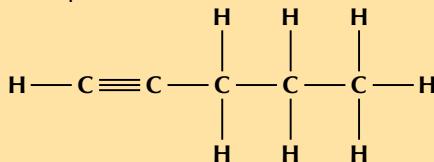
a) ethyne

The prefix eth- tells us there are two carbon atoms in the longest chain. The suffix -yne tells us there is a triple bond between the carbon atoms.



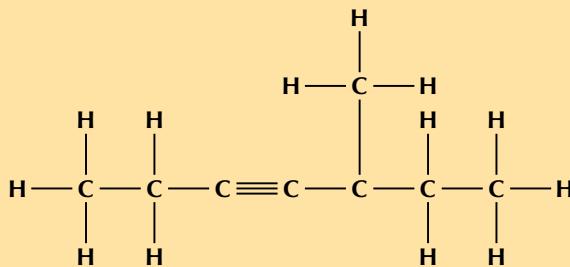
b) pent-1-yne

The prefix pent- tells us there are five carbon atoms in the longest chain. The suffix -1-yne tells us there is a triple bond between the first and second carbon atoms.

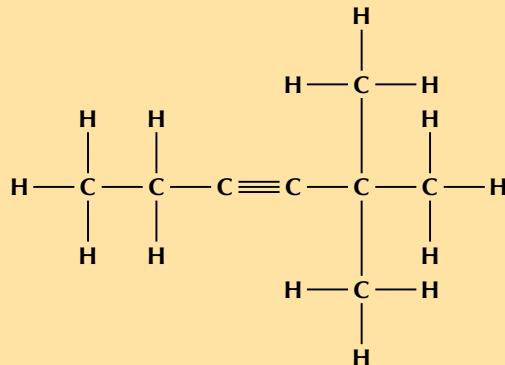


c) 5-methylhept-3-yne

The prefix hept- tells us there are seven carbon atoms in the longest chain. The suffix -3-yne tells us there is a triple bond between the third and fourth carbon atoms. 5-methyl tells us there is a methyl branched chain on the fifth carbon atom.

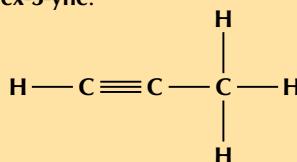


2. Give the IUPAC names for the following alkynes:



a)

There is a triple carbon-carbon bond. This compound is an alkyne and will have the suffix -yne. There are six carbon atoms in the longest chain, therefore the prefix will be hex-. The triple bond is between the third and fourth carbon atoms regardless of how you number the chain (-3-yne). There are two branched methyl groups. Depending on the order of numbering they are either on the fourth carbon atom (left to right) or the second carbon atom (right to left). The lower numbering is correct (right to left) and as there are two methyl groups this is 2,2-dimethyl. The molecule is **2,2-dimethylhex-3-yne**.

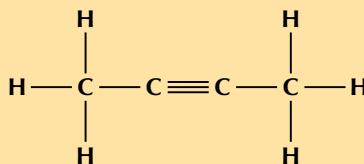


b)

There is a triple carbon-carbon bond. This compound is an alkyne and will have the suffix -yne. There are three carbon atoms in the longest chain, therefore the prefix will be prop-. The triple bond is between the first and second carbon atoms (numbering from the left) making the suffix -1-yne. There are no branched groups. This molecule is **prop-1-yne** or propyne.

c) CH₃CCCH₃

Draw the structure:



There is a triple carbon-carbon bond. This compound is an alkyne and will have the suffix -yne. There are four carbon atoms in the longest chain, therefore the prefix will be but-. The triple bond is between the second and third carbon atoms regardless of how you number the chain (-2-yne). There are no branched groups. This molecule is **but-2-yne** or 2-butyne.

3. More questions. Sign in at Everything Science online and click 'Practise Science'.

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1. 27MR 2. 27MS



Model kits are a great way to help learners understand and visualise organic molecules. If you do not have access to model kits however, substitutes can be used. A bag of jelly tots (or a similar soft sweet) would work just as well, using toothpicks to represent the bonds. It is also possible to make your own playdough (which can be coloured for different atoms using food colourants). A recipe is given here:

- 2 cups flour, 2 cups warm water, 1 cup salt, 2 tablespoons vegetable oil, 1 tablespoon of cream of tartar (this improves elasticity, and is optional).
- Mix all the ingredients together over a low heat and stir continually.
- When the dough pulls away from the sides of the pot, remove it from the heat and allow to cool.
- If your dough is still sticky just cook it a bit longer.
- Once cool, knead the dough until it becomes smooth, then separate and add food colourant, different colours for different types of atoms.
- The dough is ready. Remember to store it in an airtight container between uses. If it dries out a bit, knead in a bit of water.

The full process is provided at <http://www.instructables.com/id/How-to-Make-Playdough-Play-doh/>. This playdough can be used for all the model building activities.

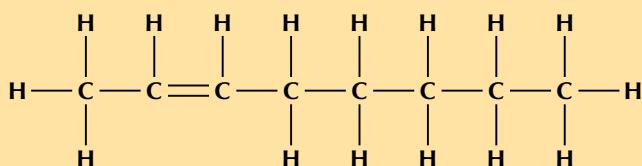
Be careful to keep the playdough away from animals, as it is edible, but contains large amounts of salt.

Exercise 4 – 11: Naming hydrocarbons

1. Give the structural formula for each of the following compounds:

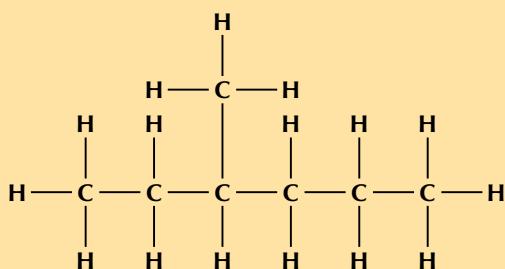
a) oct-2-ene

The prefix oct- tells us there are eight carbon atoms in the longest chain. The suffix -2-ene tells us there is a double bond between the second and third carbon atoms.



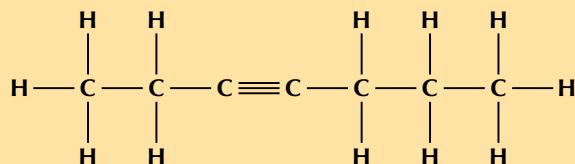
b) 3-methylhexane

The prefix hex- tells us there are six carbon atoms in the longest chain. The suffix -ane tells us this is an alkane and that there are only single carbon-carbon bonds and no other functional groups. 3-methyl tells us there is a branched methyl group on the third carbon atom.



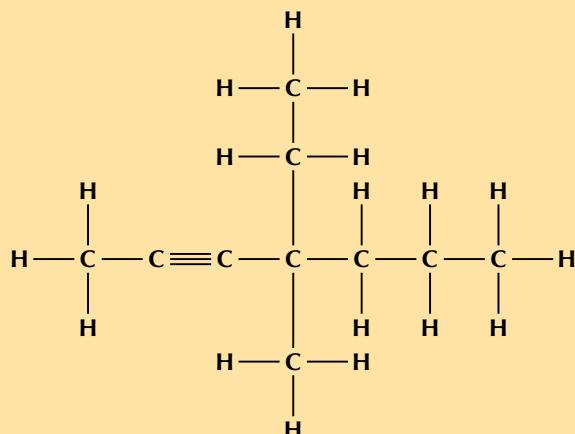
c) hept-3-yne

The prefix hept- tells us there are seven carbon atoms in the longest chain. The suffix -3-yne tells us that this is an alkyne and there is a triple bond between the third and fourth carbon atoms.



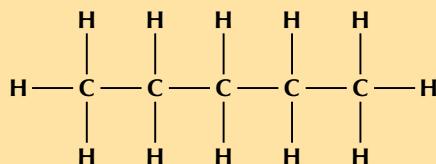
d) 4-ethyl-4-methylhept-2-yne

The prefix hept- tells us there are seven carbon atoms in the longest chain. The suffix -2-yne tells us this is an alkyne and there is a triple bond between the second and third carbon atoms. The 4-ethyl tells us there is an ethyl (CH_3CH_2-) branched group on the fourth carbon atom. The 4-methyl tells us there is a methyl (CH_3-) branched group on the fourth carbon atom.



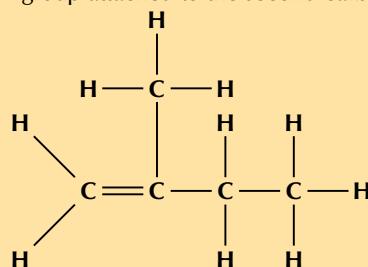
e) pentane

The prefix pent- tells us there are five carbon atoms in the longest chain. The suffix -ane tells us this is an alkane.



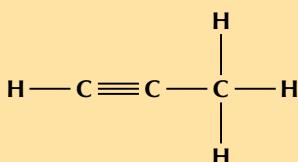
f) 2-methylbut-1-ene

The prefix but- tells us there are four carbon atoms in the longest chain containing the functional group. The suffix -1-ene tells us that this is an alkene and there is a double bond between the first and second carbon atoms. 2-methyl tells us that there is a methyl (CH_3-) group attached to the second carbon atom.

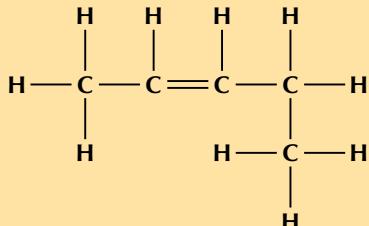


g) propyne

The prefix prop- tells us there are three carbon atoms in the longest chain. The suffix -yne tells us there is a triple carbon-carbon bond between the first and second carbon atoms.

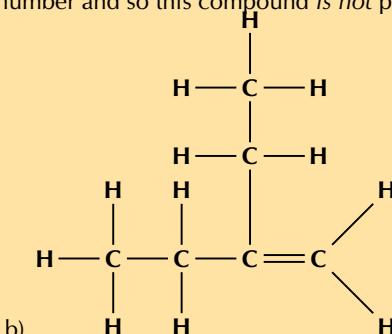


Give the IUPAC name for each of the following organic compounds:



2. a)

The compound has a double carbon-carbon bond and no other functional groups. Therefore it is an alkene and the suffix is -ene. There are five carbon atoms in the longest chain and so the prefix is pent-. There are no branched groups. The double bond occurs between carbons 2 and 3. The compound is 2-pentene or **pent-2-ene**. Note that the way we number the carbon atoms matters. The double bond is given the lowest possible number and so this compound *is not* pent-3-ene.

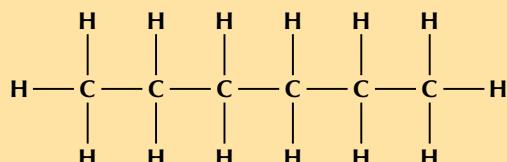


is a double carbon-carbon bond, therefore the compound is an alkene. The suffix is -ene. There are four carbon atoms in the main chain (the longest chain containing the functional group) so the prefix is but-. There is an ethyl group on the second carbon atom. The double bond occurs between carbons 1 and 2. The compound is therefore **but-1-ene**.

Remember that you have to have the functional group in the main chain so the compound is **not** a substituted pentane.

c) $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$

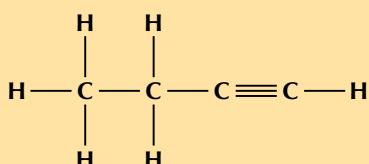
Draw the structural representation:



There are only single carbon-carbon bonds in this compound and no other functional groups, therefore it is an alkane and the suffix is -ane. There are six carbon atoms in the longest chain so the prefix is hex-. There are no branched groups in this compound. This molecule is **hexane**.

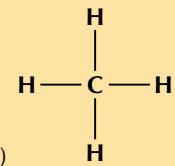
d) $\text{CH}_3\text{CH}_2\text{CCH}_3$

Draw the structural representation of the compound:



The compound has a triple carbon-carbon bond, therefore it is an alkyne and the suffix is -yne. There are four carbon atoms in the longest chain so the prefix is but-. There are no branched chains. The double bond occurs between the first and second carbon atoms. The compound is therefore **but-1-yne** or butyne.

Note that the way we number the carbon atoms matters. The double bond is given the lowest possible number and so this compound is *not* but-3-yne.



There are only single bonds in this compound and no other functional groups, therefore it is an alkane and the suffix is -ane. There is one carbon atom in the longest chain so the prefix is meth-. There are no branched groups in this compound. This molecule is **methane**.

f) C_2H_2

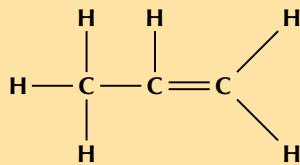
Draw the structural representation of the compound:



The compound has a triple carbon-carbon bond, therefore it is an alkyne and the suffix is -yne. There are two carbon atoms in the longest chain so the prefix is eth-. There are no branched chains. There are only two carbon atoms, so the triple bond has to be between them. The compound is **ethyne**.

g) CH_3CHCH_2

Draw the structural representation of the compound:



The compound has a double carbon-carbon bond, therefore it is an alkene and the suffix is -ene. There are three carbon atoms in the longest chain so the prefix is prop-. There are no branched chains. The double bond occurs between the first and second carbon atoms. The compound is **propene**.

Note that the way we number the carbon atoms matters. The double bond is given the lowest possible number and so this compound is *not* prop-2-ene. Also, we do not include the 1 in the name as this is *the only position* that the double bond can occur in propene.

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1. 27MT 2. 27MV



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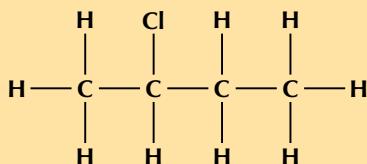
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Exercise 4 – 12: Naming haloalkanes

1. Give the structural representation for the following haloalkanes:

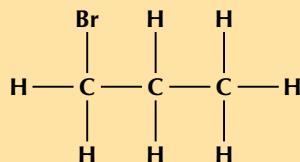
a) 2-chlorobutane

The but- tells us that there are four carbon atoms in the longest chain. The -ane tells us there are only single carbon-carbon bonds. The 2-chloro means there is a chlorine atom attached to the second carbon atom.



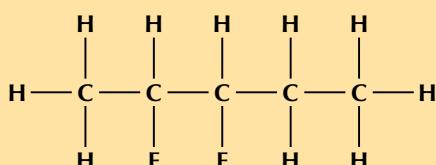
b) 1-bromopropane

The prop- tells us that there are three carbon atoms in the longest chain. The -ane tells us there are only single carbon-carbon bonds. The 1-bromo means there is a bromine atom attached to the first carbon atom.

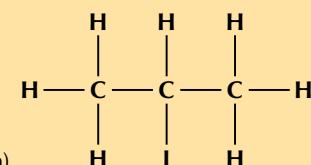


c) 2,3-difluoropentane

The pent- tells us there are five carbon atoms in the longest chain. The -ane tells us there are only single carbon-carbon bonds. The 2,3-difluoro means there are two fluorine atoms, one attached to carbon 2 and the other attached to carbon 3.



2. Give the IUPAC name for the following haloalkanes:

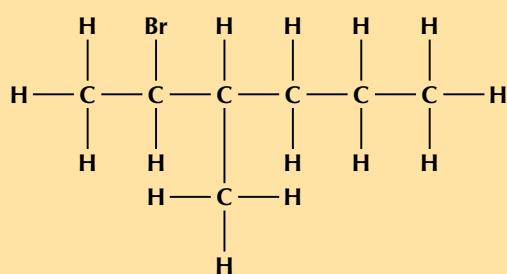


a)

There is a halogen atom and only single carbon-carbon bonds, therefore this is a haloalkane and the suffix is -ane. There are three carbon atoms in the longest chain, therefore the prefix is prop-. There is an iodine atom attached to the second carbon atom (2-iodo). There are no branched groups. Therefore this molecule is **2-iodopropane**.

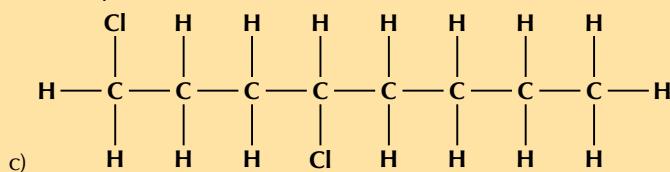
b) $\text{CH}_3\text{CH}(\text{Br})\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_2\text{CH}_3$

Draw the structural representation:



There is a halogen atom and only single carbon-carbon bonds, therefore this is a haloalkane and the suffix is -ane. There are six carbon atoms in the longest chain, therefore the prefix is hex-. There is a bromine atom attached to the second carbon atom (2-bromo). There is a branched methyl group attached to the third carbon atom (3-methyl). This molecule is

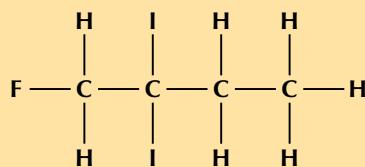
2-bromo-3-methylhexane.



There are halogen atoms and only single carbon-carbon bonds, therefore this is a haloalkane and the suffix is -ane. There are eight carbon atoms in the longest chain, therefore the prefix is oct-. There are two chlorine atoms, one attached to the first carbon atom and one attached to the fourth carbon atom (1,4-dichloro). There are no branched groups. This molecule is **1,4-dichlorooctane**.

- d) $\text{CH}_2(\text{F})\text{C}(\text{I})_2\text{CH}_2\text{CH}_3$

Draw the structural representation:



There are halogen atoms and only single carbon-carbon bonds, therefore this is a haloalkane and the suffix is -ane. There are four carbon atoms in the longest chain containing all the halogen atoms, therefore the prefix is but-. There is a fluorine atom attached to the first carbon atom (1-fluoro). There are two iodine atoms attached to the second carbon atom (2,2-diido). These must be put in alphabetical order, ignoring any prefixes on the halogen atoms. F comes before I (1-fluoro-2,2-diido). This molecule is **1-fluoro-2,2-diiodobutane**

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1. 27MW 2. 27MX



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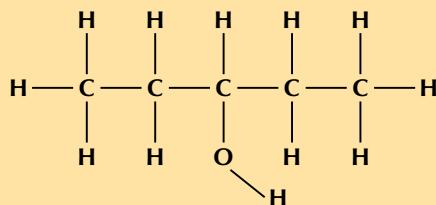
Naming alcohols

Exercise 4 – 13: Naming alcohols

1. Give the structural representation of each of the following organic compounds:

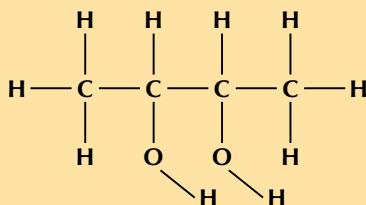
- a) pentan-3-ol

The prefix pentan- tells us there are five carbon atoms in the longest chain and only single carbon-carbon bonds. The suffix -3-ol tells us there is a hydroxyl ($-\text{OH}$) group on the third carbon atom.



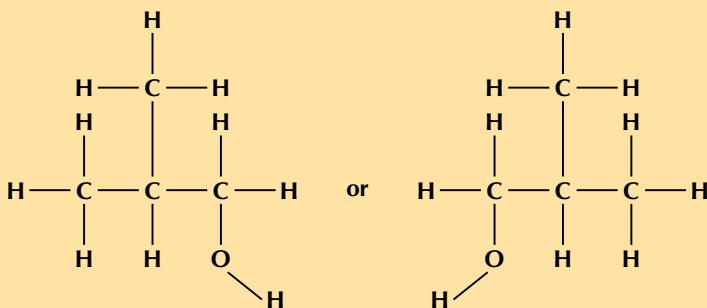
b) butan-2,3-diol

The prefix butan- tells us there are four carbon atoms in the longest chain and only single carbon-carbon bonds. The suffix -2,3-diol tells us there are two hydroxyl groups, one attached to the second carbon atom and one attached to the third carbon atom.



c) 2-methylpropan-1-ol

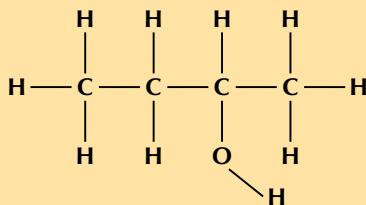
The prefix propan- tells us there are three carbon atoms in the longest chain and only single carbon-carbon bonds. The suffix -1-ol tells us there is a hydroxyl group attached to the first carbon atom. 2-methyl tells us there is a methyl branched group attached to the second carbon atom.



2. Give the IUPAC name for each of the following:

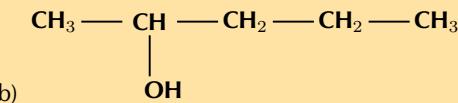
a) $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_3$

Draw the structural representation of the compound:



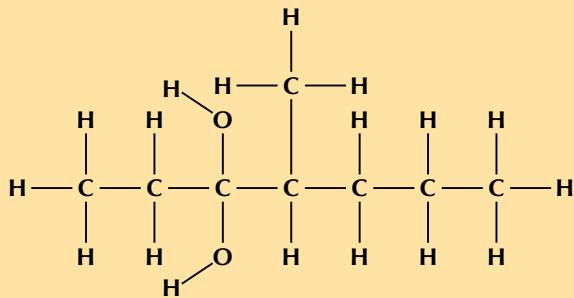
There is a hydroxyl group, therefore the compound is an alcohol and the suffix is -ol. There are four carbon atoms in the longest chain so the prefix is but-. There are only single carbon-carbon bonds, therefore the prefix becomes butan-. There are no branched groups. The hydroxyl group is attached to the second carbon atom. The molecule is **2-butanol** or **butan-2-ol**.

Note that the way we number the carbon atoms matters. The hydroxyl group is given the lowest possible number and so this compound is **not** butan-3-ol.



There is a hydroxyl group, therefore the compound is an alcohol and the suffix is -ol. There are five carbon atoms in the longest chain so the prefix is pent-. There are only single carbon-carbon bonds, therefore the prefix becomes pentan-. There are no branched groups. The hydroxyl group is attached to the second carbon atom. The molecule is **2-pentanol** or **pentan-2-ol**.

Note that the way we number the carbon atoms matters. The hydroxyl group is given the lowest possible number and so this compound is **not** pentan-4-ol.



There are two hydroxyl groups, therefore the compound is an alcohol and the suffix is -diol. There are seven carbon atoms in the longest chain so the prefix is hept-. There are only single carbon-carbon bonds, therefore the prefix becomes heptan-. The hydroxyl groups are both attached to the third carbon atom (-3,3-diol). The branched methyl chain is attached to the fourth carbon atom. The molecule is **4-methylheptan-3,3-diol**.

Note that the way we number the carbon atoms matters. The hydroxyl groups are given the lowest possible numbers and so this compound **is not** 4-methylheptan-5,5-diol.

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1. 27MY 2. 27MZ



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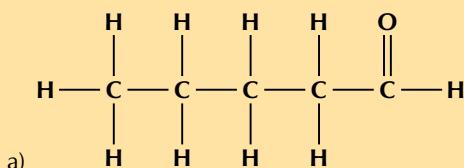


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Naming carbonyl compounds

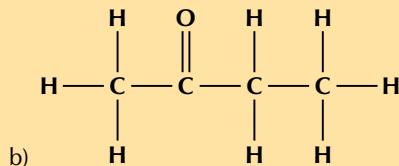
Exercise 4 – 14: Naming aldehydes and ketones

1. Give the IUPAC name for each of the following compounds:



The compound has a carbonyl group and no other functional groups. Therefore it is either an aldehyde or a ketone. The carbonyl group carbon atom **is** the last (terminal) carbon atom. Therefore this is an aldehyde and the suffix is -al. There are five carbon atoms in the longest chain, therefore the prefix is pentan-. This molecule is **pentanal**.

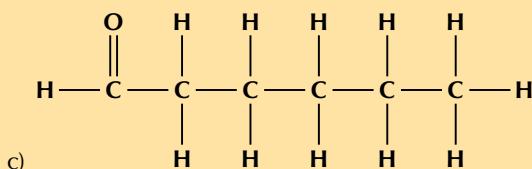
Note that no number is needed for the position of the aldehyde. We must number the chain so that the carbonyl group is always the first carbon atom.



The compound has a carbonyl group and no other functional groups. Therefore it is either an aldehyde or a ketone. The carbonyl group carbon atom **is not** the last carbon atom. Therefore this is a ketone and the suffix is -one. There are four

carbon atoms in the longest chain, therefore the prefix is butan-. This molecule is **butan-2-one** or **2-butanone**.

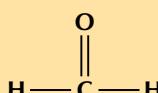
Note that the way we number the carbon atoms is important. This compound is **not** butan-3-one.



The compound has a carbonyl group and no other functional groups. Therefore it is either an aldehyde or a ketone. The carbonyl group carbon atom is a terminal carbon atom. Therefore this is an aldehyde and the suffix is -al. There are six carbon atoms in the longest chain, therefore the prefix is hexan-. This molecule is **hexanal**. Note that no number is needed for the position of the aldehyde. We must number the chain so that the carbonyl group is always the first carbon atom.

d) HCHO

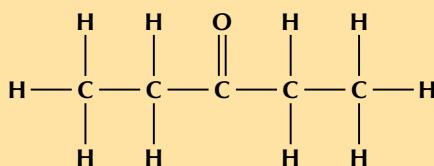
Draw the structural representation:



The compound has a carbonyl group and no other functional groups. Therefore it is either an aldehyde or a ketone. The carbonyl group carbon atom is at the end of the chain. Therefore this is an aldehyde and the suffix is -al. There is one carbon atom in the longest chain, therefore the prefix is methan-. This molecule is **methanal**.

e) CH₃CH₂COCH₂CH₃

Draw the structural representation:

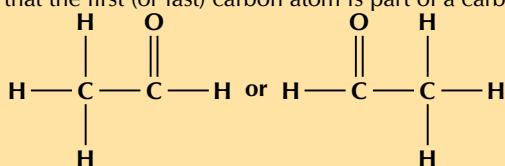


The compound has a carbonyl group and no other functional groups. Therefore it is either an aldehyde or a ketone. The carbonyl group carbon atom is the third carbon atom. Therefore this is a ketone and the suffix is -3-one. There are five carbon atoms in the longest chain, therefore the prefix is pentan-. This molecule is **pentan-3-one** or **3-pentanone**.

2. Give the structural representation for the following:

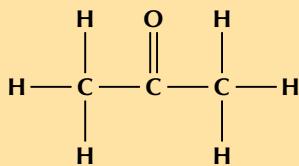
a) ethanal

The prefix eth- tells us that there are two carbon atoms in the longest chain. The suffix -al tells us that the first (or last) carbon atom is part of a carbonyl group.



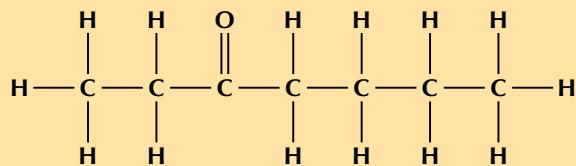
b) propanone

The prefix prop- tells us that there are three carbon atoms in the longest carbon chain. The suffix -one tells us that there is a carbonyl group and it is not on the end of the chain. There is only one carbon atom not on the end: the second carbon atom.



c) heptan-3-one

The prefix hept- tells us there are seven carbon atoms in the longest chain. The suffix -3-one tells us that the third carbon atom is part of a carbonyl group.



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1. 27N2 2. 27N3



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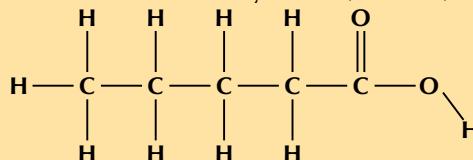
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Exercise 4 – 15: Naming carboxylic acids

1. Give the structural representation for the following:

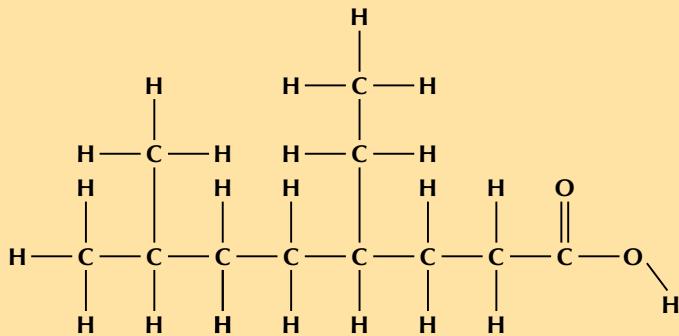
a) pentanoic acid

The prefix pent- tells us that there are five carbon atoms in the longest chain. The suffix -oic acid tells us that this is a carboxylic acid (-COOH).



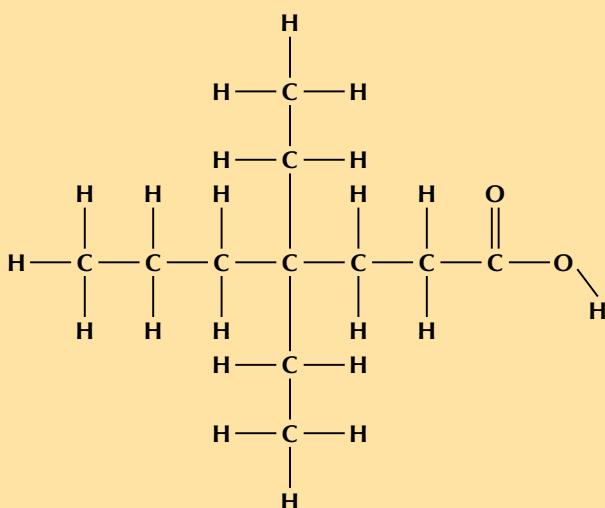
b) 4-ethyl-7-methyloctanoic acid

The prefix oct- tells us that there are eight carbon atoms in the longest chain. The suffix -oic acid tells us that this is a carboxylic acid (-COOH). 4-ethyl means that there is an ethyl branched group (CH_3CH_2-) attached to the fourth carbon atom. 7-methyl means that there is a methyl branched group (CH_3-) attached to the seventh carbon atom. Remember to always number from the carboxylic acid side of the compound.

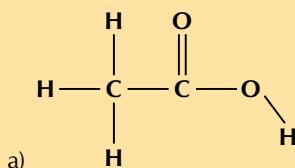


c) 4,4-diethylheptanoic acid

The prefix hept- tells us that there are seven carbon atoms in the longest chain. The suffix -oic acid tells us that this is a carboxylic acid (-COOH). 4,4-diethyl means that there are two ethyl branched groups (CH_3CH_2-) attached to the fourth carbon atom. Remember to always number from the carboxylic acid side of the compound.



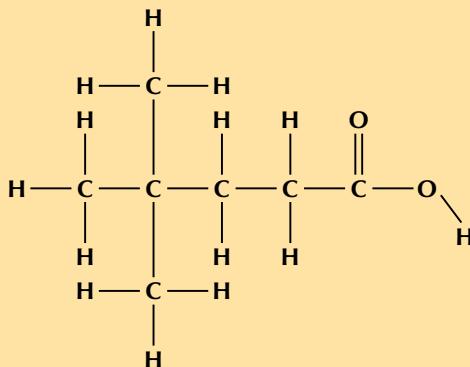
2. Give the IUPAC name for each of the following:



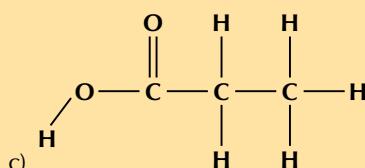
This compound contains a carbonyl group and a hydroxyl group, both attached to the same carbon atom. Therefore this is a carboxylic acid and the suffix is -oic acid. There are two carbon atoms in the longest chain, therefore the prefix is ethan-. There are no branched groups. This molecule is therefore **ethanoic acid**.

b) $\text{CH}_3\text{C}(\text{CH}_3)_2\text{CH}_2\text{CH}_2\text{COOH}$

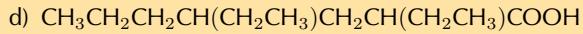
Draw the structural representation:



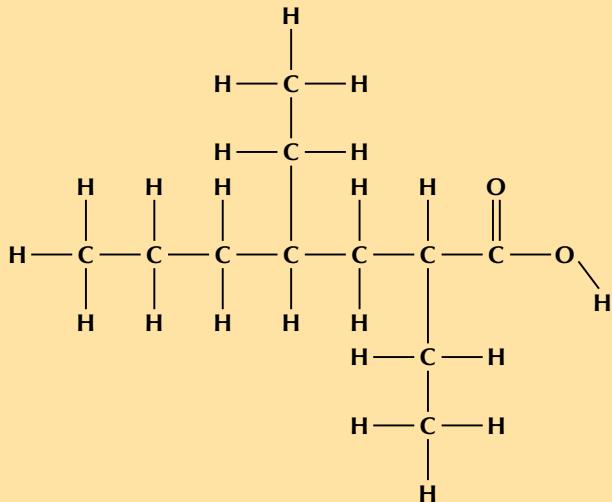
This compound contains a carbonyl group and a hydroxyl group, both attached to the same carbon atom. Therefore this is a carboxylic acid and the suffix is -oic acid. There are five carbon atoms in the longest chain, therefore the prefix is pentan-. There are two branched groups attached to the fourth carbon atom (remember to count from the carboxylic acid functional group). This molecule is therefore **4,4-dimethylpentanoic acid**.



This compound contains a carbonyl group and a hydroxyl group, both attached to the same carbon atom. Therefore this is a carboxylic acid and the suffix is -oic acid. There are three carbon atoms in the longest chain, therefore the prefix is propan-. There are no branched groups. This molecule is therefore **propanoic acid**.



Draw the structural representation:



This compound has a carbonyl group and a hydroxyl group, both attached to the same carbon atom. Therefore this is a carboxylic acid and the suffix is -oic acid. There are seven carbon atoms in the longest chain, therefore the prefix is heptan-. There are two branched ethyl groups (CH_3CH_2-), one attached to the second carbon atom and one attached to the fourth carbon atom. This molecule is therefore **2,4-diethylheptanoic acid**.

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1. 27N4 2. 27N5



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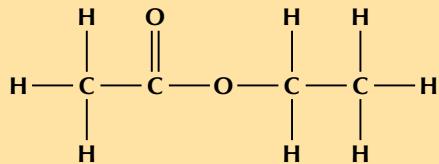
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Exercise 4 – 16: Naming esters

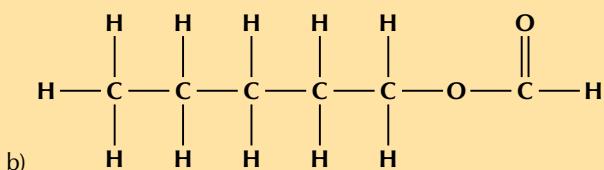
1. Give the IUPAC name for each of the following compounds:



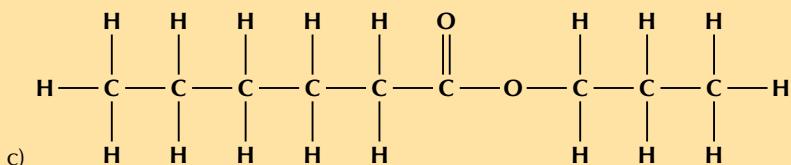
Draw the structural representation:



This compound contains a carbonyl group and an oxygen atom attached to two different carbon atoms. Therefore this is an ester and the suffix is -oate. There are two carbon atoms in the chain **without** the carbonyl group (from the alcohol), therefore this group is ethyl. There are two carbon atoms in the chain **with** the carbonyl group (from the carboxylic acid), therefore the prefix is ethan-. There are no branched groups. This molecule is therefore **ethyl ethanoate**.



This compound contains a carbonyl group and an oxygen atom attached to two different carbon atoms. Therefore this is an ester and the suffix is **-oate**. There are five carbon atoms in the chain **without** the carbonyl group (from the alcohol), therefore this group is **pentyl**. There is one carbon atom in the chain **with** the carbonyl group (from the carboxylic acid), therefore the prefix is **methan-**. There are no branched groups. This molecule is therefore **pentyl methanoate**.

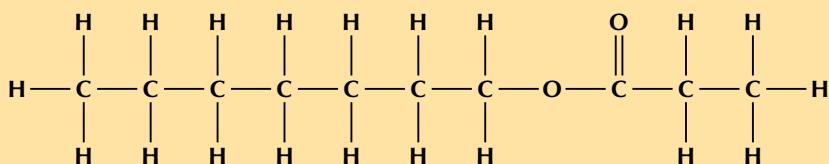


This compound contains a carbonyl group and an oxygen atom attached to two different carbon atoms. Therefore this is an ester and the suffix is **-oate**. There are three carbon atoms in the chain **without** the carbonyl group (from the alcohol), therefore this group is **propyl**. There are six carbon atoms in the chain **with** the carbonyl group (from the carboxylic acid), therefore the prefix is **hexan-**. There are no branched groups. This molecule is **propyl hexanoate**.

2. Give the structural representations for the following esters:

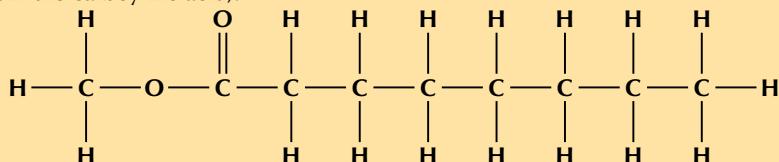
a) heptyl propanoate

The suffix **-oate** tells us that this is an ester. The heptyl tells us that there are seven carbon atoms in the chain **without** the carbonyl group (from the alcohol). The prefix **prop-** tells us that there are three carbon atoms in the chain **with** the carbonyl group (from the carboxylic acid).



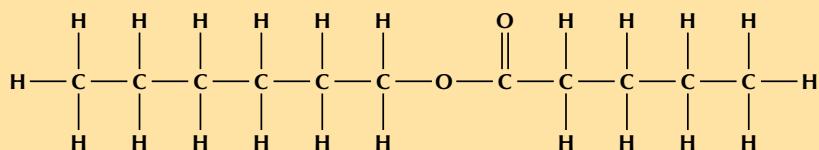
b) methyl octanoate

The suffix **-oate** tells us that this is an ester. The methyl tells us that there is one carbon atom in the chain **without** the carbonyl group (from the alcohol). The prefix **oct-** tells us that there are eight carbon atoms in the chain **with** the carbonyl group (from the carboxylic acid).



c) hexyl pentanoate

The suffix **-oate** tells us that this is an ester. The hexyl tells us that there are six carbon atoms in the chain **without** the carbonyl group (from the alcohol). The prefix **pent-** tells us that there are five carbon atoms in the chain **with** the carbonyl group (from the carboxylic acid).



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1. 27N6 2. 27N7



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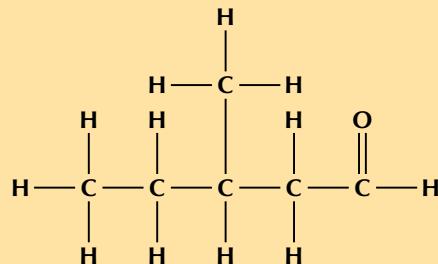
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Exercise 4 – 17: Naming carbonyl compounds

1. Give the structural representation for the following compounds::

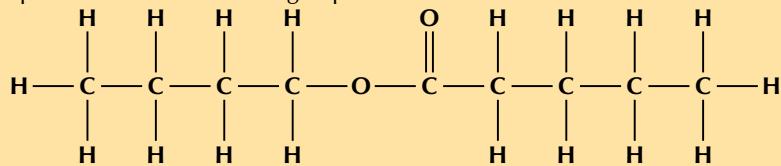
a) 3-methylpentanal

The suffix -al tells us that the compound is an aldehyde. The prefix pent- tells us that there are five carbon atoms in the longest chain. 3-methyl tells us that there is a methyl branched group on the third carbon atom.



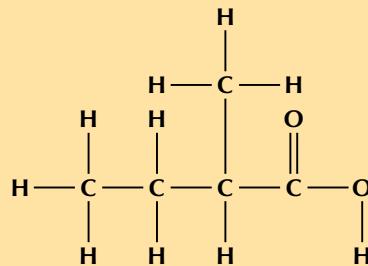
b) butyl pentanoate

The suffix -oate tells us that the compound is an ester. The prefix pent- tells us that there are five carbon atoms in the chain containing the carbonyl group. Butyl tells us that there are four carbon atoms in the chain that **does not** contain the carbonyl group. There are no branched groups.



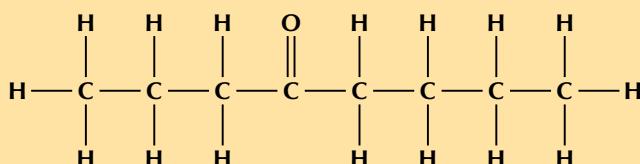
c) 2-methylbutanoic acid

The suffix -oic acid tells us that the compound is a carboxylic acid. The prefix but- tells us that there are four carbon atoms in the longest chain. 2-methyl tells us that there is a branched methyl chain attached to the second carbon atom (remember to count from the carboxylic acid carbon atom).

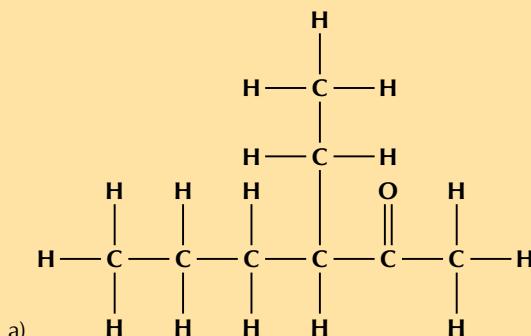


d) octan-4-one

The suffix -one tells us that the compound is a ketone and that the fourth carbon atom is the carbonyl carbon atom. The prefix oct- tells us that there are eight carbon atoms in the longest chain. There are no branched chains.



2. Give the IUPAC name for each of the following compounds:

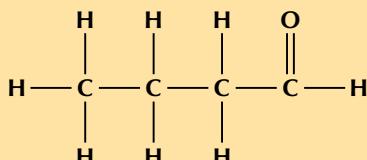


There is a carbonyl group and it is *not* on the first or last carbon atom. This compound must be a ketone and have the suffix -one. There are six carbon atoms in the longest chain containing the carbonyl functional group, therefore the prefix is hexan-. The carbonyl is on the second carbon atom. There is a branched ethyl group attached to the third carbon atom. This molecule is therefore **3-ethylhexan-2-one**.

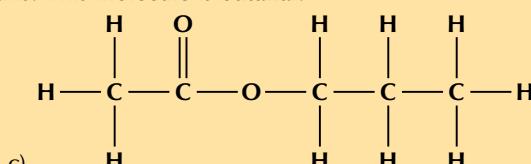
Note that the way you number this compound is important. This is **not** 4-ethylhexan-5-one.

b) CH₃CH₂CH₂CHO

Draw the structural representation:



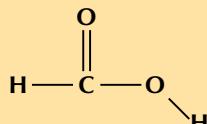
There is a carbonyl group and it is on the first/last carbon atom. This compound must be an aldehyde and have the suffix -al. There are four carbon atoms in the chain containing the carbonyl group, therefore the prefix is butan-. There are no branched chains. This molecule is **butanal**.



There is a carbonyl group and an oxygen atom attached to two different carbon atoms. This compound must be an ester and have the suffix -oate. There are three carbon atoms in the chain **without** the carbonyl group and this is propyl. There are two carbon atoms in the chain **with** the carbonyl group so the prefix is ethan-. There are no branched chains. This molecule is **propyl ethanoate**.

d) HCOOH

Draw the structural representation:



There is a carbonyl group and a hydroxyl group attached to the same carbon atom. This compound must be a carboxylic acid and have the suffix -oic acid. There is one carbon atom in the longest chain therefore the prefix is methan-. There are no branched chains (there can be no branched chains). This molecule is **methanoic acid**.

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1. 27N8 2. 27N9



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Exercise 4 – 18: IUPAC naming

1. Study the table below and answer the questions that follow:

	A Compound	B Functional group	C Number of carbon atoms
1	e.g. methane	e.g. alkane	e.g. 1
2	propanoic acid	alkyne	8
3	2-chloroethane	ketone	4
4	1-octanal	carboxylic acid	6
5	3-heptyne	aldehyde	2
6	butanone	ester	6
7	3-hexene	haloalkane	1 and 5
8	1-hexanol	alkene	3
9	methyl pentanoate	alcohol	7

a) Match the compounds in column A with the correct functional group in column B. For example methane is an alkane: **A1, B1**.

A1 (methane), B1 (alkane)

A2 (propanoic acid), B4 (carboxylic acid)

A3 (2-chloroethane), B7 (haloalkane)

A4 (1-octanal), B5 (aldehyde)

A5 (3-heptyne), B2 (alkyne)

A6 (butanone), B3 (ketone)

A7 (3-hexene), B8 (alkene)

A8 (1-hexanol), B9 (alcohol)

A9 (methyl pentanoate), B6 (ester)

b) Match the compounds in column A with the correct number of carbon atoms in column C. For example methane has one carbon atom in its longest chain: **A1, C1**.

A1 (methane), C1 (1)

A2 (propanoic acid), C8 (3)

A3 (2-chloroethane), C5 (2)

A4 (1-octanal), C2 (8)

A5 (3-heptyne), C9 (7)

A6 (butanone), C3 (4)

A7 (3-hexene), C4 or C6 (6)

A8 (1-hexanol), C4 or C6 (6)

A9 (methyl pentanoate), C7 (1 and 5)

2. Match the structural representation in column A with the condensed structural representation (column B) and IUPAC name (column C).

	A Structure	B Condensed	C IUPAC name
1	<pre> H H H H—C—C—C—H H H </pre>	CH ₃ CH(I)CH ₃	ethyl methanoate
2	<pre> H H—C—C≡C—H H </pre>	CH ₃ CH ₂ CH ₃	propanone
3	<pre> H O H H C—C—C—H H H </pre>	CH ₃ COCH ₃	propane
4	<pre> H H O H C—C—C—OH H H </pre>	HCOOCH ₂ CH ₃	propyne
5	<pre> H I H H C—C—C—H H H </pre>	CH ₃ CCH	propanal
6	<pre> H H O H C—C—O—C—H H H </pre>	CH ₃ CHCH ₂	2-iodopropane
7	<pre> H H H H C—C=C—C—H H H </pre>	CH ₃ CH ₂ CHO	propanoic acid
8	<pre> H H O H C—C—C—H H H </pre>	CH ₃ CH ₂ COOH	propene

propane - A1, B2, C3

propyne - A2, B5, C4

propanone - A3, B3, C2

propanoic acid - A4, B8, C7

2-iodopropane - A5, B1, C6

ethyl methanoate - A6, B4, C1

propene - A7, B6, C8

propanal - A8, B7, C5

3. Fill in the gaps in the table below:

IUPAC name	Functional group	Condensed	Structural
		$\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$	<pre> H H H O H—C—C—C—C=O—H H H H </pre>
ethanol			<pre> H O—H H—C—C—H H H </pre>
	carboxylic acid	$\text{CH}_3\text{CH}_2\text{CH}(\text{CH}_3)\text{CH}_2\text{COOH}$	
2-methyl pent-2-ene		$\text{CH}_3\text{C}(\text{CH}_3)\text{CHCH}_2\text{CH}_3$	
	alkane		<pre> H H—C—C—H H H H—C—C—H H H H </pre>
	ester	$\text{CH}_3\text{COOCH}_2\text{CH}_2\text{CH}_3$	
butanone	ketone		
	1-pentyne		<pre> H H H H—C≡C—C—C—H H H H </pre>
	alkyl halide	$\text{CH}_2(\text{Cl})\text{CH}_2\text{CH}_3$	

IUPAC name	Functional group	Condensed	Structural
butanal	aldehyde	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$	<pre> H H H O H—C—C—C—C=O—H H H H </pre>
ethanol	alcohol	$\text{CH}_3\text{CH}_2\text{OH}$	<pre> H O—H H—C—C—H H H </pre>
3-methyl pentanoic acid	carboxylic acid	$\text{CH}_3\text{CH}_2\text{CH}(\text{CH}_3)\text{CH}_2\text{COOH}$	<pre> H H—C—C—C—C—C=O—O H H H H </pre>
2-methyl pent-2-ene	alkene	$\text{CH}_3\text{C}(\text{CH}_3)\text{CHCH}_2\text{CH}_3$	<pre> CH₃ H H H C=C—C—C—C—H CH₃ H H </pre>
2-methyl propane	alkane	$\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_3$	<pre> H H—C—C—C—H H H H </pre>

IUPAC name	Functional group	Condensed	Structural
propyl ethanoate	ester	$\text{CH}_3\text{COOCH}_2\text{CH}_2\text{CH}_3$	<pre> O H H H C—O—C—C—C—H H H H </pre>
butanone	ketone	$\text{CH}_3\text{COCH}_2\text{CH}_3$	<pre> H O H H H—C—C—C—C—H H H H </pre>
1-pentyne	alkyne	$\text{CHCCH}_2\text{CH}_2\text{CH}_3$	<pre> H H H H—C≡C—C—C—H H H H </pre>
1-chloro propane	halo alkane	$\text{CH}_2(\text{Cl})\text{CH}_2\text{CH}_3$	<pre> H H H Cl—C—C—C—H H H H </pre>

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1. 27NB 2. 27NC 3. 27ND



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4.4 Physical properties and structure

Physical properties and intermolecular forces

Have the learners research the safety data for various compounds, especially those being used in the experiments in this section, as a way of linking the properties of organic molecules with their molecular structure.

If the glass sheet is tilted to either side during the resistance to flow activity the drops will run into each other and the activity will not work. The drops should reach the *finish* line in the order of: alcohol (least viscous), water, oil, syrup (most viscous).

In the investigation of boiling and melting points experiment learners are required to work with ethyl methanoate. This can irritate your eyes, skin, nose and lungs. Please remind the learners to be careful and wear the appropriate safety equipment when handling all chemicals. The safety equipment includes gloves, safety glasses and protective clothing. Learners should also keep all open flames away from their experiment as they are handling flammable substances.

The boiling point of propanoic acid is approximately 141 °C, which means that the cooking oil will be very hot by the time propanoic acid starts to boil. The learners should be reminded not to place their hands anywhere near the oil, and to allow it to cool before cleaning the apparatus.

This is a good opportunity to get the learners to research the hazard data sheets for butan-1-ol, propanoic acid and ethyl methanoate.

Exercise 4 – 19: Types of intermolecular forces

1. Use your knowledge of different types of intermolecular forces to explain the following statements:

- a) The boiling point of hex-1-ene is much lower than the boiling point of propanoic acid.

Propanoic acid has hydrogen bonds which are much stronger than the induced-dipole forces in hex-1-ene. In order for a liquid to boil the intermolecular forces must be broken. The stronger the intermolecular forces, the more energy it will take to overcome these forces. As a result the boiling point will be higher for propanoic acid than for hex-1-ene.

- b) Water evaporates more slowly than propanone.

Water has strong intermolecular forces (hydrogen bonds) while propanone only has weaker dipole-dipole forces. Substances with stronger intermolecular forces take longer to evaporate than substances with weaker intermolecular forces.

	IUPAC name	Boiling point (°C)
2.	A ethane	-89,0
	B ethanol	78,4
	C ethanoic acid	118,5

- a) Which of the compounds listed in the table are gases at room temperature?
ethane

- b) Name the main type of intermolecular forces for A, B and C.

- A - induced-dipole forces
B - hydrogen bonding
C - hydrogen bonding

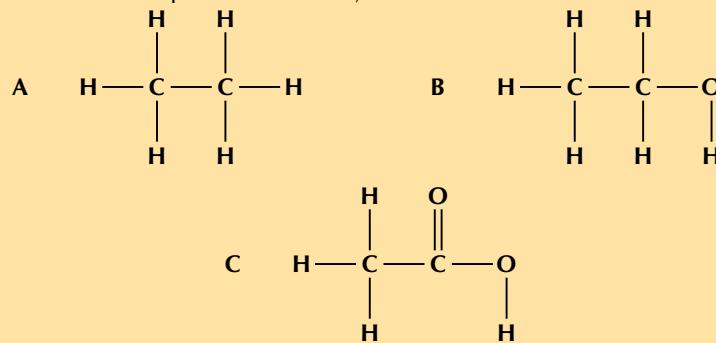
- c) Account for the difference in boiling point between A and B.

A has only induced-dipole forces (weak van der Waals forces). B has hydrogen bonding. Since hydrogen bonding is a stronger intermolecular force than van der Waals forces, more energy is required to separate the molecules of ethanol than the molecules of ethane. Thus ethanol has a higher boiling point than ethane.

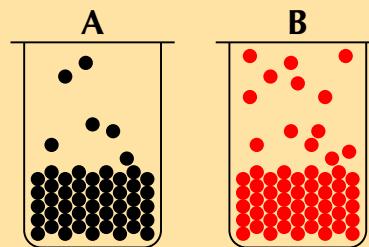
- d) Account for the difference in boiling point between B and C.

Both B and C undergo hydrogen bonding. However the hydrogen bonding in C (carbonyl and hydroxyl group) is stronger than that of B (hydroxyl group). This is because C forms a hydrogen bonding dimer, while B forms only single hydrogen bonds. Thus C has a higher boiling point than B.

- e) Draw the structural representations of A, B and C.



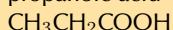
3. a) Which container (A or B) has the compound with higher vapour pressure in it? Explain your answer.



B. There are more molecules of B in the vapour phase than there are of A. More molecules in the vapour phase means a higher vapour pressure.

b) Draw the condensed structural formula for each of these compounds:

i. propanoic acid



ii. butan-1-ol



c) Propanoic acid has a vapour pressure of 0,32 kPa at 20 °C

Butan-1-ol has a vapour pressure of 0,64 kPa at 20 °C

Explain the difference in vapour pressure.

Both compounds have the same molecular mass, but propanoic acid has two sites for hydrogen bonding (can form a hydrogen bonding dimer) while butan-1-ol has only one. So butan-1-ol has weaker intermolecular forces and will go into the vapour phase easier than propanoic acid. Butan-1-ol therefore has a higher vapour pressure than propanoic acid.

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1a. 27NF 1b. 27NG 2. 27NH 3a. 27NJ 3b. 27NK 3c. 27NM



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Physical properties and functional groups

Exercise 4 – 20: Physical properties and functional groups

1. Refer to the data table below which shows the melting point and boiling point for a number of organic compounds with different functional groups.

Formula	Name	Melting point (°C)	Boiling point (°C)
C ₄ H ₁₀	butane	-137	0
C ₄ H ₈	but-1-ene	-185	-6,5
C ₄ H ₁₀ O	butan-1-ol	-90	118
C ₄ H ₈ O ₂	butanoic acid	-7,9	163,5
C ₅ H ₁₂	pentane	-130	36
C ₅ H ₁₀	pent-1-ene	-165,2	30
C ₅ H ₁₂ O	pentan-1-ol	-78	138
C ₅ H ₁₀ O ₂	pentanoic acid	-34,5	186,5

a) At room temperature (approx. 25°C), which of the organic compounds in the table are:

i. gases

butane, but-1-ene

ii. liquids

All except butane and but-1-ene

b) Look at an alkane, alkene, alcohol and carboxylic acid with the same number of carbon atoms:

i. How do their melting and boiling points compare?

The carboxylic acids have the highest melting and boiling points, then the alcohols, then the alkanes and the alkenes have the lowest melting and boiling points.

Looking at those compounds with four carbon atoms:

Butanoic acid has the highest boiling (and melting) point, the next highest boiling (and melting) point is butan-1-ol, then butane (the alkane) followed by but-1-ene (the alkene).

Looking at those compounds with five carbon atoms:

Pentanoic acid has the highest boiling (and melting) point, the next highest boiling (and melting) point is pentan-1-ol, then pentane (the alkane) followed by pent-1-ene (the alkene).

- ii. Explain why their melting points and boiling points are different?

The carboxylic acids have the strongest intermolecular forces due to their ability to form two hydrogen bonds (dimerisation). The alcohols can only form one hydrogen bond leading to lower melting and boiling points. The alkenes and alkanes cannot form hydrogen bonds. However, the alkenes are more reactive than the alkanes due to the double bond (unsaturated) and so the melting and boiling points of an alkene are lower than those of an alkane with the same number of carbon atoms.

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1. 27NN



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Physical properties and chain length

Exercise 4 – 21: Physical properties and chain length

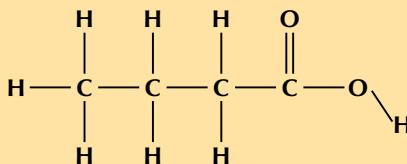
1. Refer to the table below which gives information about a number of carboxylic acids, and then answer the questions that follow.

Condensed formula	Common name	Source	IUPAC name	Melting point (°C)	Boiling point (°C)
	formic acid	ants	methanoic acid	8,4	101
CH ₃ COOH		vinegar	ethanoic acid	16,5	118,5
	propionic acid	milk	propanoic acid	-20,8	141
CH ₃ (CH ₂) ₂ COOH	butyric acid	butter		-7,9	163,5
	valeric acid	valerian root	pentanoic acid	-34,5	186,5
CH ₃ (CH ₂) ₄ COOH	caproic acid	goat skin		-3,4	205,8
	enanthic acid	vines	heptanoic acid	-7,5	223
CH ₃ (CH ₂) ₆ COOH	caprylic acid	goat milk		16,7	239,7

- a) Fill in the missing spaces in the table by writing the formula, common name or IUPAC name.

Condensed formula	Common name	Source	IUPAC name	Melting point (°C)	Boiling point (°C)
HCOOH	formic acid	ants	methanoic acid	8,4	101
CH ₃ COOH	acetic acid	vinegar	ethanoic acid	16,5	118,5
CH ₃ CH ₂ COOH	propionic acid	milk	propanoic acid	-20,8	141
CH ₃ (CH ₂) ₂ COOH	butyric acid	butter	butanoic acid	-7,9	163,5
CH ₃ (CH ₂) ₃ COOH	valeric acid	valerian root	pentanoic acid	-34,5	186,5
CH ₃ (CH ₂) ₄ COOH	caproic acid	goat skin	hexanoic acid	-3,4	205,8
CH ₃ (CH ₂) ₅ COOH	enanthic acid	vines	heptanoic acid	-7,5	223
CH ₃ (CH ₂) ₆ COOH	caprylic acid	goat milk	octanoic acid	16,7	239,7

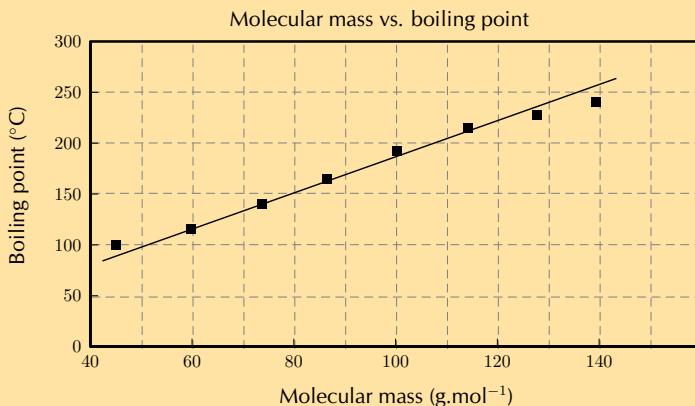
b) Draw the structural representation of butyric acid.



c) Give the molecular formula for caprylic acid.



d) i. Draw a graph to show the relationship between molecular mass (on the x-axis) and boiling point (on the y-axis)



ii. Describe the trend you see.

As the molecular mass increases, so does the boiling point OR boiling point increases with an increase in molecular mass (something along these lines).

iii. Suggest a reason for this trend.

Longer chains allow for greater van der Waals interactions leading to higher boiling points OR an increase in the surface area of the molecules leads to greater intermolecular forces which leads to increasing boiling points OR the forces holding the molecules in the solid phase are increasing and so the boiling point increases, this is because the compounds with larger molecular mass have longer chains (something along these lines).

2. Refer to the data table below which shows the melting point and boiling point for a number of organic compounds with different functional groups.

Formula	Name	Melting point (°C)	Boiling point (°C)
C ₄ H ₁₀	Butane	-137	0
C ₅ H ₁₂	Pentane	-130	36
C ₆ H ₁₄	Hexane	-95	68,5
C ₄ H ₈	But-1-ene	-185	-6,5
C ₅ H ₁₀	Pent-1-ene	-165,2	30
C ₆ H ₁₂	Hex-1-ene	-140	63

- a) At room temperature (approx. 25 °C), which of the organic compounds in the table are:

 - i. gases
butane, butene
 - ii. liquids
pentane, pentene, hexane, hexene

b) In the alkanes:

 - i. Describe what happens to the melting point and boiling point as the number of carbon atoms in the compound increases.
The melting and boiling points increase as the number of carbon atoms increase.
 - ii. Explain why this is the case.
As the number of carbon atoms increases, so does the surface area of the molecule. This leads to greater intermolecular forces, which are responsible for the increase in melting and boiling points.

3. Fill in the table below. Under boiling point put 1 for the compound with the lowest boiling point, 2 for the next lowest boiling point until you get to 6 for the compound with the highest boiling point. Do not use specific boiling point values, but rather use your knowledge of intermolecular forces.

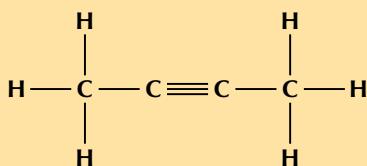
Compound	Condensed Structure	Boiling point
propane	$\text{CH}_3\text{CH}_2\text{CH}_3$	
hexane	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	
methane	CH_4	e.g. 1
octane	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	
butane	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$	
ethane	CH_3CH_3	

Compound	Condensed Structure	Boiling point
propane	$\text{CH}_3\text{CH}_2\text{CH}_3$	3
hexane	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	5
methane	CH_4	1
octane	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	6
butane	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$	4
ethane	CH_3CH_3	2

4. Draw the structural representations for each of the following compounds and answer the question that follows.

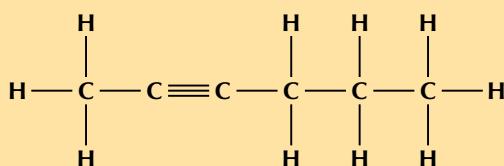
a) but-2-yne

The prefix but- tells us that there are four carbon atoms in the longest chain. The suffix -2-yne tells us that there is a triple bond between the second and third carbon atoms.



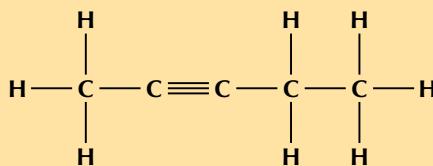
b) hex-2-yne

The prefix hex- tells us that there are six carbon atoms in the longest chain. The suffix -2-yne tells us that there is a triple bond between the second and third carbon atoms.



c) pent-2-yne

The prefix pent- tells us that there are five carbon atoms in the longest chain. The suffix -2-yne tells us that there is triple bond between the second and third carbon atoms.



d) Which of these compounds will have the highest viscosity?

hex-2-yne - All three compounds are alkynes. There is an increase in chain length with but-2-yne having the shortest chain and hex-2-yne the longest. The van der Waals forces will be stronger in the longest chain compound, hex-2-yne, because it has more sites for the van der Waals forces to act (the surface area is larger). Hex-2-yne will therefore have the highest viscosity as the molecules will have the greatest resistance to flow.

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1. 27NP 2. 27NQ 3. 27NR 4. 27NS



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Physical properties and branched groups

Exercise 4 – 22: Physical properties and branched chains

	Structural Formula	Boiling point (°C)
	<pre>graph LR; C1[H] --- C2[C]; C2 --- C3[C]; C3 --- C4[C]; C4 --- Cl1[Cl]; C1 --- H1[H]; C2 --- H2[H]; C3 --- H3[H]; C4 --- H4[H]</pre>	78
1.	<pre>graph LR; C1[H] --- C2[C]; C2 --- C3[C]; C2 --- Cl1[Cl]; C1 --- H1[H]; C2 --- H2[H]; C3 --- H3[H]</pre>	51

a) Give the IUPAC name for each compound

1-chlorobutane and 2-chloro-2-methylpropane

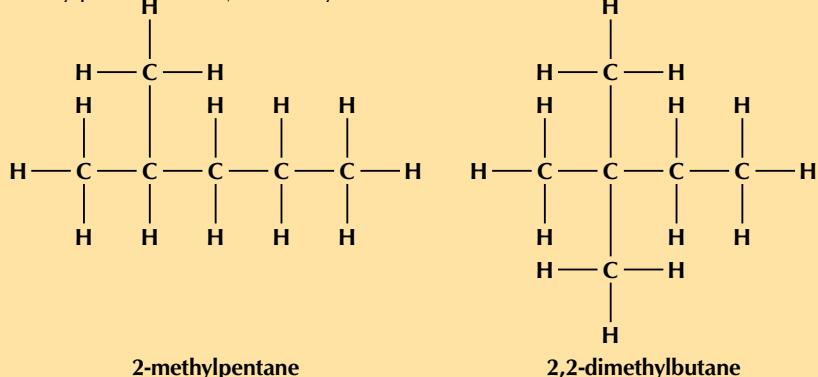
- b) Explain the difference in the melting points

The branched haloalkane (2-chloro-2-methylpropane) will have less surface area and thus weaker intermolecular forces than the straight chain haloalkane (1-chlorobutane). Less energy will be needed to break the intermolecular forces of 2-chloro-2-methylpropane, and therefore a lower boiling point is observed.

2. There are five isomers with the molecular formula C₆H₁₄.

- a) Draw the structural representations of:

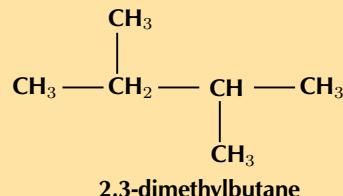
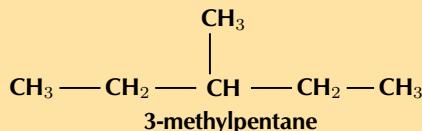
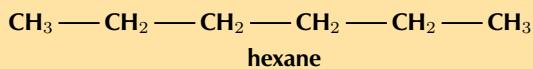
2-methylpentane and 2,2-dimethylbutane (two of the isomers)



- b) What are the names of the other three isomers?

hexane, 3-methylpentane and 2,3-dimethylbutane

- c) Draw the semi-structural representations of these three molecules.



- d) The melting points of these three isomers are: -118, -95 and -130 °C. Assign the correct melting points to the correct isomer. Give a reason for your answers.

The lowest melting point will be with the molecule with the weakest intermolecular forces. This molecule is 2,3-dimethylbutane as it is the isomer with the most branched chains. The highest melting point will be with the molecule with the strongest intermolecular forces. This molecule is hexane as it is the isomer with no branched groups.

Therefore the melting points will be:

- 2,3-dimethylbutane: -130 °C
- 3-methylpentane: -118 °C
- hexane: -95 °C

3. More questions. Sign in at Everything Science online and click 'Practise Science'.

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1. 27NT 2. 27NV



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Exercise 4 – 23: Physical properties of organic compounds

1. The table shows data collected for four organic compounds (**A** - **C**) during a practical investigation.

	Compound	Molecular Mass (g.mol ⁻¹)	Boiling point (°C)
A	CH ₃ CH ₂ CH ₃	44,08	-42
B	CH ₃ CHO	44,04	20
C	CH ₃ CH ₂ OH	46,06	78

- a) Is compound **A** saturated or unsaturated? Give a reason for your answer.

Saturated. It contains only single carbon-carbon bonds.

- b) To which homologous series does compound **B** belong?

aldehydes

- c) Write down the IUPAC name for each of the following compounds:

i. **B**
ethanal

ii. **C**
ethanol

Refer to intermolecular forces to explain the difference in boiling points between compounds **A** and **C**.

Between alkane molecules/molecules of compound A/propane molecules there are only weak van der Waals forces/intermolecular forces.

Between alcohol molecules/molecules of compound D/ethanol molecules there are strong hydrogen bonds (as well as weak van der Waals forces).

More energy is needed to overcome the intermolecular forces/hydrogen bonds between alcohol molecules/ethanol molecules/molecules of compound C

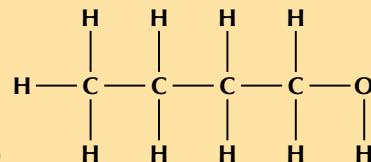
OR

Less energy is needed to overcome the intermolecular forces/van der Waals forces between alkane molecules/propane molecules/molecules of compound A

- d) Which one of compounds **B** or **C** will have the highest vapour pressure at a specific temperature? Give a reason for your answer.

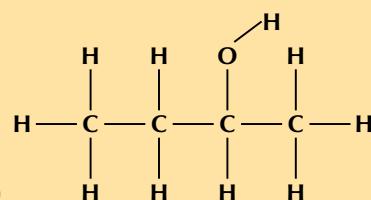
B. A lower boiling point (or weaker intermolecular forces) means that more molecules will go into the vapour phase, resulting in a higher vapour pressure.

2. Give the IUPAC names for the following compounds and answer the questions that follow.



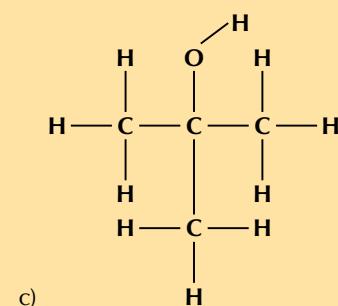
a)
Boiling point = 118 °C

butan-1-ol



b)
Boiling point = 99 °C

butan-2-ol



c)

Boiling point = 82,5 °C

2-methylpropan-2-ol

- d) Explain the difference in boiling points.

The hydrogen bonding hydroxyl group is located on an end carbon atom in butan-1-ol. This allows it to form hydrogen bonds more easily than butan-2-ol. The branched group in 2-methylpropan-2-ol means that it is even more difficult for hydrogen bonds to form between these molecules (weak intermolecular forces). The greater the intermolecular forces, the more energy that is required to overcome them, and the higher the boiling point will be.

3. More questions. Sign in at Everything Science online and click 'Practise Science'.

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1. 27NW 2a. 27NX 2b. 27NY 2c. 27NZ 2d. 27P2



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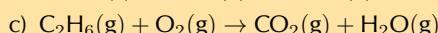
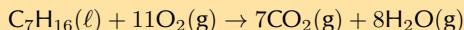
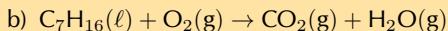
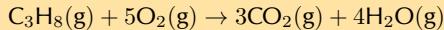
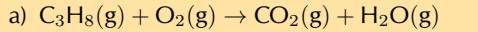
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4.5 Applications of organic chemistry

Alkanes as fossil fuels

Exercise 4 – 24: Alkanes as fossil fuels

1. Balance the following complete combustion equations:



2. Write the balanced equation for the complete combustion of:

- a) octane



- b) pentane



- c) hexane



- d) butane



3. Is the combustion of alkanes exothermic or endothermic? What does that mean?

It is exothermic. This means that energy is released during the combustion of an alkane.

4. More questions. Sign in at Everything Science online and click 'Practise Science'.

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1a. 27P4 1b. 27P5 1c. 27P6 2a. 27P7 2b. 27P8 2c. 27P9

2d. 27PB 3. 27PC



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Esters

In the preparation of esters experiment learners are required to work with many different ester compounds, as well as a strong acid. Some esters can irritate your eyes, skin, nose and lungs, and strong, concentrated acids can cause serious burns. Please remind the learners to be careful and wear the appropriate safety equipment when handling all chemicals. The safety equipment includes gloves, safety glasses and protective clothing. Learners should also keep all open flames away from their experiment as they are handling flammable substances.

This is a good opportunity to get the learners to research the hazard data sheets for methanol, ethanol, pentanol, methanoic acid and ethanoic acid. They can also reasearch the products: methyl methanoate, methyl ethanoate, ethyl methanoate, ethyl ethanoate and pentyl ethanoate.

If vapour bubbles start to form, porcelain chips can be added to the test tube. If the learners can only smell the acid a few drops of sodium carbonate can help neutralise those acid fumes.

The exact volumes mentioned in the experiment are not that important, as long as the reactants are in approximately this ratio. Boiled water can be used instead of a water bath.

Exercise 4 – 25: Esters

1. Give the IUPAC name for the product in the esterification of ethanoic acid with:

a) methanol	b) octanol
methyl ethanoate	octyl ethanoate
c) hexanol	d) propanol
hexyl ethanoate	propyl ethanoate
2. What is another name for the type of reaction in the question above?
acid-catalysed condensation
3. Give the IUPAC name for the product in the reaction of butanol with:

a) ethanoic acid	b) pentanoic acid
butyl ethanoate	butyl pentanoate
c) heptanoic acid	d) methanoic acid
butyl heptanoate	butyl methanoate
4. Fill in the missing reactant or part of the product name in the reactions below:

a) octanol + _____ → _____ hexanoate
octanol + hexanoic acid → octyl hexanoate
b) _____ + propanoic acid → hexyl _____
hexanol + propanoic acid → hexyl propanoate
c) _____ + butanol → _____ pentanoate
pentanoic acid + butanol → butyl pentanoate
5. More questions. Sign in at Everything Science online and click 'Practise Science'.

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- 1a. 27PD 1b. 27PF 1c. 27PG 1d. 27PH 2. 27PJ 3a. 27PK
3b. 27PM 3c. 27PN 3d. 27PP 4a. 27PQ 4b. 27PR 4c. 27PS



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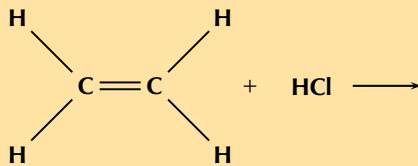
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4.6 Addition, elimination and substitution reactions

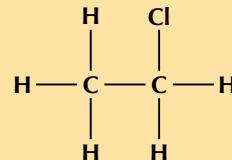
Mechanisms and arrow-pushing are not required by CAPS. The learners need to know the types of reactants, the types of reactions and the reaction conditions.

Exercise 4 – 26: Addition reactions

1. The following diagram shows the reactants in an addition reaction.



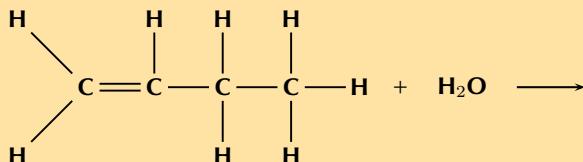
- a) Draw the structural representation of the final product in this reaction.



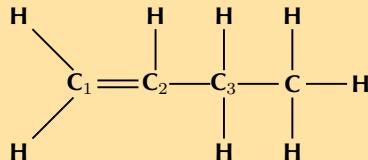
- b) What is the condensed structural representation of the product?



2. The following diagram shows the reactants in an addition reaction.

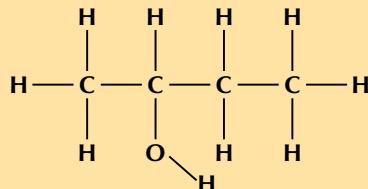


- a) Draw the structural representation of the major product in this reaction and give reasons.

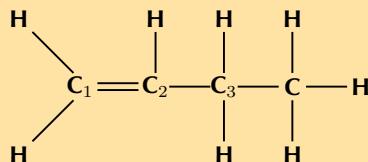


The hydroxyl anion (OH^-) can bond to carbon one, or carbon two. Carbon atom one is bonded only to carbon atom two. Carbon atom two is bonded to carbon atom one and carbon atom three.

Therefore, carbon atom one is less substituted and carbon atom two is more substituted. In the major product, the hydroxyl anion will add to the more substituted carbon atom (two).

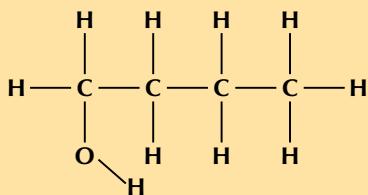


- b) Draw the structural representation of the minor product in this reaction and give reasons.



The hydroxyl anion (OH^-) can bond to carbon one, or carbon two. Carbon atom one is bonded only to carbon atom two. Carbon atom two is bonded to carbon atom one and carbon atom three.

Therefore, carbon atom one is less substituted and carbon atom two is more substituted. In the minor product, the hydroxyl anion will add to the less substituted carbon atom (one).



- c) What type of addition reaction is this reaction?

Hydration reaction

3. a) Which types of homologous series can undergo addition reactions?

Any series where the functional group contains double or triple bonds (e.g. alkenes, alkynes).

- b) Is this a saturated or unsaturated series?

Unsaturated

4. More questions. Sign in at Everything Science online and click 'Practise Science'.

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1. 27PT 2. 27PV 3. 27PW



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Elimination reactions

Exercise 4 – 27: Elimination reactions

1. Answer the following questions about elimination reactions:

- a) What two compounds do you need for a dehydrohalogenation reaction?

Haloalkane and a base

- b) What carbon atom will the hydrogen atom be removed from in a dehydration reaction (major product)?

The more substituted carbon atom of those atoms directly bonded to the carbon atom the hydroxyl group is attached to. That is the carbon atom bonded to the most other carbon atoms.

2. a) Are the reactants in an elimination reaction saturated or unsaturated?

saturated

- b) Name the elimination reaction that is considered the reverse of a hydration addition reaction

dehydration reaction (of an alcohol)

3. More questions. Sign in at Everything Science online and click 'Practise Science'.

Think you got it? Get this answer and more practice on our Intelligent Practice Service

1. 27PX 2. 27PY



Substitution reactions

Exercise 4 – 28: Substitution reactions

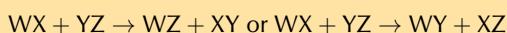
1. When forming haloalkanes through a substitution reaction with alcohols is it best to use a tertiary, secondary or primary alcohol? Give a reason for your answer.

A tertiary alcohol. The reaction works best with tertiary alcohols (it can occur at room temperature). Higher temperatures are required for secondary and primary alcohols and the reaction is much slower.

2. a) What is a substitution reaction?

An exchange of elements in the reactants must take place. The initial reactants are transformed or 'swopped around' to give the final products.

- b) Write the general equation for a substitution reaction using the reactants WX and YZ



3. More questions. Sign in at Everything Science online and click 'Practise Science'.

Think you got it? Get this answer and more practice on our Intelligent Practice Service

1. 27PZ 2. 27Q2



Exercise 4 – 29: Addition, elimination and substitution reactions

1. a) Answer the following questions about hydration reactions:

- i. What type of reaction is a hydration reaction?
An addition reaction

- ii. What is the most common catalyst used in this reaction?
 H_3PO_4

- b) Name one of the most common catalysts used in a hydrogenation reaction.

Platinum OR palladium OR nickel

- c) Answer the following questions about alkane reactions

- i. Are alkanes reactive compared to alkenes and alkynes?
No

- ii. In a haloalkane reaction an alkane and a halogen react. What condition is necessary for this reaction to take place?
Energy in the form of light

- d) Look at the general equations given below and answer the questions that follow:

- i. haloalkane + base $\rightarrow A + B$

- A. Name A and B for a hydrolysis reaction.
alcohol and salt (containing the halogen atom).

- B. What type of reaction is a hydrolysis reaction?
substitution

- ii. haloalkane + base $\rightarrow A + B + C$

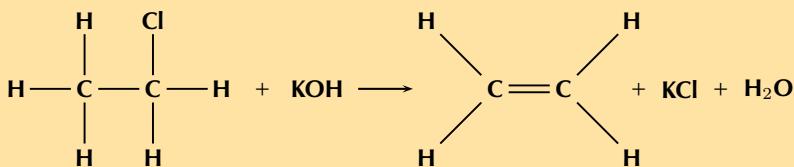
- A. Name A, B and C for a dehydrohalogenation reaction.
alkene, salt and water

- B. What type of reaction is a dehydrohalogenation reaction?
elimination
- iii. Fill in the reaction conditions required for dehydrohalogenation and hydrolysis reactions in the table below:

	Dehydrohalogenation	Hydrolysis
Temperature		
Solvent		
Concentration of base		

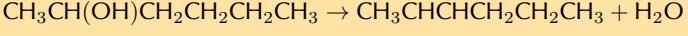
	Dehydrohalogenation	Hydrolysis
Temperature	high (70°C)	low (room temperature)
Solvent	alcoholic	aqueous
Concentration of base	concentrated	dilute

2. Refer to the diagram below and then answer the questions that follow:



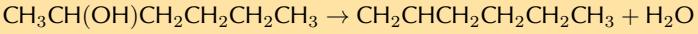
- a) What type of reaction is this reaction?
Elimination
- b) Give a reason for your answer above.
A single bond becomes a double bond and a hydrogen atom and a chlorine atom are eliminated from the reactant.
- c) What are the required reaction conditions?
Heat, under reflux (approximately 70°C), a concentrated alcoholic (ethanol) solution of a strong base (e.g. NaOH or KOH).
3. Write the equation for the following reactions using the condensed structural representation. Say what type of reaction they are:

- a) The dehydration of hexan-2-ol ($\text{CH}_3\text{CH}(\text{OH})\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$)



hexan-2-ol → hex-2-ene + water (major product)

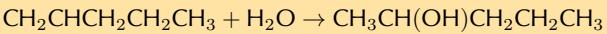
OR



hexan-2-ol → hex-1-ene + water (minor product)

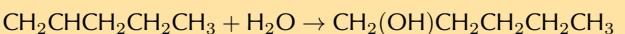
Elimination

- b) The hydration of pent-1-ene ($\text{CH}_2\text{CHCH}_2\text{CH}_2\text{CH}_3$)



pent-1-ene + water → pentan-2-ol (major product)

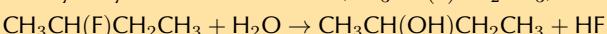
OR



pent-1-ene + water → pentan-1-ol (minor product)

Addition

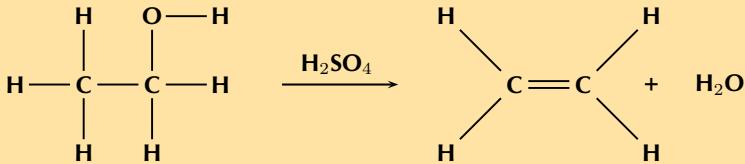
- c) The hydrolysis of 2-fluorobutane ($\text{CH}_3\text{CH}(\text{F})\text{CH}_2\text{CH}_3$) with water (no base).



2-fluorobutane + water → butan-2-ol + hydrofluoric acid

Substitution

4. The following reaction takes place:



a) What type of reaction is this?

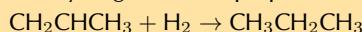
Elimination

b) Give a reason for your answer.

A saturated compound (alcohol) becomes an unsaturated compound (alkene) with a molecule of water eliminated from the reactant (alcohol).

5. Write the equations for the following reactions using condensed structural representations. State the type of reaction as well.

a) The hydrogenation of propene (CH_2CHCH_3)

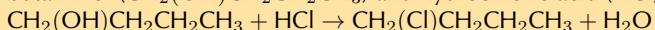


propene + hydrogen → propane

Addition

b) The formation of a haloalkane from:

i. butan-1-ol ($\text{CH}_2(\text{OH})\text{CH}_2\text{CH}_2\text{CH}_3$) and hydrochloric acid (HCl)

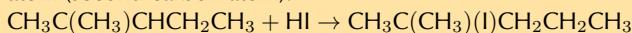


butan-1-ol + hydrochloric acid → 1-chlorobutane + water

Substitution

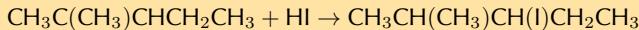
ii. 2-methylpent-2-ene ($\text{CH}_3\text{C}(\text{CH}_3)\text{CHCH}_2\text{CH}_3$) and hydroiodic acid (HI). Indicate the major and minor products and give reasons.

In the major product the hydrogen will add to the less substituted carbon atom (third carbon atom), and the iodine will add to the more substituted carbon atom (second carbon atom):



2-methylpent-2-ene + hydroiodic acid → 2-ido-2-methylpentane

In the minor product the hydrogen will add to the more substituted carbon atom (second carbon atom), and the iodine will add to the less substituted carbon atom (third carbon atom):

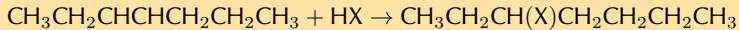


2-methylpent-2-ene + hydroiodic acid → 3-ido-2-methylpentane

Addition

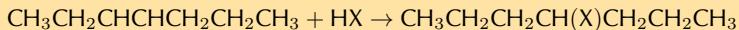
c) Write balanced equations for the following reactions involving hept-3-ene ($\text{CH}_3\text{CH}_2\text{CHCHCH}_2\text{CH}_2\text{CH}_3$) and name the product.

i. Hydrohalogenation, choose any halogen



hept-3-ene + hydrochloric acid (e.g.) → 3-chloroheptane

OR

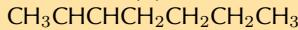


hept-3-ene + hydrochloric acid (e.g.) → 4-chloroheptane

Either product is possible as the carbons on either side of the double bond are equally substituted (bonded to two carbon atoms and one hydrogen atom).

Addition

ii. The dehydrohalogenation with potassium hydroxide (KOH) of the product from c) i



3-chloroheptane + potassium hydroxide → hept-2-ene

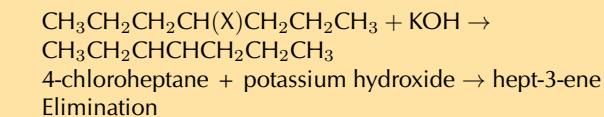
OR



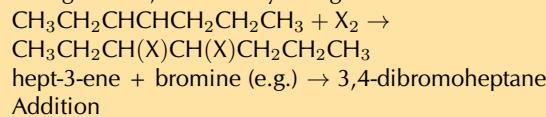
3-chloroheptane + potassium hydroxide → hept-3-ene

Either product is possible as the carbons on either side of the double bond are equally substituted (bonded to two carbon atoms and one hydrogen atom).

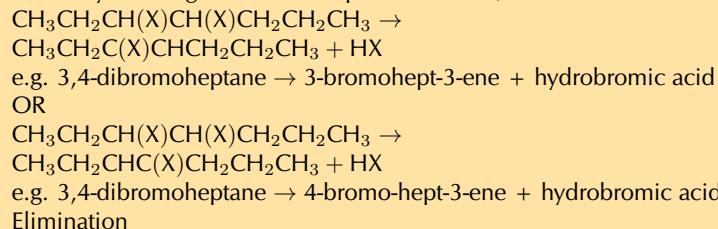
OR



iii. Halogenation, choose any halogen



iv. The dehydrohalogenation of the product from c) iii



6. More questions. Sign in at Everything Science online and click 'Practise Science'.

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- 1a. 27Q3 1b. 27Q4 1c. 27Q5 1d. 27Q6 2. 27Q7 3. 27Q8
4. 27Q9 5. 27QB



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4.7 Plastics and polymers

What is a polymer?

The learners should come back to the *What is a polymer?* concept map throughout this section, whenever they have new information to add. This can then be used as a study tool.

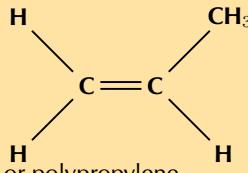
How do polymers form?

Exercise 4 – 30: Addition polymers

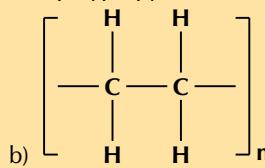
1. What trend is visible when comparing the melting points of monomers and their polymers?

Polymerisation increases the melting point OR while the monomers are in the gas or liquid phase the polymers are solid.

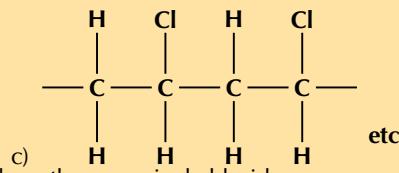
2. Name the monomer (where polymer is given) or polymer (where monomer is given) for the following:



The polymer is polypropene or polypropylene.



The monomer is ethene or ethylene.



c) The monomer is chloroethene or vinyl chloride.

3. More questions. Sign in at Everything Science online and click 'Practise Science'.

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1. 27QH 2. 27QJ



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Exercise 4 – 31: Condensation polymers

1. What is the main difference between the reactants used in an addition polymerisation and those used in a condensation polymerisation?

A condensation reaction requires two monomer molecules (or a monomer with two functional groups) while an addition reaction requires only one.

OR

An addition polymerisation is an addition reaction while a condensation polymerisation is a substitution reaction.

OR

An addition polymerisation requires an unsaturated monomer while a condensation polymerisation does not.

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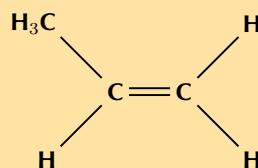


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In the *making polymer slime* experiment make sure the learners keep the slime away from their clothes as it can permanently stain. You can store the slime by dipping it in some water and then storing it in an air-tight container. However, it may become mouldy after a few days, at that stage throw it away (not down the sink).

Exercise 4 – 32: Polymers

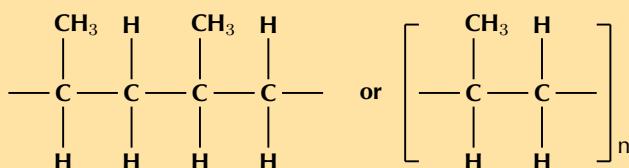
1. The following monomer is a reactant in a polymerisation reaction:



a) What is the IUPAC name of this monomer?

propene

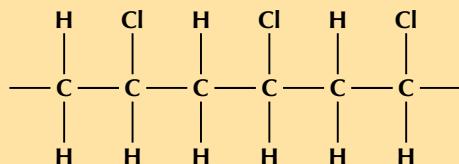
b) Give the structural representation of the polymer that is formed in this polymerisation reaction.



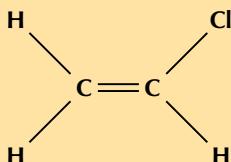
c) Is the reaction an addition or condensation reaction?

Addition

2. The polymer below is the product of a polymerisation reaction.



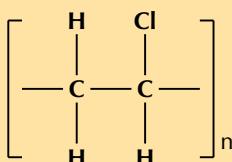
a) Give the structural formula of the monomer used to form this polymer.



b) What is the name of the monomer?

The monomer is chloroethene or vinyl chloride.

c) Draw the abbreviated structural formula for the polymer (the repeat unit).



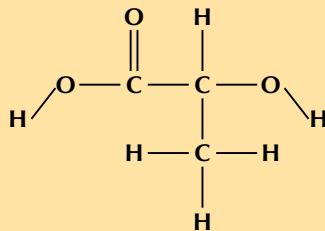
d) Has this polymer been formed through an addition or condensation polymerisation reaction?

Addition

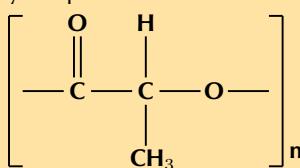
3. A polymerisation reaction takes place between two lactic acid monomers.

a) Give the structural representation for:

i. lactic acid



ii. the repeat unit of the polymer product



b) What is the name of the product?

polylactic acid

- c) Was this polymer formed through an addition or a condensation reaction?
Condensation

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1. 27QP 2. 27QQ 3. 27QR



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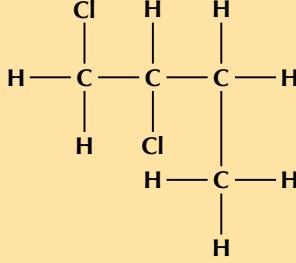
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4.8 Chapter summary

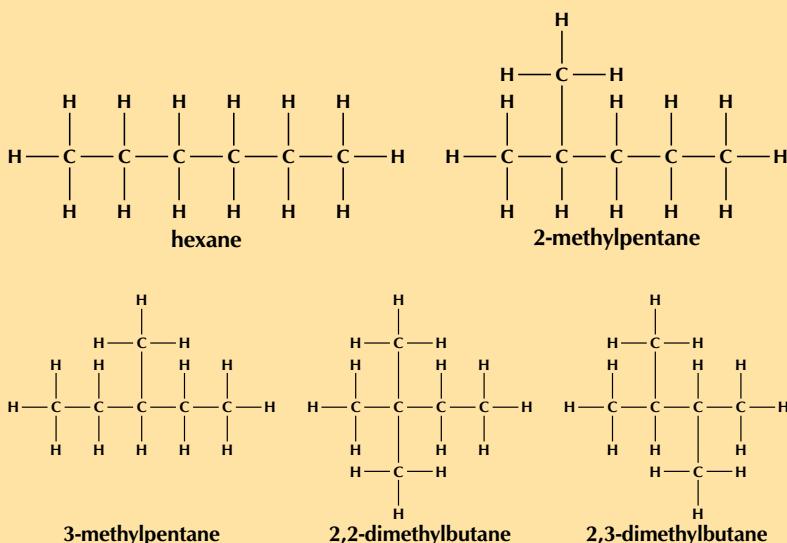
Exercise 4 – 33:

1. Give **one word or phrase** for each of the following descriptions:
 - a) The name of the homologous series to which 2-methylpropene belongs.
Alkenes
 - b) The name of the functional group that gives alcohols their properties.
Hydroxyl group
 - c) The group of organic compounds that have acidic properties.
Carboxylic acid
 - d) The IUPAC name of the organic compound that is found in vinegar.
Ethanoic acid
 - e) The name of the organic compound that is found in alcoholic beverages.
Ethanol
2. When 1-propanol is oxidised by acidified potassium permanganate, the possible product formed is:

<ul style="list-style-type: none">• propane• methyl propanol	<ul style="list-style-type: none">• propanoic acid• propyl methanoate
---	--

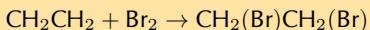
(IEB 2004)
propanoic acid
3. What is the IUPAC name for the compound represented by the following structure?

 - 1,2-dichlorobutane
 - 1,2-dichloro-3-methylpropane
 - 2,2-dichlorobutane
 - 1,1-dichloro-3-methylpropane

(IEB 2003)
1,2-dichlorobutane
4. Give the structural representation and IUPAC name of all possible isomers for C_6H_{14}
(hint: there are 5)



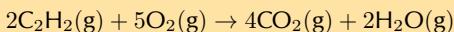
5. Write balanced equations for the following reactions:

a) Ethene reacts with bromine (use condensed structural representations)

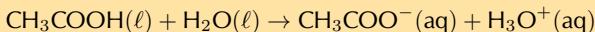


ethene + bromine → 1,2-dibromoethane

b) The complete combustion of ethyne gas (used molecular formula)



c) Ethanoic acid ionises in water



6. The table below gives the boiling point of ten organic compounds.

	Compound	Molecular formula	Boiling Point (°C)
1	methane	CH_4	-162
2	ethane	C_2H_6	-89
3	propane	C_3H_8	-42
4	butane	C_4H_{10}	0
5	pentane	C_5H_{12}	36
6	methanol	CH_4O	64,7
7	ethanol	$\text{C}_2\text{H}_6\text{O}$	78,4
8	propan-1-ol	$\text{C}_3\text{H}_8\text{O}$	97
9	propan-1,2-diol	$\text{C}_3\text{H}_8\text{O}_2$	188
10	propan-1,2,3-triol	$\text{C}_3\text{H}_8\text{O}_3$	290

The following questions refer to the compounds shown in the above table.

a) To which homologous series do the following compounds belong?

i. Compounds 1 - 5

Alkanes

ii. Compounds 6 - 10

Alcohols

b) Which of the above compounds are gases at room temperature?

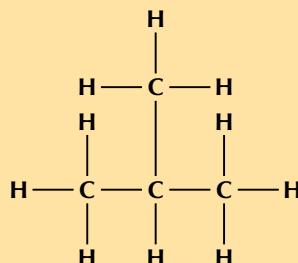
Methane, ethane, propane and butane (i.e. compounds 1 - 4)

c) What is the reason for the trend of increasing boiling points seen in compounds 1 to 5?

As the alkanes increase in chain length so does their surface area. This leads to stronger intermolecular forces and an increase in boiling point.

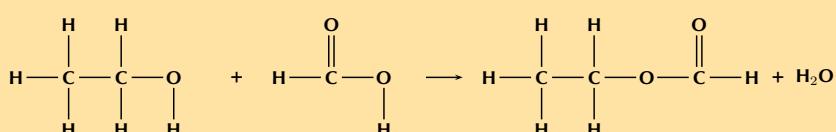
- d) Despite the fact that the length of the carbon chain in compounds 8,9 and 10 is the same, the boiling point of propan-1,2,3-triol is much higher than the boiling point of propan-1-ol. What is responsible for this large difference in boiling point?
As each hydroxyl group is added the strength of the intermolecular forces increases. The compound can form more hydrogen bonds. This leads to an increase in the boiling point.

e) Give the IUPAC name and the structural representation of an isomer of butane.
2-methylpropane

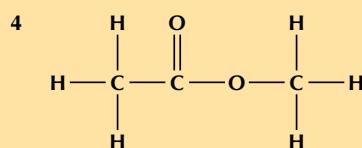
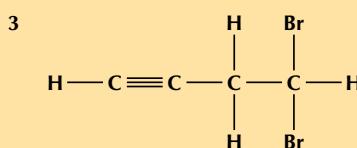
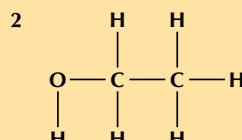
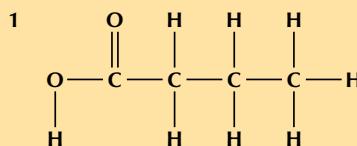


- f) Which **one** of the compounds is used as a reactant in the preparation of the ester ethyl methanoate?
Ethanol (7)

g) Using structural representation, write an equation for the reaction which produces ethyl methanoate.



7. Refer to the numbered diagrams below and then answer the questions that follow.



- a) Which one of the above compounds is produced from the fermentation of starches and sugars in plant matter?
compound 2, ethanol

b) To which one of the following homologous series does compound 1 belong?

 - i. esters
 - ii. alcohols
 - iii. aldehydes
 - iv. carboxylic acids

c) The correct IUPAC name for compound 3 is...

 - i. 1,1-dibromobut-3-yne
 - ii. 4,4-dibromobut-1-yne
 - iii. 2,4-dibromobut-1-yne
 - iv. 4,4-dibromoprop-1-yne

d) What is the correct IUPAC name for compound 4?

 - i. propanoic acid
 - ii. ethyl methanoate
 - iii. methyl ethanoate
 - iv. methyl propanoate

(IEB 2005)

iii) methyl ethanoate

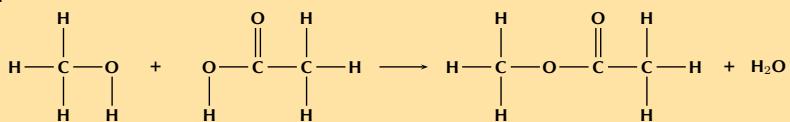
8. Answer the following questions:

- a) Explain the term homologous series.

A homologous series is a series of compounds with the same general formula. All molecules in this series will contain the same functional groups. For example the alkanes are a homologous series: they have the general formula C_nH_{2n+2} ; for every extra carbon atom there are two extra hydrogen atoms.

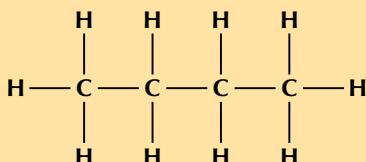
- b) A mixture of ethanoic acid and methanol is warmed in the presence of concentrated sulfuric acid.

- i. Using structural representations, give an equation for the reaction which takes place.



- ii. What is the IUPAC name of the organic compound formed in this reaction?
methyl ethanoate

- c) Consider the following hydrocarbon:



- i. Give the IUPAC name for this compound.

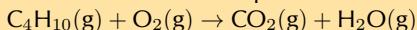
There are four carbon atoms, therefore the prefix is but-. There are only single carbon-carbon bonds and no other functional group, therefore this is an alkane and the suffix is -ane.

butane

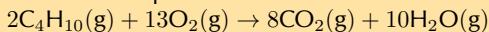
- ii. Give the balanced equation for the complete combustion of this compound in excess oxygen (use molecular formulae).

(IEB Paper 2, 2003)

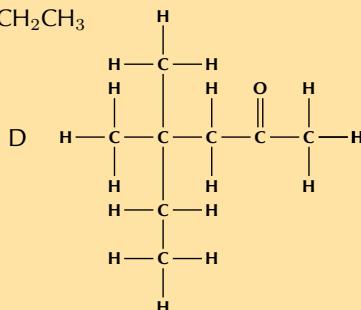
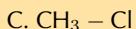
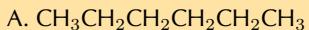
Write the unbalanced equation:



Balance the equation:



9. Consider the organic compounds labelled A to D.



- a) Write a balanced chemical equation for the preparation of compound C using an alkane as one of the reactants.

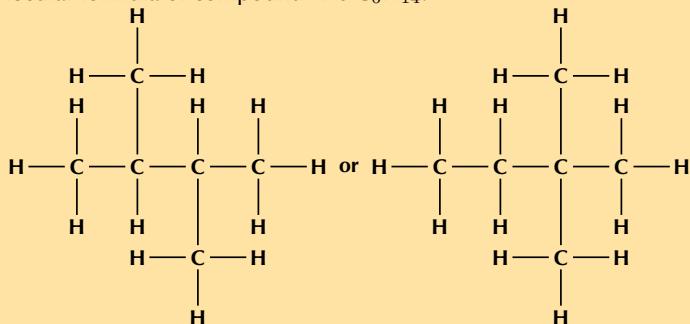


- b) Write down the IUPAC name for compound D.

There are six carbon atoms in the longest chain containing the functional group so the prefix is hex-. The compound is a ketone and the ketone carbon is the second carbon atom, so the suffix is -2-one. There are 2 methyl groups attached to the fourth carbon atom (4,4-dimethyl). The compound is 4,4-dimethylhexan-2-one.

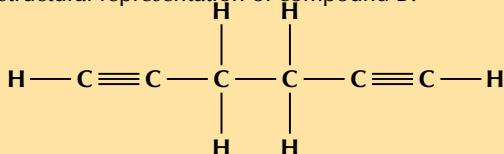
- c) Write down the structural representation of an isomer of compound A that has only FOUR carbon atoms in the longest chain.

The molecular formula of compound A is C₆H₁₄.

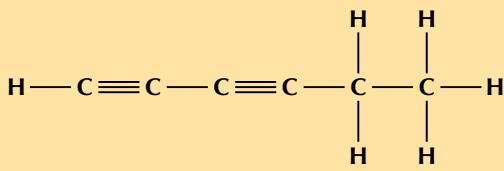


Note that these are the only two possibilities.

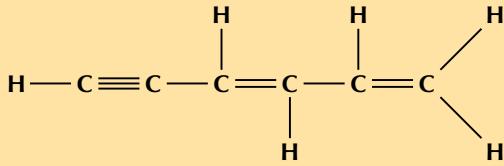
- d) Write down the structural representation of compound B.



or



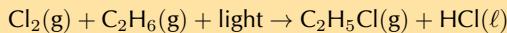
or



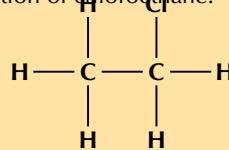
Any one of the above structures is reasonable. Learners can also draw benzene.

10. Chlorine and ethane react to form chloroethane and hydrochloric acid.

- a) Write a balanced chemical equation for this reaction, using molecular formulae.



- b) Give the structural representation of chloroethane.

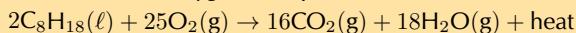


- c) What type of reaction has taken place in this example?

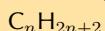
Substitution

11. Petrol is in fact not pure C₈H₁₈ but a mixture of various *alkanes*. The *octane rating* of petrol refers to the percentage of the petrol which is C₈H₁₈. For example, 93 octane fuel contains 93% C₈H₁₈ and 7% other alkanes. The *isomer* of C₈H₁₈ referred to in the *octane rating* is in fact not octane but 2,2,4-trimethylpentane.

- a) Write a balanced equation for the chemical reaction which takes place when C₈H₁₈ burns in excess oxygen (complete combustion).



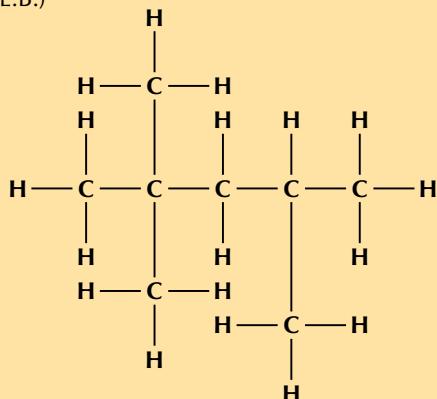
- b) Give the general formula of the *alkanes*.



- c) Define the term *isomer*.

Isomers are two (or more) organic compounds that have the same molecular formula but a different structural formula.

- d) Use the information given in this question and your knowledge of naming organic compounds to deduce and draw the full structural formula for 2,2,4-trimethylpentane.(I.E.B.)



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- | | | | | | |
|----------|----------|----------|----------|----------|---------|
| 1a. 27QV | 1b. 27QW | 1c. 27QX | 1d. 27QY | 1e. 27QZ | 2. 27R2 |
| 3. 27R3 | 4. 27R4 | 5a. 27R5 | 5b. 27R6 | 5c. 27R7 | 6. 27R8 |
| 7. 27R9 | 8. 27RB | 9. 27RC | 10. 27RD | 11. 27RF | |



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CHAPTER

5

Work, energy and power

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5.4	<i>Conservation of energy</i>	142
5.5	<i>Power</i>	145
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5.1 Introduction

Work:

- Define word done on an object by a force.
- Understand that work is a scalar.
- Calculations done on the net work done on an object.
- Understand the difference of positive, negative and no work done.
- Drawing of force diagrams to determine the net work done on an object - Ignore perpendicular forces.

Work-energy theorem:

- Know the difference between conservative and non-conservative forces.
- Understand the result of a net force working in on an object.
- Application of the work-energy theorem to objects on horizontal and inclined planes.
- Calculations of different motions of objects.

Conservation of energy:

- Definition of conservative and non-conservative forces and examples.
- Know the relationship between conservative and non-conservative forces and mechanical energy.
- Calculations done on the conservation of energy.
- Using calculations to prove the relationship between non-conservative forces and mechanical energy.

Power:

- Definition of power as the rate at which work is done.
- Calculations done when work is done.
- Understand what is needed to keep an object moving at a constant speed.
- Calculations done when an object moves at a constant speed.
- Calculations done on power.
- Calculations done on maximum and minimum power.

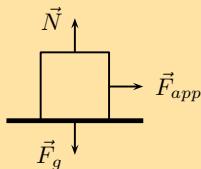
Key Mathematics Concepts

- Units and unit conversions — Physical Sciences, Grade 10, Science skills
- Equations — Mathematics, Grade 10, Equations and inequalities
- Techniques of vector addition — Physical Sciences, Grade 10, Vectors and scalars
- Newton's laws — Physical Sciences, Grade 11, Forces
- Force diagrams — Physical Sciences, Grade 11, Forces

5.2 Work

Exercise 5 – 1: Work

1. A 10 N force is applied to push a block across a frictionless surface for a displacement of 5,0 m to the right. The block has a weight \vec{F}_g of 20 N. Determine the work done by the following forces: normal force, weight \vec{F}_g , applied force.



Normal force acts perpendicular and therefore does no work.

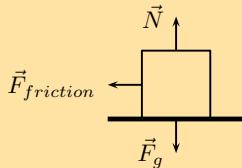
The weight acts perpendicular to the direction of motion and does no work.

The applied force:

$$\begin{aligned}W_{\text{applied}} &= F \Delta x \cos \theta \\&= (10)(5) \\&= 50 \text{ J}\end{aligned}$$

Normal force: 0 J, weight: 0 J, applied force: 50 J.

2. A 10 N frictional force slows a moving block to a stop after a displacement of 5,0 m to the right. The block has a weight of 20 N. Determine the work done by the following forces: normal force, weight, frictional force.



Normal force acts perpendicular and therefore does no work.

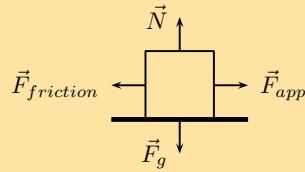
The weight acts perpendicular to the direction of motion and does no work.

The frictional force:

$$\begin{aligned}W_{\text{friction}} &= F \Delta x \cos \theta \\&= (10)(5) \cos(180) \\&= -50 \text{ J}\end{aligned}$$

Normal force: 0 J, weight: 0 J, frictional force: -50 J.

3. A 10 N force is applied to push a block across a frictional surface at constant speed for a displacement of 5,0 m to the right. The block has a weight of 20 N and the frictional force is 10 N. Determine the work done by the following forces: normal force, weight, applied force and frictional force.



Normal force acts perpendicular and therefore does no work.

The weight acts perpendicular to the direction of motion and does no work.

The frictional force:

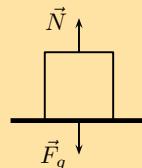
$$\begin{aligned} W_{friction} &= F \Delta x \cos \theta \\ &= (10)(5) \cos(180) \\ &= -50 \text{ J} \end{aligned}$$

The applied force:

$$\begin{aligned} W_{applied} &= F \Delta x \cos \theta \\ &= (10)(5) \\ &= 50 \text{ J} \end{aligned}$$

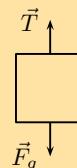
Normal force: 0 J, weight: 0 J, frictional force: -50 J, applied force: 50 J.

4. An object with a weight of 20 N is sliding at constant speed across a frictionless surface for a displacement of 5 m to the right. Determine if there is any work done.



No work is done as all the forces act perpendicular to the direction of displacement.

5. An object with a weight of 20 N is pulled upward at constant speed by a 20 N force for a vertical displacement of 5 m. Determine if there is any work done.



The applied force:

$$\begin{aligned} W_{applied} &= F \Delta x \cos \theta \\ &= (20)(5) \\ &= 100 \text{ J} \end{aligned}$$

The gravitational force:

$$\begin{aligned} W_{gravitational} &= F \Delta x \cos \theta \\ &= (20)(5) \cos(180) \\ &= -(20)(5) \\ &= -100 \text{ J} \end{aligned}$$

Work done by applied force is 100 J, work done by gravity is -100 J

6. Before beginning its descent, a roller coaster is always pulled up the first hill to a high initial height. Work is done on the roller coaster to achieve this initial height. A coaster designer is considering three different incline angles **of the hill** at which to drag the 2000 kg car train to the top of the 60 m high hill. In each case, the force applied to the car will be applied parallel to the hill. Her critical question is: which angle would require the least work? Analyse the data, determine the work done in each case, and answer this critical question.

Angle of Incline	Applied Force	Distance	Work
35°	$1,1 \times 10^4 \text{ N}$	100 m	
45°	$1,3 \times 10^4 \text{ N}$	90 m	
55°	$1,5 \times 10^4 \text{ N}$	80 m	

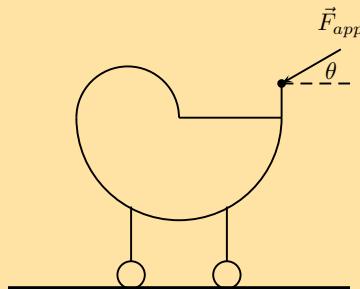
Angle of Incline	Applied Force	Distance	Work
35°	$1,1 \times 10^4 \text{ N}$	100 m	$9,01 \times 10^5 \text{ J}$
45°	$1,3 \times 10^4 \text{ N}$	90 m	$8,27 \times 10^5 \text{ J}$
55°	$1,5 \times 10^4 \text{ N}$	80 m	$6,88 \times 10^5 \text{ J}$

An angle of 55° requires the least amount of work to be done.

7. A traveller carries a 150 N suitcase up four flights of stairs (a total height of 12 m) and then pushes it with a horizontal force of 60 N at a constant speed of $0,25 \text{ m}\cdot\text{s}^{-1}$ for a horizontal distance of 50 m on a frictionless surface. How much work does the traveller do on the suitcase during this entire trip?

1800 J up stairs and 3000 J along passage.

8. A parent pushes down on a pram with a force of 50 N at an angle of 30° to the horizontal. The pram is moving on a frictionless surface. If the parent pushes the pram for a horizontal distance of 30 m, how work is done on the pram?



$$\begin{aligned}
 W &= F\Delta x \cos \theta \\
 &= (50)(30) \cos(30) \\
 &= 1299,00 \text{ J}
 \end{aligned}$$

1,30 kJ

9. How much work is done by the force required to raise a 2000 N lift 5 floors vertically at a constant speed? The vertical distance between floors is 5 m high.

$$\begin{aligned}
 W &= F\Delta x \cos \theta \\
 &= (2000)(5 \times 5) \cos(0) \\
 &= 2000 \times 25 \\
 &= 50\,000 \text{ J}
 \end{aligned}$$

50 000 J

10. A student with a mass of 60 kg runs up three flights of stairs in 15 s, covering a vertical distance of 10 m. Determine the amount of work done by the student to elevate her body to this height.

$$\begin{aligned}W &= F\Delta x \cos \theta \\&= mg\Delta x \cos \theta \\&= (60)(9,8)(10) \\&= 5880 \text{ J}\end{aligned}$$

5 880 J

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1. 27RH 2. 27RJ 3. 27RK 4. 27RM 5. 27RN 6. 27RP
7. 27RQ 8. 27RR 9. 27RS 10. 27RT



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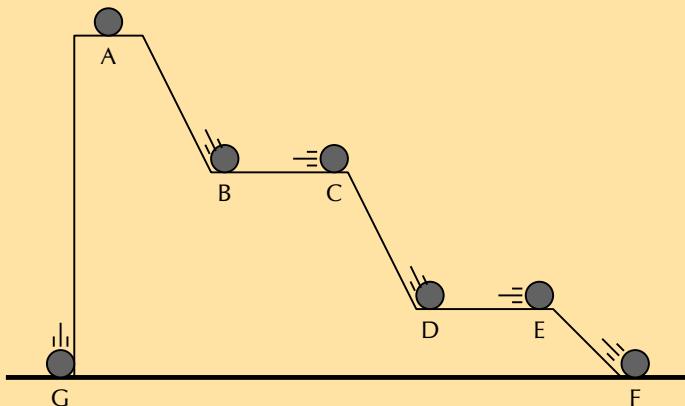
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5.3 Work-energy theorem

Conservative and non-conservative forces

Exercise 5 – 2: Energy

1. Fill in the table with the missing information using the positions of the 1 kg ball in the diagram below combined with the work-energy theorem.



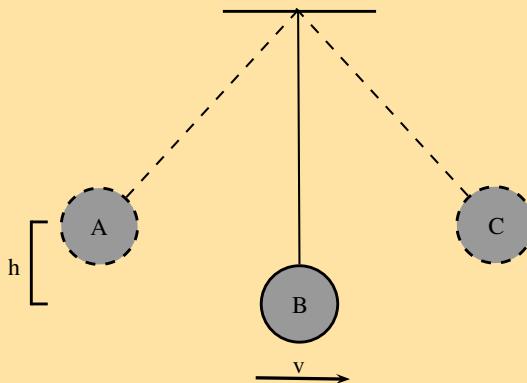
position	EK	PE	v
A		50 J	
B		30 J	
C			
D		10 J	
E			
F			
G			

position	EK	PE	v
A	0	50 J	0
B	20	30 J	6,3
C	20	30 J	6,3
D	40	10 J	8,9
E	40	10 J	8,9
F	50	0 J	10
G	50	0 J	10

2. A falling ball hits the ground at $10 \text{ m}\cdot\text{s}^{-1}$ in a vacuum. Would the speed of the ball be increased or decreased if air resistance were taken into account. Discuss using the work-energy theorem.

We can assume that the only force acting on the ball is gravity. The speed of the ball would be decreased when it hit the ground if air resistance were taken into account. Air resistance, just like friction on a surface, will be a force opposing the motion and will result in negative work done. By the work energy theorem, this will reduce the net work done on the object falling and therefore reduce the total change in Kinetic Energy.

3. A pendulum with mass 300 g is attached to the ceiling. It is pulled up to point A which is a height $h = 30 \text{ cm}$ from the equilibrium position.



Calculate the speed of the pendulum when it reaches point B (the equilibrium point). Assume that there are no non-conservative forces acting on the pendulum.

We can apply the work energy theorem. The only force that does work on the pendulum is gravity and we know from the conservation of mechanical energy that the change in gravitational potential energy will correspond to the opposite change in kinetic energy. That is, if gravitational potential energy decreases by an amount kinetic energy will increase by the same amount and vice versa.

Height is not in S.I. units and should be converted.

$$\begin{aligned}
 PE_i + KE_i &= PE_f + KE_f \\
 mgh_i + (0) &= mgh_f + KE_f \\
 mgh_i - mgh_f &= KE_f \\
 mg(h_i - h_f) \frac{1}{2}mv^2 & \\
 g(h_i - h_f) \frac{1}{2}v^2 & \\
 2g(0.30) = v^2 & \\
 v &= \sqrt{2(9,8)(0.30)} \\
 &= 2,42 \text{ m}\cdot\text{s}^{-1}
 \end{aligned}$$

$2,42 \text{ m}\cdot\text{s}^{-1}$

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1. 27RV 2. 27RW 3. 27RX



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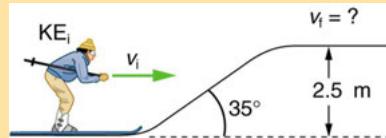
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5.4 Conservation of energy

Non-conservative forces and work-energy theorem

Exercise 5 – 3: Energy conservation

1. A 60,0 kg skier with an initial speed of $12,0 \text{ m}\cdot\text{s}^{-1}$ coasts up a 2,50 m-high rise as shown in the figure. Find her final speed at the top, given that the coefficient of friction between her skis and the snow is 0,0800. (Hint: Find the distance traveled up the incline assuming a straight-line path as shown in the figure.)



We need to determine the length of the slope as this is the distance over which friction acts as well as the normal force of the skier on the slope to determine the magnitude of the force due to friction. The normal force balances the component of gravity perpendicular to the slope, therefore:

$$\begin{aligned} F_{friction} &= -\mu N \\ &= -\mu F_g \cos \theta \\ &= -\mu mg \cos \theta \end{aligned}$$

The length of the slope will be $\Delta x = \frac{h}{\sin \theta}$.

$$\begin{aligned} W_{non-conservative} + E_{k,i} + E_{p,i} &= E_{k,f} + E_{p,f} \\ -\mu mg \cos \theta \frac{h}{\sin \theta} + \frac{1}{2}mv_i^2 + mgh_i &= \frac{1}{2}mv_f^2 + mgh_f \\ -\mu g \cos \theta \frac{h}{\sin \theta} + \frac{1}{2}v_i^2 + gh_i &= \frac{1}{2}v_f^2 + gh_f \\ \frac{1}{2}v_f^2 + gh_f &= -\mu g \cos \theta \frac{h}{\sin \theta} + \frac{1}{2}v_i^2 + gh_i \\ \frac{1}{2}v_f^2 &= -\mu g \cos \theta \frac{h}{\sin \theta} + \frac{1}{2}v_i^2 + g(h_i - h_f) \\ v_f^2 &= -2\mu g \cos \theta \frac{h}{\sin \theta} + v_i^2 + 2g(h_i - h_f) \end{aligned}$$

$$v_f^2 = -2(0,08)(9,8) \cos(35) \frac{2,5}{\sin(35)} + (12)^2 + 2(9,8)(-2,5)$$

$$v_f = \sqrt{89,4016598}$$

$$v_f = 9,46 \text{ m}\cdot\text{s}^{-1}$$

$$9,46 \text{ m}\cdot\text{s}^{-1}$$

2. a) How high a hill can a car coast up (engine disengaged) if work done by friction is negligible and its initial speed is $110 \text{ km}\cdot\text{h}^{-1}$?

$$\begin{aligned} 110 \text{ km/hr} &= 110 \times \frac{1000}{3600} \\ &= 30,56 \text{ m}\cdot\text{s}^{-1} \end{aligned}$$

$$\begin{aligned} mgh &= \frac{1}{2}mv^2 \\ h &= \frac{v^2}{2g} \\ &= \frac{(30,56)^2}{2(9,8)} \\ &= 47,65 \text{ m} \end{aligned}$$

$$47,65 \text{ m}$$

- b) If, in actuality, a 750 kg car with an initial speed of $110 \text{ km}\cdot\text{h}^{-1}$ is observed to coast up a hill to a height 22,0 m above its starting point, how much thermal energy was generated by friction?

Kinetic energy was converted into potential energy. The addition of friction as a dissipative force ensures that some of the kinetic energy is lost as thermal energy. The difference in the potential energy gained with and without friction is the energy lost to friction. The gravitational potential energy gained is only related to height so the difference in height allows us to determine the energy lost to friction quickly.

Without friction the car rose to a height of 47,65m, with friction the height was only 22m. The energy lost to friction is equivalent to the energy required to increase the gravitational potential energy by raising the vehicle a height of 25,65m. Therefore the energy lost to friction is:

$$\begin{aligned} W &= mgh \\ &= (750)(9,8)(25,65) \\ &= 188\,527,5 \text{ J} \end{aligned}$$

We calculated the gravitational potential energy that was lost as friction but the correct answer will be negative this quantity as the work done by friction is negative: $-188\,527,5 \text{ J}$

- c) What is the average force of friction if the hill has a slope $2,5^\circ$ above the horizontal?

We will assume a constant force of friction. The distance over which the friction acted is the length of the slope, we know the angle of the slope and the vertical height so we can calculate the distance (hypotenuse). We can use the definition of work to calculate the force, remember that friction acts opposite to the displacement:

$$\begin{aligned}
W_{friction} &= F_{friction} \Delta x \cos \theta \\
&= -F \Delta x \\
&= -F \frac{h}{\sin(2.5)} \\
-188\ 527,5 &= -F \frac{h}{\sin(2.5)} \\
F &= 188\ 527,5 \frac{\sin(2.5)}{22} \\
F &= 373,79 \text{ N}
\end{aligned}$$

373,79 N

3. A bullet traveling at 100 m/s just pierces a wooden plank of 5 m. What should be the speed (in m/s) of the bullet to pierce a wooden plank of same material, but having a thickness of 10m?

Final speed and hence final kinetic energy are zero in both cases. From "work-kinetic energy" theorem, initial kinetic energy is equal to work done by the force resisting the motion of bullet. As the material is same, the resisting force is same in either case. If subscript "1" and "2" denote the two cases respectively, then:

5m:

$$\begin{aligned}
0 - \frac{1}{2}mv_1^2 &= -Fx_1 \\
\frac{1}{2}m(100)^2 &= F \times 5
\end{aligned}$$

10m:

$$\begin{aligned}
0 - \frac{1}{2}mv_2^2 &= -Fx_2 \\
\frac{1}{2}mv_2^2 &= F \times 10
\end{aligned}$$

Take the ratio of these two equations:

$$\begin{aligned}
\frac{v_2^2}{(100)^2} &= \frac{F \times 10}{F \times 5} = 2 \\
v_2^2 &= 2 \times 10000 = 20000 \\
v_2 &= 141,4 \text{ m}\cdot\text{s}^{-1}
\end{aligned}$$

141,4 m·s⁻¹

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1. 27RY 2. 27RZ 3. 27S2



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5.5 Power

Exercise 5 – 4: Power

1. [IEB 2005/11 HG] Which of the following is equivalent to the SI unit of power:

- a) $V \cdot A$
- b) $V \cdot A^{-1}$
- c) $\text{kg} \cdot \text{m} \cdot \text{s}^{-1}$
- d) $\text{kg} \cdot \text{m} \cdot \text{s}^{-2}$

$$V \cdot A$$

2. Two students, Bill and Bob, are in the weight lifting room of their local gym. Bill lifts the 50 kg barbell over his head 10 times in one minute while Bob lifts the 50 kg barbell over his head 10 times in 10 seconds. Who does the most work? Who delivers the most power? Explain your answers.

The displacement is 0 and so there is no work done. Since power is the rate at which work is done, the power is also 0.

3. Jack and Jill ran up the hill. Jack is twice as massive as Jill; yet Jill ascended the same distance in half the time. Who did the most work? Who delivered the most power? Explain your answers.

With comparative problems we always write the values for one of the objects/people in terms of the values for the other. So:

$$\begin{aligned}m_{Jack} &= 2 \times m_{Jill} \\ \frac{1}{2}t_{Jack} &= t_{Jill} \\ t_{Jack} &= 2 \times t_{Jill}\end{aligned}$$

The work done was to increase the gravitational potential energy of the system. If the hill has a height of h then:

$$\begin{aligned}W_{Jill} &= m_{Jill}gh \\ W_{Jack} &= m_{Jack}gh \\ W_{Jack} &= (2 \times m_{Jill})gh \\ W_{Jack} &= 2 \times (m_{Jill}gh) \\ W_{Jack} &= 2 \times W_{Jill}\end{aligned}$$

The power comparison is similar:

$$\begin{aligned}P_{Jill} &= \frac{W_{Jill}}{t_{Jill}} \\ P_{Jack} &= \frac{W_{Jack}}{t_{Jack}} \\ P_{Jack} &= \frac{2 \times W_{Jill}}{2 \times t_{Jill}} \\ P_{Jack} &= \frac{W_{Jill}}{t_{Jill}} \\ P_{Jack} &= P_{Jill}\end{aligned}$$

Jack did twice as much work as Jill but the same power.

4. When doing a chin-up, a physics student lifts her 40 kg body a distance of 0,25 m in 2 s. What is the power delivered by the student's biceps?

The work done by the biceps (a non-conservative force) increased the net mechanical energy of the system. The kinetic energy is zero at the top and bottom so we are only interested in the gravitational potential energy.

$$\begin{aligned}W_{\text{non-conservative}} &= \Delta E_k + \Delta E_p \\&= E_{p,f} - E_{p,i} \\&= mgh(h_f - h_i) \\&= (40)(9,8)(0,25) \\&= 98 \text{ J}\end{aligned}$$

$$\begin{aligned}P &= \frac{W}{t} \\&= \frac{(98)}{2} \\&= 49 \text{ W}\end{aligned}$$

49 W

5. The unit of power that is used on a monthly electricity account is *kilowatt-hours* (symbol kWh). This is a unit of energy delivered by the flow of 1 kW of electricity for 1 hour. Show how many joules of energy you get when you buy 1 kWh of electricity.

$$1\text{kWh} = 1000\text{Wh} = 1000\text{Wh} \times \frac{3600}{h} = 3\,600\,000 \text{ J}$$

6. An escalator is used to move 20 passengers every minute from the first floor of a shopping mall to the second. The second floor is located 5-meters above the first floor. The average passenger's mass is 70 kg. Determine the power requirement of the escalator in order to move this number of passengers in this amount of time.

The work done will be to move the total mass of the 20 passengers vertically 5 m. We are not given the mass of the elevator itself so we assume we can ignore it. The total mass will be: $m_{\text{total}} = (20)(70) = 1400 \text{ kg}$

$$\begin{aligned}W &= mgh \\&= (1400)(9,8)(5) \\&= 68\,600 \text{ J}\end{aligned}$$

$$\begin{aligned}P &= \frac{W}{t} \\&= \frac{68600}{60} \\&= 1143,33 \text{ W}\end{aligned}$$

1143,33 W

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1. 27S3 2. 27S4 3. 27S5 4. 27S7 5. 27S8 6. 27S9



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5.6 Chapter summary

Exercise 5 – 5:

- How much work does a person do in pushing a shopping trolley with a force of 200 N over a distance of 80 m in the direction of the force?

$$\begin{aligned}W &= F\Delta x \cos \theta \\&= (200)(80) \cos(0) \\&= 16000(1) \\&= 16\ 000 \text{ J}\end{aligned}$$

16 000 J

- How much work does the force of gravity do in pulling a 20 kg box down a 45° frictionless inclined plane of length 18 m?

The component of the gravitational force parallel to the slope (i.e. in line with the direction of the displacement) is $F_{gx} = F_g \sin \alpha_{slope} = mg \sin \alpha_{slope}$. The work done can then be calculated:

$$\begin{aligned}W &= F\Delta x \cos \theta \\&= mg \sin \alpha_{slope} \Delta x \cos \theta \\&= (20)(9,8) \sin(45)(18) \cos(0) \\&= 2494,67 \text{ J}\end{aligned}$$

2494,67 J

- [IEB 2001/11 HG1] Of which one of the following quantities is $\text{kg}\cdot\text{m}^2\cdot\text{s}^{-3}$ the base S.I. unit?

a	Energy	c	Power
b	Force	d	Momentum

Power

- [IEB 2003/11 HG1] A motor is used to raise a mass m through a vertical height h in time t . What is the power of the motor while doing this?

a	$mght$	c	$\frac{mgt}{h}$
b	$\frac{mgh}{t}$	d	$\frac{ht}{mg}$

$\frac{mgh}{t}$

- [IEB 2002/11 HG1] An electric motor lifts a load of mass M vertically through a height h at a constant speed v . Which of the following expressions can be used to calculate the power transferred by the motor to the load while it is lifted at constant speed?

a	Mgh	c	Mgv
b	$Mgh + \frac{1}{2}Mv^2$	d	$Mgv + \frac{1}{2}\frac{Mv^3}{h}$

Mgv

6. A set 193 kg containers need to be lifted onto higher floors during a building operation. The distance that they need to be raised is 7.5 m, at constant speed. The project manager has determined that in order to keep to budget and time this has to happen in as close to 5,0 s as possible. The power ratings for three motors are listed as 1,0 kW, 3,5 kW, and 5,5 kW. Which motor is best for the job?

The best motor to use is the 3.5 kW motor. The 1.0 kW motor will not be fast enough, and the 5.5 kW motor will be too fast.

7. [IEB 2003/11 HG1] In which of the following situations is there no work done on the object?

- a) An apple falls to the ground.
- b) A brick is lifted from the ground to the top of a building.
- c) A car slows down to a stop.
- d) A box moves at constant velocity across a frictionless horizontal surface.

A box moves at constant velocity across a frictionless horizontal surface.

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1. 27SF 2. 27SG 3. 27SH 4. 27SJ 5. 27SK 6. 27SM
7. 27SN



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CHAPTER

6

Doppler effect

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6.2	<i>The Doppler effect with sound</i>	150
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6 Doppler effect

6.1 Introduction

The Doppler Effect with sound:

- Definition of the Doppler Effect with examples.
- Explanation to what happens with sound when objects move relative to each other.
- Calculations done to determine the frequency when one of the two objects are moving.
- Description of applications with ultra sound waves.

THE Doppler Effect with light:

- Understand the relationship between light and the Doppler Effect.
- Application of the Doppler Effect and light concerning the universe.

Key Mathematics Concepts

- Units and unit conversions — Physical Sciences, Grade 10, Science skills
- Equations — Mathematics, Grade 10, Equations and inequalities
- Sound waves — Physical Sciences, Grade 10, Sound
- Electromagnetic radiation — Physical Sciences, Grade 10, Electromagnetic radiation

6.2 The Doppler effect with sound

Exercise 6 – 1: The Doppler effect with sound

1. Suppose a train is approaching you as you stand on the platform at the station. As the train approaches the station, it slows down. All the while, the engineer is sounding the hooter at a constant frequency of 400 Hz. Describe the pitch of the hooter and the changes in pitch of the hooter that you hear as the train approaches you. Assume the speed of sound in air is $340 \text{ m}\cdot\text{s}^{-1}$.

The frequency of the sound gradually increases as the train moves towards you. The pitch increases. You would hear a higher pitched sound.

2. Passengers on a train hear its whistle at a frequency of 740 Hz. Anja is standing next to the train tracks. What frequency does Anja hear as the train moves directly toward her at a speed of $25 \text{ m}\cdot\text{s}^{-1}$? Assume the speed of sound in air is $340 \text{ m}\cdot\text{s}^{-1}$.

$$\begin{aligned}f_L &= \left(\frac{v + v_L}{v + v_S} \right) f_S \\f_L &= \left(\frac{340 + 0}{340 - 25} \right) (740) \\&= 798,73 \text{ Hz}\end{aligned}$$

798,73 Hz

3. A small plane is taxiing directly away from you down a runway. The noise of the engine, as the pilot hears it, has a frequency 1.15 times the frequency that you hear. What is the speed of the plane? Assume the speed of sound in air is $340 \text{ m}\cdot\text{s}^{-1}$.

You, the listener are stationary so your velocity is 0. The source is moving away from you at an unknown velocity. This velocity must be positive. We also know that:

$$f_s = 1.15 f_L$$

$$\begin{aligned} f_L &= \left(\frac{v + v_S}{v + v_S} \right) f_S \\ f_L &= \left(\frac{340 + 0}{340 + v_S} \right) (1.15 f_S) \\ 340 + v_S &= (340)(1.15) \\ v_S &= 51 \text{ m}\cdot\text{s}^{-1} \end{aligned}$$

$$51 \text{ m}\cdot\text{s}^{-1}$$

4. In places like Canada during winter temperatures can get as low as -35°C . This affects the speed of sound in air and you can use the Doppler effect to determine what the speed of sound is. On a winter's day in Canada with a temperature of -35°C , a source emits sound at a frequency of 1050 Hz and moves away from an observer at $25 \text{ m}\cdot\text{s}^{-1}$. The frequency that the observer measures is 971.41 Hz, what is the speed of sound?

The observer is stationary, so $v_L = 0$.

$$\begin{aligned} f_L &= \left(\frac{v + v_L}{v + v_S} \right) f_S \\ \frac{f_L}{f_S} &= \left(\frac{v + 0}{v + v_S} \right) \\ \frac{f_S}{f_L} &= \left(\frac{v + v_S}{v} \right) \\ \frac{f_S}{f_L} &= 1 + \frac{v_S}{v} \\ \frac{v_S}{v} &= \frac{f_S}{f_L} - 1 \\ \frac{v_S}{v} &= \frac{f_S - f_L}{f_L} \\ v &= v_S \left(\frac{f_L}{f_S - f_L} \right) \\ &= 25 \left(\frac{971.41}{1050 - 971.41} \right) \\ &= 309 \text{ m}\cdot\text{s}^{-1} \end{aligned}$$

The speed of sound in air at -35 degrees celsius is $309 \text{ m}\cdot\text{s}^{-1}$

5. Cecil approaches a source emitting sound with a frequency of 437.1 Hz.

- a) How fast does Cecil need to move to observe a frequency that is 20 percent higher?
- b) If he passes the source at this speed, what frequency will he measure when he is moving away?
- c) What is a practical means of achieving this speed?

Assume the speed of sound in air is $340 \text{ m}\cdot\text{s}^{-1}$.

First we need to determine Cecil's approach speed. The source is stationary, so $v_S = 0$. We are given:

$f_L = 1.2f_S$. Rearranging the Doppler formula:

$$\begin{aligned}\frac{f_L}{f_S} &= \left(\frac{v + v_L}{v + 0} \right) \\ \frac{1.2f_S}{f_S} &= \left(\frac{v + v_L}{v} \right) \\ 1.2 &= 1 + \frac{v_L}{v} \\ 1.2 - 1 &= \frac{v_L}{340} \\ v_L &= 68 \text{ m}\cdot\text{s}^{-1}\end{aligned}$$

The second part of the question asks what the frequency will be that Cecil hears after passing the source and moving away:

$$\begin{aligned}\frac{f_L}{f_S} &= \left(\frac{v - v_L}{v} \right) \\ \frac{f_L}{f_S} &= \left(\frac{340 - 68}{340} \right) \\ f_L &= 0,8f_S \\ &= 0,8(437,1) \\ &= 349,7 \text{ Hz}\end{aligned}$$

Converting $68 \text{ m}\cdot\text{s}^{-1}$ to $\text{km}\cdot\text{h}^{-1}$:

$$68 \frac{\text{m}}{\text{s}} \times \frac{1\text{km}}{1000\text{m}} \times \frac{3600\text{s}}{1\text{h}} = 244,8 \text{ km}\cdot\text{h}^{-1}.$$

This sort of speed could be reached if the observer was in a high-speed train or a racing car.

The approach speed is $68 \text{ m}\cdot\text{s}^{-1}$.

The frequency observed when moving away is $349,7 \text{ Hz}$.

A speed of $68 \text{ m}\cdot\text{s}^{-1}$ or equivalently, $244,8 \text{ km}\cdot\text{h}^{-1}$, could be reached if the observer was in a high-speed train or a racing car.

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1. 27ST 2. 27SV 3. 27SW 4. 27SX 5. 27SY



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6.4 Chapter summary

Exercise 6 – 2:

1. Write a definition for each of the following terms.
 - a) Doppler effect
 - b) Redshift
 - c) Ultrasound
- a) The Doppler effect occurs when a source of waves and/or an observer move relative to each other, resulting in the observer measuring a different frequency of the waves than the frequency at which the source is emitting.

- b) Redshift is the shift in the position of spectral lines to longer wavelengths due to the relative motion of a source away from the observer.
- c) Ultrasound or ultra-sonic waves are sound waves with a frequency greater than 20 000 Hz (or 20 kHz).
2. The hooter of an approaching taxi has a frequency of 500 Hz. If the taxi is travelling at $30 \text{ m}\cdot\text{s}^{-1}$ and the speed of sound is $340 \text{ m}\cdot\text{s}^{-1}$, calculate the frequency of sound that you hear when
- the taxi is approaching you.
 - the taxi passed you and is driving away.

Draw a sketch of the observed frequency as a function of time.

- a) The observer is not moving, so $v_L = 0$, and the source is approaching. Therefore:
- $$f_L = \left(\frac{v}{v - v_S} \right) f_S$$
- $$= \left(\frac{340}{340 - 30} \right) (500)$$
- $$= 548,4 \text{ Hz}$$
- b) Now the taxi is moving away from the observer, so:
- $$f_L = \left(\frac{v}{v + v_S} \right) f_S$$
- $$= \left(\frac{340}{340 + 30} \right) (500)$$
- $$= 459,5 \text{ Hz}$$
- 548,4 Hz
 - 459,5 Hz
3. A truck approaches you at an unknown speed. The sound of the truck's engine has a frequency of 210 Hz, however you hear a frequency of 220 Hz. The speed of sound is $340 \text{ m}\cdot\text{s}^{-1}$.
- Calculate the speed of the truck.
 - How will the sound change as the truck passes you? Explain this phenomenon in terms of the wavelength and frequency of the sound.
 - The observer is stationary, so $v_L = 0$. Therefore:

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

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

$$1 - \frac{v_S}{v} = \frac{f_S}{f_L}$$

$$\frac{v_S}{v} = 1 - \frac{f_S}{f_L}$$

$$v_S = 340 \left(1 - \frac{210}{220} \right)$$

$$= 15,5 \text{ m}\cdot\text{s}^{-1}$$

- As the truck goes by, the frequency goes from higher to lower and the wavelength of the sound waves goes from shorter to longer.
- $15,5 \text{ m}\cdot\text{s}^{-1}$
- As the truck goes by, the frequency goes from higher to lower and the wavelength of the sound waves goes from shorter to longer.

4. [Extension question] A police car is driving towards a fleeing suspect at $\frac{v}{35} \text{ m} \cdot \text{s}^{-1}$, where v is the speed of sound. The frequency of the police car's siren is 400 Hz. The suspect is running away at $\frac{v}{68}$. What frequency does the suspect hear?

$$f_L = \left(\frac{v \pm v_L}{v \pm v_S} \right) f_S$$

The source is moving towards the listener, so we need to put: $-v_S$

and the listener is moving away from the source, so we need to put: $-v_L$

So we use the formula as :

$$f_L = \left(\frac{v - v_L}{v - v_S} \right) f_S$$

We are given that $v_L = \frac{v}{68} \text{ m} \cdot \text{s}^{-1}$ and $v_S = \frac{v}{35} \text{ m} \cdot \text{s}^{-1}$. Substituting into the formula:

$$\begin{aligned} f_L &= \left(\frac{v - \frac{v}{68}}{v - \frac{v}{35}} \right) f_S \\ &= \left(\frac{\frac{68v-v}{68}}{\frac{35v-v}{35}} \right) f_S \\ &= \left(\frac{\left(\frac{67}{68}\right)v}{\left(\frac{34}{35}\right)v} \right) f_S \\ &= \left(\frac{\left(\frac{67}{68}\right)}{\left(\frac{34}{35}\right)} \right) 400 \end{aligned}$$

$$f_L = 405,7 \text{ Hz}$$

405,7 Hz

5. Explain how the Doppler effect is used to determine the direction of flow of blood in veins.

An instrument called a Doppler flow meter can be used to transmit ultrasonic waves into a person's body. The sound waves will be reflected by tissue, bone, blood etc., and measured by the flow meter. If blood flow is being measured in an artery for example, the moving blood cells will reflect the transmitted wave and due to the movement of the cells, the reflected sound waves will be Doppler shifted to higher frequency if the blood is moving towards the flow meter and to lower frequency if the blood is moving away from the flow meter.

6. A person in a car travelling at $22,2 \text{ m} \cdot \text{s}^{-1}$ approaches a source emitting sound waves with a frequency of 410 Hz. What is the frequency of the sound waves observed by the person? Assume the speed of sound in air is $340 \text{ m} \cdot \text{s}^{-1}$.

The Doppler formula is:

$$f_L = \left(\frac{v \pm v_L}{v \pm v_S} \right) f_S$$

The source is stationary so $v_S = 0$. Rearranging the formula:

$$\begin{aligned} f_L &= \left(\frac{v + v_L}{v} \right) f_S \\ f_L &= \left(\frac{340 + 22,2}{340} \right) (410) \\ &= 436,8 \text{ Hz} \end{aligned}$$

436,8 Hz

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CHAPTER

7

Rate and Extent of Reaction

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7.1 Introduction

In this chapter learners will look at the rates of different reactions and the factors that affect those rates. In grade 11 learners were introduced to the energies involved in chemical reactions as well as activation energy graphs. These topics will be explored more thoroughly in this chapter. It is important that this section is covered thoroughly to give the learners a deep understanding that they can use in the following chapters (particularly Chapter 8).

The following topics are covered in this chapter.

- **What the term *reaction rate* means**

In this section learners will look at what a reaction rate is and the different ways of determining the rate of a reaction. They will do calculations based on the rates of different reactions.

- **The factors affecting reaction rates**

Learners will be introduced to the concept of collision theory as a way of understanding why certain factors affect the rate of a reaction. They will investigate (with experiments) how the nature of the reactants, the surface area, the concentration and the temperature affect the rate of a reaction. The effect of a catalyst will also be studied.

- **How to measure rates of reaction**

In this section learners will look at methods of measuring reaction rates including the collection of gas, the formation of precipitate, a change in colour and a change in mass. They will perform experiments and calculate reaction rates to better understand these concepts.

- **The mechanisms of reaction and the effect of catalysts**

In this section learners will explore the mechanisms behind reaction rates, specifically focusing on activation energy. The effect of catalysts on activation energy will be covered in detail.

There are several experiments in this chapter. The learners will be using dangerous chemicals and should be properly instructed on the correct use of safety equipment, including safety goggles, gloves and protective clothing. They should also be reminded not to sniff any chemicals as the fumes can be dangerous as well. More information on laboratory procedures as well as safety precautions is provided in Chapter 1 (Science skills).

In the informal assessment the learners must determine a quantitative reaction rate in the reaction of $\text{Na}_2\text{S}_2\text{O}_3$ and HCl. Learners are required to perform the experiment, calculate quantitative reaction rates (using the formation of precipitate), and plot a graph of their results. More information for each experiment is provided in the relevant sections.

7.2 Rates of reaction and factors affecting rate

Exercise 7 – 1: Thinking about reaction rates

1. Think about each of the following reactions:

(Hint: look at your Grade 11 textbook for a reminder on these processes)

- corrosion (e.g. the rusting of iron)
- photosynthesis
- weathering of rocks (e.g. limestone rocks being worn away by water)
- combustion (e.g. propane burning in O_2)

- a) For each of the reactions above, write a balanced chemical equation for the reaction that takes place.

- Choosing iron as an example of a metal that rusts:

$$4\text{Fe(s)} + 3\text{O}_2\text{(g)} \rightarrow 2\text{Fe}_2\text{O}_3\text{(s)}$$
- Photosynthesis:

$$6\text{CO}_2\text{(g)} + 6\text{H}_2\text{O(l)} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6\text{(s)} + 6\text{O}_2\text{(g)}$$
- For weathering of rocks we will use limestone (calcium carbonate) as an example:

$$\text{CaCO}_3\text{(s)} + \text{CO}_2\text{(g)} + 2\text{H}_2\text{O(l)} \rightarrow \text{Ca}^{2+}\text{(aq)} + 2\text{HCO}_3^-\text{(aq)}$$
- Combustion (e.g. of carbon):

$$\text{C(s)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}$$

- b) Rank these reactions in order from the fastest to the slowest.
 Combustion is the fastest and weathering is the slowest. The order of reactivity from fastest to slowest is: combustion, photosynthesis, rusting, weathering.
- c) How did you decide which reaction was the fastest and which was the slowest?
 Answers could include mention of the fact that coal and paper burn fast, whereas rocks do not disappear overnight. Also plants use photosynthesis to make food and this process has to happen relatively fast but not too fast.
- d) Think of some other examples of chemical reactions. How fast or slow is each of these reactions, compared with those listed earlier?
- Decomposition of hydrogen peroxide, relatively fast
 - Synthesis of water, very fast
 - Any other reasonable answers

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What is a reaction rate?

Exercise 7 – 2: Reaction rates

1. A number of different reactions take place. The table below shows the number of moles of reactant that are used in a particular time for each reaction.

Reaction	Reactants used (mol)	Time (s)	Reaction rate (mol.s^{-1})
1	2	30	
2	5	120	
3	1	90	
4	3,2	90	
5	5,9	30	

- a) Complete the table by calculating the average rate of each reaction.

The reaction rate is the number of moles used up divided by the time in seconds.

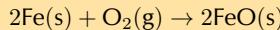
Reaction	Reactants used (mol)	Time (s)	Reaction rate (mol.s^{-1})
1	2	30	0,067
2	5	120	0,042
3	1	90	0,011
4	3,2	90	0,036
5	5,9	30	0,2

- b) Which is the *fastest* reaction?

The fastest reaction is reaction 5

- c) Which is the *slowest* reaction?
The slowest reaction is reaction 3

2. Iron reacts with oxygen as shown in the balanced reaction:



2 g of Fe and 0,57 g of O₂ are used during the reaction. 2,6 g of FeO is produced. The reaction takes 30 minutes to go to completion.

Calculate the average rate of reaction for:

- a) the use of Fe.

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

$$M(\text{Fe}) = 55,8 \text{ g.mol}^{-1}$$

$$n = \frac{2 \text{ g}}{55,8 \text{ g.mol}^{-1}} = 0,0358 \text{ mol}$$

Rate of reaction is number of moles Fe used up per second.

$$\text{time} = 30 \text{ minutes} \times \frac{60 \text{ s}}{1 \text{ minute}} = 1800 \text{ s}$$

$$\text{Average rate of reaction for Fe} = \frac{0,0358 \text{ mol}}{1800 \text{ s}} = 1,99 \times 10^{-5} \text{ mol.s}^{-1}$$

- b) the use of O₂.

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

$$M(\text{O}_2) = 16 \text{ g.mol}^{-1} \times 2 = 32 \text{ g.mol}^{-1}$$

$$n = \frac{0,57 \text{ g}}{32 \text{ g.mol}^{-1}} = 0,0178 \text{ mol}$$

Rate of reaction is number of moles O₂ used up per second.

$$\text{Average rate of reaction for O}_2 = \frac{0,0178 \text{ mol}}{1800 \text{ s}} = 9,89 \times 10^{-6} \text{ mol.s}^{-1}$$

- c) the formation of FeO.

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

$$M(\text{FeO}) = 55,8 \text{ g.mol}^{-1} + 16 \text{ g.mol}^{-1} = 71,8 \text{ g.mol}^{-1}$$

$$n = \frac{2,6 \text{ g}}{71,8 \text{ g.mol}^{-1}} = 0,0362 \text{ mol}$$

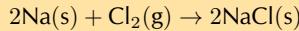
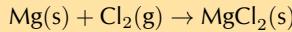
Rate of reaction is number of moles FeO produced per second.

$$\text{Average rate of reaction for FeO} = \frac{0,0362 \text{ mol}}{1800 \text{ s}} = 2,01 \times 10^{-5} \text{ mol.s}^{-1}$$

Note that the rates of the individual reactions follow the stoichiometric rates ratios in the balanced equation:

$$1,99 \times 10^{-5} : 9,89 \times 10^{-6} : 2,01 \times 10^{-5} \text{ is } 2 : 1 : 2$$

3. Two reactions occur simultaneously in separate reaction vessels. The reactions are as follows:



After 1 minute, 2 g of MgCl₂ has been produced in the first reaction.

- a) How many moles of MgCl₂ are produced after 1 minute?

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

$$M(\text{MgCl}_2) = 24,3 \text{ g.mol}^{-1} + 2 \times 35,45 \text{ g.mol}^{-1} = 95,2 \text{ g.mol}^{-1}$$

$$n = \frac{2 \text{ g}}{95,2 \text{ g.mol}^{-1}} = 0,021 \text{ mol}$$

- b) Calculate the average rate of the reaction, using the amount of product that is produced.

$$\text{time} = 1 \text{ minute} \times \frac{60 \text{ s}}{1 \text{ minute}} = 60 \text{ s}$$

$$\text{Average rate} = \frac{\text{moles product}}{\text{time (s)}} = \frac{0,021 \text{ mol}}{60 \text{ s}} = 3,5 \times 10^{-4} \text{ mol.s}^{-1}$$

c) Assuming that the second reaction also proceeds at the same rate, calculate:

i. the number of moles of NaCl produced after 1 minute.

$$n = \text{rate} \times \text{time} = 3,5 \times 10^{-4} \text{ mol.s}^{-1} \times 60 \text{ s} = 0,021 \text{ mol}$$

ii. the minimum mass (in g) of sodium that is needed for this reaction to take place for 1 min.

For every 2 moles of NaCl produced 2 moles of Na is required.

n(Na) required = 0,021 mol

M(Na) = 23,0 g.mol⁻¹

$$m = n \times M = 0,021 \text{ mol} \times 23,0 \text{ g.mol}^{-1} = 0,48 \text{ g}$$

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Factors affecting reaction rates

In the nature of reactants, surface area and concentration experiments learners are required to work with concentrated, strong acids. These acids can cause serious burns. Please remind the learners to be careful and wear the appropriate safety equipment when handling all chemicals, especially concentrated acids. The safety equipment includes gloves, safety glasses and protective clothing.

In the concentration and rate project the learners should design their own experiment in the following format:

- Aim
- Apparatus
- Method

They can also perform the experiment and write up results and conclusions as well.

This experiment should focus on the effect of **concentration** on the rate. The easiest way to do this is to vary the concentration of the vinegar and keep the mass of baking soda constant.

In the temperature and reaction rate experiment make sure the learners do not shake the test tubes. Shaking gives energy to the reaction and affects the rate. The test tubes should be left as still as possible once the effervescent tablets have been added.

Plastic bottles, such as those shown in the picture, can be used instead of test tubes.

In the first catalyst and reaction rate experiment (with manganese dioxide and hydrogen peroxide) it is important to note that hydrogen peroxide can cause burns. The learners should wear safety equipment, as always when handling chemicals. If the concentration of hydrogen peroxide is too high the liquid hydrogen peroxide may splash out of the container along with the oxygen gas. As a result the learners should be particularly careful around the mouth of the containers.

In the second experiment the learners are again working with a strong acid and should follow all the usual safety procedures.

In the iodine clock experiment it is important that the learners start timing the experiment as soon as the sulfuric acid and hydrogen peroxide solution is added to the potassium iodide solution. There should be a sudden colour change from colourless to purple when the sodium thiosulfate is used up and free iodine is available in the solution. The free iodine is what gives the reaction the purple colour.

This experiment is best done in groups (3 - 4 is often a good size). You can divide your class into groups and assign each group a different experiment. Afterwards the groups can present their results and conclusions to the class. If you have time you can also vary the concentration of the hydrogen peroxide.

As always, learners need to work carefully with acids, in particular with the concentrated acids. Remind them to always add the acid to the water.

Exercise 7 – 3: Rates of reaction

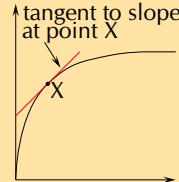
- Hydrochloric acid and calcium carbonate react according to the following equation:



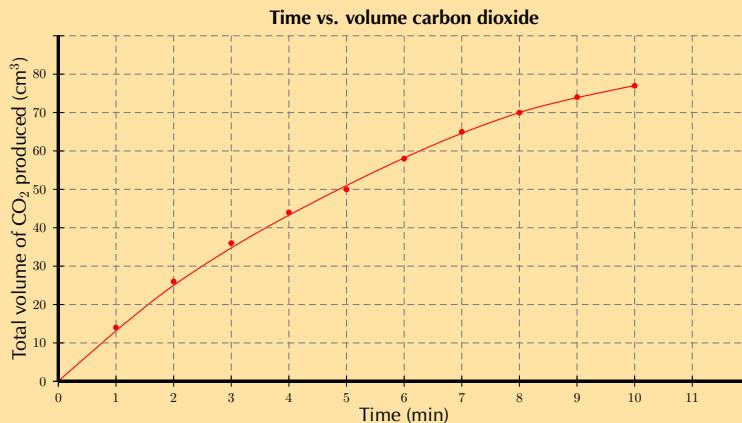
The volume of carbon dioxide that is produced during the reaction is measured at different times. The results are shown in the table below.

Time (mins)	Total Volume of CO ₂ produced (cm ³)
1	14
2	26
3	36
4	44
5	50
6	58
7	65
8	70
9	74
10	77

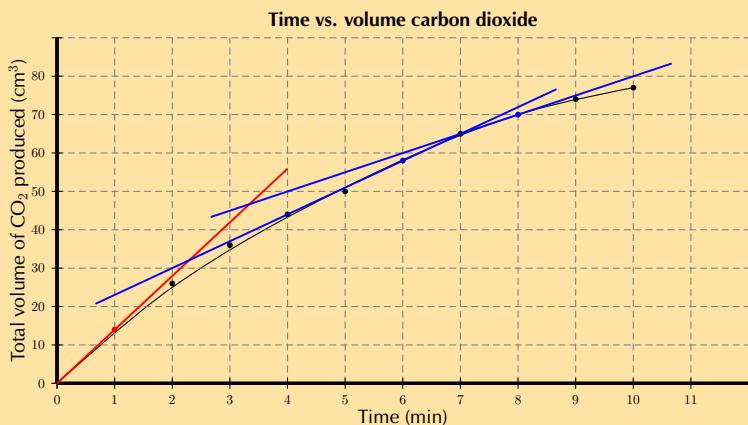
Note: On a graph of production against time, it is the gradient of the tangent to the graph that shows the rate of the reaction at that time. e.g.



- Use the data in the table to draw a graph showing the volume of gas that is produced in the reaction, over a period of 10 minutes.
(Remember to label the axes and plot the graph on graphing paper)

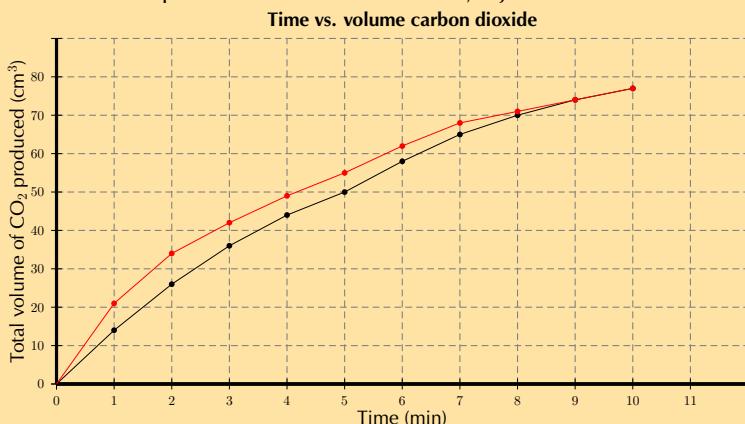


- At which of the following times is the reaction *fastest*: 1 minute; 6 minutes or 8 minutes. Explain.



Time = 1 minute. This is where the gradient of a tangent to the graph is the steepest (the red line on the graph). The steeper the gradient the faster the rate at that time.

- c) Suggest a reason why the reaction slows down over time.
As the reaction proceeds the reactants are used up (form products). With a lower concentration of reactants the rate of the reaction decreases.
- d) Use the graph to estimate the volume of gas that will have been produced after 11 minutes.
Approximately 79 cm^3
- e) How long do you think the reaction will take to stop (give a time in minutes)?
Any answer between 15 and 25 minutes is reasonable. To see this extend the line and find approximate the time that the gradient flattens out.
- f) If the experiment was repeated using a more concentrated hydrochloric acid solution:
 - i. would the average rate of the reaction increase or decrease from the one shown in the graph?
The rate would increase.
 - ii. draw a line on the same set of axes to show how you would expect the reaction to proceed with a more concentrated HCl solution.
The red line indicates roughly how the reaction would proceed. Note that the reaction does not produce more carbon dioxide, it just reacts faster.



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7.3 Measuring rates of reaction

Measuring the volume of gas produced per unit time

In the zinc and hydrochloric acid experiment the learners collect gas in a balloon. **Do not** light the gas in the balloon or allow it to be near flame. There will be an explosion.

Precipitate reactions

For the reaction of sodium thiosulfate with hydrochloric acid it would be good to break your class up into groups and assign different experiments to them at this point. They can report back to the rest of the class.

This experiment is recommended for informal assessment in CAPS. Remember to remind the learners about laboratory safety procedures, especially when handling acids.

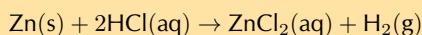
7.4 Mechanism of reaction and catalysis

Exercise 7 – 4: Reaction rates

1. For each of the following, say whether the statement is **true** or **false**. If it is false, re-write the statement correctly.

- A catalyst increases the energy of reactant molecules so that a chemical reaction can take place.
False. A catalyst lowers the activation energy of a reaction, so that a chemical reaction can take place.
- Increasing the temperature of a reaction has the effect of increasing the number of reactant particles that have more energy than the activation energy.
True
- A catalyst does not become part of the final product in a chemical reaction.
True

2. 5 g of zinc pieces are added to 400 cm³ of 0,5 mol·dm⁻³ hydrochloric acid. To investigate the average rate of the reaction, the change in the mass of the flask containing the zinc and the acid is measured by placing the flask on a direct reading balance. The reading on the balance shows that there is a decrease in mass during the reaction. The reaction which takes place is given by the following equation:



- Why is there a decrease in mass during the reaction?

The reaction does not take place in a sealed container and so the hydrogen gas can escape from the reaction vessel.

- The experiment is repeated, this time using 5 g of powdered zinc instead of pieces of zinc. How will this influence the average rate of the reaction?

The rate will increase since there will be a greater surface area of zinc to react with the acid.

- The experiment is repeated once more, this time using 5 g of zinc pieces and 600 cm³ of 0,5 mol·dm⁻³ hydrochloric acid. How does the average rate of this reaction compare with the **original** reaction rate?

There is a larger volume of hydrochloric acid. However the concentration is not increased and so the reaction rate is unchanged.

- What effect would a catalyst have on the average rate of this reaction?

(IEB Paper 2 2003)

The average rate of reaction would increase.

3. 5 g of calcium carbonate powder reacts with 20 cm³ of a 0,1 mol·dm⁻³ solution of hydrochloric acid. The gas that is produced at a temperature of 25°C is collected in a gas syringe.

- a) Write a balanced chemical equation for this reaction.



- b) The average rate of the reaction is determined by measuring the volume of gas that is produced in the first minute of the reaction. How would the average rate of the reaction be affected if:

- i. a lump of calcium carbonate of the same mass is used

The surface area is decreased, therefore the average rate of reaction would decrease.

- ii. 20 cm³ of 0,2 mol·dm⁻³ hydrochloric acid is used

The average rate of reaction depends on the concentration of liquid reactants and not on the volume. The concentration is increased however, so the rate will increase.

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7.5 Chapter summary

Exercise 7 – 5:

1. Explain the following:

- a) Reaction rate

The reaction rate describes how quickly reactants are used up or how quickly products are formed.

- b) Collision theory

Reactant particles must collide with the correct energy and orientation for the reactants to change into products.

For a reaction to occur the reactant particles must:

- collide
- have enough energy
- have the right orientation at the moment of impact

- c) Activation energy

The minimum energy required for a chemical reaction to proceed.

- d) Catalyst

A catalyst speeds up a chemical reaction. It increases the reaction rate by lowering the activation energy for a reaction and remains unchanged after the reaction is complete.

2. $2\text{Mg}(\text{s}) + \text{O}_2(\text{g}) \rightarrow 2\text{MgO}(\text{s})$

1 g of Mg is oxidised. The reaction takes 1 day to reach completion. Which is the correct reaction rate for the oxidation of Mg?

- a) $2,87 \times 10^{-7} \text{ mol}\cdot\text{s}^{-1}$
c) $4,76 \times 10^{-7} \text{ mol}\cdot\text{s}^{-1}$

- b) $1,74 \times 10^{-3} \text{ mol}\cdot\text{s}^{-1}$
d) $3,62 \times 10^{-7} \text{ mol}\cdot\text{s}^{-1}$

$$M(Mg) = 24,3 \text{ g.mol}^{-1}$$

$$n = \frac{m(\text{g})}{M(\text{g.mol}^{-1})} = \frac{1 \text{ g}}{24,3 \text{ g.mol}^{-1}} = 0,0412 \text{ mol}$$

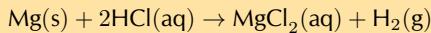
$$\text{time} = 1 \text{ day} \times \frac{24 \text{ hours}}{1 \text{ day}} = 24 \text{ hours} \times \frac{60 \text{ minutes}}{1 \text{ hour}} = 1,44 \times 10^3 \text{ minutes}$$

$$1,44 \times 10^3 \text{ minutes} \times \frac{60 \text{ seconds}}{1 \text{ minute}} = 8,64 \times 10^4 \text{ s}$$

$$\text{reaction rate} = \frac{n(\text{mol})}{t(\text{s})} = \frac{0,0412 \text{ mol}}{8,64 \times 10^4 \text{ s}} = \text{c)} 4,76 \times 10^{-7} \text{ mol.s}^{-1}$$

3. 10 g of magnesium ribbon reacts with a 0,15 mol.dm⁻³ solution of hydrochloric acid at a temperature of 25 °C.

a) Write a balanced chemical equation for the reaction.



b) State **two** ways of increasing the average rate of production of H₂ (g).

Cut the magnesium into small pieces, increase the concentration of hydrochloric acid.

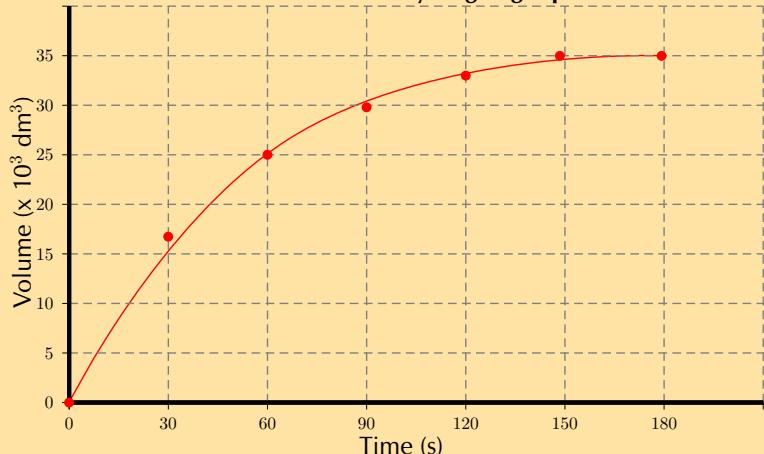
c) A table of the results is given below:

Time elapsed (min)	Vol of H ₂ (g) (cm ³)
0	0
0,5	17
1,0	25
1,5	30
2,0	33
2,5	35
3,0	35

i. Plot a graph of volume versus time for these results.

Remember to convert time to seconds and volume to dm³:

Time vs. volume for hydrogen gas production

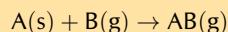


- ii. Explain the shape of the graph during the following two time intervals: t = 0 to t = 120 s and then t = 150 and t = 180 s by referring to the volume of H₂ (g) produced.

(IEB Paper 2, 2001)

There is a sharp increase in the volume of hydrogen gas produced for the first 120 seconds. This is when the reaction is starting and there are lots of reactants. Between 150 and 180 seconds equilibrium is established and so the volume of hydrogen gas that has been produced remains constant.

4. Consider the following reaction, which takes place in a closed container:



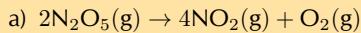
If you wanted to increase the average rate of the reaction, which of the following would you do?

- a) decrease the concentration of B
- b) grind A into a fine powder
- c) decrease the pressure

(IEB Paper 2, 2002)

- b)** grind A to a fine powder

5. Consider the following reaction and calculate the reaction rates for the situations that follow:



i. 1,35 mol N_2O_5 is used and the reaction goes to completion in 30 minutes.

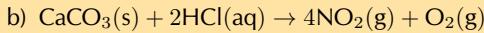
$$\text{time} = 30 \text{ minutes} \times \frac{60 \text{ s}}{1 \text{ minute}} = 1800 \text{ s}$$

$$\text{reaction rate of } \text{N}_2\text{O}_5 \text{ used is} = \frac{1,35 \text{ mol}}{1800 \text{ s}} = 7,5 \times 10^{-4} \text{ mol.s}^{-1}$$

ii. 2,7 mol N_2O_5 is used instead and the reaction goes to completion in 60 minutes.

$$\text{time} = 60 \text{ minutes} \times \frac{60 \text{ s}}{1 \text{ minute}} = 3600 \text{ s}$$

$$\text{reaction rate of } \text{N}_2\text{O}_5 \text{ used is} = \frac{2,7 \text{ mol}}{3600 \text{ s}} = 7,5 \times 10^{-4} \text{ mol.s}^{-1}$$



i. 2 g of CaCO_3 is placed in excess HCl. The reaction goes to completion over 4 hours.

$$M(\text{CaCO}_3) = (40,1 + 12 + 3 \times 16) \text{ g.mol}^{-1} = 100,1 \text{ g.mol}^{-1}$$

$$n = \frac{m}{M} = \frac{2 \text{ g}}{100,1 \text{ g.mol}^{-1}} = 0,02 \text{ mol}$$

$$\text{time} = 4 \text{ hours} \times \frac{60 \text{ minutes}}{1 \text{ hour}} = 240 \text{ minutes} \times \frac{60 \text{ s}}{1 \text{ minute}} = 14400 \text{ s}$$

$$\text{reaction rate CaCO}_3 \text{ used is} = \frac{0,02 \text{ mol}}{14400 \text{ s}} = 1,39 \times 10^{-6} \text{ mol.s}^{-1}$$

ii. The concentration of the HCl is increased and so the reaction takes 2,5 hours instead.

$$M(\text{CaCO}_3) = 100,1 \text{ g.mol}^{-1}$$

$$n = \frac{m}{M} = \frac{0,02 \text{ mol}}{100,1 \text{ g.mol}^{-1}}$$

$$\text{time} = 2,5 \text{ hours} \times \frac{60 \text{ minutes}}{1 \text{ hour}} = 150 \text{ minutes} \times \frac{60 \text{ s}}{1 \text{ minute}} = 9000 \text{ s}$$

$$\text{reaction rate CaCO}_3 \text{ used is} = \frac{0,02 \text{ mol}}{9000 \text{ s}} = 2,22 \times 10^{-6} \text{ mol.s}^{-1}$$

iii. 3,3 g of CaCO_3 is used with a dilute HCl. 0,6 g of solid CaCO_3 remains after 4,7 hours.

$$M(\text{CaCO}_3) = 100,1 \text{ g.mol}^{-1}$$

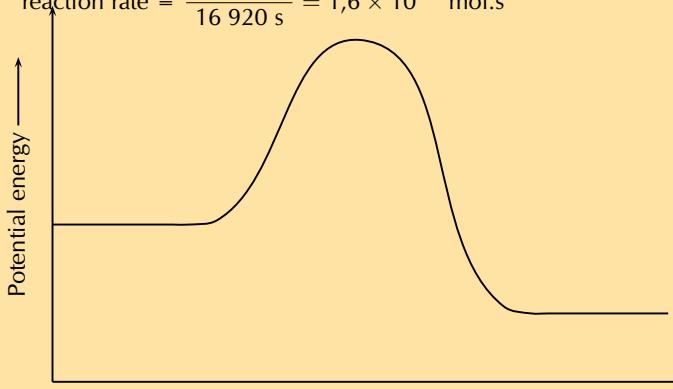
$$\text{m of CaCO}_3 \text{ used during the reaction} = 3,3 - 0,6 = 2,7 \text{ g}$$

$$n = \frac{m}{M} = \frac{2,7 \text{ g}}{100,1 \text{ g.mol}^{-1}} = 0,027 \text{ mol}$$

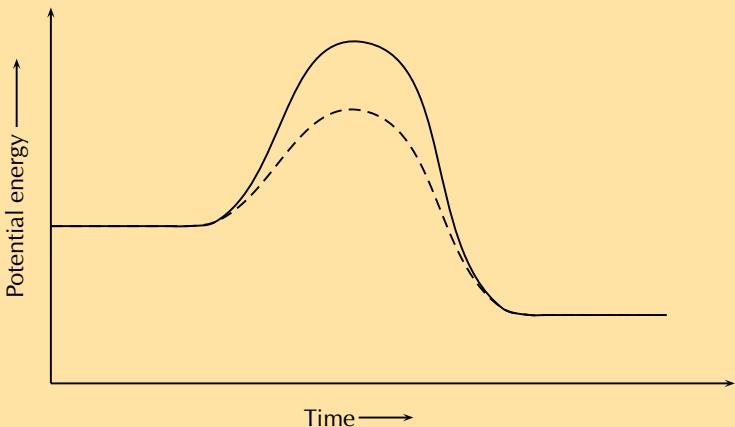
$$\text{time} = 4,7 \text{ hours} \times \frac{60 \text{ minutes}}{1 \text{ hour}} = 282 \text{ minutes} \times \frac{60 \text{ s}}{1 \text{ minute}} = 16920 \text{ s}$$

$$\text{reaction rate} = \frac{0,027 \text{ mol}}{16920 \text{ s}} = 1,6 \times 10^{-6} \text{ mol.s}^{-1}$$

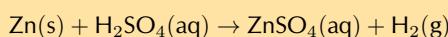
6. Given:



A catalyst is added to this reaction. On the same set of axes draw the graph to represent this.



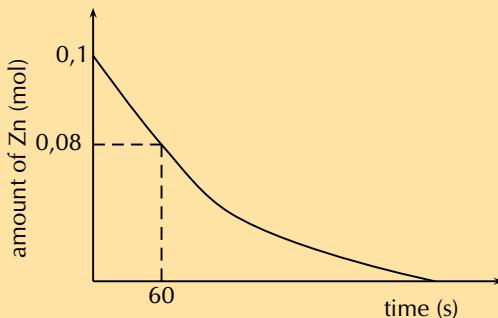
7. A group of learners use the reaction between zinc and sulfuric acid to investigate one of the factors that affects reaction rate. The equation below represents the reaction that takes place.



They add 6,5 g of zinc granules to excess *dilute* sulfuric acid and measure the mass of zinc used per unit time.

The learners then repeat the experiment using excess *concentrated* sulfuric acid.

The results obtained for the reaction using *dilute* sulfuric acid are represented in the graph below:



- a) Define the term *reaction rate*

Amount of reactants used per unit time or amount of products formed per unit time.

- b) Give a reason why the acid must be in excess

To ensure that (nearly) all zinc is used up or to ensure that zinc is a limiting reagent (and the acid is not a limiting reagent).

- c) Write down a hypothesis for this investigation.

(Learners must correctly identify the **dependent and independent** variables. They must predict the **correct relationship** between these variables)

Reaction rate increases with increase in concentration.

Reaction rate decreases with decrease in concentration.

Reaction rate is directly proportional to concentration.

The higher the concentration the faster the average rate of the reaction.

- d) Give a reason why the learners must use the same amount of *zinc granules* in both experiments.

To make it a fair test.

or

Ensure validity (reliability) of results.

or

So that the contact/surface area may not influence the reaction rate. The surface area must not change.

or

It is the controlled variable.

or

To ensure there is only one independent variable.

- e) Using the graph, calculate the mass of zinc used from $t = 0$ s to $t = 60$ s.

Number of moles used = $0,1 - 0,08 = 0,02$ mol

$$M(Zn) = 65,4 \text{ g}$$

$$n = \frac{m}{M}, \text{ therefore } m = n \times M$$

$$m = 0,02 \text{ mol} \times 65,4 \text{ g mol}^{-1} = 1,31 \text{ g}$$

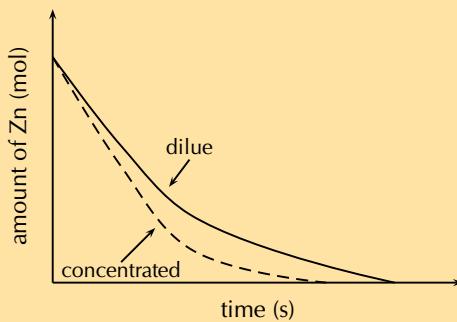
- f) Calculate the average rate of the reaction (in grams per second) during the first 60 s.

$$\text{Average rate} = \frac{\text{mass Zn used (g)}}{\text{time (s)}} = \frac{1,31 \text{ g}}{60 \text{ s}} = 0,022 \text{ g.s}^{-1}$$

- g) Copy the above graph and *on the same set of axes* use a dotted line to show the curve that will be obtained when concentrated sulfuric acid is used. No numerical values are required.

(NSC, Paper 2, 2011)

Criteria for graph - Concentrated sulfuric graph has steeper slope than original graph and intercepts with x-axis earlier.



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Chemical equilibrium

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8 Chemical equilibrium

In this chapter learners will explore the concept of chemical equilibrium in detail. Before starting this chapter it is essential that the learners have a thorough understanding of rates of reactions and chemical kinetics as covered in Chapter 7. In Grade 11 the definition of equilibrium in physics was covered, it is important that the learners understand the difference between this and a dynamic, chemical equilibrium.

The following topics are covered in this chapter.

- **What the term *chemical equilibrium* means**

In this section learners will be introduced to the concept of chemical equilibrium including everyday examples. Covered under this introduction are the concepts of open and closed systems, and the fact that reactions cannot reach equilibrium in an open system. Chemical equilibrium reactions require reversible reactions that can form a dynamic equilibrium, these concepts are also covered here.

- **The equilibrium constant**

The equilibrium constant is used to determine whether reactants or products are favoured in a reaction at chemical equilibrium. Aside from introducing the meaning of K_c values, this section will require the learners to calculate equilibrium constants from known concentrations, as well as to calculate the concentrations of reactants and products. To do that they should use a RICE table. The acronym makes it easier for learners to remember the information necessary, and the table helps them to organise the information they have and see what information they still need.

It is important that learners have a thorough understanding of equilibrium constants before they begin Chapter 9.

- **Le Chatelier's principle**

The concept of understanding how a reaction will be affected by an external stress, without actually doing an experiment, is quite abstract and the learners often struggle with it. Lots of examples with different reactions would be a good idea here to make sure they understand the concepts, before you move on to the more advanced interpretations of graphs. The Haber process could be used as an example to make sure they understand the concepts, before you move on to that section.

The informal assessment in this chapter requires the use of concentrated hydrochloric acid. The learners should be properly instructed on the correct use of safety equipment, including safety goggles, gloves and protective clothing. They should also be reminded not to sniff any chemicals as the fumes can be dangerous as well. More information on laboratory procedures as well as safety precautions is provided in Chapter 1 (Science skills). The initial solution at room temperature should be purple. When heated the solution should turn a deep blue, and when cooled it should turn a pink or red colour. More information is provided in the relevant section.

8.1 What is chemical equilibrium?

Open and closed systems

The important thing for the students to understand in this experiment is that there is constant movement. Molecules at the surface of the water in the closed beaker are constantly evaporating, and gas molecules are constantly condensing. There is no change in the level of the liquid and the total number molecules in the liquid and the gas state remain constant.

Point out that the level of water in the sealed container also drops initially, before finally remaining constant. This concept will help learners understand how the rate of the forward reaction decreases until equilibrium is reached.

Exercise 8 – 1: Chemical equilibrium

1. Which of the following situations describes a closed system?

- a) i. A pot of water (without a lid) heated to 80°C
- ii. A pot of water (with a lid) heated to 80°C

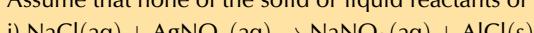
The water is being heated, therefore there is water in the liquid and the gas phase.

The water vapour can leave the pot (system) if there is no lid.

- ii) A closed pot of water (with a lid) heated to 80°C

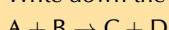
- b) i. $\text{NaCl(aq)} + \text{AgNO}_3\text{(aq)} \rightarrow \text{NaNO}_3\text{(aq)} + \text{AlCl(s)}$
in an open container.
- ii. $2\text{CO(g)} + \text{MoO}_2\text{(s)} \rightarrow 2\text{CO}_2\text{(g)} + \text{Mo(s)}$
in an open container.

Assume that none of the solid or liquid reactants or products go into the gas phase.



2. For the reaction: $\text{A} + \text{B} \rightleftharpoons \text{C} + \text{D}$

- a) Write down the forward reaction



- b) Write down the reverse reaction



- c) This reaction is said to be (fill in the missing word)

This reaction is said to be reversible

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8.2 The equilibrium constant

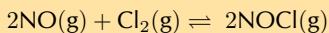
The meaning of K_c values

Exercise 8 – 2: The equilibrium constant

1. Write the equilibrium constant expression, K_c , or balanced chemical equation for the following reactions:

- a) NO and Cl_2 are both reactants. NOCl is the product. They are all in the gas state and will be included in the equilibrium constant expression.

NO has a coefficient of **2**, Cl_2 has a coefficient of **1** and NOCl has a coefficient of **2**.



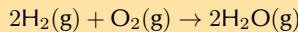
$$K_c = \frac{[\text{NOCl}]^2}{[\text{NO}]^2[\text{Cl}_2]}$$

$$\text{b) } K_c = \frac{[\text{H}_2\text{O(g)}]^2}{[\text{H}_2\text{(g)}]^2[\text{O}_2\text{(g)}]}$$

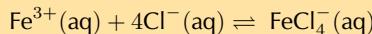
The $\text{H}_2\text{O(g)}$ must be the product and have a coefficient of 2.

The H₂(g) must be a reactant and have a coefficient of 2.

The O₂(g) must be a reactant and have a coefficient of 1.



2. The following reaction takes place:



K_c for the reaction is $7,5 \times 10^{-2}$. At equilibrium, the concentration of FeCl₄⁻(aq) is $0,95 \times 10^{-4}$ mol·dm⁻³ and the concentration of Fe³⁺(aq) is 0,2 mol·dm⁻³. Calculate the concentration of chloride ions at equilibrium.

We know the value of K_c and the concentration of two of the three substances at equilibrium. So we use the expression for K_c to find the concentration of chloride ions.

FeCl₄⁻(aq) is the product and has a coefficient of 1.

Fe³⁺(aq) is a reactant and has a coefficient of 1.

Cl⁻(aq) is a reactant and has a coefficient of 4.

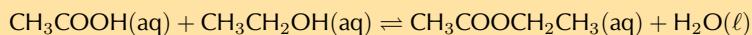
$$K_c = \frac{[\text{FeCl}_4^-]}{[\text{Fe}^{3+}][\text{Cl}^-]^4}$$

$$[\text{Cl}^-]^4 = \frac{[\text{FeCl}_4^-]}{[\text{Fe}^{3+}][K_c]}$$

$$[\text{Cl}^-]^4 = \frac{0,95 \times 10^{-4}}{(0,2)(7,5 \times 10^{-2})} = 0,0063$$

$$[\text{Cl}^-] = 0,28 \text{ mol}\cdot\text{dm}^{-3}$$

3. Ethanoic acid (CH₃COOH) reacts with ethanol (CH₃CH₂OH) to produce ethyl ethanoate and water. The reaction is:



At the beginning of the reaction, there is 0,5 mol of ethanoic acid and 0,5 mol of ethanol. At equilibrium, 0,3 mol of ethanoic acid was left unreacted. The volume of the reaction container is 2 dm³. Calculate the value of K_c.

Fill in a RICE table with the initial moles, the change in moles in terms of x and the number of moles at equilibrium in terms of x:

Reaction	1CH ₃ COOH	1CH ₃ CH ₂ OH	1CH ₃ COOCH ₂ CH ₃	1H ₂ O
Initial quantity (mol)	0,5	0,5	0	0
Change (mol)	-x	-x	+x	+x
Equilibrium quantity (mol)	0,5 - x	0,5 - x	+x	+x
Equilibrium concentration (mol·dm ⁻³)				

Calculate x:

n(CH₃COOH) = 0,3 mol at equilibrium. Therefore:

$$0,5 \text{ mol} - x = 0,3 \text{ mol}$$

$$x = 0,5 - 0,3 \text{ mol} = 0,2 \text{ mol}$$

Substitute x into the RICE table:

Reaction	1CH ₃ COOH	1CH ₃ CH ₂ OH	1CH ₃ COOCH ₂ CH ₃	1H ₂ O
Initial quantity (mol)	0,5	0,5	0	0
Change (mol)	-0,2	-0,2	0,2	0,2
Equilibrium quantity (mol)	0,3	0,3	0,2	0,2
Equilibrium concentration (mol·dm ⁻³)				

Calculate the concentration of each of the reactants and products at equilibrium using $C = \frac{n}{V}$ where $V = 2 \text{ dm}^3$.

$$C(\text{CH}_3\text{COOH}) = C(\text{CH}_3\text{CH}_2\text{OH}) = \frac{0,3 \text{ mol}}{2\text{dm}^3} = 0,15 \text{ mol}\cdot\text{dm}^{-3}$$

$$C(\text{CH}_3\text{COOCH}_2\text{CH}_3) = C(\text{H}_2\text{O}) = \frac{0,2 \text{ mol}}{2\text{dm}^3} = 0,1 \text{ mol}\cdot\text{dm}^{-3}$$

Reaction	1CH₃COOH	1CH₃CH₂OH	1CH₃COOCH₂CH₃	1H₂O
Initial quantity (mol)	0,5	0,5	0	0
Change (mol)	-0,2	-x	0,2	0,2
Equilibrium quantity (mol)	0,3	0,3	0,2	0,2
Equilibrium concentration (mol·dm ⁻³)	0,15	0,15	0,1	0,1

CH₃COOH and CH₃CH₂OH are reactants, and CH₃COOCH₂CH₃ and H₂O are products.

However, H₂O is a pure liquid and is not included in the K_c expression. So the equilibrium constant is:

$$K_c = \frac{[\text{CH}_3\text{COOCH}_2\text{CH}_3]}{[\text{CH}_3\text{COOH}][\text{CH}_3\text{CH}_2\text{OH}]} = \frac{(0,1)}{(0,15)(0,15)} = 4,44$$

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8.3 Le Chatelier's principle

The effect of concentration on equilibrium

Although not required by CAPS the common-ion effect is a useful concept for the students to know if there is time.

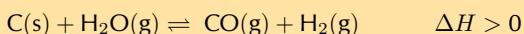
The effect of temperature on equilibrium

In the informal experiment on Le Chatelier's principle, the solution should be purple to start. To achieve this CoCl₂ must be dissolved in ethanol and a few drops of water must be added. This solution is **toxic**, and all the usual laboratory precautions should be taken.

The hot water will make the solution a deep blue, the cold water will make the solution a pink/red colour. If necessary the test tube can be gently shaken to ensure mixing.

Exercise 8 – 3: Equilibrium

- The following reaction has reached equilibrium in a closed container:



The pressure of the system is then decreased. How will the concentration of the H₂(g) and the value of K_c be affected when the new equilibrium is established? Assume that the temperature of the system remains unchanged.

	Hydrogen concentration	K _c
(a)	increases	increases
(b)	increases	stays the same
(c)	stays the same	stays the same
(d)	decreases	stays the same

(IEB Paper 2, 2004)

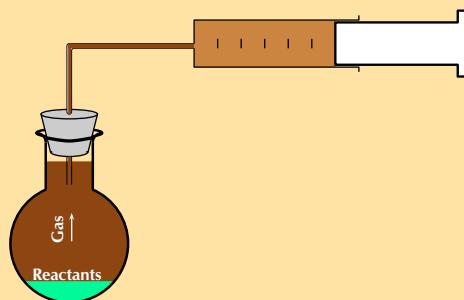
Equilibrium will shift to increase the number of gas molecules. That is to the right and so the concentration of hydrogen will increase. Only temperature affects the value of K_c, therefore K_c remains the same.

b) Hydrogen concentration increases and equilibrium constant stays the same

2. During a classroom experiment copper metal reacts with concentrated nitric acid to produce NO₂ gas.



The NO₂ is collected in a gas syringe.



When enough gas has collected in the syringe, the delivery tube is clamped so that no gas can escape. The brown NO₂ gas collected reaches an equilibrium with colourless N₂O₄ gas as represented by the following equation:



Once this equilibrium has been established, there are 0,01 moles of NO₂ gas and 0,03 moles of N₂O₄ gas present in the syringe.

- a) A learner, noticing that the colour of the gas mixture in the syringe is no longer changing, comments that all chemical reactions in the syringe must have stopped. Is this assumption correct? Explain.

No. The learner is not correct. A dynamic chemical equilibrium has been reached and the products are changing into reactants at the same rate as reactants are changing into products. This results in no colour change being observed in the syringe.

- b) The gas in the syringe is cooled. The volume of the gas is kept constant during the cooling process. Will the gas be lighter or darker at the lower temperature? Explain your answer.

The forward reaction is exothermic ($\Delta H < 0$). A decrease in temperature will favour the forward reaction. N₂O₄(g) is colourless, therefore the gas will be lighter at the lower temperature.

- c) The volume of the syringe is now reduced (at constant temperature) to 75 cm³ by pushing the plunger in and holding it in the new position. There are 0,032 moles of N₂O₄ gas present once the equilibrium has been re-established at the reduced volume (75 cm³). Calculate the value of the equilibrium constant for this equilibrium.

(IEB Paper 2, 2004)

The volume is reduced, so the pressure is increased. This means that the forward reaction will be favoured to reduce the number of gas molecules.

There are 0,01 moles of NO₂ and 0,03 moles of N₂O₄ initially.

For every 2x moles of NO₂ used, 1x moles of N₂O₄ are produced.

Reaction	2NO ₂ (g)	1N ₂ O ₄ (g)
Initial quantity (mol)	0,01	0,03
Change (mol)	-2x	+x
Equilibrium quantity (mol)	0,01-2x	0,03+x
Equilibrium concentration (mol.dm ⁻³)		

There are 0,032 mol N₂O₄ at the new equilibrium.

Therefore 0,03 mol + x = 0,032 mol

$$x = 0,032 - 0,03 \text{ mol} = 0,002 \text{ mol}$$

$$n(\text{NO}_2) \text{ at equilibrium} = 0,01 \text{ mol} - 2 \times 0,002 \text{ mol} = 0,006 \text{ mol}$$

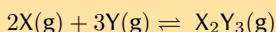
$$C(\text{NO}_2) \text{ at equilibrium} = \frac{0,006 \text{ mol}}{0,075 \text{ dm}^3} = 0,08 \text{ mol.dm}^{-3}$$

$$C(\text{N}_2\text{O}_4) \text{ at equilibrium} = \frac{0,032 \text{ mol}}{0,075 \text{ dm}^3} = 0,43 \text{ mol.dm}^{-3}$$

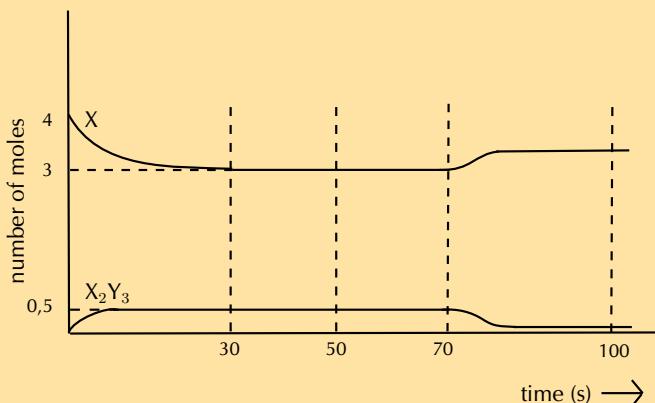
Reaction	2NO ₂ (g)	1N ₂ O ₄ (g)
Initial quantity (mol)	0,01	0,03
Change (mol)	-2x	+x
Equilibrium quantity (mol)	0,01-2x	0,03+x
Equilibrium concentration (mol.dm ⁻³)	0,08	0,43

$$K_c = \frac{[\text{N}_2\text{O}_4]}{[\text{NO}_2]^2} = \frac{0,43}{(0,08)^2} = 67,19$$

3. Gases X and Y are pumped into a 2 dm³ container. When the container is sealed, 4 moles of gas X and 4 moles of gas Y are present. The following equilibrium is established:



The graph below shows the number of moles of gas X and gas X₂Y₃ that are present from the time the container is sealed.



- a) How many moles of gas X₂Y₃ are formed by the time the reaction reaches equilibrium at 30 seconds?

From the graph: 0,5 mol

- b) Calculate the value of the equilibrium constant at t = 50 s.

Draw up a RICE table.

Reaction	2X(g)	3Y(g)	X ₂ Y ₃ (g)
Initial quantity (mol)	4	4	0
Change (mol)	-2x	-3x	+x
Equilibrium quantity (mol)	4 - 2x	4 - 3x	0 + x
Equilibrium concentration (mol.dm ⁻³)			

There are 0,5 mol of X present at equilibrium.

Therefore x = 0,5 mol

From the graph n(X) = 3 mol

$$n(Y) = 4 - 3 \times 0,5 \text{ mol} = 2,5 \text{ mol}$$

Reaction	2X(g)	3Y(g)	X ₂ Y ₃ (g)
Initial quantity (mol)	4	4	0
Change (mol)	-1	-1,5	+0,5
Equilibrium quantity (mol)	3	2,5	0,5
Equilibrium concentration (mol.dm ⁻³)			

$$C(X) = \frac{3 \text{ mol}}{2 \text{ dm}^3} = 1,5 \text{ mol.dm}^{-3}$$

$$C(Y) = \frac{2,5 \text{ mol}}{2 \text{ dm}^3} = 1,25 \text{ mol.dm}^{-3}$$

$$C(X_2Y_3) = \frac{0,5 \text{ mol}}{2 \text{ dm}^3} = 0,25 \text{ mol.dm}^{-3}$$

Reaction	2X(g)	3Y(g)	X ₂ Y ₃ (g)
Initial quantity (mol)	4	4	0
Change (mol)	-1	-1,5	+0,5
Equilibrium quantity (mol)	3	2,5	0,5
Equilibrium concentration (mol.dm ⁻³)	1,5	1,25	0,25

$$K_c = \frac{[X_2Y_3]}{[X]^2[Y]^3} = \frac{0,25}{(1,5)^2(1,25)^3} = 0,057$$

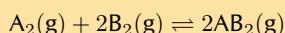
- c) At 70 s the temperature is increased. Is the forward reaction endothermic or exothermic? Explain in terms of Le Chatelier's Principle.

Exothermic. The amount of product decreases (and amount of reactants increases) when the temperature is increased indicating that the reverse reaction is favoured. Le Chatelier's principle states that an increase in temperature will favour the endothermic reaction (cooling the reaction vessel). Therefore the reverse reaction must be endothermic and the forward reaction is exothermic.

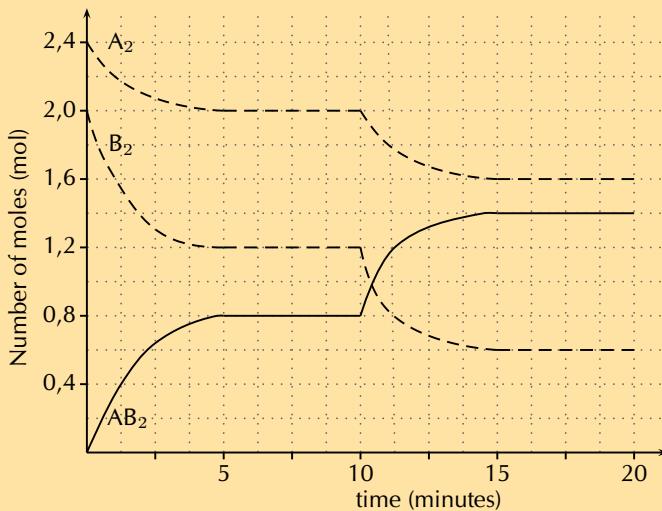
- d) How will this increase in temperature affect the value of the equilibrium constant?

An increase in temperature is the only thing that affects the equilibrium constant. The amount of product decreased and the amount of reactants increased, therefore the equilibrium constant will decrease.

4. Consider the following hypothetical reaction that takes place in a **closed** 2 dm³ flask at 298 K.



The graph beneath represents the change in the number of moles of each gas in the flask over a period of 20 minutes.



- a) State how long (in minutes) it took for the reaction to reach equilibrium for the first time.

The number of moles of each reactant and the product is constant (have reached equilibrium) after $t = 5$ minutes

- b) Write down an expression for the equilibrium constant, K_c , for this particular reaction.

$$K_c = \frac{[AB_2]^2}{[A_2][B_2]^2}$$

- c) Calculate the concentration of each of the reactants and the product using figures from the graph between 5 minutes and 10 minutes and hence calculate the equilibrium constant K_c for this reaction at 298 K

The concentration values are read off the graph.

$$C(A_2) = \frac{2,0 \text{ mol}}{2 \text{ dm}^3} = 1,0 \text{ mol.dm}^{-3}$$

$$C(B_2) = \frac{1,2 \text{ mol}}{2 \text{ dm}^3} = 0,6 \text{ mol.dm}^{-3}$$

$$C(AB_2) = \frac{0,8 \text{ mol}}{2 \text{ dm}^3} = 0,4 \text{ mol.dm}^{-3}$$

$$K_c = \frac{[AB_2]^2}{[A_2][B_2]^2} = \frac{0,4^2}{(1,0)(0,6)^2} = 0,44$$

- d) State what a low value of K_c indicates about the yield of product for a reaction.

A value of K_c between 0 and 1 indicates that the equilibrium lies to the left. Therefore the yield of product is low (more reactants than products).

- e) Why is it not possible to calculate K_c using figures from the graph during the first 5 minutes

K_c is the equilibrium constant, therefore it cannot be calculated except when the reaction is in equilibrium. During the first 5 minutes the reaction is not in equilibrium.

- f) State Le Chatelier's principle.

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

- g) At 10 minutes the temperature of the flask was increased. Using Le Chatelier's principle, determine if the production of AB_2 is exothermic or endothermic?

AB_2 is produced through the forward reaction. Le Chatelier's principle states that if the temperature is increased the equilibrium will change to decrease the temperature of the vessel. That is the reaction that takes in heat (endothermic) will be favoured.

The number of moles of the reactants decreases after the temperature increase, while the number of moles of the product increases. Therefore the temperature

increase favours the forward reaction. This means that the forward reaction is endothermic.

- h) How would the equilibrium **constant** be affected by each of the following changes: (state either increase, decrease or no effect)

- i. Increasing the pressure of the flask with no change to temperature.
no effect
- ii. Adding a catalyst to the flask.
no effect
- iii. Increasing the temperature of the flask.
increase

5. More questions. Sign in at Everything Science online and click 'Practise Science'.

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1. 27VS 2. 27VT 3. 27VV 4. 27VW



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Industrial applications

Exercise 8 – 4: Applying equilibrium principles

1. Look at the values of K_c calculated for the Haber process reaction at different temperatures, and then answer the questions that follow:

$T\ (^{\circ}\text{C})$	K_c
25	$6,4 \times 10^2$
200	$4,4 \times 10^{-1}$
300	$4,3 \times 10^{-3}$
400	$1,6 \times 10^{-4}$
500	$1,5 \times 10^{-5}$

- a) What happens to the value of K_c as the temperature increases?
The value of K_c decreases
- b) Which reaction is being favoured when the temperature is $300\ ^{\circ}\text{C}$?
A value of K_c between 0 and 1 means that there are more reactants than products. Therefore the reverse reaction is favoured.
- c) According to this table, which temperature would be best if you wanted to produce as much ammonia as possible? Explain.
 $25\ ^{\circ}\text{C}$. At this temperature the forward reaction is favoured and so the maximum yield of ammonia is achieved.

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8.4 Chapter Summary

Exercise 8 – 5:

1. Explain the following concepts:

a) Chemical equilibrium

A reaction is in **chemical equilibrium** when the rate of the forward reaction equals the rate of the reverse reaction.

b) A closed system

A closed system is one in which energy can enter or leave the system, but matter cannot.

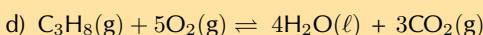
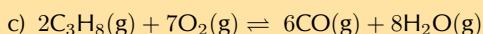
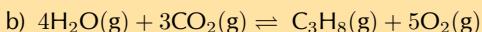
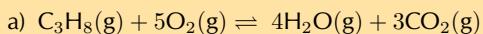
c) A reversible reaction

A reversible reaction is a chemical reaction that can proceed in both the forward and reverse directions. In other words, the reactants and products of one reaction may reverse roles.

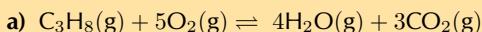
2. The following equilibrium constant expression is given for a particular reaction:

$$K_c = \frac{[H_2O]^4 [CO_2]^3}{[C_3H_8] [O_2]^5}$$

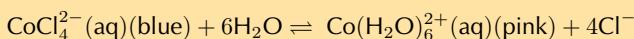
For which one of the following reactions is the above expression of K_c correct?



(IEB Paper 2, 2001)



3. Cobalt chloride crystals are dissolved in a beaker containing ethanol and then a few drops of water are added. After a period of time, the reaction reaches equilibrium as follows:



The solution, which is now purple, is poured into three test tubes. State, in each case, what colour changes, if any, will be observed if the following are added in turn to each test tube:

a) 1 cm³ of distilled water

The concentration of reactant (water) is increased, therefore the equilibrium will shift to the right and so the colour will change to pink.

b) A few crystals of sodium chloride

The concentration of product (Cl^-) is increased, therefore the equilibrium will shift to the left and the colour will change to blue.

(IEB Paper 2, 2001)

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1. 27VY 2. 27VZ 3. 27W2



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CHAPTER

9

Acids and bases

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9.1 Acids and bases

In this chapter learners will look at acids and bases. In Grade 11 learners were introduced to a lot of the concepts that are expanded on in this chapter. These include acid and base models and definitions, conjugate acid-base pairs, and some basic acid-base reactions. It is important that the learners have a good understanding of the work covered in Chapter 8, specifically equilibrium constants, before studying this chapter.

New concepts related to acids and bases will also be covered in this chapter. These include pH, more in depth information on titrations and indicators, and real world applications of acids and bases.

The following topics are covered in this chapter.

- **What are acids and bases?**

This section is largely revision from Grade 11. The Arrhenius and Brønsted-Lowry models for acids and bases are discussed. Conjugate acid-base pairs are also covered in detail in this section, including worked examples on how to determine the conjugate base of an acid and the conjugate acid of a base.

- **Strong and weak acids and bases, and concentrated and dilute solutions**

The concept of strong and weak acids and bases is often confused with the concept of concentrated and dilute solutions. It is important that the learners understand the difference between these concepts, which are discussed in detail in this section. The exercises will help to determine if the learners truly understand this work.

- **K_a and K_b**

Although learners will not have encountered these terms before, the idea of an equilibrium constant should be familiar to them after encountering the equilibrium constant (K_c) in Chapter 8. The values of K_a and K_b should be tied to the ideas of strong and weak acids and bases.

- **Acid-base reactions**

These neutralisation reactions should be familiar to learners from Grade 11. They should revise these reactions through the revision activity provided. It is important that learners understand how salts are formed from the acid and base, as well as the other products that are likely in each type of reaction.

- **pH**

The pH scale is a logarithmic scale with a base of 10. So a change in pH of 3 is a significant change in the concentration of H^+ ions. A good understanding of pH is also essential to understanding how indicators work. This section covers why a neutralised solution will not necessarily have a pH of 7, the concept of K_w , and the hydrolysis of salts. Indicators are also covered in this section and it is important that learners understand how to choose an indicator for an experiment before starting the next section on titrations.

- **Titrations**

Titration are covered in great detail in this section. This includes learners preparing their own standard solutions, performing several titration experiments, and doing titration calculations. The learners will be working with acids and bases a lot in this section and so should be reminded of proper laboratory safety procedures. Each experiment will take a large amount of time and at least an entire class should be dedicated to these experiments. If possible one class should be for the preparation of a standard solution and the first titration experiment, while another, separate class is for the second titration experiment.

- **Applications of acids and bases**

The applications covered are the production of chlorine in industry and the use of bases in hair products. The production of chlorine is not covered in great detail in this chapter, for more detail see Chapter 13. The hair care products discussed include: hair permanent waving applications, hair relaxers, and hair dyes. The learners must also perform an experiment using drain cleaners or caustic soda. These products have a high pH and can burn skin. This lesson can also be used to consolidate information by going through the chapter summary and doing the end of chapter exercises.

There are several experiments in this chapter. The learners will be using dangerous chemicals and should be properly instructed on the correct use of safety equipment, including safety goggles, gloves and protective clothing. They should also be reminded not to sniff any chemicals as the fumes can be dangerous as well. More information on laboratory procedures as well as safety precautions is provided in Chapter 1 (Science skills).

In the informal assessment the learners must determine the temperature change caused by the exothermic reaction of sodium hydroxide and hydrochloric acid. They should understand why the temperature stops changing when all the sodium hydroxide has been neutralised.

The formal assessment requires that the learners prepare a standard solution of sodium hydroxide. It is important that the learners understand why the mass must be known to a high accuracy, why the beakers must be rinsed with water (with the rinsings added to the volumetric flask), why the sides of the volumetric flask must be washed with water, and why it is important to have their eye level with the mark on the volumetric flask when filling to that mark. More information for each experiment is provided in the relevant sections.

The term dissociate should be used for ionic solids that break into their component parts when dissolved in water. Ionise should be used when a reaction with water takes place and ions, that were not present in the original compound, are formed.

For example, NaOH is an ionic solid composed of Na^+ ions and OH^- ions. Upon dissolution it **dissociates** into its component parts.

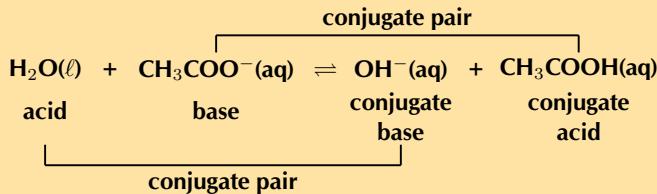
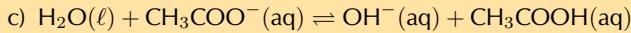
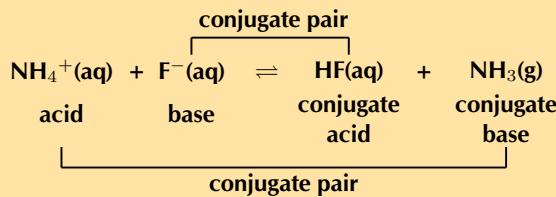
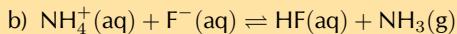
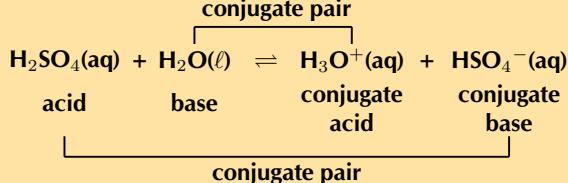
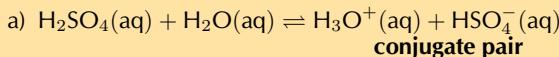
On the other hand, HCl is a covalent molecule. When dissolved in water it **ionises** to form H^+ and Cl^- ions.

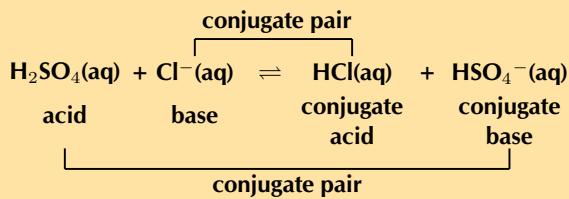
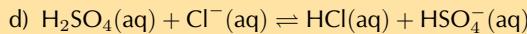
In general, strong bases dissociate, bases such as ammonia and organic amines ionise. All acids ionise.

Conjugate acid-base pairs

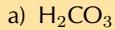
Exercise 9 – 1: Acids and bases

1. In each of the following reactions, label the conjugate acid-base pairs.





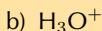
2. Write the conjugate base for:



This is an acid. A proton needs to be donated to form the conjugate base:



HCO_3^- is the conjugate base of H_2CO_3 .



This is an acid. A proton needs to be donated to form the conjugate base:



H_2O is the conjugate base of H_3O^+ .



This is an acid. A proton needs to be donated to form the conjugate base:

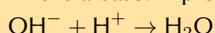


HPO_4^{2-} is the conjugate base of H_2PO_4^- .

3. Write the conjugate acid for:



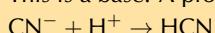
This is a base. A proton needs to be accepted to form the conjugate acid:



H_2O is the conjugate acid of OH^- .



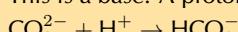
This is a base. A proton needs to be accepted to form the conjugate acid:



HCN is the conjugate acid of CN^- .



This is a base. A proton needs to be accepted to form the conjugate acid:



HCO_3^- is the conjugate acid of CO_3^{2-} .

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1. 27W3 2a. 27W4 2b. 27W5 2c. 27W6 3a. 27W7 3b. 27W8
3c. 27W9



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Dilute and concentrated solutions

Exercise 9 – 2: Types of acids and bases

- Say whether the solutions of the acids and bases in the following situations are concentrated or dilute.
 - For every 1 mole of a solvent there are 50 moles of lithium hydroxide (LiOH).
Concentrated. There are many more moles of the base than the solvent.

- b) For every 100 moles of a solvent there are 5 moles of nitric acid (HNO_3).
 Dilute. There are many more moles of the solvent than the acid.
2. 95% of an unknown acid donates protons when the acid is added to water. The pH of the final solution is 6,5.
- Is the acid a strong or a weak acid? Give a reason for your answer.
 The acid is a strong acid. 95% of the acid ionises in the water. This means that it almost completely forms ions in solution and is therefore a strong acid.
 - Is a solution with a pH of 6,5 strongly or weakly acidic?
 The solution is weakly acidic.
 - Is the solution concentrated or dilute? Give a reason for your answer.
 The solution is dilute. Although this is a strong acid the solution is only weakly acidic. This means that there must be a very small number of moles of the acid in the total volume of the solution.
3. Calculate the concentration for of the following solutions.
- 27 g of sodium bicarbonate (NaHCO_3) added to 22,6 cm³ of water.
 You have the volume (V) and the mass (m). You need the number of moles (n) and the molar mass (M).
 $M(\text{NaHCO}_3) = 23 + 1,01 + 12 + (3 \times 16) = 84,01 \text{ g.mol}^{-1}$.
 $n(\text{NaHCO}_3) = \frac{m \text{ (g)}}{M \text{ (g.mol}^{-1})} = \frac{27 \text{ g}}{84,01 \text{ g.mol}^{-1}} = 0,32 \text{ mol}$
 $V = 22,6 \text{ cm}^3 \times \frac{0,001 \text{ dm}^3}{1 \text{ cm}^3} = 0,0226 \text{ dm}^3$
 $C(\text{NaHCO}_3) = \frac{n \text{ (mol)}}{V \text{ (dm}^3)} = \frac{0,32 \text{ mol}}{0,0226 \text{ dm}^3} = 14,16 \text{ mol.dm}^{-3}$
 - 0,893 mol of phosphoric acid (H_3PO_4) added to 4,79 dm³ of a solvent.
 You have the volume (V) and number of moles (n). You can calculate the concentration.
 $C(\text{H}_3\text{PO}_4) = \frac{n \text{ (mol)}}{V \text{ (dm}^3)} = \frac{0,893 \text{ mol}}{4,79 \text{ dm}^3} = 0,186 \text{ mol.dm}^{-3}$
 - 32,8 mg of hydrochloric acid (HCl) added to 12,76 cm³ of water.
 You have the volume (V) and the mass (m). You need the number of moles (n) and the molar mass (M).
 $M(\text{HCl}) = 1,01 + 35,45 = 36,46 \text{ g.mol}^{-1}$.
 $m(\text{HCl}) = 32,8 \text{ mg} \times \frac{0,001 \text{ g}}{1 \text{ mg}} = 0,0328 \text{ g}$
 $n(\text{HCl}) = \frac{m \text{ (g)}}{M \text{ (g.mol}^{-1})} = \frac{0,0328 \text{ g}}{36,46 \text{ g.mol}^{-1}} = 9,0 \times 10^{-4} \text{ mol}$
 $V = 12,76 \text{ cm}^3 \times \frac{0,001 \text{ dm}^3}{1 \text{ cm}^3} = 0,01276 \text{ dm}^3$
 $C(\text{HCl}) = \frac{n \text{ (mol)}}{V \text{ (dm}^3)} = \frac{9,0 \times 10^{-4} \text{ mol}}{0,01276 \text{ dm}^3} = 0,07 \text{ mol.dm}^{-3}$
 - 1,12 dm³ of a 6,54 mol.dm⁻³ concentration solution of ammonia (NH_3) added to 0,50 dm³ of water.
 You have the volume (V) and original concentration of the ammonia solution, you need number of moles (n) in that original solution.
 $C = \frac{n \text{ (mol)}}{V \text{ (dm}^3)}$. Therefore $n = C \times V$
 $n(\text{original solution of NH}_3) = 6,54 \text{ mol.dm}^{-3} \times 1,12 \text{ dm}^3 = 7,32 \text{ mol}$.
 The final volume used to calculate the concentration must be the volume of the water plus the volume of ammonia added.
 $V(\text{total}) = 0,50 \text{ dm}^3 + 1,12 \text{ dm}^3 = 1,62 \text{ dm}^3$
 $C(\text{final solution of NH}_3) = \frac{n \text{ (mol)}}{V \text{ (dm}^3)} = \frac{7,32 \text{ mol}}{1,62 \text{ dm}^3} = 4,52 \text{ mol.dm}^{-3}$
4. More questions. Sign in at Everything Science online and click 'Practise Science'.

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- 1a. 27WB 1b. 27WC 2. 27WD 3a. 27WF 3b. 27WG 3c. 27WH
3d. 27WJ



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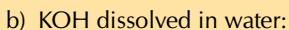
K_a and K_b

Exercise 9 – 3: Acids and bases

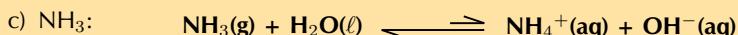
1. State whether the acids and bases in the following balanced chemical equations are strong or weak and give a reason for your answer.



Weak acid. The equilibrium lies far to the left meaning that only a small percentage of the hydrofluoric acid molecules donate a proton, ionisation is not favoured.



Strong base. The equilibrium lies far to the right meaning that a large percentage of the potassium hydroxide molecules dissociate in water, dissociation is favoured.



Weak base. The equilibrium lies far to the left meaning that only a small percentage of the ammonia molecules accept a proton, ionisation is not favoured.



Strong acid. The equilibrium lies far to the right meaning that a large percentage of the hydrochloric acid molecules donate a proton, ionisation is favoured.

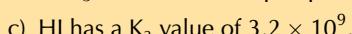
2. State whether the acids and bases in the following questions are strong or weak and give a reason for your answer.



Weak acid. K_a is very small, meaning that only a small percentage of the ethanoic acid (CH₃COOH) molecules donate a proton, ionisation is not favoured.



Weak base. K_b is very small, meaning that only a small percentage of the ammonia (NH₃) molecules accept a proton, ionisation is not favoured.



Strong acid. K_a is very large, meaning that almost all of the hydroiodic acid (HI) molecules donate a proton, ionisation is favoured.

3. More questions. Sign in at Everything Science online and click 'Practise Science'.

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- 1a. 27WK 1b. 27WM 1c. 27WN 1d. 27WP 2a. 27WQ 2b. 27WR
2c. 27WS



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9.2 Acid-base reactions

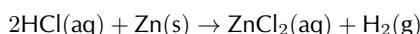
Neutralisation reactions

The *temperature changes in neutralisation reactions* experiment can be used for an informal assessment. It will help determine if the learners understand what happens in a neutralisation reaction. Learners are working with a strong acid and a strong base in this reaction. Concentrated, strong acids and bases can cause serious burns. Please remind the learners to be careful and wear the appropriate safety equipment when handling all chemicals, especially concentrated acids and bases. The safety equipment includes gloves, safety glasses, and protective clothing.

The following is an example of how the learners **acids and metals compounds report** could look:

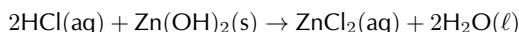
- **Acid + metal → salt + hydrogen**

A dilute acid is added to a pure metal to form a salt and hydrogen gas. The salt is formed by the metal cation and the anion from the acid. In this reaction the metal is acting as a base. For example:



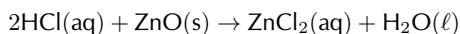
- **Acid + metal hydroxide → salt + water**

A dilute acid is added to a metal hydroxide to form a salt and water. The salt is formed by the metal cation and the anion from the acid. In this reaction the metal hydroxide is acting as a base. For example:



- **Acid + metal oxide → salt + water**

A dilute acid is added to a metal oxide to form a salt and water. The salt is formed by the metal cation and the anion from the acid. In this reaction the metal oxide is acting as a base. For example:



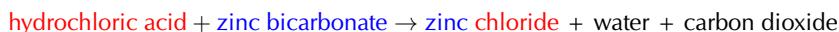
- **Acid + metal carbonate → salt + water + carbon dioxide**

A dilute acid is added to a metal carbonate to form a salt, water and carbon dioxide gas. The salt is formed by the metal cation and the anion from the acid. In this reaction the metal carbonate is acting as a base. For example:



- **Acid + metal hydrogen carbonate → salt + water + carbon dioxide**

A dilute acid is added to a metal hydrogen carbonate to form a salt, water and carbon dioxide gas. The salt is formed by the metal cation and the anion from the acid. In this reaction the metal hydrogen carbonate is acting as a base. For example:



The following is an example of the sort of information on the hazards of an acid or base that learners should report on:

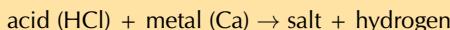
Hydrochloric acid

Hydrochloric acid is used industrially to clean rust from iron or steel as well as in the refining of ores. If released into the environment hydrochloric acid will lower the pH of any water it pollutes. This change in pH can seriously affect the growth of plants and damage ecosystems.

Exercise 9 – 4: Reactions of acids and bases

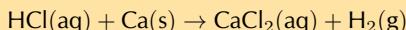
1. Write balanced equations for these acid and metal reactions:

a) Hydrochloric acid and calcium

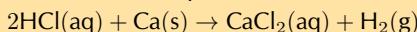


Anion (from acid) is Cl^- , cation (from metal) is Ca^{2+} .

Therefore salt is CaCl_2 .



To balance this equation there must be two HCl molecules.

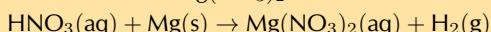


b) Nitric acid and magnesium

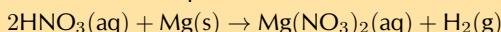


Anion (from acid) is NO_3^- , cation (from metal) is Mg^{2+} .

Therefore salt is $\text{Mg(NO}_3)_2$.

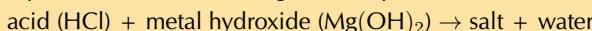


To balance this equation there must be two HNO_3 molecules.



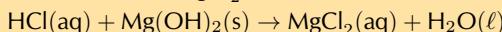
2. Write balanced equations for these acid and metal hydroxide reactions:

a) Hydrochloric acid and magnesium hydroxide

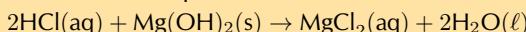


Anion (from acid) is Cl^- , cation (from metal) is Mg^{2+} .

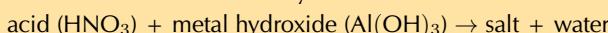
Therefore salt is MgCl_2 .



To balance this equation there must be two HCl molecules and two H_2O molecules.

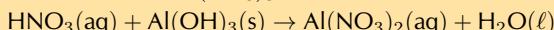


b) Nitric acid and aluminium hydroxide

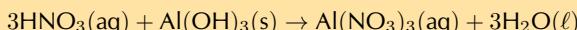


Anion (from acid) is NO_3^- , cation (from metal) is Al^{3+} .

Therefore salt is $\text{Al(NO}_3)_3$.



To balance this equation there must be three HNO_3 molecules and three H_2O molecules.



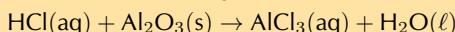
3. Write balanced equations for these acid and metal oxide reactions:

a) Hydrochloric acid and aluminium oxide



Anion (from acid) is Cl^- , cation (from metal) is Al^{3+} .

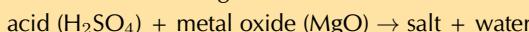
Therefore salt is AlCl_3 .



To balance this equation there must be six HCl molecules, two AlCl_3 molecules, and three H_2O molecules.



b) Sulfuric acid and magnesium oxide



Anion (from acid) is SO_4^{2-} , cation (from metal) is Mg^{2+} .

Therefore salt is MgSO_4 .



This equation is balanced.

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9.3 pH

pH calculations

Exercise 9 – 5: Calculating pH

- Calculate the pH of each of the following solutions:

(Tip: $[\text{H}_3\text{O}^+][\text{OH}^-] = 1 \times 10^{-14}$ can be used to determine $[\text{H}_3\text{O}^+]$)

- A KOH solution with a $0,2 \text{ mol}\cdot\text{dm}^{-3}$ concentration of OH^- .

Remember that $[\text{OH}^-][\text{H}_3\text{O}^+] = 1 \times 10^{-14}$.

$$\text{Therefore } [\text{H}_3\text{O}^+] = \frac{1 \times 10^{-14}}{[\text{OH}^-]}$$

$$[\text{H}_3\text{O}^+] = \frac{1 \times 10^{-14}}{0,2}$$

$$[\text{H}_3\text{O}^+] = 5 \times 10^{-14} \text{ mol}\cdot\text{dm}^{-3}$$

$$\text{pH} = -\log[\text{H}_3\text{O}^+]$$

$$\text{pH} = -\log(5 \times 10^{-14})$$

$$\text{pH} = 13.3$$

OR

$$\text{p}[\text{OH}^-] = -\log[0,2 \text{ mol}\cdot\text{dm}^{-3}]$$

$$\text{p}[\text{OH}^-] = 0.699$$

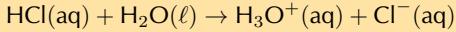
$$\text{pH} = 14 - \text{p}[\text{OH}^-]$$

$$\text{pH} = 14 - 0.699$$

$$\text{pH} = 13.3$$

- An aqueous solution with a $1,83 \times 10^{-7} \text{ mol}\cdot\text{dm}^{-3}$ concentration of HCl molecules at equilibrium ($K_a = 1,3 \times 10^6$)

To determine the concentration of H_3O^+ ions in solution we must first write the expression for K_a , and to do that we need the balanced equation:



$$K_a = \frac{[\text{H}_3\text{O}^+][\text{Cl}^-]}{[\text{HCl}]}$$

$$[\text{H}_3\text{O}^+] = \frac{K_a \times [\text{HCl}]}{[\text{Cl}^-]}$$

The concentration of H_3O^+ will be the same as the concentration of Cl^- , therefore we can say:

$$[\text{H}_3\text{O}^+]^2 = K_a \times [\text{HCl}] = 1,3 \times 10^6 \times 1,83 \times 10^{-7} = 0,24$$

$$[\text{H}_3\text{O}^+] = 0,49 \text{ mol}\cdot\text{dm}^{-3}$$

$$\text{pH} = -\log[\text{H}_3\text{O}^+]$$

$$\text{pH} = -\log(0,49)$$

$$\text{pH} = 0.31$$

- What is the concentration of H_3O^+ ions in a solution with a pH of 12?

$$\text{pH} = -\log[\text{H}^+] = -\log[\text{H}_3\text{O}^+]$$

$$\text{Therefore } \log[\text{H}_3\text{O}^+] = -\text{pH}$$

$$\log[\text{H}_3\text{O}^+] = -12$$

$$[\text{H}_3\text{O}^+] = 1 \times 10^{-12} \text{ mol}\cdot\text{dm}^{-3}$$

- In a typical sample of seawater the concentration of the hydronium (H_3O^+) ions is $1 \times 10^{-8} \text{ mol}\cdot\text{dm}^{-3}$, while the concentration of the hydroxide (OH^-) ions is $1 \times 10^{-6} \text{ mol}\cdot\text{dm}^{-3}$.

- Is the seawater acidic or basic?

The concentration of H_3O^+ is lower than that of OH^- . The seawater is therefore basic.

b) What is the pH of the seawater?

$$\text{pH} = -\log[\text{H}_3\text{O}^+]$$

$$\text{pH} = -\log(1 \times 10^{-8})$$

$$\text{pH} = 8$$

This confirms that the seawater is slightly basic

c) Give a possible explanation for the pH of the seawater.

Mineral salts are generally alkaline. There are lots of mineral salts dissolved in the ocean and this leads to alkaline (basic) seawater.

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Indicators

The indicators experiment looks at the change in colour of an indicator during an acid-base reaction. It is effectively a very rough titration experiment. Principles that can be applied to titrations, such as adding a small volume of acid, then swirling, can be applied here as well. It is important that the learners understand that the pH range that the indicator changes colour in is not always around 7.

Learners are working with a strong acid and a strong base in this reaction. Concentrated, strong acids and bases can cause serious burns. Please remind the learners to be careful and wear the appropriate safety equipment when handling all chemicals, especially concentrated acids and bases. The safety equipment includes gloves, safety glasses, and protective clothing.

9.4 Titrations

Titration calculations

The formal assessment requires that the learners prepare a standard solution of sodium hydroxide. It is important that the learners understand that in order for the concentration of a standard solution to be accurately known:

- The mass must be precisely measured.
- The beakers must be rinsed with water (and the rinsings added to the volumetric flask) so that no residue of the sodium hydroxide is left behind.
- The sides of the volumetric flask must be washed with water for the same reason.
- It is important to have their eye level with the mark on the volumetric flask when filling to that mark so that the volume is precise.

Learners are working with a strong base in this reaction. Concentrated, strong bases can cause serious burns. Please remind the learners to be careful and wear the appropriate safety equipment when handling all chemicals, especially concentrated bases. The safety equipment includes gloves, safety glasses, and protective clothing.

A less accurate alternative to the titration of acetic acid with sodium hydroxide experiment is provided here (if titration equipment is not available).

Experiment: Titrations

Aim:

To determine the concentration of acetic acid (ethanoic acid) in a sample of vinegar.

Apparatus and materials:

- 4 conical flasks, plastic droppers, two measuring cylinders
- a white piece of paper or a white tile
- the standard NaOH solution prepared in the previous experiment, white vinegar, phenolphthalein

Method:

WARNING!

Concentrated acids and bases can cause serious burns. We suggest using gloves and safety glasses whenever you work with an acid or a base. Handle all chemicals with care.

1. Label a conical flask **1** and add 20 cm³ of the sodium hydroxide solution to the conical flask using a measuring cylinder.
2. Add a few drops of the phenolphthalein indicator to conical flask **1**.
3. Measure 10 cm³ vinegar in the second measuring cylinder.
4. Pour the 10 cm³ vinegar into conical flask **1**. Swirl the flask.
5. If there is no colour change measure 5 cm³ vinegar in the measuring cylinder and add this to conical flask **1**. Swirl the flask.
6. Repeat step 5 until the colour change remains after swirling. Calculate the volume of vinegar added. This is your *rough titration*.
7. Repeat steps 1 and 2 with a second conical flask (label it **2**).
8. Add a volume of vinegar **no more than** 5 cm³ less than your rough titration volume to conical flask **2**. This is your initial volume added.
9. Measure 10 cm³ of vinegar in the second measuring cylinder.
10. Use a dropper to transfer vinegar from the measuring cylinder to the conical flask. Swirl between each drop and be careful not to spill. If you get vinegar on the side of the conical flask, rinse with water.
11. When there is a permanent colour change after swirling, the end-point has been reached. Determine the volume added:
Total volume added = initial volume added + (10 cm³ - final volume in measuring cylinder)
12. Repeat steps 7 - 11, labelling the conical flasks **3** and **4**.

Continue with the rest of the experiment as laid out in the learners textbook:

Although this method will not be as accurate, it will give the learners an idea of what a titration is like.

Different concentrations of the standard solution may be used, and the calculations will have to be adjusted in that case.

It is possible to put the sodium hydroxide in the burette and the vinegar in the conical flask. This is likely to clog the burette though, so if you do this make sure to wash your burette thoroughly after use to avoid the stopcock being damaged. It may be necessary to drain a few cm³ of the vinegar to remove all air bubbles from the burette. In this case add more vinegar to the burette after removing the air bubbles so that the top of the vinegar is between the 0 cm³

and 1 cm³ marks.

Learners are working with a strong base in this reaction. Concentrated, strong bases can cause serious burns. Please remind the learners to be careful and wear the appropriate safety equipment when handling all chemicals, especially strong, concentrated bases. The safety equipment includes gloves, safety glasses, and protective clothing.

A less accurate alternative to the titration of sodium hydroxide with oxalic acid experiment is provided here (if titration equipment is not available).

Experiment: Titrations

Aim:

To determine the concentration of a sodium hydroxide solution of unknown concentration.

Apparatus and materials:

- one 250 cm³ volumetric flask, 4 conical flasks, two plastic droppers, two measuring cylinders, one beaker
- a weighing scale, a spatula, a clean piece of paper, a white sheet of paper or a white tile
- solid sodium hydroxide (NaOH), solid oxalic acid (H₂C₂O₄), phenolphthalein

Method:

WARNING!

Concentrated acids and bases can cause serious burns. We suggest using gloves and safety glasses whenever you work with an acid or a base. Handle all chemicals with care.

1. Prepare a standard solution using 11,00 g of oxalic acid in the 250 cm³ volumetric flask (remember to follow the method from the formal *preparation of a standard solution* experiment).
2. Label one of the beakers NaOH. Use a measuring cylinder to measure approximately 100 cm³ of water into the beaker. Add approximately 4 g of NaOH to the beaker and stir.
3. Label a conical flask 1 and transfer 20 cm³ of the sodium hydroxide to the conical flask.
4. Add a few drops of the phenolphthalein indicator to conical flask 1.
5. Measure 10 cm³ of the oxalic acid solution in the second measuring cylinder.
6. Pour the 10 cm³ oxalic acid solution into conical flask 1. Swirl the flask.
7. If there is no colour change measure 5 cm³ oxalic acid in the measuring cylinder and add this to conical flask 1. Swirl the flask.
8. Repeat step 7 until the colour change remains after swirling. Calculate the volume of oxalic acid solution added. This is your *rough titration*.
9. Repeat steps 3 and 4 with a second conical flask (label it 2).
10. Add a volume of oxalic acid **no more than** 5 cm³ less than your rough titration volume to conical flask 2. This is your initial volume added.
11. Measure 10 cm³ of oxalic acid in the second measuring cylinder.
12. Use a dropper to transfer oxalic acid from the measuring cylinder to the conical flask. Swirl between each drop and be careful not to spill. If you get oxalic acid on the side of the conical flask, rinse with water.

- When there is a permanent colour change after swirling, the end-point has been reached.
Determine the volume added:
Total volume added = initial volume added + (10 cm³ - final volume in measuring cylinder)
- Repeat steps 9 - 13, labelling the conical flasks 3 and 4.

Continue with the rest of the experiment as laid out in the learners textbook:

Although this method will not be as accurate, it will give the learners an idea of what a titration is like.

Different concentrations of the standard solution may be used, and the calculations will have to be adjusted in that case.

It is possible to put the sodium hydroxide in the burette and the oxalic acid in the conical flask. This is likely to clog the burette though, so if you do this make sure to wash your burette thoroughly after use to avoid the stopcock being damaged. It may be necessary to drain a few cm³ of the oxalic acid to remove all air bubbles from the burette. In this case add more oxalic acid solution to the burette after removing the air bubbles so that the top of the solution is between the 0 cm³ and 1 cm³ marks.

Learners are working with a strong base in this reaction. Concentrated, strong bases can cause serious burns. Please remind the learners to be careful and wear the appropriate safety equipment when handling all chemicals, especially strong, concentrated bases. The safety equipment includes gloves, safety glasses, and protective clothing.

Exercise 9 – 6: Acids and bases

- A learner is asked to prepare a *standard solution* of the weak acid, oxalic acid (H₂C₂O₄), for use in a titration. The volume of the solution must be 500 cm³ and the concentration must be 0,2 mol·dm⁻³.

- Calculate the mass of oxalic acid which the learner must dissolve to make up the required standard solution.

We need the mass of oxalic acid. However, we don't know the number of moles yet.

$$V = 500 \text{ cm}^3 \times \frac{0,001 \text{ dm}^3}{1 \text{ cm}^3} = 0,5 \text{ dm}^3$$

$$C = \frac{n}{V}, \text{ therefore } n = C \times V$$

$$n = 0,2 \text{ mol} \cdot \text{dm}^{-3} \times 0,5 \text{ dm}^3 = 0,1 \text{ mol}$$

$$M(H_2C_2O_4) = (2 \times 1,01 + 2 \times 12,0 + 4 \times 16,0) \text{ g} \cdot \text{mol}^{-1} = 90,02 \text{ g} \cdot \text{mol}^{-1}$$

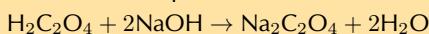
$$n = \frac{m}{M}, \text{ therefore } m = n \times M$$

$$m = 0,1 \text{ mol} \times 90,02 \text{ g} \cdot \text{mol}^{-1} = 9,00 \text{ g}$$

- The learner titrates this 0,2 mol·dm⁻³ oxalic acid solution against a solution of sodium hydroxide. He finds that 40 cm³ of the oxalic acid solution completely neutralises 35 cm³ of the sodium hydroxide solution.

Calculate the concentration of the sodium hydroxide solution.

The balanced equations is:



The number of moles of oxalic acid used is the number of moles in 40 cm³ of the standard solution:

$$V = 40 \text{ cm}^3 \times \frac{0,001 \text{ dm}^3}{1 \text{ cm}^3} = 0,04 \text{ dm}^3$$

$$n = C \times V = 0,2 \text{ mol} \cdot \text{dm}^{-3} \times 0,04 \text{ dm}^3 = 0,008 \text{ mol}$$

The molar ratio of oxalic acid to sodium hydroxide is 1:2. For every one mole of oxalic acid there are two moles of sodium hydroxide.

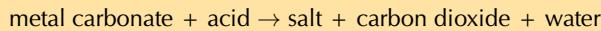
$$n(\text{NaOH}) = 2 \times 0,008 \text{ mol} = 0,016 \text{ mol}$$

$$V(\text{NaOH}) = 35 \text{ cm}^3 \times \frac{0,001 \text{ dm}^3}{1 \text{ cm}^3} = 0,035 \text{ dm}^3$$

$$C(\text{NaOH}) = \frac{n}{V} = \frac{0,016 \text{ mol}}{0,035 \text{ dm}^3} = 0,46 \text{ mol} \cdot \text{dm}^{-3}$$

2. 25,0 cm³ of a 0,1 mol·dm⁻³ standard solution of sodium carbonate was used to neutralise 35,0 cm³ of a solution of hydrochloric acid.

a) Write a balanced chemical equation for the reaction.



The cation will be from the metal (Na^+), the anion will be from the acid (Cl^-). Therefore the salt will be NaCl.



b) Calculate the concentration of the acid.

(DoE Grade 11 Exemplar, 2007)

$$C = \frac{n}{V} \text{ therefore } n = C \times V$$

$$V(\text{Na}_2\text{CO}_3) = 25,0 \text{ cm}^3 \times \frac{0,001 \text{ dm}^3}{1 \text{ cm}^3} = 0,0250 \text{ dm}^3$$

$$n(\text{Na}_2\text{CO}_3) = C \times V = 0,1 \text{ mol} \cdot \text{dm}^{-3} \times 0,0250 \text{ dm}^3 = 0,0025 \text{ mol}$$

From the balanced equation for every 1 mol of Na_2CO_3 there are 2 mol HCl.

$$n(\text{HCl}) = 2 \times 0,0025 \text{ mol} = 0,005 \text{ mol}$$

$$V(\text{HCl}) = 35,0 \text{ dm}^3 \times \frac{0,001 \text{ dm}^3}{1 \text{ cm}^3} = 0,0350 \text{ dm}^3$$

$$C(\text{HCl}) = \frac{n}{V} = \frac{0,005 \text{ mol}}{0,0350 \text{ dm}^3} = 0,143 \text{ mol} \cdot \text{dm}^{-3}$$

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9.5 Applications of acids and bases

Although they are common household items, drain cleaners and caustic soda are extremely corrosive. Learners are working with a strong base and concentrated, strong bases can cause serious burns. Please remind the learners to be careful and wear the appropriate safety equipment when handling all chemicals, especially concentrated bases. The safety equipment includes gloves, safety glasses, and protective clothing.

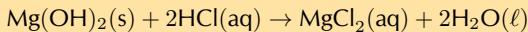
9.6 Chapter summary

Exercise 9 – 7:

1. The stomach secretes gastric juice, which contains hydrochloric acid. The gastric juice helps with digestion. Sometimes there is an overproduction of acid, leading to heartburn or indigestion. Antacids, such as milk of magnesia, can be taken to neutralise the excess acid. Milk of magnesia is only slightly soluble in water and has the chemical formula $\text{Mg}(\text{OH})_2$.
 - a) Write a balanced chemical equation to show how the antacid reacts with the acid.
base + acid → salt + water

The cation (from the base) is Mg^{2+} . The anion (from the acid) is Cl^- .

Therefore the salt is $MgCl_2$



- b) The instructions on the bottle recommend that children under the age of 12 years take one teaspoon of milk of magnesia, whereas adults can take two teaspoons of the antacid. Briefly explain why the dosages are different.

Adults have a bigger mass and generally produce more acid than children. Adults will therefore need more antacid to neutralise the excess acid. If children were to take the same dosage as adults they would have excess base in their stomach.

- c) Why is it not advisable to take an overdose of the antacid? Refer to the hydrochloric acid concentration in the stomach in your answer.

(DoE Grade 11 Exemplar, 2007)

A low acid concentration (pH too high) in the stomach may slow down food digestion or may cause further stomach upset.

2. The compound $NaHCO_3$ is commonly known as baking soda. A recipe requires 1,6 g of baking soda, mixed with other ingredients, to bake a cake.

- a) Calculate the number of moles of $NaHCO_3$ used to bake the cake.

$$M(NaHCO_3) = 23,0 + 1,01 + 12,0 + (3 \times 16,0) = 84,01 \text{ g.mol}^{-1}$$

$$n(NaHCO_3) = \frac{m}{M} = \frac{1,6 \text{ g}}{84,01 \text{ g.mol}^{-1}} = 0,019 \text{ mol}$$

- b) How many atoms of oxygen are there in 1,6 g of baking soda?

$$N_A (\text{Avogadro's number}) = 6,022 \times 10^{23} \text{ atoms.mol}^{-1}$$

$$\text{Number of atoms} = n \times N_A = 0,019 \text{ mol} \times 6,022 \times 10^{23} \text{ atoms.mol}^{-1}$$

$$\text{Number of atoms} = 1,14 \times 10^{22} \text{ atoms.}$$

- c) During the baking process, baking soda reacts with an acid (e.g. acetic acid in vinegar) to produce carbon dioxide and water, as shown by the reaction equation below:

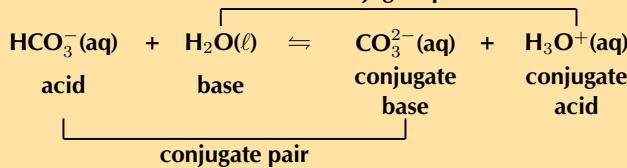
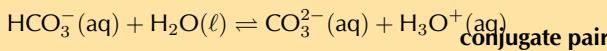


Use the above equation to explain why the cake rises during this baking process.

(DoE Grade 11 Paper 2, 2007)

The carbon dioxide gas that is formed during the reaction forms bubbles in the cake mixture causing it to rise along with the expanding volume of the gas bubbles.

3. Label the acid-base conjugate pairs in the following equation:



4. A certain antacid tablet contains 22,0 g of baking soda ($NaHCO_3$). It is used to neutralise the excess hydrochloric acid in the stomach. The balanced equation for the reaction is:



The hydrochloric acid in the stomach has a concentration of 1,0 mol. dm^{-3} . Calculate the volume of the hydrochloric acid that can be neutralised by the antacid tablet.

(DoE Grade 11 Paper 2, 2007)

$$M(NaHCO_3) = 23,0 + 1,01 + 12,0 + (3 \times 16,0) = 84,01 \text{ g.mol}^{-1}$$

$$n(NaHCO_3) = \frac{m}{M}$$

$$n = \frac{22,0 \text{ g}}{84,01 \text{ g.mol}^{-1}} = 0,26 \text{ mol}$$

From the balanced equation we see that the molar ratio of $NaHCO_3$ to HCl is 1:1.

$$\text{Therefore, } n(HCl) = n(NaHCO_3) = 0,26 \text{ mol}$$

$$C = \frac{n}{V} \text{ therefore } V = \frac{n}{C}$$

$$V(HCl) = \frac{0,26 \text{ mol}}{1,0 \text{ mol.dm}^{-3}} = 0,26 \text{ dm}^3$$

5. A learner finds some sulfuric acid solution in a bottle labelled 'dilute sulfuric acid'. He wants to determine the concentration of the sulfuric acid solution. To do this, he decides to titrate the sulfuric acid against a standard potassium hydroxide (KOH) solution.

a) What is a standard solution?

A standard solution is a solution that contains a precisely known concentration of a substance. This substance can then be used in titrations.

b) Calculate the mass of KOH which he must use to make 300 cm^3 of a $0,2 \text{ mol.dm}^{-3}$ KOH solution.

$$V(KOH) = 300 \text{ cm}^3 \times \frac{0,001 \text{ dm}^3}{1 \text{ cm}^3} = 0,3 \text{ dm}^3$$

$$C = \frac{n}{V}, \text{ therefore } n = C \times V$$

$$n(KOH) = 0,2 \text{ mol.dm}^{-3} \times 0,3 \text{ dm}^3 = 0,06 \text{ mol}$$

$$M(KOH) = (39,1 + 16,0 + 1,01) \text{ g.mol}^{-1} = 56,11 \text{ g.mol}^{-1}$$

$$n = \frac{m}{M}, \text{ therefore } m = n \times M$$

$$m(KOH) = 0,06 \text{ mol} \times 56,11 \text{ g.mol}^{-1} = 3,37 \text{ g}$$

c) Calculate the pH of the $0,2 \text{ mol.dm}^{-3}$ KOH solution (assume standard temperature).

KOH is a very strong base and will completely dissociate in water. Therefore the concentration of OH^- ions is the same as the concentration of the solution.

pH is defined as: $\text{pH} = -\log[\text{H}^+]$

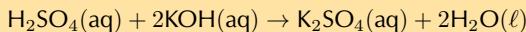
However, we can also define pOH in a similar way: $\text{pOH} = -\log[\text{OH}^-]$

The relationship between the two is: $14 = \text{pH} + \text{pOH}$, therefore $\text{pH} = 14 - \text{pOH}$

$$\text{pH} = 14 - (-\log[\text{OH}^-]) = 14 - (-\log[0,2]) = 14 - 0,7 = 13,3$$

d) Write a balanced chemical equation for the reaction between H_2SO_4 and KOH.

Sulfuric acid is a strong acid and potassium hydroxide is a strong base, therefore the equation is:



e) During the titration the learner finds that 15 cm^3 of the KOH solution neutralises 20 cm^3 of the H_2SO_4 solution. Calculate the concentration of the H_2SO_4 solution. (IEB Paper 2, 2003)

$$V(KOH) = 15 \text{ cm}^3 \times \frac{0,001 \text{ dm}^3}{1 \text{ cm}^3} = 0,015 \text{ dm}^3$$

The number of moles of KOH used to neutralise the H_2SO_4 is:

$$n(KOH) = C \times V = 0,2 \text{ mol.dm}^{-3} \times 0,015 \text{ dm}^3 = 0,003 \text{ mol}$$

From the balanced equation we see that the mole ratio of H_2SO_4 to KOH is 1:2. There is one mole of sulfuric acid for every two moles of potassium hydroxide.

$$n(\text{H}_2\text{SO}_4) = \frac{0,003 \text{ mol}}{2} = 0,0015 \text{ mol}$$

$$V(\text{H}_2\text{SO}_4) = 20 \text{ cm}^3 \times \frac{0,001 \text{ dm}^3}{1 \text{ cm}^3} = 0,020 \text{ dm}^3$$

Therefore, the concentration of the sulfuric acid is:

$$C(\text{H}_2\text{SO}_4) = \frac{n}{V} = \frac{0,0015 \text{ mol}}{0,020 \text{ dm}^3} = 0,075 \text{ mol.dm}^{-3}$$

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Electric circuits

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10.1 Introduction

Series and parallel networks of resistors:

- Understanding of Ohm's Law.
- The meaning of conservation of charge and energy for different types of circuits.
- Calculations done using series and parallel circuits.
- Solve problems involving current, voltage and resistance for circuits.

Batteries and internal resistance:

- State that a real battery has internal resistance.
- Definition of a load.
- Do experiments of finding the internal resistance of a battery.
- Do calculations by using circuits with batteries with internal resistance.

Evaluating internal resistance in circuits:

- Solve circuit problems using batteries with internal resistance with series, parallel and series-parallel circuits.

Extension: Wheatstone Bridge:

- Definition of a Wheatstone Bridge.
- Solve problems concerning the Wheatstone Bridge.

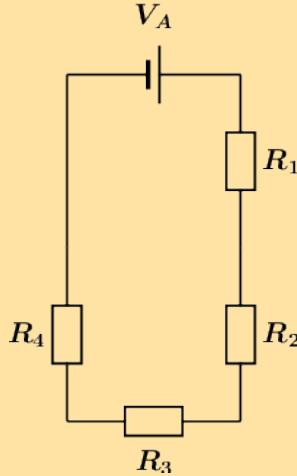
Key Mathematics Concepts

- Units and unit conversions — Physical Sciences, Grade 10, Science skills
- Circuit components — Physical Sciences, Grade 10, Electric circuits
- Ohm's law — Physical Sciences, Grade 11, Electric circuits
- Series and parallel components — Physical Sciences, Grade 11, Electric circuits
- Equations — Mathematics, Grade 10, Equations and inequalities

10.2 Series and parallel resistor networks (Revision)

Exercise 10 – 1: Series and parallel networks

1. The diagram shows an electric circuit consisting of a battery and four resistors.



The **potential difference** (voltage) over the battery is $V_A = 2,8 \text{ V}$

The resistors are rated as follows:

- $R_1 = 7,2 \Omega$
- $R_2 = 4,3 \Omega$
- $R_3 = 7,5 \Omega$
- $R_4 = 4,1 \Omega$

Assume that positive charge is flowing in the circuit (conventional current).

Using the concepts of **Ohm's law**, and **electric circuits**, determine the following:

- a) What type of circuit is shown in the diagram?

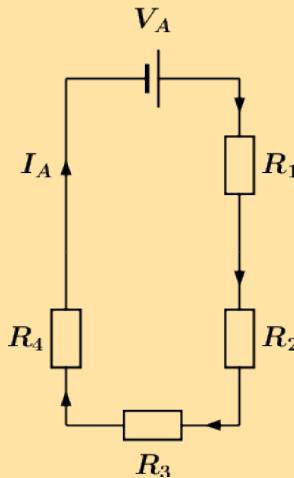
We need to determine whether the circuit is a series, parallel, or combination type of circuit. We do this by looking at how current flows through a circuit.

Recall that current is the movement of electric charge from a higher potential to a lower potential.

We assume that the flowing charge is positive (conventional current). This means that the charges start at the positive terminal of our power source (battery). Here the charges have lots of electrical potential energy.

The charges then move towards the negative terminal through the path that is created by the components and wires of the circuit. During this process, the electrical potential energy is converted into thermal energy by the resistors. Therefore, the charges have less electrical potential energy when they reach the negative terminal of the power source (battery).

The flow of current is indicated by the arrows in the diagram below:



From the diagram it is clear that there is only one path for the current to flow, since the circuit does not split into two or more paths. This means that the current flows through all the components, one after the other (in series). We will label this current I_A .

The circuit shown in the diagram is a **series** circuit.

0

b) What is the **total equivalent resistance** R_{eq} of the circuit?

- round your answer to 1 digit after the decimal comma
- use the values for any physical constants you might need, as listed here: <http://www.everythingscience.co.za/physical-constants>

We know that the circuit in the diagram is a series type circuit.

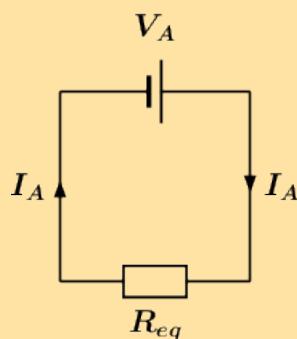
Recall that in a series circuit the equivalent resistance can be calculated by summing the resistance values of the individual resistors:

$$R_{eq,S} = R_1 + R_2 + R_3 + \dots \quad (1)$$

We can rewrite (1) for the circuit in question as:

$$R_{eq} = R_1 + R_2 + R_3 + R_4 \quad (2)$$

We can represent this by drawing an equivalent circuit:



We are given the following information:

- the resistance of $R_1 = 7,2 \Omega$
- the resistance of $R_2 = 4,3 \Omega$
- the resistance of $R_3 = 7,5 \Omega$
- the resistance of $R_4 = 4,1 \Omega$

Substituting the above values in (2), we get:

$$\begin{aligned}
 R_{eq} &= R_1 + R_2 + R_3 + R_4 \\
 &= 7,2 + 4,3 + 7,5 + 4,1 \\
 &= 23,1 \Omega
 \end{aligned}$$

Therefore, the total equivalent resistance in the circuit, or $R_{eq} = 23,1 \Omega$

23.1

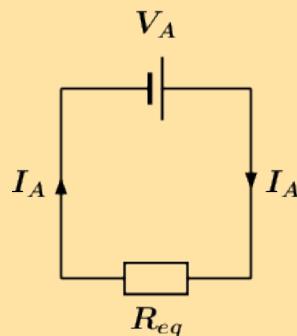
- c) What is the potential difference (voltage) across R_1 , or V_1 ?

- round your answer to 3 digits after the decimal comma
- use the values for any physical constants you might need, as listed here: <http://www.everythingscience.co.za/physical-constants>

Potential difference, or voltage is a way to describe the difference in electrical potential energy across a component in a circuit. Remember that a resistor converts electrical potential energy into thermal energy, so the electrical potential is higher on the "in" side compared to the "out" side of a resistor.

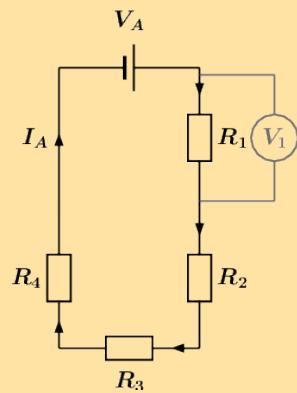
Ohm's law describes the relationship between the total current I through an ohmic conductor, its resistance R , and the potential difference V across it:

$$I = \frac{V}{R} \quad (3)$$



For the equivalent circuit, we can rewrite (3) as:

$$I_A = \frac{V_A}{R_{eq}} \quad (4)$$



We are asked to calculate the potential difference V_1 over R_1 , as shown in the circuit diagram above, so we use Ohm's law and rewrite (3) to get:

$$V_1 = I_1 R_1 \quad (5)$$

Since the circuit in question is a series circuit, we know that the current I_1 flowing through R_1 , is the same as the current I_A . This is represented as:

$$I_1 = I_A \quad (6)$$

Substituting (6) into (5) we get:

$$V_1 = I_A R_1 \quad (7)$$

Substituting (4) into (7) we get:

$$V_1 = I_A R_1 = \left(\frac{V_A}{R_{eq}} \right) R_1 = \frac{V_A R_1}{R_{eq}} \quad (8)$$

Recall from **Question 2**:

$$R_{eq} = R_1 + R_2 + R_3 + R_4 \quad (2)$$

Substituting (2) into (8) we get:

$$V_1 = \frac{V_A R_1}{R_1 + R_2 + R_3 + R_4} \quad (9)$$

We are given the following information:

- the resistance of $R_1 = 7,2 \Omega$
- the resistance of $R_2 = 4,3 \Omega$
- the resistance of $R_3 = 7,5 \Omega$
- the resistance of $R_4 = 4,1 \Omega$
- the potential difference (voltage) over the battery $V_A = 2,8 \text{ V}$

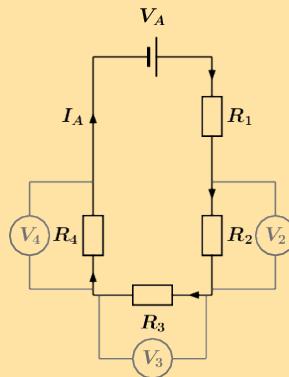
Substituting the above values in (9), we get:

$$\begin{aligned} V_1 &= \frac{V_A R_1}{R_1 + R_2 + R_3 + R_4} \\ &= \frac{(2,8)(7,2)}{7,2 + 4,3 + 7,5 + 4,1} \\ &= 0,87273\dots \quad (\text{calculated}) \\ &\approx 0,873 \text{ V} \quad (\text{rounded}) \end{aligned}$$

Therefore, the potential difference (voltage) across R_1 , or $V_1 \approx 0,873 \text{ V}$.
0.873

- d) What is the potential difference (voltage) across R_2 , R_3 , and R_4 , or V_2 , V_3 , and V_4 ?
- round your answers to 3 digits after the decimal comma
 - use the values for any physical constants you might need, as listed here:
<http://www.everythingscience.co.za/physical-constants>

We are asked to calculate the three remaining potential differences, V_2 , V_3 , and V_4 . This is shown in the diagram below:



We will use the same method to obtain three expression for V_2 , V_3 , and V_4 as was used in **Question 3** for V_1 . We get:

$$V_2 = \frac{V_A R_2}{R_1 + R_2 + R_3 + R_4} \quad (10)$$

$$V_3 = \frac{V_A R_3}{R_1 + R_2 + R_3 + R_4} \quad (11)$$

$$V_4 = \frac{V_A R_4}{R_1 + R_2 + R_3 + R_4} \quad (12)$$

We are given the following information:

- the resistance of $R_1 = 7,2 \Omega$
- the resistance of $R_2 = 4,3 \Omega$
- the resistance of $R_3 = 7,5 \Omega$
- the resistance of $R_4 = 4,1 \Omega$
- the potential difference (voltage) over the battery $V_A = 2,8 \text{ V}$

Substituting the above values in (10), (11), and (12) we get:

$$\begin{aligned} V_2 &= \frac{V_A R_2}{R_1 + R_2 + R_3 + R_4} \\ &= \frac{(2,8)(4,3)}{7,2 + 4,3 + 7,5 + 4,1} \\ &= 0,52121\dots \quad (\text{calculated}) \\ &\approx 0,521 \text{ V} \quad (\text{rounded}) \end{aligned}$$

$$\begin{aligned} V_3 &= \frac{V_A R_3}{R_1 + R_2 + R_3 + R_4} \\ &= \frac{(2,8)(7,5)}{7,2 + 4,3 + 7,5 + 4,1} \\ &= 0,90909\dots \quad (\text{calculated}) \\ &\approx 0,909 \text{ V} \quad (\text{rounded}) \end{aligned}$$

$$\begin{aligned} V_4 &= \frac{V_A R_4}{R_1 + R_2 + R_3 + R_4} \\ &= \frac{(2,8)(4,1)}{7,2 + 4,3 + 7,5 + 4,1} \\ &= 0,49697\dots \quad (\text{calculated}) \\ &\approx 0,497 \text{ V} \quad (\text{rounded}) \end{aligned}$$

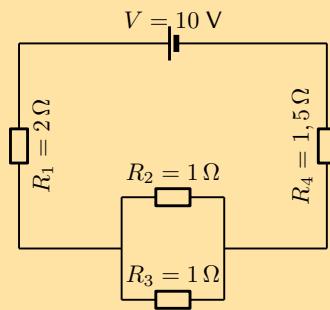
Therefore, the potential difference (voltage) across R_2 , or $V_2 \approx 0,521 \text{ V}$.

The potential difference (voltage) across R_3 , or $V_3 \approx 0,909 \text{ V}$.

The potential difference (voltage) across R_4 , or $V_4 \approx 0,497 \text{ V}$.

0.521 0.909 0.497

2. For the following circuit, calculate:



- a) the current through the cell

To find the current we first need to find the equivalent resistance. We start by calculating the equivalent resistance of the parallel combination:

$$\begin{aligned}\frac{1}{R_p} &= \frac{1}{R_2} + \frac{1}{R_3} \\ &= \frac{1}{1} + \frac{1}{1} \\ &= 2 \\ R_p &= 0,5 \Omega\end{aligned}$$

Now we have a circuit with two resistors in series so we can calculate the equivalent resistance:

$$\begin{aligned}R_s &= R_1 + R_4 + R_p \\ &= 2 + 1,5 + 0,5 \\ &= 4 \Omega\end{aligned}$$

So the current through the cell is:

$$\begin{aligned}I &= \frac{V}{R} \\ &= \frac{10}{4} \\ &= 2,5 \text{ A}\end{aligned}$$

- b) the potential difference across R_4

The current through all the resistors is 2,5 A. (The current is the same through series combinations of resistors and we can consider the entire parallel set of resistors as one series resistor.)

Using this we can find the potential difference through R_4 :

$$\begin{aligned}V &= I \cdot R \\ &= (2,5)(1,5) \\ &= 3,75 \text{ V}\end{aligned}$$

- c) the current through R_2

The current through all the resistors is 2,5 A. (The current is the same through series combinations of resistors and we can consider the entire parallel set of resistors as one series resistor.)

Using this we can find the current through R_2 .

We first need to find the potential difference across the parallel combination:

$$\begin{aligned}V &= I \cdot R \\ &= (2,5)(0,5) \\ &= 1,25 \text{ V}\end{aligned}$$

Now we can find the current through R_2 using the fact that the potential difference is the same across each resistor in the parallel combination:

$$\begin{aligned}I &= \frac{V}{R} \\ &= \frac{1,25}{1} \\ &= 1,25 \text{ A}\end{aligned}$$

3. Calculate the equivalent resistance of:

- a) three $2\ \Omega$ resistors in series;
- b) two $4\ \Omega$ resistors in parallel;
- c) a $4\ \Omega$ resistor in series with a $8\ \Omega$ resistor;
- d) a $6\ \Omega$ resistor in series with two resistors ($4\ \Omega$ and $2\ \Omega$) in parallel.

- a) three $2\ \Omega$ resistors in series:

$$\begin{aligned}R_T &= R_1 + R_2 + R_3 \\&= (2) + (2) + (2) \\&= 6\ \Omega\end{aligned}$$

- b) two $4\ \Omega$ resistors in parallel:

$$\begin{aligned}\frac{1}{R_T} &= \frac{1}{R_1} + \frac{1}{R_2} \\ \frac{1}{R_T} &= \frac{1}{4} + \frac{1}{4} \\ \frac{1}{R_T} &= \frac{2}{4} \\ R_T &= \frac{4}{2} \\ R_T &= 2\ \Omega\end{aligned}$$

- c) a $4\ \Omega$ resistor in series with a $8\ \Omega$ resistor:

$$\begin{aligned}R_T &= R_1 + R_2 \\&= (4) + (8) \\&= 12\ \Omega\end{aligned}$$

- d) a $6\ \Omega$ resistor in series with two resistors ($4\ \Omega$ and $2\ \Omega$) in parallel:

First determine the equivalent resistance of the two resistors in parallel:

$$\begin{aligned}\frac{1}{R_P} &= \frac{1}{R_1} + \frac{1}{R_2} \\ \frac{1}{R_P} &= \frac{1}{4} + \frac{1}{2} \\ \frac{1}{R_P} &= \frac{3}{4} \\ R_P &= \frac{4}{3} \\ R_P &= 1,33\ \Omega\end{aligned}$$

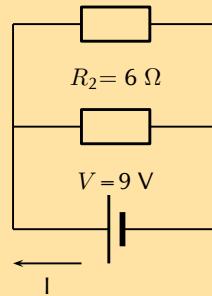
The parallel pair are in series with the third resistor, therefore the total resistance is:

$$\begin{aligned}R_T &= R_1 + R_P \\&= (6) + (1,33) \\&= 7,33\ \Omega\end{aligned}$$

$6\ \Omega$; $2\ \Omega$; $12\ \Omega$; $7,33\ \Omega$

4. Calculate the total current in this circuit if both resistors are ohmic.

$$R_1 = 3 \Omega$$



There are two resistors in parallel so we calculate the equivalent resistance of the combination:

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

$$\frac{1}{R_p} = \frac{1}{3} + \frac{1}{6} = \frac{2}{6} + \frac{1}{6} = \frac{3}{6}$$

$$R_p = 2\Omega$$

Now we can use Ohm's law to find the current:

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

$$I = \frac{9}{2} = 4,5A$$

5. Two ohmic resistors are connected in series. The resistance of the one resistor is 4 Ω. What is the resistance of the other resistor if a current of 0,5 A flows through the resistors when they are connected to a voltage supply of 6 V

We first use Ohm's law to find the total resistance:

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

$$R = \frac{6}{0,5} = 12\Omega$$

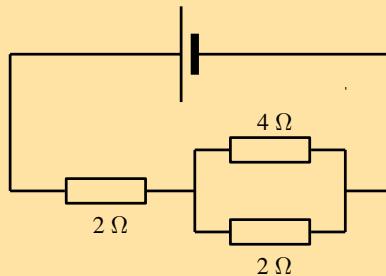
Now we can find the resistance of the other resistor:

$$R_s = R_1 + R_2$$

$$12 = 4 + R_2$$

$$R_2 = 8\Omega$$

6. Determine the equivalent resistance of the following circuits:



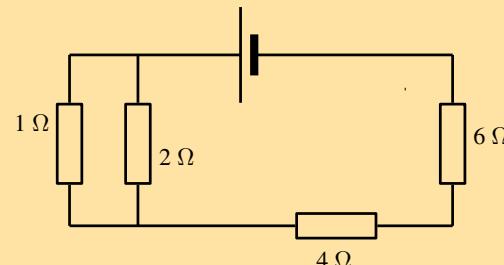
We first determine the resistance of the parallel component:

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{4} + \frac{1}{2} = \frac{3}{4}$$

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

Now we can calculate the total resistance:

$$R_s = R_3 + R_p = 2 + \frac{4}{3} = \frac{10}{3}\Omega$$



7.

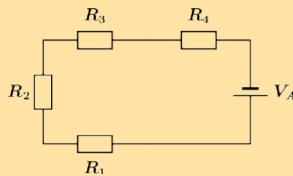
We first calculate the equivalent resistance of the parallel part:

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{2} + \frac{1}{1} = \frac{3}{2}$$

Now we calculate the total resistance:

$$R_s = R_p + R_3 + R_4 = \frac{3}{2} + 4 + 6 = 11,5\Omega$$

8. The diagram shows an electric circuit consisting of a battery and four resistors.



The **potential difference** (voltage) over the battery is $V_A = 1,2\text{ V}$

The the resistors are rated as follows:

- $R_1 = 4,2\Omega$
- $R_2 = 2,9\Omega$
- $R_3 = 3,8\Omega$
- $R_4 = 3,5\Omega$

Assume that positive charge is flowing in the circuit (conventional current).

Using the concepts of **Ohm's law**, and **electric circuits**, determine the following:

- a) What type of circuit is shown in the diagram?

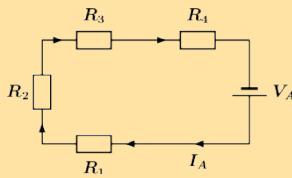
We need to determine whether the circuit is a series, parallel, or combination type of circuit. We do this by looking at how current flows through a circuit.

Recall that current is the movement of electric charge from a higher potential to a lower potential.

We assume that the flowing charge is positive (conventional current). This means that the charges start at the positive terminal of our power source (battery). Here the charges have lots of electrical potential energy.

The charges then move towards the negative terminal through the path that is created by the components and wires of the circuit. During this process, the electrical potential energy is converted into thermal energy by the resistors. Therefore, the charges have less electrical potential energy when they reach the negative terminal of the power source (battery).

The flow of current is indicated by the arrows in the diagram below:



From the diagram it is clear that there is only one path for the current to flow, since the circuit does not split into two or more paths. This means that the current flows through all the components, one after the other (in series). We will label this current I_A .

The circuit shown in the diagram is a **series** circuit.

0

b) What is the **total equivalent resistance** R_{eq} of the circuit?

- round your answer to 1 digit after the decimal comma
- use the values for any physical constants you might need, as listed here: <http://www.everythingscience.co.za/physical-constants>

We know that the circuit in the diagram is a series type circuit.

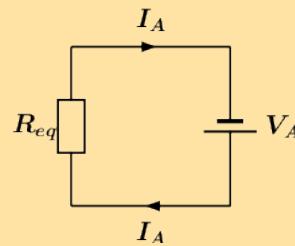
Recall that in a series circuit the equivalent resistance can be calculated by summing the resistance values of the individual resistors:

$$R_{eq,S} = R_1 + R_2 + R_3 + \dots \quad (1)$$

We can rewrite (1) for the circuit in question as:

$$R_{eq} = R_1 + R_2 + R_3 + R_4 \quad (2)$$

We can represent this by drawing an equivalent circuit:



We are given the following information:

- the resistance of $R_1 = 4,2 \Omega$
- the resistance of $R_2 = 2,9 \Omega$
- the resistance of $R_3 = 3,8 \Omega$
- the resistance of $R_4 = 3,5 \Omega$

Substituting the above values in (2), we get:

$$\begin{aligned} R_{eq} &= R_1 + R_2 + R_3 + R_4 \\ &= 4,2 + 2,9 + 3,8 + 3,5 \\ &= 14,4 \Omega \end{aligned}$$

Therefore, the total equivalent resistance in the circuit, or $R_{eq} = 14,4 \Omega$

14.4

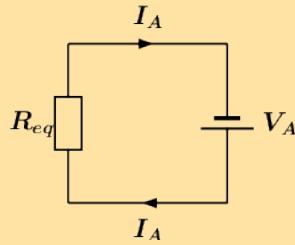
c) What is the potential difference (voltage) across R_1 , or V_1 ?

- round your answer to 3 digits after the decimal comma
- use the values for any physical constants you might need, as listed here: <http://www.everythingscience.co.za/physical-constants>

Potential difference, or voltage is a way to describe the difference in electrical potential energy across a component in a circuit. Remember that a resistor converts electrical potential energy into thermal energy, so the electrical potential is higher on the "in" side compared to the "out" side of a resistor.

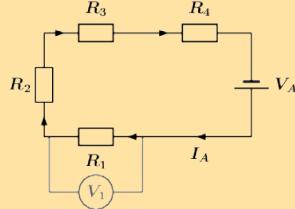
Ohm's law describes the relationship between the total current I through an ohmic conductor, its resistance R , and the potential difference V across it:

$$I = \frac{V}{R} \quad (3)$$



For the equivalent circuit, we can rewrite (3) as:

$$I_A = \frac{V_A}{R_{eq}} \quad (4)$$



We are asked to calculate the potential difference V_1 over R_1 , as shown in the circuit diagram above, so we use Ohm's law and rewrite (3) to get:

$$V_1 = I_1 R_1 \quad (5)$$

Since the circuit in question is a series circuit, we know that the current I_1 flowing through R_1 , is the same as the current I_A . This is represented as:

$$I_1 = I_A \quad (6)$$

Substituting (6) into (5) we get:

$$V_1 = I_A R_1 \quad (7)$$

Substituting (4) into (7) we get:

$$V_1 = I_A R_1 = \left(\frac{V_A}{R_{eq}} \right) R_1 = \frac{V_A R_1}{R_{eq}} \quad (8)$$

Recall from **Question 2**:

$$R_{eq} = R_1 + R_2 + R_3 + R_4 \quad (2)$$

Substituting (2) into (8) we get:

$$V_1 = \frac{V_A R_1}{R_1 + R_2 + R_3 + R_4} \quad (9)$$

We are given the following information:

- the resistance of $R_1 = 4,2 \Omega$
- the resistance of $R_2 = 2,9 \Omega$
- the resistance of $R_3 = 3,8 \Omega$
- the resistance of $R_4 = 3,5 \Omega$
- the potential difference (voltage) over the battery $V_A = 1,2 \text{ V}$

Substituting the above values in (9), we get:

$$\begin{aligned} V_1 &= \frac{V_A R_1}{R_1 + R_2 + R_3 + R_4} \\ &= \frac{(1,2)(4,2)}{4,2 + 2,9 + 3,8 + 3,5} \\ &= 0,35000\ldots \quad (\text{calculated}) \\ &\approx 0,350 \text{ V} \quad (\text{rounded}) \end{aligned}$$

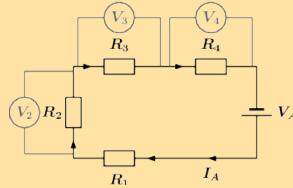
Therefore, the potential difference (voltage) across R_1 , or $V_1 \approx 0,350$ V.

0,350

- d) What is the potential difference (voltage) across R_2 , R_3 , and R_4 , or V_2 , V_3 , and V_4 ?

- round your answers to 3 digits after the decimal comma
- use the values for any physical constants you might need, as listed here: <http://www.everythingscience.co.za/physical-constants>

We are asked to calculate the three remaining potential differences, V_2 , V_3 , and V_4 . This is shown in the diagram below:



We will use the same method to obtain three expression for V_2 , V_3 , and V_4 as was used in **Question 3** for V_1 . We get:

$$V_2 = \frac{V_A R_2}{R_1 + R_2 + R_3 + R_4} \quad (10)$$

$$V_3 = \frac{V_A R_3}{R_1 + R_2 + R_3 + R_4} \quad (11)$$

$$V_4 = \frac{V_A R_4}{R_1 + R_2 + R_3 + R_4} \quad (12)$$

We are given the following information:

- the resistance of $R_1 = 4,2 \Omega$
- the resistance of $R_2 = 2,9 \Omega$
- the resistance of $R_3 = 3,8 \Omega$
- the resistance of $R_4 = 3,5 \Omega$
- the potential difference (voltage) over the battery $V_A = 1,2$ V

Substituting the above values in (10), (11), and (12) we get:

$$\begin{aligned} V_2 &= \frac{V_A R_2}{R_1 + R_2 + R_3 + R_4} \\ &= \frac{(1,2)(2,9)}{4,2 + 2,9 + 3,8 + 3,5} \\ &= 0,24167\dots \quad (\text{calculated}) \\ &\approx 0,242 \text{ V} \quad (\text{rounded}) \end{aligned}$$

$$\begin{aligned} V_3 &= \frac{V_A R_3}{R_1 + R_2 + R_3 + R_4} \\ &= \frac{(1,2)(3,8)}{4,2 + 2,9 + 3,8 + 3,5} \\ &= 0,31667\dots \quad (\text{calculated}) \\ &\approx 0,317 \text{ V} \quad (\text{rounded}) \end{aligned}$$

$$\begin{aligned} V_4 &= \frac{V_A R_4}{R_1 + R_2 + R_3 + R_4} \\ &= \frac{(1,2)(3,5)}{4,2 + 2,9 + 3,8 + 3,5} \\ &= 0,29167\dots \quad (\text{calculated}) \\ &\approx 0,292 \text{ V} \quad (\text{rounded}) \end{aligned}$$

Therefore, the potential difference (voltage) across R_2 , or $V_2 \approx 0,242$ V.

The potential difference (voltage) across R_3 , or $V_3 \approx 0,317$ V.

The potential difference (voltage) across R_4 , or $V_4 \approx 0,292$ V.

0.242 0.317 0.292

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1. 27XC 2. 27XD 3. 27XF 4. 27XG 5. 27XH 6. 27XJ
7. 27XK 8. 27XM



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10.3 Batteries and internal resistance

Exercise 10 – 2:

1. Describe what is meant by the *internal resistance* of a real battery.

Real batteries are made from materials which have resistance. This means that real batteries are not just sources of potential difference (voltage), but they also possess internal resistance.

So internal resistance is a measure of the resistance of the material that the battery is made of.

2. Explain why there is a difference between the emf and terminal voltage of a battery if the load (external resistance in the circuit) is comparable in size to the battery's internal resistance

The emf of a battery is essentially constant because it only depends on the chemical reaction (that converts chemical energy into electrical energy) going on inside the battery. Therefore, we can see that the voltage across the terminals of the battery is dependent on the current drawn by the load. The higher the current, the lower the voltage across the terminals, because the emf is constant. By the same reasoning, the voltage only equals the emf when the current is very small.

3. What is the internal resistance of a battery if its emf is 6 V and the potential difference across its terminals is 5,8 V when a current of 0,5 A flows in the circuit when it is connected across a load?

The voltage drop across the internal resistance is the difference between the emf and the terminal voltage when the battery is connected across a load. The internal resistance we treat as an ohmic resistor in series with a perfect battery. We know the voltage with and without a load and we know the current so we can use Ohm's law to determine the internal resistance:

$$\begin{aligned}V_r &= Ir \\(6) - (5,8) &= (0,5)r \\r &= \frac{0,2}{0,5} \\&= 0,4 \Omega\end{aligned}$$

0,4 Ω

4. A 12,0 V battery has an internal resistance of 7,0 Ω.

- What is the maximum current this battery could supply?
- What is the potential difference across its terminals when it is supplying a current of 150.0 mA?
- Draw a sketch graph to show how the terminal potential difference varies with the current supplied if the internal resistance remains constant. How could the internal resistance be obtained from the graph?

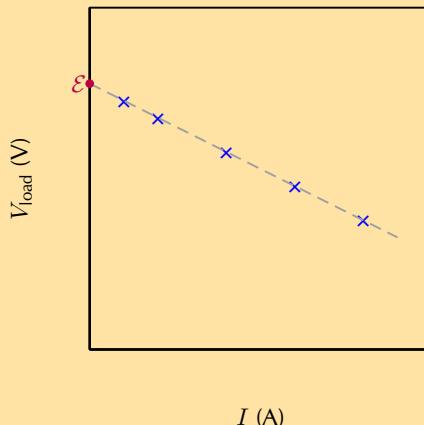
What is the maximum current this battery could supply?

$$\begin{aligned}I_{max} &= \frac{\mathcal{E}}{r} \\&= \frac{12,0}{7,0} \\&= 1,71428 \\&= 1,71 \text{ A}\end{aligned}$$

What is the potential difference across its terminals when it is supplying a current of 150.0 mA?

$$\begin{aligned}V &= \mathcal{E} - Ir \\&= (12,0) - (1,50 \times 10^{-3})(7,0) \\&= 10,95 \\&= 10,95 \text{ V}\end{aligned}$$

Draw a sketch graph to show how the terminal potential difference varies with the current supplied if the internal resistance remains constant. How could the internal resistance be obtained from the graph?



The slope of the graph is the internal resistance.

- In a hearing aid a battery supplies a current of 25.0 mA through a resistance of 400 Ω . When the volume is increased, the resistance is changed to 100 Ω and the current rises to 60 mA. What is the emf and internal resistance of the cell?

We have two unknowns but information for two different scenarios so we can solve simultaneously.

In the first case:

$$\begin{aligned}V &= \mathcal{E} - Ir \\(2,50 \times 10^{-2})(400) &= \mathcal{E} - (2,50 \times 10^{-2})r \\ \mathcal{E} &= (2,50 \times 10^{-2})(400) + (2,50 \times 10^{-2})r\end{aligned}$$

In the second case we will get:

$$V = \mathcal{E} - Ir$$

$$(6,0 \times 10^{-2})(100) = \mathcal{E} - (6,0 \times 10^{-2})r$$

$$\mathcal{E} = (6,0 \times 10^{-2})(100) + (6,0 \times 10^{-2})r$$

Subtracting the equation from the second case from the equation from the first case:

$$\mathcal{E} - \mathcal{E} = ((2,50 \times 10^{-2})(400) + (2,50 \times 10^{-2})r) - ((6,0 \times 10^{-2})(100) + (6,0 \times 10^{-2})r)$$

$$0 = 10 + 2,50 \times 10^{-2}r - 6 - 6,0 \times 10^{-2}r$$

$$-4 = -3,5 \times 10^{-2}r$$

$$r = \frac{4}{3,5 \times 10^{-2}}$$

$$= 1,1428 \times 10^{-2}$$

We substitute this back into one of the equations to get \mathcal{E} :

$$\mathcal{E} = (2,50 \times 10^{-2})(400) + (2,50 \times 10^{-2})r$$

$$\mathcal{E} = (2,50 \times 10^{-2})(400) + (2,50 \times 10^{-2})(1,1428 \times 10^{-2})$$

$$\mathcal{E} = 10$$

The emf is 10,0 V and the internal resistance is $1,1428 \times 10^{-2} \Omega$.

6. A battery is connected in series with a rheostat and an ammeter. When the resistance of the resistor is 10 Ω the current is 2,0 A. When the resistance is 5 Ω the current is 3,8 A. Find the emf and the internal resistance of the battery.

We have two unknowns but information for two different scenarios so we can solve simultaneously.

In the first case:

$$V = \mathcal{E} - Ir$$

$$(2)(10) = \mathcal{E} - (2)r$$

$$\mathcal{E} = (2)(10) + (2)r$$

In the second case we will get:

$$V = \mathcal{E} - Ir$$

$$(3,8)(5) = \mathcal{E} - (3,8)r$$

$$\mathcal{E} = (3,8)(5) + (3,8)r$$

Subtracting the equation from the second case from the equation from the first case:

$$\mathcal{E} - \mathcal{E} = ((2)(10) + (2)r) - ((3,8)(5) + (3,8)r)$$

$$0 = 20 + 2r - 19 - 3,8r$$

$$r = \frac{1}{1,8}$$

$$= 0,55555$$

We substitute this back into one of the equations to get \mathcal{E} :

$$\begin{aligned}\mathcal{E} &= (2)(10) + (2)r \\ \mathcal{E} &= (2)(10) + (2)(0,55555) \\ \mathcal{E} &= 21,11111\end{aligned}$$

The emf is 21,11 V and the internal resistance is 0,55 Ω .

7. When a cell is connected directly across a high resistance voltmeter the reading is 1,5 V. When the cell is shorted through a low resistance ammeter the current is 2,5 A. What is the emf and internal resistance of the cell?

In the case of the very high resistance voltmeter we need to assume that the current is zero. This means that the measurement is actually the emf and the potential difference across the internal resistance obeys Ohm's law, $V = Ir = (0)r = 0$.

In the case of a very low resistance ammeter, we can assume that the current that is flowing is the maximum current possible. We know the emf and the maximum current so we can find r :

$$\begin{aligned}I_c &= \frac{\mathcal{E}}{r} \\ (2,5) &= \frac{1,5}{r} \\ r &= \frac{1,5}{2,5} \\ r &= 0,6 \Omega\end{aligned}$$

The emf is 1,5 V and the internal resistance is 0,6 Ω .

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1. 27XN 2. 27XP 3. 27XQ 4. 27XR 5. 27XS 6. 27XT
7. 27XV



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10.6 Chapter summary

Exercise 10 – 3:

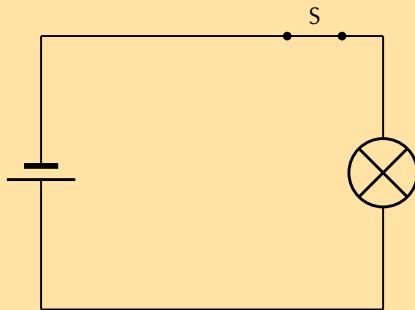
1. [IEB 2001/11 HG1] - **Emf**

- a) Explain the meaning of each of these two statements:
 - i. "The current through the battery is 50 mA."
 - ii. "The emf of the battery is 6 V."
- b) A battery tester measures the current supplied when the battery is connected to a resistor of 100 Ω . If the current is less than 50 mA, the battery is "flat" (it needs to be replaced). Calculate the maximum internal resistance of a 6 V battery that will pass the test.

$$\begin{aligned}
 V &= IR \\
 \mathcal{E} - Ir &= IR \\
 r &= \frac{IR - \mathcal{E}}{-I} \\
 &= \frac{(5,0 \times 10^{-2})(100) - (6)}{-(5,0 \times 10^{-2})} \\
 &= \frac{-1}{-0,05} \\
 &= 20 \Omega
 \end{aligned}$$

20 Ω

2. [IEB 2005/11 HG] The electric circuit of a torch consists of a cell, a switch and a small light bulb, as shown in the diagram below.



The electric torch is designed to use a D-type cell, but the only cell that is available for use is an AA-type cell. The specifications of these two types of cells are shown in the table below:

Cell	emf	Appliance for which it is designed	Current drawn from cell when connected to the appliance for which it is designed
D	1,5 V	torch	300 mA
AA	1,5 V	TV remote control	30 mA

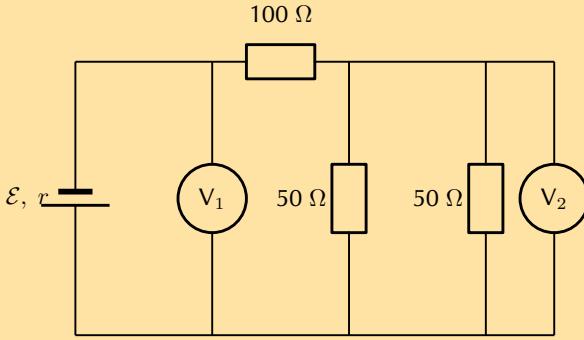
What is likely to happen and why does it happen when the AA-type cell replaces the D-type cell in the electric torch circuit?

	What happens	Why it happens
(a)	the bulb is dimmer	the AA-type cell has greater internal resistance
(b)	the bulb is dimmer	the AA-type cell has less internal resistance
(c)	the brightness of the bulb is the same	the AA-type cell has the same internal resistance
(d)	the bulb is brighter	the AA-type cell has less internal resistance

The internal resistance of the type AA cell is greater than that for the type D cell. The bulb will be dimmer.

The correct answer is option A.

3. [IEB 2005/11 HG1] A battery of emf \mathcal{E} and internal resistance $r = 25 \Omega$ is connected to this arrangement of resistors.



The resistances of voltmeters V_1 and V_2 are so high that they do not affect the current in the circuit.

- Explain what is meant by "the emf of a battery".
The power dissipated in the 100Ω resistor is 0,81 W.
- Calculate the current in the 100Ω resistor.
- Calculate the reading on voltmeter V_2 .
- Calculate the reading on voltmeter V_1 .
- Calculate the emf of the battery.

To-do

- [SC 2003/11] A kettle is marked 240 V; 1500 W.

- Calculate the resistance of the kettle when operating according to the above specifications.
- If the kettle takes 3 minutes to boil some water, calculate the amount of electrical energy transferred to the kettle.

a) Explain what is meant by "the emf of a battery":
The emf of a battery is the maximum electrical potential energy it can impart to a unit charge in a circuit.
The power dissipated in the 100Ω resistor is 0,81 W.
- Calculate the current in the 100Ω resistor:
We can use the power dissipated in a known resistor to determine the current through the resistor:

$$\begin{aligned} P &= I^2 R \\ (0,81) &= I^2(100) \\ I &= \sqrt{\frac{0,81}{100}} \\ &= 0,09 \text{ A} \end{aligned}$$

- Calculate the reading on voltmeter V_2 .
 V_2 is the potential difference across the parallel combination. We know the current so we can determine the resistance and then the potential difference. The equivalent resistance is:

$$\begin{aligned} \frac{1}{R_P} &= \frac{1}{R_1} + \frac{1}{R_2} \\ \frac{1}{R_P} &= \frac{1}{50} + \frac{1}{50} \\ \frac{1}{R_P} &= \frac{2}{50} \\ R_p &= 25 \Omega \end{aligned}$$

The total current through the equivalent resistance is the same as we calculated as the parallel network is in series with the $100\ \Omega$ resistor. Therefore the potential difference across the parallel combination is:

$$\begin{aligned}V_P &= IR_P \\&= 0,0925 \\&= 2,25\text{ V}\end{aligned}$$

- d) Calculate the reading on voltmeter V_1 .

We can calculate the potential difference across the $100\ \Omega$ and add it to the potential difference across the parallel combination to determine the potential difference measured by V_1 .

$$\begin{aligned}V_{100} &= IR \\&= 0,09(100) \\&= 9\text{ V}\end{aligned}$$

$$\begin{aligned}V_1 &= V_{100} + V_P \\&= 9 + 2,25 \\&= 11,25\text{ V}\end{aligned}$$

- e) Calculate the emf of the battery.

The emf of the battery will be V_1 , the potential difference across the load added to the potential difference across the internal resistance.

$$\begin{aligned}V_r &= Ir \\&= 0,0925 \\&= 2,25\text{ V}\end{aligned}$$

$$\begin{aligned}\mathcal{E} &= 2,25 + 11,25 \\&= 13,50\text{ V}\end{aligned}$$

$0,09\text{ A}; 2,25\text{ V}; 11,25\text{ V}; 13,50\text{ V}$

5. [IEB 2001/11 HG1] - Electric Eels

Electric eels have a series of cells from head to tail. When the cells are activated by a nerve impulse, a potential difference is created from head to tail. A healthy electric eel can produce a potential difference of 600 V .

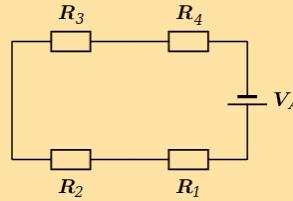
- What is meant by "a potential difference of 600 V "?
- How much energy is transferred when an electron is moved through a potential difference of 600 V ?

The work done on a charge q when moving through a potential difference V is:

$$\begin{aligned}W &= Vq \\&= (600)(1,6 \times 10^{-19}) \\&= (600)(1,6 \times 10^{-19}) \\&= 9,6 \times 10^{-17}\text{ J}\end{aligned}$$

$9,6 \times 10^{-17}\text{ J}$

6. The diagram shows an electric circuit consisting of a battery and four resistors.



The **potential difference** (voltage) over the battery is $V_A = 7,6 \text{ V}$

The resistors are rated as follows:

- $R_1 = 4,7 \Omega$
- $R_2 = 6,9 \Omega$
- $R_3 = 4,9 \Omega$
- $R_4 = 4,3 \Omega$

Assume that positive charge is flowing in the circuit (conventional current).

Using the concepts of **Ohm's law**, and **electric circuits**, determine the following:

- a) What type of circuit is shown in the diagram?

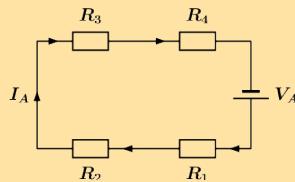
We need to determine whether the circuit is a series, parallel, or combination type of circuit. We do this by looking at how current flows through a circuit.

Recall that current is the movement of electric charge from a higher potential to a lower potential.

We assume that the flowing charge is positive (conventional current). This means that the charges start at the positive terminal of our power source (battery). Here the charges have lots of electrical potential energy.

The charges then move towards the negative terminal through the path that is created by the components and wires of the circuit. During this process, the electrical potential energy is converted into thermal energy by the resistors. Therefore, the charges have less electrical potential energy when they reach the negative terminal of the power source (battery).

The flow of current is indicated by the arrows in the diagram below:



From the diagram it is clear that there is only one path for the current to flow, since the circuit does not split into two or more paths. This means that the current flows through all the components, one after the other (in series). We will label this current I_A .

The circuit shown in the diagram is a **series** circuit.

0

- b) What is the **total equivalent resistance** R_{eq} of the circuit?

- round your answer to 1 digit after the decimal comma
- use the values for any physical constants you might need, as listed here: <http://www.everythingscience.co.za/physical-constants>

We know that the circuit in the diagram is a series type circuit.

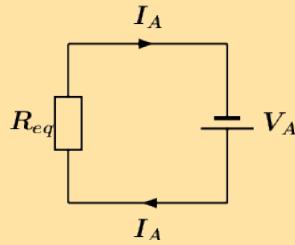
Recall that in a series circuit the equivalent resistance can be calculated by summing the resistance values of the individual resistors:

$$R_{eq,S} = R_1 + R_2 + R_3 + \dots \quad (1)$$

We can rewrite (1) for the circuit in question as:

$$R_{eq} = R_1 + R_2 + R_3 + R_4 \quad (2)$$

We can represent this by drawing an equivalent circuit:



We are given the following information:

- the resistance of $R_1 = 4,7 \Omega$
- the resistance of $R_2 = 6,9 \Omega$
- the resistance of $R_3 = 4,9 \Omega$
- the resistance of $R_4 = 4,3 \Omega$

Substituting the above values in (2), we get:

$$\begin{aligned} R_{eq} &= R_1 + R_2 + R_3 + R_4 \\ &= 4,7 + 6,9 + 4,9 + 4,3 \\ &= 20,8 \Omega \end{aligned}$$

Therefore, the total equivalent resistance in the circuit, or $R_{eq} = 20,8 \Omega$
20.8

c) Question 3

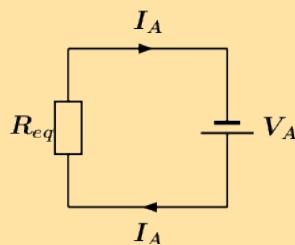
What is the potential difference (voltage) across R_1 , or V_1 ?

- round your answer to 3 digits after the decimal comma
- use the values for any physical constants you might need, as listed here: <http://www.everythingscience.co.za/physical-constants>

Potential difference, or voltage is a way to describe the difference in electrical potential energy across a component in a circuit. Remember that a resistor converts electrical potential energy into thermal energy, so the electrical potential is higher on the "in" side compared to the "out" side of a resistor.

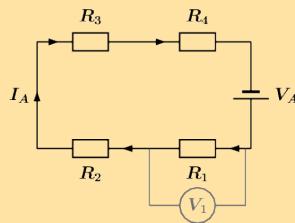
Ohm's law describes the relationship between the total current I through an ohmic conductor, its resistance R , and the potential difference V across it:

$$I = \frac{V}{R} \quad (3)$$



For the equivalent circuit, we can rewrite (3) as:

$$I_A = \frac{V_A}{R_{eq}} \quad (4)$$



We are asked to calculate the potential difference V_1 over R_1 , as shown in the circuit diagram above, so we use Ohm's law and rewrite (3) to get:

$$V_1 = I_1 R_1 \quad (5)$$

Since the circuit in question is a series circuit, we know that the current I_1 flowing through R_1 , is the same as the current I_A . This is represented as:

$$I_1 = I_A \quad (6)$$

Substituting (6) into (5) we get:

$$V_1 = I_A R_1 \quad (7)$$

Substituting (4) into (7) we get:

$$V_1 = I_A R_1 = \left(\frac{V_A}{R_{eq}} \right) R_1 = \frac{V_A R_1}{R_{eq}} \quad (8)$$

Recall from **Question 2**:

$$R_{eq} = R_1 + R_2 + R_3 + R_4 \quad (2)$$

Substituting (2) into (8) we get:

$$V_1 = \frac{V_A R_1}{R_1 + R_2 + R_3 + R_4} \quad (9)$$

We are given the following information:

- the resistance of $R_1 = 4,7 \Omega$
- the resistance of $R_2 = 6,9 \Omega$
- the resistance of $R_3 = 4,9 \Omega$
- the resistance of $R_4 = 4,3 \Omega$
- the potential difference (voltage) over the battery $V_A = 7,6 \text{ V}$

Substituting the above values in (9), we get:

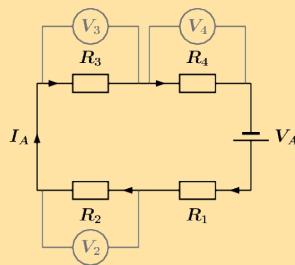
$$\begin{aligned} V_1 &= \frac{V_A R_1}{R_1 + R_2 + R_3 + R_4} \\ &= \frac{(7,6)(4,7)}{4,7 + 6,9 + 4,9 + 4,3} \\ &= 1,71731\dots \quad (\text{calculated}) \\ &\approx 1,717 \text{ V} \quad (\text{rounded}) \end{aligned}$$

Therefore, the potential difference (voltage) across R_1 , or $V_1 \approx 1,717 \text{ V}$.

1.717

- d) What is the potential difference (voltage) across R_2 , R_3 , and R_4 , or V_2 , V_3 , and V_4 ?
- round your answers to 3 digits after the decimal comma
 - use the values for any physical constants you might need, as listed here: <http://www.everythingscience.co.za/physical-constants>

We are asked to calculate the three remaining potential differences, V_2 , V_3 , and V_4 . This is shown in the diagram below:



We will use the same method to obtain three expression for V_2 , V_3 , and V_4 as was used in **Question 3** for V_1 . We get:

$$V_2 = \frac{V_A R_2}{R_1 + R_2 + R_3 + R_4} \quad (10)$$

$$V_3 = \frac{V_A R_3}{R_1 + R_2 + R_3 + R_4} \quad (11)$$

$$V_4 = \frac{V_A R_4}{R_1 + R_2 + R_3 + R_4} \quad (12)$$

We are given the following information:

- the resistance of $R_1 = 4,7 \Omega$
- the resistance of $R_2 = 6,9 \Omega$
- the resistance of $R_3 = 4,9 \Omega$
- the resistance of $R_4 = 4,3 \Omega$
- the potential difference (voltage) over the battery $V_A = 7,6 \text{ V}$

Substituting the above values in (10), (11), and (12) we get:

$$\begin{aligned} V_2 &= \frac{V_A R_2}{R_1 + R_2 + R_3 + R_4} \\ &= \frac{(7,6)(6,9)}{4,7 + 6,9 + 4,9 + 4,3} \\ &= 2,52115\dots \quad (\text{calculated}) \\ &\approx 2,521 \text{ V} \quad (\text{rounded}) \end{aligned}$$

$$\begin{aligned} V_3 &= \frac{V_A R_3}{R_1 + R_2 + R_3 + R_4} \\ &= \frac{(7,6)(4,9)}{4,7 + 6,9 + 4,9 + 4,3} \\ &= 1,79038\dots \quad (\text{calculated}) \\ &\approx 1,790 \text{ V} \quad (\text{rounded}) \end{aligned}$$

$$\begin{aligned} V_4 &= \frac{V_A R_4}{R_1 + R_2 + R_3 + R_4} \\ &= \frac{(7,6)(4,3)}{4,7 + 6,9 + 4,9 + 4,3} \\ &= 1,57115\dots \quad (\text{calculated}) \\ &\approx 1,571 \text{ V} \quad (\text{rounded}) \end{aligned}$$

Therefore, the potential difference (voltage) across R_2 , or $V_2 \approx 2,521 \text{ V}$.

The potential difference (voltage) across R_3 , or $V_3 \approx 1,790 \text{ V}$.

The potential difference (voltage) across R_4 , or $V_4 \approx 1,571 \text{ V}$.

2.521 1.790 1.571

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1. 27XX 2. 27XY 3. 27XZ 4. 27Y2 5. 27Y3 6. 27Y4



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Electrodynamics

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11.1 Introduction

Electrical machines - generators and motors:

- State the difference between generators and motors.
- Definition of Farady's Law.
- Using Farady's Law for explanations.
- Definition of a generator
- Explaining the principle of an AC and DC generator using words and pictures.
- Explaining the difference between AC and DC generators.
- Explains what happens when a current carrying coil is placed in a magnetic field.
- Explaining the principle of an electric motor using word and pictures.
- Definition of Lorent Force.
- Examples of AC and DC generators and the use of motors.

Alternating current:

- Explaining advantages of alternating current.
- Write different expressions.
- Definition of the root mean square values and explains why they are useful.
- Calculations done on the average power.
- Drawing of graphs.
- Solve different kinds of problems using alternating current.

11.2 Electrical machines - generators and motors

Exercise 11 – 1: Generators and motors

1. State the difference between a generator and a motor.

An electrical generator is a mechanical device to convert energy from a source into electrical energy.

An electrical motor is a mechanical device to convert electrical energy from a source into another form energy.

2. Use Faraday's Law to explain why a current is induced in a coil that is rotated in a magnetic field.

Faraday's law says that a changing magnetic flux can induce an emf, when the coil rotates in a magnetic field it is possible for the rotation to change the flux thereby inducing an emf.

If the rotation of the coil is such that the flux doesn't change, i.e. the surface of the coil remains parallel to the magnetic field, then there will be no induced emf.

3. Explain the basic principle of an AC generator in which a coil is mechanically rotated in a magnetic field. Draw a diagram to support your answer.
4. Explain how a DC generator works. Draw a diagram to support your answer. Also, describe how a DC generator differs from an AC generator.
5. Explain why a current-carrying coil placed in a magnetic field (but not parallel to the field) will turn. Refer to the force exerted on moving charges by a magnetic field and the torque on the coil.

A current-carrying coil in a magnetic field experiences a force on both sides of the coil that are not parallel to the magnetic field, creating a twisting force (called a torque) which makes it turn. Any coil carrying current can feel a force in a magnetic field. The force is due to the magnetic component of the Lorentz force on the moving charges in the conductor, called Ampere's Law. The force on opposite sides of the coil will be in opposite directions because the charges are moving in opposite directions.

6. Explain the basic principle of an electric motor. Draw a diagram to support your answer.

7. Give examples of the use of AC and DC generators.

Cars (both AC and DC), electricity generation (AC only), anywhere where a power supply is needed.

8. Give examples of the uses of motors.

Pumps, fans, appliances, power tools, household appliances, office equipment.

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1. 27Y6 2. 27Y7 3. 27Y8 4. 27Y9 5. 27YB 6. 27YC
7. 27YD 8. 27YF



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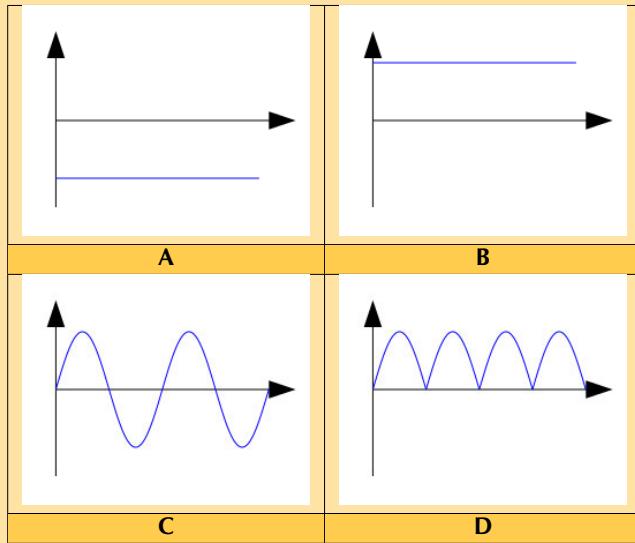
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11.3 Alternating current

Current and voltage

Exercise 11 – 2: Alternating current

1. Explain the advantages of alternating current.
 - Easy to be transformed (step up or step down using a transformer).
 - Easier to convert from AC to DC than from DC to AC.
 - Easier to generate.
 - It can be transmitted at high voltage and low current over long distances with less energy lost.
 - High frequency used in AC makes it suitable for motors.
2. Which of the following graphs correctly shows the current vs. time graph for an AC generator?



For an alternating current generator, the current vs. time graph is a sine wave and alternates between positive and negative values.

For a direct current generator, the current vs. time graph is the absolute value of a sine wave and does not alternate between positive and negative values.

The correct answer is C.

3. Write expressions for the current and voltage in an AC circuit.

$$i = I_{\max} \sin(2\pi ft + \phi)$$

$$v = V_{\max} \sin(2\pi ft)$$

4. Define the rms (root mean square) values for current and voltage for AC.

The root mean square is the value that we use for AC and is what its DC equivalent would be.

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

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

5. What is the frequency of the AC generated in South Africa?

In South Africa the frequency is 50 Hz

6. If V_{\max} at a power station generator is 340 V AC, what is the mains supply (rms voltage) in our household?

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

$$= \frac{340}{\sqrt{2}}$$

$$= 240,42 \text{ V}$$

7. Given: I_{\max} is 10 A

Calculate the rms (root mean square) current to two decimal places.

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

$$I_{\text{rms}} = \frac{10 \text{ A}}{\sqrt{2}} \\ = 7,07 \text{ A}$$

Therefore $I_{\text{rms}} = 7,07 \text{ A}$

7.07

8. Given: V_{max} is 266 V

Calculate the rms (root mean square) voltage to two decimal places.

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

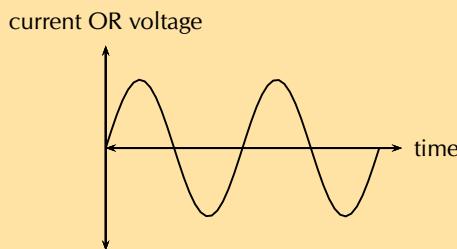
$$V_{\text{rms}} = \frac{266 \text{ V}}{\sqrt{2}} \\ = 188,09 \text{ V}$$

Therefore $V_{\text{rms}} = 188,09 \text{ V}$

188,09 V

9. Draw a graph of voltage vs time and current vs time for an AC circuit.

The graph is the same for both voltage and for current:



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1. 27YG 2. 27YH 3. 27YJ 4. 27YK 5. 27YM 6. 27YN
7. 27YP 8. 27YQ 9. 27YR



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11.4 Chapter summary

Exercise 11 – 3:

1. [SC 2003/11] Explain the difference between alternating current (AC) and direct current (DC).

Direct current (DC), which is electricity flowing in a constant direction. DC is the kind of electricity made by a battery, with definite positive and negative terminals. However, we have seen that the electricity produced by some generators alternates and is therefore known as alternating current (AC). So the main difference is that in AC the movement of

electric charge periodically reverses direction while in DC the flow of electric charge is only in one direction.

2. Explain how an AC generator works. You may use sketches to support your answer.
3. What are the advantages of using an AC motor rather than a DC motor.

While DC motors need brushes to make electrical contact with moving coils of wire, AC motors do not. The problems involved with making and breaking electrical contact with a moving coil are sparking and heat, especially if the motor is turning at high speed. If the atmosphere surrounding the machine contains flammable or explosive vapours, the practical problems of spark-producing brush contacts are even greater.

4. Explain how a DC motor works.

Instead of rotating the loops through a magnetic field to create electricity, as is done in a generator, a current is sent through the wires, creating electromagnets. The outer magnets will then repel the electromagnets and rotate the shaft as an electric motor. If the current is DC, split-ring commutators are required to create a DC motor.

5. At what frequency is AC generated by Eskom in South Africa?

In South Africa the frequency is 50 Hz

6. (IEB 2001/11 HG1) - Work, Energy and Power in Electric Circuits

Mr. Smith read through the agreement with Eskom (the electricity provider). He found out that alternating current is supplied to his house at a frequency of 50 Hz. He then consulted a book on electric current, and discovered that alternating current moves to and fro in the conductor. So he refused to pay his Eskom bill on the grounds that every electron that entered his house would leave his house again, so therefore Eskom had supplied him with nothing!

Was Mr. Smith correct? Or has he misunderstood something about what he is paying for? Explain your answer briefly.

Mr Smith is not correct. He has misunderstood what power is and what Eskom is charging him for.

AC voltage and current can be described as:

$$i = I_{\max} \sin(2\pi ft + \phi)$$
$$v = V_{\max} \sin(2\pi ft)$$

This means that for $\phi = 0$, i.e. if resistances have no complex component or if a student uses a standard resistor, the voltage and current waveforms are in-sync.

Power can be calculated as $P = VI$. If there is no phase shift, i.e. if resistances have no complex component or if a student uses a standard resistor then power is always positive since:

- when the voltage is negative (-), the current is negative (-), resulting in positive (+) power.
- when the voltage is positive (+), the current is positive (+), resulting in positive (+) power.

7. You are building a laser that takes alternating current and it requires a very high peak voltage of 180 kV. By your calculations the entire laser setup can be treated at a single resistor with an equivalent resistance of 795 ohms. What is the rms value for the voltage and the current and what is the average power that your laser is dissipating?

At peak voltage the peak current will be:

$$V = IR$$
$$I = \frac{V}{R}$$
$$= \frac{180 \times 10^3}{795}$$
$$= 226,42 \text{ A}$$

$$\begin{aligned}P_{rms} &= V_{rms} I_{rms} \\&= \frac{180 \times 10^3}{\sqrt{2}} \frac{226,415094}{\sqrt{2}} \\&= 20,38 \times 10^6 \text{ W}\end{aligned}$$

$$20,38 \times 10^6 \text{ W}$$

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- 1. 27YT 2. 27YV 3. 27YW 4. 27YX 5. 27YY 6. 27YZ
- 7. 27Z2



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Optical phenomena and properties of matter

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12.2	<i>The photoelectric effect</i>	232
12.3	<i>Emission and absorption spectra</i>	235
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12.1 Introduction

Photoelectric effect:

- Description of the photoelectric effect.
- Give the significance of the photoelectric effect.
- Definition of the cut-off frequency.
- Definition of the work function and that it is material specific
- The relationship between the cut-off frequency and maximum wavelength.
- Calculations using the photoelectric equation.
- Knowing the relationship between the number of electrons and intensity of the incident radiation.
- Understanding the nature between the photoelectric effect and the particle of nature of light.

Emission and absorption spectra:

- Explanation of the source atomic emission spectra and their unique relationship to each element.
- Relation between the atomic spectrum and the electron transitions between energy levels.
- Explaining the difference between atomic absorption and emission spectra.
- Applications of emission and absorption spectra.

Key Mathematics Concepts

- Units and unit conversions — Physical Sciences, Grade 10, Science skills
- Equations — Mathematics, Grade 10, Equations and inequalities
- Electronic configuration — Physical Sciences, Grade 10, The atom
- Electromagnetic radiation — Physical Sciences, Grade 10, Electromagnetic radiation

12.2 The photoelectric effect

History and expectations as to the photoelectric effect

For a paper on the history of the photoelectric effect and the analysis of its treatment in a variety of textbooks see: <http://onlinelibrary.wiley.com/doi/10.1002/sce.20389/pdf>

Exercise 12 – 1: The photoelectric effect

1. Describe the photoelectric effect.

The photoelectric effect is the process whereby an electron is emitted by a metal when light shines on it, on the condition that the energy of the photons (light energy packets) are greater than or equal to the work function of the metal.

2. List two reasons why the observation of the photoelectric effect was significant.

Two reasons why the observation of the photoelectric effect was significant are (1) that it provides evidence for the particle nature of light and (2) that it opened up a new branch for technological advancement e.g. photocathodes (like in old TVs) and night vision devices.

3. Refer to tab:work_{fun}: If I shine ultraviolet light with a wavelength of 288 nm onto some aluminium foil, what would the kinetic energy of the emitted electrons be?

$$\begin{aligned}E_k &= E_{\text{photon}} - W_0 \\&= h \frac{c}{\lambda} - W_0 \\&= (6,63 \times 10^{-34} \text{ m}^2 \text{kg} \cdot \text{s}^{-1}) \frac{3 \times 10^8 \text{ m} \cdot \text{s}^{-1}}{288 \times 10^{-9} \text{ m}} - 6,9 \times 10^{-19} \text{ J} \\&= 6,25 \times 10^{-22} \text{ J}\end{aligned}$$

$$6,25 \times 10^{-22} \text{ J}$$

4. I shine a light of an unknown wavelength onto some silver foil. The light has only enough energy to eject electrons from the silver foil but not enough to give them kinetic energy. (Refer to tab:work_{fun} when answering the questions below :)

- If I shine the same light onto some copper foil, would electrons be ejected?
- If I shine the same light onto some silicon, would electrons be ejected?
- If I increase the intensity of the light shining on the silver foil, what happens?
- If I increase the frequency of the light shining on the silver foil, what happens?

- The kinetic energy of the ejected photon is given by

$$E_k = E_{\text{photon}} - W_0$$

and if for silver foil $E_k = 0$ then $E_{\text{photon}} = W_0$ silver. Therefore, if the same light falls on copper foil we require $E_{\text{photon}} > W_0$ copper for electrons to be ejected.

The work function for silver is W_0 silver = $6,9 \times 10^{-19}$ J and the work function for copper is W_0 copper = $7,5 \times 10^{-19}$ J. Now

$$\begin{aligned}W_0 \text{ silver} &< W_0 \text{ copper} \\ \therefore E_{\text{photon}} &< W_0 \text{ copper}\end{aligned}$$

and thus no electrons will be ejected.

- Similarly to the previous question we know the kinetic energy of the ejected photon is given by

$$E_k = E_{\text{photon}} - W_0$$

and if for silver foil $E_k = 0$ then $E_{\text{photon}} = W_0$ silver. Therefore, if the same light falls on copper foil we require $E_{\text{photon}} > W_0$ silicon for electrons to be ejected.

The work function for silver is W_0 silver = $6,9 \times 10^{-19}$ J and the work function for silicon is W_0 silicon = $1,8 \times 10^{-19}$ J. Now

$$\begin{aligned}W_0 \text{ silver} &> W_0 \text{ silicon} \\ \therefore E_{\text{photon}} &> W_0 \text{ silicon}\end{aligned}$$

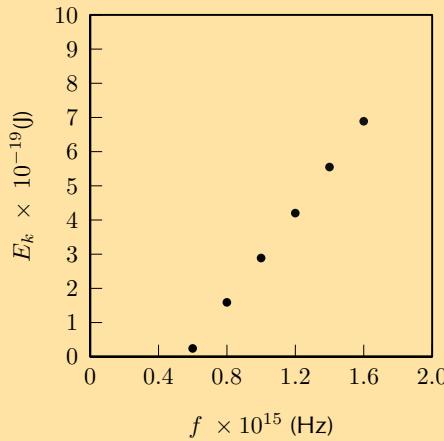
and thus electrons will be ejected.

- c) More electrons will be ejected from the silver.
- d) Increasing the frequency of the light would increase E_{photon} and therefore $E_{photon} > W_0$ silver which means that the electron will be ejected with a kinetic energy of $E_k = E_{photon} - W_0$ silver > 0.

5. The following results were obtained from a photoelectric effect experiment.

$f \times 10^{15}$ Hz	$E_k \times 10^{-19}$ J
0.60	0.24
0.80	1.59
1.00	2.89
1.20	4.20
1.40	5.55
1.60	6.89

- a) Plot a graph of E_k on the y axis and f on the x axis
- b) Calculate the gradient of the graph.
- c) The metal used in the experiment is Sodium which has a work function of 3.7×10^{-19} . Calculate the cut-off frequency for sodium.
- d) Determine the x intercept. Compare your x intercept value with the cut-off frequency you calculated.
- e) If the sodium metal was replaced with another metal with double the work function, sketch on the same graph for sodium, the result you would expect to obtain.



a) $E_k \times 10^{-19}$ J

$f \times 10^{15}$ (Hz)

b) gradient = 6.6×10^{-34}

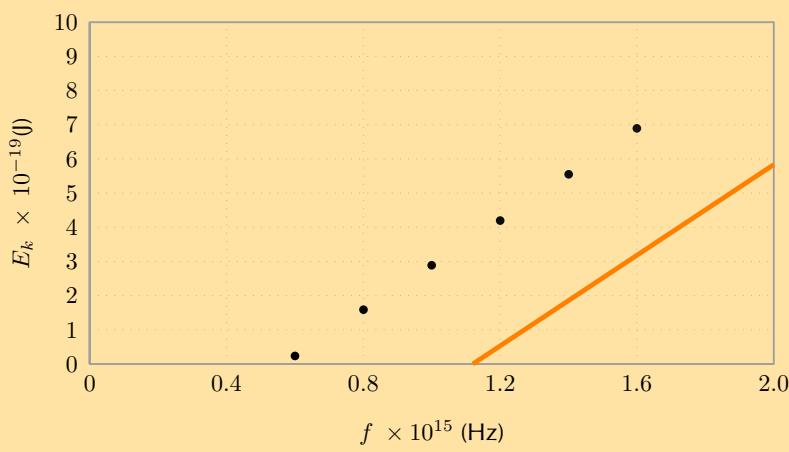
c)

$$W_0 = h f_0$$

$$3.7 \times 10^{-19} = 6.6 \times 10^{-34} f_0$$

$$f_0 = 0.56 \times 10^{15} \text{ Hz}$$

- d) Check that your x intercept is close to 0.56×10^{15} which is the cut-off frequency



e)

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1. 27Z7 2. 27Z8 3. 27Z9 4. 27ZB 5. 27ZC



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12.3 Emission and absorption spectra

Exercise 12 – 2: Emission and absorption spectra

1. Explain how atomic emission spectra arise and how they relate to each element on the periodic table.

Atomic emission spectra arise from electrons dropping from higher energy levels to lower energy levels within the atom, photons (light packets) with specific wavelengths are released. The energy levels in an atom are specific/unique to each element on the periodic table therefore the wavelength of light emitted can be used to determine which element the light came from.

2. How do the lines on the atomic spectrum relate to electron transitions between energy levels?

The lines on the atomic spectrum relate to electron transitions between energy levels, if the electron drops an energy level a photon is released resulting in an emission line and if the electron absorbs a photon and rises an energy level an absorption line is observed on the spectrum.

3. Explain the difference between atomic absorption and emission spectra.

The difference between absorption and emission spectra are that absorption lines are where light has been absorbed by the atom thus you see a dip in the spectrum whereas emission spectra have spikes in the spectra due to atoms releasing photons at those wavelengths.

4. Describe how the absorption and emission spectra of the gases in the atmosphere give rise to the Greenhouse Effect.

The following needs to be in your answer: in what wavelength range the sunlight reaches the earth, the absorption of the sunlight and the re-radiation as infrared light, and finally the scattering of the infrared light by the carbon-dioxide and how this scattering contributes to the Greenhouse Effect.

5. Using t:Optic:Colours calculate the frequency range for yellow light.

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

The frequency range of yellow light is 502 THz – 520 THz. ($1 \text{ THz} = 10^{12} \text{ Hz}$)

6. What colour is the light emitted by hydrogen when an electron makes the transition from energy level 5 down to energy level 2? (Use fig:Henergy to find the energy of the released photon.)

$$\begin{aligned}\Delta E &= E_5 - E_2 \\ &= 21,0 \times 10^{-19} \text{ J} - 16,3 \times 10^{-19} \text{ J} \\ &= 4,7 \times 10^{-19} \text{ J}\end{aligned}$$

$$\begin{aligned}\lambda &= \frac{hc}{\Delta E} \\ &= \frac{(6,63 \times 10^{-34} \text{ m}^2\text{kg}\cdot\text{s}^{-1})(3 \times 10^8 \text{ m}\cdot\text{s}^{-1})}{4,7 \times 10^{-19} \text{ J}} \\ &= 423 \text{ nm}\end{aligned}$$

The colour of light emitted at 423 nm is violet.

7. I have a glass tube filled with hydrogen gas. I shine white light onto the tube. The spectrum I then measure has an absorption line at a wavelength of 474 nm. Between which two energy levels did the transition occur? (Use fig:Henergy in solving the problem.)

$$\begin{aligned}\Delta E &= \frac{hc}{\lambda} \\ &= \frac{(6,63 \times 10^{-34} \text{ m}^2\text{kg}\cdot\text{s}^{-1})(3 \times 10^8 \text{ m}\cdot\text{s}^{-1})}{474 \times 10^{-9} \text{ nm}} \\ &= 4,20 \times 10^{-19} \text{ J}\end{aligned}$$

This energy interval corresponds to a transition from energy level 4 to energy level 2.

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1. 27ZD 2. 27ZF 3. 27ZG 4. 27ZH 5. 27ZJ 6. 27ZK
7. 27ZM



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12.4 Chapter summary

Exercise 12 – 3:

1. Calculate the energy of a photon of red light with a wavelength of 400 nm.
We first calculate the energy of the photons:

$$\begin{aligned}
 E &= \frac{hc}{\lambda} \\
 &= \frac{(3 \times 10^8)(6,63 \times 10^{-34})}{400 \times 10^{-9}} \\
 &= 2,01 \times 10^{-19} \text{ J}
 \end{aligned}$$

Next convert the work function energy into J:

$$2,9 \times 1,6 \times 10^{-19} = 4,64 \times 10^{-19} \text{ J}$$

The energy of the photons is less than the work function of calcium and so no electrons will be emitted.

2. Will ultraviolet light with a wavelength of 990 nm be able to emit electrons from a sheet of calcium with a work function of 2,9 eV?

$$\begin{aligned}
 E &= \frac{hc}{\lambda} \\
 &= \frac{(3 \times 10^8)(6,63 \times 10^{-34})}{990 \times 10^{-9}} \\
 &= 4,97 \times 10^{-19} \text{ J}
 \end{aligned}$$

Think you got it? Get this answer and more practice on our Intelligent Practice Service

1. 27ZP 2. 27ZQ



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CHAPTER

13

Electrochemical reactions

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13.7	<i>Applications of electrochemistry</i>	256
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13 Electrochemical reactions

This chapter is allocated 8 hours in CAPS and covers electrochemical reactions, the galvanic cell, the electrolytic cell, and applications of electrochemistry. The first step should be to revise redox reactions, oxidation numbers, and oxidation and reduction before continuing with the chapter. Note that the sections are not ordered in this way in the CAPS document, but learners are more likely to struggle if you do not revise these concepts first. A good understanding of these topics is essential.

The chapter ends with applications of electrochemistry in industry, this is a good opportunity to make sure the learners understand the principles, but it is not necessary for them to learn the reactions by heart or study the industry itself.

The following topics are covered in this chapter.

- **Revision of oxidation, reduction and redox reactions**

It is important to revise the concepts of oxidation number, oxidation and reduction reactions, as well as how to write and balance redox reactions and half-reactions. An understanding of these concepts is very important in every aspect of this chapter.

- **Galvanic and electrolytic cells**

This section introduces the concept of an electrochemical reaction, it may be worth a brief revision of the zinc-copper experiment performed in Grade 11. Two types of electrochemical cell are covered: galvanic cells and electrolytic cells. Galvanic cells convert chemical potential energy to electrical potential energy, while electrolytic cells convert electrical potential energy to chemical potential energy. Learners should be able to draw and label a simple diagram of both of these types of cells and write the standard cell notation for the cell.

- **Processes in electrochemical cells**

This section is a more indepth look at the oxidation and reduction reactions taking place at the anode and cathode in electrochemical cells. Learners should be able to predict whether an electrode is the anode or cathode depending on the half-reaction taking place there. They must also know which half-reaction will take place at the anode and which will take place at the cathode.

- **Effects of current and potential on rate and equilibrium**

Learners should understand that when a cell is flat the reactions inside are in equilibrium and the concentration of the reactants and products are constant. There is no potential difference and so no current can flow. The more current there is, the faster the electrons are flowing and the higher the rate of the reaction must be. None of the cells they deal with in this chapter are in equilibrium, because then there would be nothing to measure.

- **Standard electrode potentials**

A standard hydrogen electrode is used to help determine the EMF of cells. The learners should understand that the electrode potentials in the table of standard electrode potentials are **relative** electrode potentials, and allow us to compare different metals without having to set up a new reaction each time. They should realise that the table provided is for the reduction half-reactions and that the oxidation half-reaction table would have the reactions reversed and the E° V value with the opposite sign. They need to be able to use the table to:

- determine which metal is more likely to be reduced or oxidised when comparing two metals
- and determine whether a reaction is spontaneous or not.

- **Applications of electrochemistry**

The applications covered in this section are electroplating, the chloralkali industry, and the extraction of aluminium. The learners should understand the processes involved, but do not need to memorise the exact reactions, and need not study the industries themselves.

There are several experiments in this chapter. The learners will be using dangerous chemicals and should be properly instructed on the correct use of safety equipment, including safety goggles, gloves and protective clothing. They should also be reminded not to sniff any chemicals as the fumes can be dangerous as well. More information on laboratory procedures as well as safety precautions is provided in Chapter 1 (Science skills).

The informal experiment is the electrolysis of sodium iodide and water. It is a very effective experiment, and should be easy to perform. The learners will need to be careful as they handle concentrated sulfuric acid. It is advisable to test that current will run through the pencils before the experiment, in case the pencil lead is broken inside. If you have access to graphite rods these can be used instead. More information for each experiment is provided in the relevant sections.

13.1 Revision of oxidation and reduction

Exercise 13 – 1: Oxidation and reduction

1. Define the following terms:

a) oxidation

Oxidation is the loss of electrons by a molecule, atom or ion.

b) reduction

Reduction is the gain of electrons by a molecule, atom or ion.

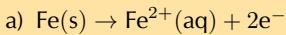
c) oxidising agent

The molecule, atom or ion that is reduced, or the molecule, atom or ion that causes oxidation.

d) reducing agent

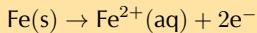
The molecule, atom or ion that is oxidised, or the molecule, atom or ion that causes reduction.

2. In each of the following reactions say whether the reactant **iron species** (Fe , Fe^{2+} , Fe^{3+}) is oxidised or reduced.

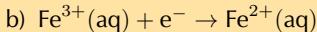


The oxidation number of Fe in:

- Fe(s) is 0
- $\text{Fe}^{2+}(\text{aq})$ is + 2

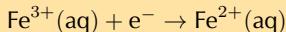


Fe loses two electrons to become Fe^{2+} . The iron species (Fe(s)) is oxidised.

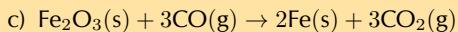


The oxidation number of Fe in:

- $\text{Fe}^{3+}(\text{aq})$ is + 3
- $\text{Fe}^{2+}(\text{aq})$ is + 2



Fe^{3+} gains one electron to become Fe^{2+} . The iron species ($\text{Fe}^{3+}(\text{aq})$) is reduced.

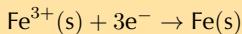


The oxidation number of O is -2. Therefore the oxidation number of O_3 in Fe_2O_3 is -6.

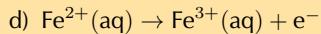
Therefore the oxidation number of Fe_2 in Fe_2O_3 is + 6.

The oxidation number of Fe in:

- $\text{Fe}_2\text{O}_3(\text{s})$ is + 3
- Fe(s) is 0

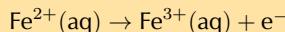


Fe^{3+} gains three electrons to become Fe(s) . The iron species ($\text{Fe}^{3+}(\text{s})$) is **reduced**.

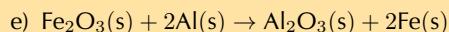


The oxidation number of Fe in:

- $\text{Fe}^{2+}(\text{aq})$ is +2
- $\text{Fe}^{3+}(\text{aq})$ is +3



Fe^{2+} loses an electron to become Fe^{3+} . The iron species ($\text{Fe}^{2+}(\text{aq})$) is **oxidised**.

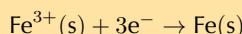


The oxidation number of O is -2. Therefore the oxidation number of O_3 in Fe_2O_3 is -6.

Therefore the oxidation number of Fe_2 in Fe_2O_3 is +6.

The oxidation number of Fe in:

- $\text{Fe}_2\text{O}_3(\text{s})$ is +3
- $\text{Fe}(\text{s})$ is 0



Fe^{3+} gains three electrons to become $\text{Fe}(\text{s})$. The iron species ($\text{Fe}^{3+}(\text{aq})$) is **reduced**.

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13.2 Writing redox and half-reactions

Balancing redox reactions

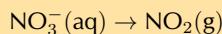
Exercise 13 – 2: Balancing redox reactions

1. Balance the following equations:

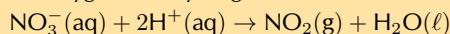


Pb^{2+} is a spectator ion.

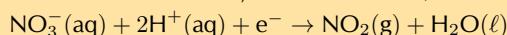
The unbalanced reduction half-reaction is:



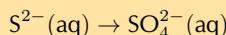
Add water molecules to the right and H^+ ions to the left (acid medium) to balance the oxygen and hydrogen atoms:



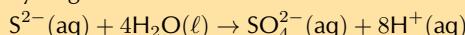
Balance the charge by adding an electron to the left (this makes sense as this is the reduction half-reaction, and $\text{N}^{5+} \rightarrow \text{N}^{4+}$):



The unbalanced oxidation half-reaction is:



Add water molecules to the left and H^+ ions to the right to balance the oxygen and hydrogen atoms:



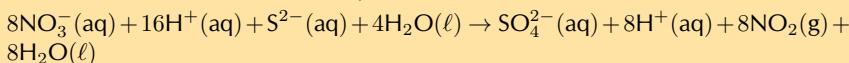
Balance the charge by adding eight electrons to the right (this makes sense as this is the oxidation half-reaction, and $\text{S}^{2-} \rightarrow \text{S}^{6+}$):



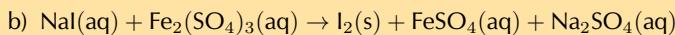
We multiply the reduction half-reaction reaction by 8 to balance the number of electrons in both equations:



Adding the two equations together gives the balanced equation (electrons are equal on both sides and can be removed):

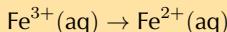


Putting the spectator ions back into the equation and removing any extra H^+ ions and water molecules we get:



Na^+ and SO_4^{2-} are spectator ions.

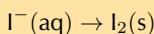
Fe has the oxidation number +3 in $\text{Fe}_2(\text{SO}_4)_3$, and +2 in FeSO_4 . This must be the reduction half-reaction:



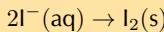
The atoms are balanced. Balance the charge by adding an electron to the left:



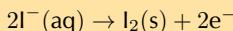
The unbalanced oxidation half-reaction is:



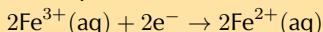
There must be 2 I^- to balance the atoms:



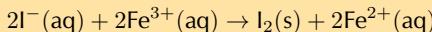
Balance the charge by adding two electrons to the right:



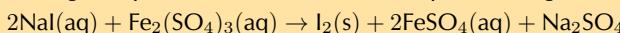
We multiply the reduction half-reaction by 2 to balance the number of electrons in both equations:



Adding the two equations together and removing the electrons gives:

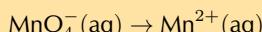


Putting the spectator ions back into the equation we get:



2. Permanganate(VII) ions (MnO_4^-) oxidise hydrogen peroxide (H_2O_2) to oxygen gas. The reaction is done in an acid medium. During the reaction, the permanganate(VII) ions are reduced to manganese(II) ions (Mn^{2+}). Write a balanced equation for the reaction.

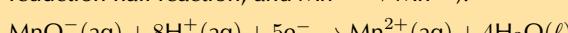
The unbalanced reduction half-reaction is:



As this is in an acid medium, we can add water molecules to the right and H^+ ions to the left to balance the oxygen and hydrogen atoms:



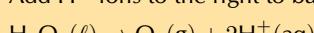
Balance the charge by adding five electrons to the left (this makes sense as this is the reduction half-reaction, and $\text{Mn}^{7+} \rightarrow \text{Mn}^{2+}$):



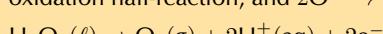
The unbalanced oxidation half-reaction is:



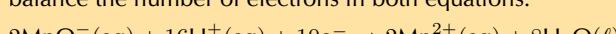
Add H^+ ions to the right to balance the hydrogen atoms:



Balance the charge by adding two electrons to the right (this makes sense as this is the oxidation half-reaction, and $2\text{O}^- \rightarrow \text{O}_2$):



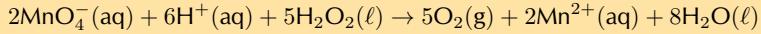
We multiply the reduction half-reaction by 2 and the oxidation half-reaction by 5 to balance the number of electrons in both equations:



Adding the two equations together gives the balanced equation (electrons are equal on both sides and can be removed):



Removing any extra H^+ ions we get:



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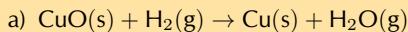
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13.3 Galvanic and electrolytic cells

Electrochemical reactions

Exercise 13 – 3: Electrochemical reactions

1. In each of the following equations, say which elements in the reactants are oxidised and which are reduced.

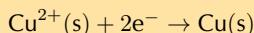


The oxidation number of O is -2 . O is neither oxidised nor reduced.

The oxidation number of Cu in:

- $\text{CuO}(\text{s})$ is $+2$

- $\text{Cu}(\text{s})$ is 0

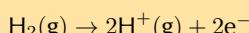


Cu^{2+} gains two electrons to form Cu. Copper is **reduced**

The oxidation number of H in:

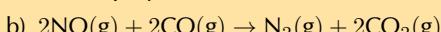
- $\text{H}_2(\text{g})$ is 0

- $\text{H}_2\text{O}(\text{g})$ is $+1$



H_2 loses two electrons to form 2H^+ . Hydrogen is **oxidised**.

Note: Each hydrogen atom in H_2 releases one electron, and these two electrons are taken up by a Cu^{2+} ion.

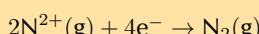


The oxidation number of O is -2 . O is neither oxidised nor reduced.

The oxidation number of N in:

- $\text{NO}(\text{g})$ is $+2$

- $\text{N}_2(\text{g})$ is 0

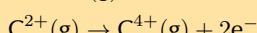


Two N^{2+} each gain two electrons to become N_2 . Nitrogen is **reduced**.

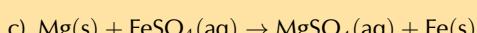
The oxidation number of C in:

- $\text{CO}(\text{g})$ is $+2$

- $\text{CO}_2(\text{g})$ is $+4$



C^{2+} loses two electrons to form C^{4+} . Carbon is **oxidised**.



The oxidation number of the ion SO_4 is -2 as both a reactant and a product.

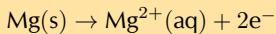
The oxidation number of O is -2 . O is neither oxidised nor reduced.

The oxidation number of O_4 in SO_4^{2-} is -8 . Therefore the oxidation number of S in SO_4^{2-} is $+6$. S is neither oxidised nor reduced.

The oxidation number of Mg in:

- $\text{Mg}(\text{s})$ is 0

- $\text{MgSO}_4(\text{aq})$ is $+2$

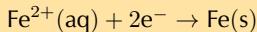


Mg loses two electrons to become Mg^{2+} . Magnesium is **oxidised**.

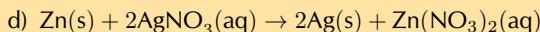
The oxidation number of Fe in:

- $\text{FeSO}_4(\text{aq})$ is +2

- Fe(s) is 0



Fe^{2+} gains two electrons to become Fe. Iron is **reduced**.



The oxidation number of the ion NO_3 is -1 as both a reactant and a product.

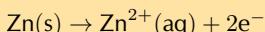
The oxidation number of O is -2. O is neither oxidised nor reduced.

The oxidation number of O_3 in NO_3 is -6. Therefore the oxidation number of N in NO_3^- is +5. N is neither oxidised nor reduced.

The oxidation number of Zn in:

- Zn(s) is 0

- $\text{Zn}(\text{NO}_3)_2(\text{aq})$ is +2

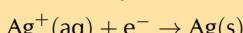


Zn loses two electrons to become Zn^{2+} . Zinc is **oxidised**.

The oxidation number of Ag in:

- $\text{AgNO}_3(\text{aq})$ is +1

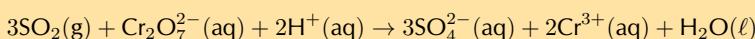
- Ag(s) is 0



Ag^+ gains an electron to form Ag. Silver is **reduced**.

Note: The two electrons released by Zn are taken up by two Ag^+ ions, this is shown in the balanced chemical equation.

2. Which one of the substances listed below acts as the oxidising agent in the following reaction?



- a) H^+ b) Cr^{3+} c) SO_2 d) $\text{Cr}_2\text{O}_7^{2-}$

The oxidising agent causes another reactant to be oxidised and is itself reduced.

H^+ remains as H^+ in H_2O

Cr^{3+} is a product.

SO_2 contains S^{4+} , while SO_4^{2-} contains S^{6+} . Therefore S^{4+} loses two electrons and is oxidised.

$\text{Cr}_2\text{O}_7^{2-}$ contains Cr^{6+} . Therefore Cr^{6+} gains three electrons to become Cr^{3+} and is reduced. It is the oxidising agent.

- d) $\text{Cr}_2\text{O}_7^{2-}$

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Galvanic cells

In the galvanic cell experiment, make sure that the sodium chloride paste is highly concentrated and fills the U-tube for the best results.

Electrolytic cells

In the movement of coloured ions experiment, to make the ammonia and ammonium chloride buffer solution you need to combine equimolar amounts of ammonia and ammonium chloride. The volume doesn't matter, so long as there are the same number of moles of each compound in the solution.

Concentrated, strong bases can cause serious burns. Please remind the learners to be careful and wear the appropriate safety equipment when handling all chemicals, especially strong, concentrated bases. The safety equipment includes gloves, safety glasses, and protective clothing.

In the electrolytic cell experiment it is important that the learners weigh the copper electrodes carefully before the experiment, and wash and dry the electrodes before weighing after the experiment.

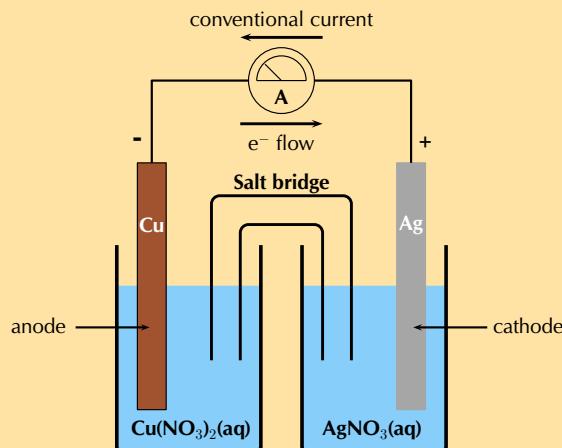
The informal experiment is the electrolysis of sodium iodide and water. It would be advisable to check that current flows through the pencils, as the pencil lead may be broken. If you have access to graphite rods they can be used instead. In the second part of the experiment, there should be an obvious colour change when the phenolphthalein and NaOH mix at the cathode.

Learners are required to work with a concentrated, strong acid. Concentrated, strong acids can cause serious burns. Please remind the learners to be careful and wear the appropriate safety equipment when handling all chemicals, especially concentrated acids. The safety equipment includes gloves, safety glasses and protective clothing.

Exercise 13 – 4: Galvanic and electrolytic cells

1. An electrolytic cell consists of two electrodes in a silver chloride (AgCl) solution, connected to a source of current. A current is passed through the solution and Ag⁺ ions are reduced to a silver metal deposit on one of the electrodes.
 - a) What is the name of this process?
Electrolysis
 - b) Does reduction occur at the electrode where the deposit formed?
Yes. Reduction is a gain of electrons. In an electrolytic cell the electrode connected to the negative terminal of the battery is negative. When the metal cations encounter this electrode they gain electrons and form metal atoms that deposit on the electrode (Ag⁺(aq) + e⁻ → Ag(s)).
 - c) Give the equation for the reduction half-reaction.
$$\text{Ag}^+(\text{aq}) + \text{e}^- \rightarrow \text{Ag}(\text{s})$$
 - d) Give the equation for the oxidation half-reaction.
$$\text{Ag}(\text{s}) \rightarrow \text{Ag}^+(\text{aq}) + \text{e}^-$$
2. A galvanic cell consists of two half-cells: a copper anode in a copper nitrate (Cu(NO₃)₂(aq)) solution, and a silver cathode in a silver nitrate (AgNO₃(aq)) solution.
 - a) Give equations for the half-reactions that take place at the anode and cathode.
You are told that the copper electrode is the anode, oxidation is a loss of electrons at the anode:
Anode half-reaction: Cu(s) → Cu²⁺(aq) + 2e⁻
You are told that the silver electrode is the cathode, reduction is a gain of electrons at the cathode:
Cathode half-reaction: Ag⁺(aq) + e⁻ → Ag(s)
 - b) Write the overall reaction for this cell.
$$\text{Cu}(\text{s}) + 2\text{Ag}^+(\text{aq}) \rightarrow \text{Cu}^{2+}(\text{aq}) + 2\text{Ag}(\text{s})$$

OR
$$\text{Cu}(\text{s}) + 2\text{AgNO}_3(\text{aq}) \rightarrow \text{Cu}(\text{NO}_3)_2(\text{aq}) + 2\text{Ag}(\text{s})$$
 - c) Give standard cell notation for this cell.
$$\text{Cu}(\text{s})|\text{Cu}^{2+}(\text{aq})||\text{Ag}^+(\text{aq})|\text{Ag}(\text{s})$$
 - d) Draw a simple diagram of the galvanic cell.
On your diagram, show the direction in which current flows.

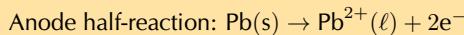


Remember that conventional current flow is in the opposite direction to electron flow.

3. Electrolysis takes place in a solution of molten lead bromide ($PbBr_2$) to produce lead atoms.

- a) Give equations for the half-reactions that take place at the anode and cathode.

Oxidation is a loss of electrons at the anode:

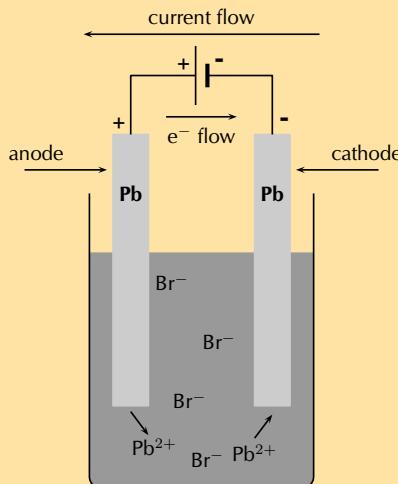


Reduction is a gain of electrons at the cathode:



- b) Draw a simple diagram of the electrolytic cell.

On your diagram, show the direction in which current flows.



Remember that conventional current flow is in the opposite direction to electron flow.

4. Fill in the table below to summarise the information on galvanic and electrolytic cells:

Galvanic cells	Electrolytic cells
spontaneity	
type of energy	
anode	
cathode	
cell set-up	

	Galvanic cells	Electrolytic cells
spontaneity	spontaneous reactions	non-spontaneous reactions
type of energy	converts chemical potential energy to electrical energy	converts electrical energy to chemical potential energy
anode	is negative , oxidation occurs at anode	is positive , oxidation occurs at anode
cathode	is positive , reduction occurs at cathode	is negative , reduction occurs at cathode
cell set-up	two half-cells, one electrode in each, connected by a salt-bridge	one cell, both electrodes in cell, no salt-bridge

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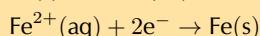
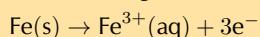
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13.4 Processes in electrochemical cells

Half-cells and half-reactions

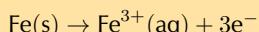
Exercise 13 – 5: Galvanic cells

1. The following half-reactions take place in an electrochemical cell:



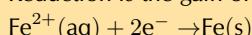
a) Which is the oxidation half-reaction?

Oxidation is the loss of electrons.



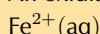
b) Which is the reduction half-reaction?

Reduction is the gain of electrons.



c) Name the oxidising agent.

An oxidising agent causes oxidation and is itself reduced.



d) Name the reducing agent.

A reducing agent causes reduction and is itself oxidised.



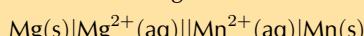
e) Use standard notation to represent this electrochemical cell.

Oxidation is loss at the anode, therefore Fe(s) in oxidation half-reaction is the anode.

Reduction is gain at the cathode, therefore Fe(s) in reduction half-reaction is the cathode.

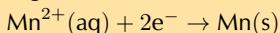


2. For the following cell:



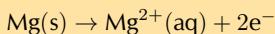
- a) Give the cathode half-reaction.

The cathode is written on the right, therefore manganese is the cathode. Reduction is gain at the cathode.



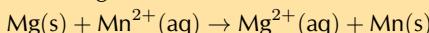
- b) Give the anode half-reaction.

The anode is written on the left, therefore magnesium is the anode. Oxidation is loss at the anode.



- c) Give the overall equation for the electrochemical cell.

The charge of the two half-reactions is balanced.



- d) What metals could be used for the electrodes in this electrochemical cell?

Magnesium metal and manganese metal

- e) Suggest two electrolytes for this electrochemical cell.

Magnesium sulfate and manganese sulfate, or magnesium nitrate and manganese nitrate

- f) In which direction will the current flow?

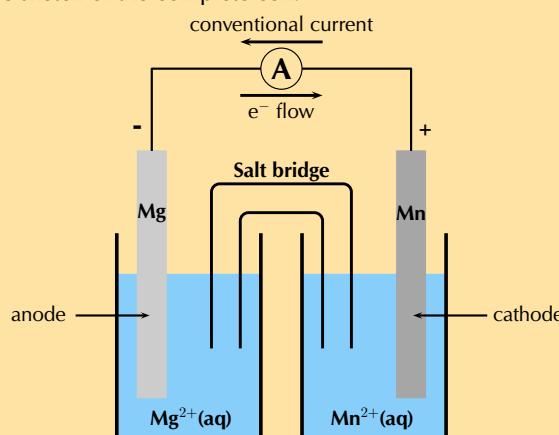
The solid Mg is oxidised to form Mg^{2+} ions at the anode. This makes the anode negative.

The Mn^{2+} ions are reduced to form $\text{Mn}(\text{s})$ at the cathode. This makes the cathode positive.

Electron flow is from negative to positive, so from the anode to the cathode. Conventional current is in the opposite direction (from cathode to anode).

Therefore conventional current is from the manganese plate to the magnesium plate.

- g) Draw a simple sketch of the complete cell.



3. For the following cell:



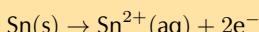
- a) Give the cathode half-reaction.

The cathode is written on the right, therefore silver is the cathode. Reduction is gain at the cathode.



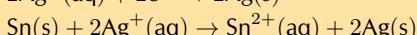
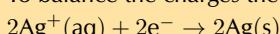
- b) Give the anode half-reaction.

The anode is written on the left, therefore tin is the anode. Oxidation is loss at the anode.

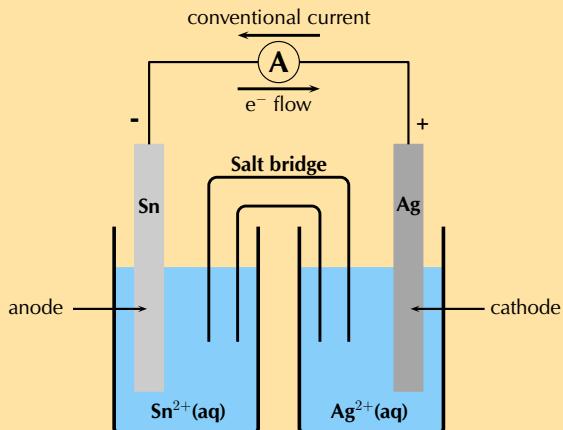


- c) Give the overall equation for the electrochemical cell.

To balance the charges the cathode half-reaction must be multiplied by 2.



d) Draw a simple sketch of the complete cell.



4. More questions. Sign in at Everything Science online and click 'Practise Science'.

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13.6 Standard electrode potentials

Standard electrode potentials

The voltages produced in the ice cube tray experiment may be significantly different from the E° calculations. This is because the salt-bridge is not that effective (being only a piece of string soaked in electrolyte). To get the best results use a saturated sodium nitrate solution when soaking the string.

Exercise 13 – 6: Table of standard electrode potentials

1. Give the standard electrode potential for each of the following metals:

- | | | |
|--------------|---------|-----------|
| a) magnesium | b) lead | c) nickel |
| -2,37 V | -0,13 V | -0,25 V |

2. Refer to the electrode potentials in Table 13.2.

- a) Which of the metals is most likely to be oxidised?

lithium

- b) Which metal ion is most likely to be reduced?

cobalt(III) (fluorine is not a metal)

- c) Which metal is the strongest reducing agent?

lithium

- d) If the other electrode is magnesium, is reduction or oxidation more likely to take place in the copper half-reaction? Explain your answer.

Reduction. The values given are for the reduction half-reactions. Copper is more easily reduced (positive electrode potential) than magnesium (negative electrode potential)

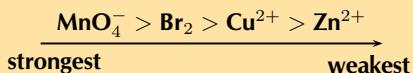
- e) If the other electrode is tin, is reduction or oxidation more likely to take place in the mercury half-reaction? Explain your answer.

Reduction. The values given are for the reduction half-reactions. Mercury is more easily reduced (large, positive electrode potential) than tin (small, negative electrode potential).

3. Use the table of standard electrode potentials to put the following in order from the **strongest oxidising agent** to the **weakest oxidising agent**.



The strongest oxidising agent will be the compound that is most easily reduced. That is the compound with the largest, positive E° value in the table of standard reduction potentials.



4. Look at the following half-reactions:



- a) Which substance is the strongest oxidising agent?

Chlorine is the strongest oxidising agent.

- b) Which substance is the strongest reducing agent?

Calcium is the strongest reducing agent.

5. More questions. Sign in at Everything Science online and click 'Practise Science'.

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Uses of the standard electrode potentials

In the displacement experiment you can use xylene, toluene or carbon disulfide instead of paraffin. These are not great chemicals to work with however. If you do use one of these chemicals make sure the learners research the hazards of the materials they are working with.

Learners are required to work with a concentrated, strong acid. Concentrated, strong acids can cause serious burns. Please remind the learners to be careful and wear the appropriate safety equipment when handling all chemicals, especially concentrated acids. The safety equipment includes gloves, safety glasses and protective clothing.

Exercise 13 – 7: Using standard electrode potentials

1. If silver was added to a solution of copper(II) sulfate, would it displace the copper from the copper(II) sulfate solution? Explain your answer.

No.

We use the table of standard electrode potentials to find the electrode potential for silver and for copper.

Silver: $\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$ ($E^\circ = +0,80 \text{ V}$)

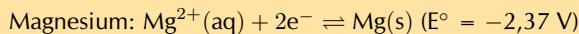
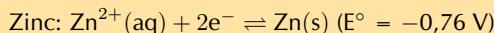
Copper: $\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cu}(\text{s})$ ($E^\circ = +0,34 \text{ V}$)

Silver has a larger, positive E° than copper. Therefore silver is more easily reduced (more easily forms solid metal) than copper (more easily forms copper ions) and will not be able to displace the copper ions from the solution.

2. If zinc is added to a solution of magnesium sulfate, will the zinc displace the magnesium from the solution? Give a detailed explanation for your answer.

No.

We use the table of standard electrode potentials to find the electrode potential for zinc and for magnesium.

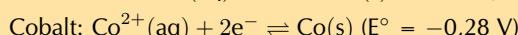
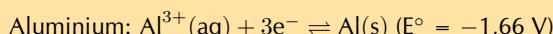


Zinc has a smaller, negative E° than magnesium. Therefore zinc is more easily reduced (more easily forms solid metal) than magnesium (more easily forms magnesium ions) and will not be able to displace the magnesium ions from the solution.

3. If aluminium is added to a solution of cobalt sulfate, will the aluminium displace the cobalt from the solution? Give a detailed explanation for your answer.

Yes.

We use the table of standard electrode potentials to find the electrode potential for aluminium and for cobalt.



Aluminium has a larger, negative E° than cobalt. Therefore aluminium is more easily oxidised (more easily forms aluminium ions) than cobalt (more easily forms solid metal) and will be able to displace the cobalt ions from the solution.

4. More questions. Sign in at Everything Science online and click 'Practise Science'.

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EMF of a cell

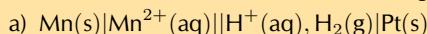
Exercise 13 – 8: Standard electrode potentials

1. In your own words, explain what is meant by the 'electrode potential' of a metal.

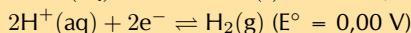
Electrode potential of a metal is the: 'EMF of a cell in which the electrode on the left is a standard hydrogen electrode and the electrode on the right is the electrode in question' - from the IUPAC Gold Book (goldbook.iupac.org)

That is, the standard electrode potential for a metal was measured in a cell where there was a standard hydrogen electrode on the left, and the metal being studied on the right. The EMF measured for that cell is the standard electrode potential of that metal. The positive or negative value obtained depends on whether the metal is more, or less easily reduced than hydrogen.

2. Calculate the EMF for each of the following standard electrochemical cells:

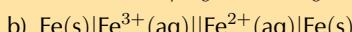


The anode is written on the left, the cathode is written on the right.

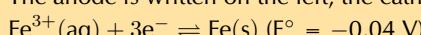


$$\text{E}^\circ_{\text{(cell)}} = \text{E}^\circ_{\text{(cathode)}} - \text{E}^\circ_{\text{(anode)}}$$

$$\text{E}^\circ_{\text{(cell)}} = \text{E}^\circ_{\text{(hydrogen)}} - \text{E}^\circ_{\text{(manganese)}} = 0 - (-1,18) = +1,18 \text{ V}$$



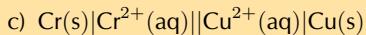
The anode is written on the left, the cathode is written on the right.





$$\text{E}^\circ_{\text{(cell)}} = \text{E}^\circ_{\text{(cathode)}} - \text{E}^\circ_{\text{(anode)}}$$

$$\text{E}^\circ_{\text{(cell)}} = \text{E}^\circ_{\text{(iron(II)}} - \text{E}^\circ_{\text{(iron(III))}} = -0,44 - (-0,04) = -0,4 \text{ V}$$

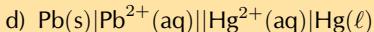


The anode is written on the left, the cathode is written on the right.

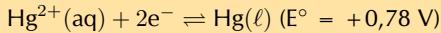


$$\text{E}^\circ_{\text{(cell)}} = \text{E}^\circ_{\text{(cathode)}} - \text{E}^\circ_{\text{(anode)}}$$

$$\text{E}^\circ_{\text{(cell)}} = \text{E}^\circ_{\text{(copper)}} - \text{E}^\circ_{\text{(chromium)}} = +0,34 - (-0,74) = +1,08 \text{ V}$$



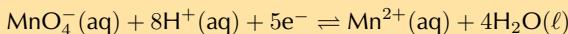
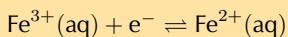
The anode is written on the left, the cathode is written on the right.



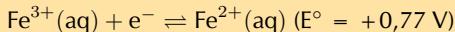
$$\text{E}^\circ_{\text{(cell)}} = \text{E}^\circ_{\text{(cathode)}} - \text{E}^\circ_{\text{(anode)}}$$

$$\text{E}^\circ_{\text{(cell)}} = \text{E}^\circ_{\text{(mercury)}} - \text{E}^\circ_{\text{(lead)}} = +0,78 - (-0,13) = +0,91 \text{ V}$$

3. Given the following two half-reactions:



a) Give the standard electrode potential for each half-reaction.



b) Which reaction takes place at the cathode and which reaction takes place at the anode?

The permanganate ion has a larger, positive E° than an iron(III) ion. Therefore permanganate is more easily reduced. Reduction occurs at the cathode, therefore the permanganate ion is the cathode.

The iron ion is more easily oxidised. Oxidation occurs at the anode, therefore iron(II) ion is the anode.

c) Represent the electrochemical cell using standard notation (the cathode and anode reactions take place at inert platinum electrodes).



d) Calculate the EMF of the cell

$$\text{E}^\circ_{\text{(cell)}} = \text{E}^\circ_{\text{(cathode)}} - \text{E}^\circ_{\text{(anode)}}$$

$$\text{E}^\circ_{\text{(cell)}} = \text{E}^\circ_{\text{(permanganate ion)}} - \text{E}^\circ_{\text{(iron ion)}} = 1,52 - 0,77 = +0,75 \text{ V}$$

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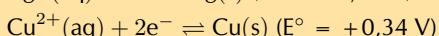
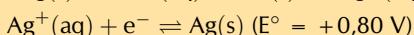
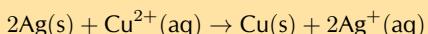


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Spontaneity

Exercise 13 – 9: Predicting spontaneity

1. Will the following reaction take place spontaneously or not? Show all your working.



In the balanced chemical equation solid Ag is oxidised and copper ions are reduced:

Oxidation half-reaction: $\text{Ag(s)} \rightarrow \text{Ag}^+(aq) + \text{e}^-$

Reduction half-reaction: $\text{Cu}^{2+}(aq) + 2\text{e}^- \rightarrow \text{Cu(s)}$

$$E^\circ_{(cell)} = E^\circ_{(reduction)} - E^\circ_{(oxidation)}$$

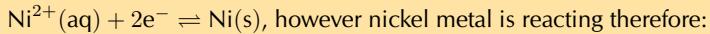
$$E^\circ_{(cell)} = E^\circ_{(copper)} - E^\circ_{(silver)}$$

$$E^\circ_{(cell)} = +0,34 \text{ V} - (+0,80 \text{ V}) = -0,46 \text{ V}$$

The $E^\circ_{(cell)}$ is negative, therefore this reaction is not spontaneous.

2. Nickel metal reacts with an acid, $\text{H}^+(aq)$ to produce hydrogen gas.

- a) Write an equation for the reaction, using the table of electrode potentials.



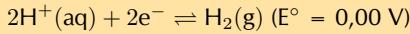
Oxidation half-reaction: $\text{Ni(s)} \rightarrow \text{Ni}^{2+}(aq) + 2\text{e}^-$

Reduction half-reaction: $2\text{H}^+(aq) + 2\text{e}^- \rightarrow \text{H}_2(g)$

Therefore the overall balanced chemical equation is:



- b) Predict whether the reaction will take place spontaneously. Show your working.



$$E^\circ_{(cell)} = E^\circ_{(reduction)} - E^\circ_{(oxidation)}$$

$$E^\circ_{(cell)} = E^\circ_{(hydrogen ion)} - E^\circ_{(nickel)}$$

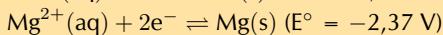
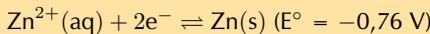
$$E^\circ_{(cell)} = 0,00 \text{ V} - (-0,25 \text{ V}) = +0,25 \text{ V}$$

The $E^\circ_{(cell)}$ is positive, therefore this reaction is spontaneous.

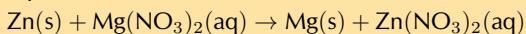
3. Zinc is added to a beaker containing a solution. Will a spontaneous reaction take place if the solution is:

- a) $\text{Mg(NO}_3)_2$

The reaction uses zinc and magnesium:



The reaction involves solid zinc and magnesium ions therefore the overall balanced equation is:



Oxidation half-reaction: $\text{Zn(s)} \rightarrow \text{Zn}^{2+}(aq) + 2\text{e}^-$

Reduction half-reaction: $\text{Mg}^{2+}(aq) + 2\text{e}^- \rightarrow \text{Mg(s)}$

$$E^\circ_{(cell)} = E^\circ_{(reduction)} - E^\circ_{(oxidation)}$$

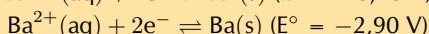
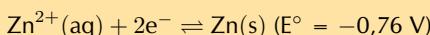
$$E^\circ_{(cell)} = E^\circ_{(magnesium)} - E^\circ_{(zinc)}$$

$$E^\circ_{(cell)} = -2,37 \text{ V} - (-0,76 \text{ V}) = -1,61 \text{ V}$$

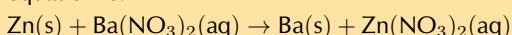
The sign of the $E^\circ_{(cell)}$ is negative, therefore this reaction is not spontaneous.

- b) $\text{Ba(NO}_3)_2$

The reaction uses zinc and barium:



The reaction involves solid zinc and barium ions therefore the overall balanced equation is:



Oxidation half-reaction: $\text{Zn(s)} \rightarrow \text{Zn}^{2+}(aq) + 2\text{e}^-$

Reduction half-reaction: $\text{Ba}^{2+}(aq) + 2\text{e}^- \rightarrow \text{Ba(s)}$

$$E^\circ_{(cell)} = E^\circ_{(reduction)} - E^\circ_{(oxidation)}$$

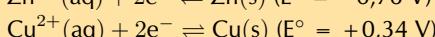
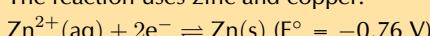
$$E^\circ_{(cell)} = E^\circ_{(barium)} - E^\circ_{(zinc)}$$

$$E^\circ_{(cell)} = -2,90 \text{ V} - (-0,76 \text{ V}) = -2,14 \text{ V}$$

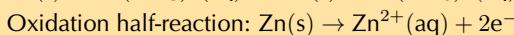
The sign of the $E^\circ_{(cell)}$ is negative, therefore this reaction is not spontaneous.

- c) $\text{Cu(NO}_3)_2$

The reaction uses zinc and copper:



The reaction involves solid zinc and copper ions therefore the overall balanced equation is:



$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(reduction)}} - E^\circ_{\text{(oxidation)}}$$

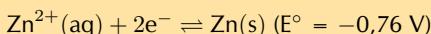
$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(copper)}} - E^\circ_{\text{(zinc)}}$$

$$E^\circ_{\text{(cell)}} = 0,34 \text{ V} - (-0,76 \text{ V}) = +1,1 \text{ V}$$

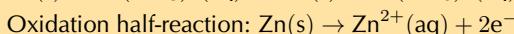
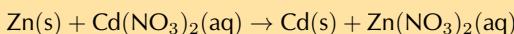
The sign of the $E^\circ_{\text{(cell)}}$ is positive, therefore this reaction is spontaneous.

- d) Cd(NO₃)₂

The reaction uses zinc and cadmium:



The reaction involves solid zinc and cadmium ions therefore the overall balanced equation is:



$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(reduction)}} - E^\circ_{\text{(oxidation)}}$$

$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(cadmium)}} - E^\circ_{\text{(zinc)}}$$

$$E^\circ_{\text{(cell)}} = -0,40 \text{ V} - (-0,76 \text{ V}) = +0,36 \text{ V}$$

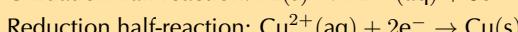
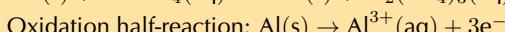
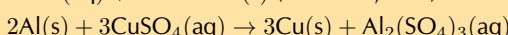
The sign of the $E^\circ_{\text{(cell)}}$ is positive, therefore this reaction is spontaneous.

4. State whether the following solutions can be stored in an aluminium container.

- a) CuSO₄

The solution can be stored in an aluminium container if the displacement of solid aluminium by the metal ions is a non-spontaneous reaction:

The reaction uses aluminium and copper:



$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(reduction)}} - E^\circ_{\text{(oxidation)}}$$

$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(copper)}} - E^\circ_{\text{(aluminium)}}$$

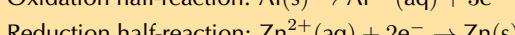
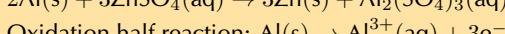
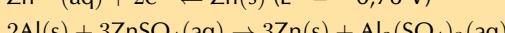
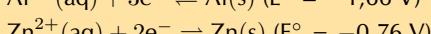
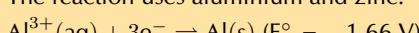
$$E^\circ_{\text{(cell)}} = +0,34 \text{ V} - (-1,66 \text{ V}) = +2,00 \text{ V}$$

The sign of the $E^\circ_{\text{(cell)}}$ is positive so this reaction is spontaneous. Therefore, CuSO₄ cannot be stored in an aluminium container.

- b) ZnSO₄

The solution can be stored in an aluminium container if the displacement of solid aluminium by the metal ions is a non-spontaneous reaction:

The reaction uses aluminium and zinc:



$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(reduction)}} - E^\circ_{\text{(oxidation)}}$$

$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(zinc)}} - E^\circ_{\text{(aluminium)}}$$

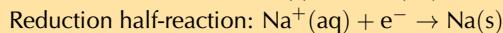
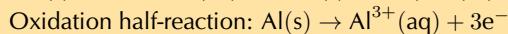
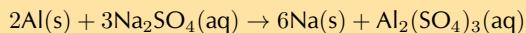
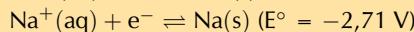
$$E^\circ_{\text{(cell)}} = -0,76 \text{ V} - (-1,66 \text{ V}) = +0,90 \text{ V}$$

The sign of the $E^\circ_{\text{(cell)}}$ is positive so this reaction is spontaneous. Therefore, ZnSO₄ cannot be stored in an aluminium container.

c) NaCl

The solution can be stored in an aluminium container if the displacement of solid aluminium by the metal ions is a non-spontaneous reaction:

The reaction uses aluminium and sodium:



$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(reduction)}} - E^\circ_{\text{(oxidation)}}$$

$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(sodium)}} - E^\circ_{\text{(aluminium)}}$$

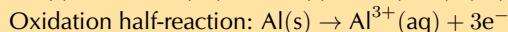
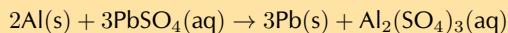
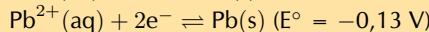
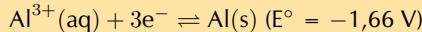
$$E^\circ_{\text{(cell)}} = -2,71 \text{ V} - (-1,66 \text{ V}) = -1,05 \text{ V}$$

The sign of the $E^\circ_{\text{(cell)}}$ is negative so this reaction is not spontaneous. Therefore, NaCl can be stored in an aluminium container.

d) Pb(NO₃)₂

The solution can be stored in an aluminium container if the displacement of solid aluminium by the metal ions is a non-spontaneous reaction:

The reaction uses aluminium and lead:



$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(reduction)}} - E^\circ_{\text{(oxidation)}}$$

$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(lead)}} - E^\circ_{\text{(aluminium)}}$$

$$E^\circ_{\text{(cell)}} = -0,13 \text{ V} - (-1,66 \text{ V}) = +1,53 \text{ V}$$

The sign of the $E^\circ_{\text{(cell)}}$ is positive, so this reaction is spontaneous. Therefore, Pb(NO₃)₂ cannot be stored in an aluminium container.

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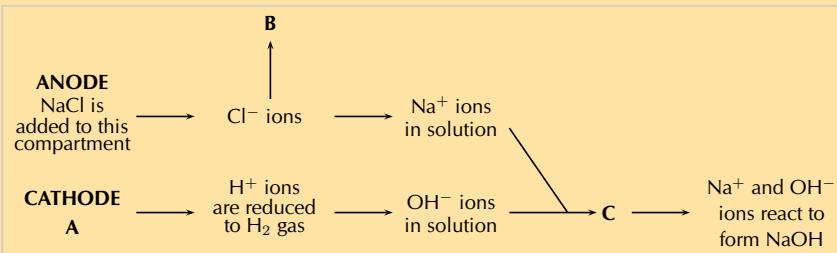
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13.7 Applications of electrochemistry

The chloralkali industry

Exercise 13 – 10: The chloralkali industry

- Refer to the flow diagram, which shows the reactions that take place in the membrane cell, and then answer the questions that follow.



a) What liquid is present in the cathode compartment at A?

Water and dilute NaOH

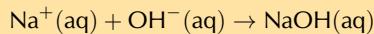
b) Identify the gas that is produced at B.

Chlorine gas

c) Explain one feature of this cell that allows the Na⁺ and OH⁻ ions to react at C.

This type of cell has an ion permeable membrane that allows the positive Na⁺ ions to move from the anode compartment to the cathode compartment and interact with the OH⁻ ions.

d) Give a balanced equation for the reaction that takes place at C.

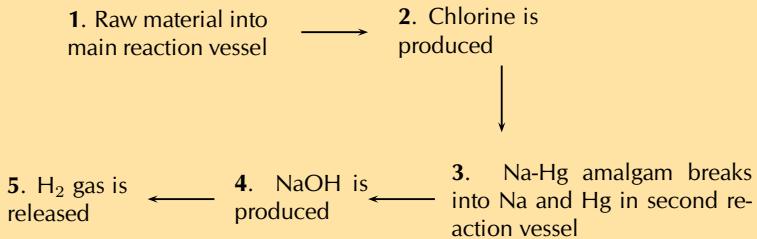


2. Summarise what you have learnt about the three types of cells in the chloralkali industry by completing the table below:

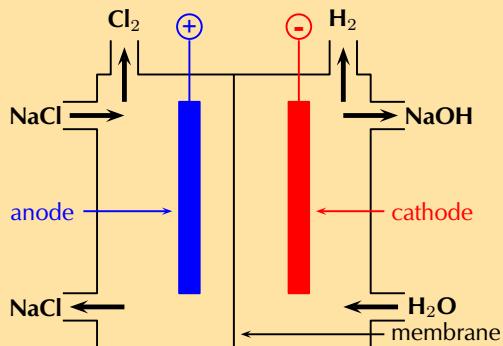
	Mercury cell	Diaphragm cell	Membrane cell
Main raw material			
Mechanism of Cl ₂ and NaOH separation			
Anode reaction			
Cathode reaction			
Purity of NaOH produced			
Purity of Cl ₂ produced			
Energy consumption			
Environmental impact			
Cost of production			

	Mercury cell	Diaphragm cell	Membrane cell
Main raw material	brine	brine	brine
Mechanism of separating Cl ₂ and NaOH	reduction of Na ⁺ to Na in Hg amalgam	use of a porous diaphragm	use of a membrane (charge specific)
Anode reaction	Cl ⁻ ions → Cl ₂ gas	Cl ⁻ ions → Cl ₂ gas	Cl ⁻ ions → Cl ₂ gas
Cathode reaction	$\text{Na}^+ \text{ ions} \rightarrow 2\text{Na}(\text{Hg})$ $2\text{Na}(\text{Hg}) + 2\text{H}_2\text{O}(\ell) \rightarrow 2\text{NaOH}(\text{aq}) + \text{H}_2(\text{g})$	$2\text{Na}^+(\text{aq}) + \text{H}_2\text{O}(\ell) \rightarrow 2\text{NaOH}(\text{aq}) + \text{H}_2(\text{g})$	$2\text{Na}^+(\text{aq}) + \text{H}_2\text{O}(\ell) \rightarrow 2\text{NaOH}(\text{aq}) + \text{H}_2(\text{g})$
Purity of NaOH	low purity	medium purity low concentration	high purity
Purity of Cl ₂	high purity	mixed with O ₂	mixed with O ₂
Energy consumption	high	less than the mercury cell	low energy
Environmental impact	high	lower than the mercury cell	lower than the diaphragm and mercury cell
Cost of production	expensive	expensive, as product must be purified	low production cost

3. The diagram below shows the sequence of steps that take place in the mercury cell.



- a) Name the 'raw material' in step 1.
Aqueous sodium chloride (NaCl, brine)
- b) Give the chemical equation for the reaction that produces chlorine gas in step 2.
 $2\text{Cl}^-(\text{aq}) \rightarrow \text{Cl}_2(\text{g}) + 2\text{e}^-$
- c) What other product is formed in step 2.
sodium mercury amalgam
- d) Name the reactants in step 4.
sodium mercury amalgam and water
4. Approximately 30 million tonnes of chlorine are used throughout the world annually. Chlorine is produced industrially by the electrolysis of brine. The diagram represents a membrane cell used in the production of Cl₂ gas.



- a) What ions are present in the electrolyte in the left hand compartment of the cell?
Chloride ions (Cl⁻) and sodium ions (Na⁺).
- b) Give the equation for the reaction that takes place at the anode.
 $2\text{Cl}^-(\text{aq}) \rightarrow \text{Cl}_2(\text{g}) + 2\text{e}^-$
- c) Give the equation for the reaction that takes place at the cathode and forms a gas.
 $2\text{H}_2\text{O}(\ell) + 2\text{e}^- \rightarrow \text{H}_2(\text{g}) + 2\text{OH}^-(\text{aq})$
- d) What ion passes through the membrane while these reactions are taking place?
Sodium ions
- e) Chlorine is used to purify drinking water and swimming pool water. The substance responsible for this process is the weak acid, hypochlorous acid (HOCl). One way of putting HOCl into a pool is to bubble chlorine gas through the water. Give an equation showing how bubbling Cl₂(g) through water produces HOCl.
 $\text{Cl}_2(\text{g}) + \text{H}_2\text{O}(\ell) \rightarrow \text{HOCl}(\text{aq}) + \text{HCl}(\text{aq})$
- f) A common way of treating pool water is by adding 'granular chlorine'. Granular chlorine consists of the salt calcium hypochlorite, Ca(OCl)₂. Give an equation showing how this salt dissolves in water. Indicate the phase of each substance in the equation.
(IEB Paper 2, 2003)
 $\text{Ca}(\text{OCl})_2(\text{s}) \rightarrow \text{Ca}^{2+}(\text{aq}) + 2\text{OCl}^-(\text{aq})$

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13.8 Chapter summary

Exercise 13 – 11:

1. A cell is set up. There is a negative charge on the anode.

- a) What type of cell is this?

Galvanic cell

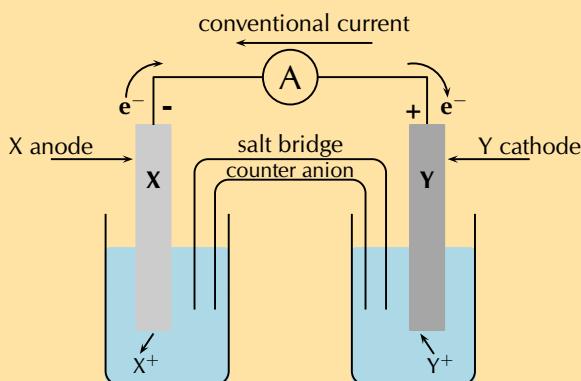
- b) What type of reaction is occurring at the cathode?

Reduction

- c) Can the electrodes have the same reaction potential?

No, a galvanic cell requires two electrodes with different reaction potentials (different metals).

- d) Draw and label a diagram of this cell.



2. For each of the following, say whether the statement is **true** or **false**. If it is false, re-write the statement correctly.

- a) The anode in an electrolytic cell has a negative charge.

False. The anode in an electrolytic cell has a positive charge.

- b) The reaction $2\text{KClO}_3(\text{s}) \rightarrow 2\text{KCl}(\text{s}) + 3\text{O}_2(\text{g})$ is an example of a redox reaction.

True

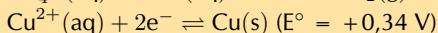
- c) Lead is a stronger oxidising agent than nickel.

True

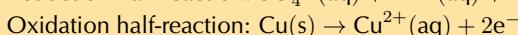
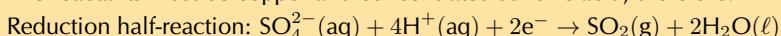
3. Sulfur dioxide gas can be prepared in the laboratory by heating a mixture of copper turnings and concentrated sulfuric acid in a suitable flask.

- a) Derive a balanced ionic equation for this reaction using the half-reactions that take place.

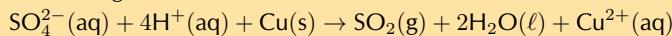
The reaction uses copper and concentrated sulfuric acid and produces sulfur dioxide. Look for a suitable reaction on the table of standard electrode potentials:



The reactants must be copper and concentrated sulfuric acid, therefore:



Adding the two half-reactions together and cancelling out the electrons (the charge balances) gives us:



- b) Give the E° value for the overall reaction.

$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(reduction)}} - E^\circ_{\text{(oxidation)}} = 0,17 - 0,34 = -0,17 \text{ V}$$

- c) Explain why it is necessary to heat the reaction mixture.

The EMF of the cell is negative, so the reaction is non-spontaneous. Therefore, heat will be needed to make the reaction happen.

(IEB Paper 2, 2002)

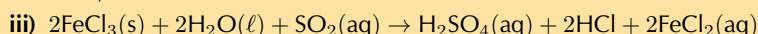
4. For each of the following questions, choose the **one correct** answer.

- a) Which one of the following reactions is a redox reaction?

- $\text{HCl}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\ell)$
- $\text{AgNO}_3(\text{s}) + \text{NaI}(\text{s}) \rightarrow \text{Agl}(\text{s}) + \text{NaNO}_3(\text{s})$
- $2\text{FeCl}_3(\text{aq}) + 2\text{H}_2\text{O}(\ell) + \text{SO}_2(\text{aq}) \rightarrow \text{H}_2\text{SO}_4(\text{aq}) + 2\text{HCl}(\text{aq}) + 2\text{FeCl}_2(\text{aq})$
- $\text{BaCl}_2(\text{s}) + \text{MgSO}_4(\text{s}) \rightarrow \text{MgCl}_2(\text{s}) + \text{BaSO}_4(\text{s})$

(IEB Paper 2, 2003)

Only (iii) has both oxidation and reduction occurring (i.e. a change in the oxidation numbers).



- b) Consider the reaction represented by the following equation:



Which one of the following statements about this reaction is correct?

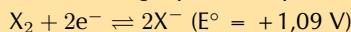
- bromine is oxidised
- bromine acts as a reducing agent
- the iodide ions are oxidised
- iodine acts as a reducing agent

(IEB Paper 2, 2002)

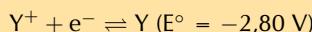
Bromine gains electrons (is reduced), therefore bromine acts as a oxidising agent. Iodide loses electrons (is oxidised), therefore iodide acts as a reducing agent. In the reverse reaction iodine would gain electrons (be reduced) and act as an oxidising agent.

iii) the iodide ions are oxidised

- c) The following equations represent two hypothetical half-reactions:



and



Which one of the following substances from these half-reactions has the greatest tendency to lose electrons?

- X^-
- X_2
- Y
- Y^+

Loss of electrons is oxidation. The larger, negative value will be oxidised more easily. $\text{Y} \rightarrow \text{Y}^+ + \text{e}^-$

iii) Y

- d) Which one of the following redox reactions will **not** occur spontaneously at room temperature?

- $\text{Mn}(\text{s}) + \text{Cu}^{2+}(\text{aq}) \rightarrow \text{Mn}^{2+}(\text{aq}) + \text{Cu}(\text{s})$
- $\text{Fe}^{3+}(\text{aq}) + 3\text{NO}_2(\text{g}) + 3\text{H}_2\text{O}(\ell) \rightarrow \text{Fe}(\text{s}) + 3\text{NO}_3^-(\text{aq}) + 6\text{H}^+(\text{aq})$
- $\text{Zn}(\text{s}) + \text{SO}_4^{2-}(\text{aq}) + 4\text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{SO}_2(\text{g}) + 2\text{H}_2\text{O}(\ell)$
- $5\text{H}_2\text{S}(\text{g}) + 2\text{MnO}_4^-(\text{aq}) + 6\text{H}^+(\text{aq}) \rightarrow 5\text{S}(\text{s}) + 2\text{Mn}^{2+}(\text{aq}) + 8\text{H}_2\text{O}(\ell)$

(DoE Exemplar Paper 2, 2008)

$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(reduction)}} - E^\circ_{\text{(oxidation)}}$$

$$E^\circ_{\text{(cell)}} \text{ for (i)} = E^\circ_{\text{(copper)}} - E^\circ_{\text{(manganese)}} = 0,16 - (-1,18) = +1,34 \text{ V.}$$

Therefore spontaneous.

$$E^\circ_{\text{(cell)}} \text{ for (ii)} = E^\circ_{\text{(iron)}} - E^\circ_{\text{(nitrogen dioxide)}} = (-0,04) - 0,78 = -0,82 \text{ V.}$$

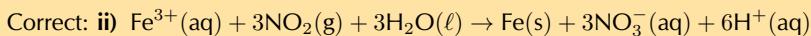
Therefore non-spontaneous.

$$E^\circ_{\text{(cell)}} \text{ for (iii)} = E^\circ_{\text{(sulfate ion)}} - E^\circ_{\text{(zinc)}} = 0,17 - (-0,76) = +0,93 \text{ V.}$$

Therefore spontaneous.

$$E^\circ_{\text{(cell)}} \text{ for (iv)} = E^\circ_{\text{(permanganate ion)}} - E^\circ_{\text{(hydrogen sulfide)}} = 1,52 - 0,14 = +1,38 \text{ V.}$$

Therefore spontaneous.



5. In order to investigate the rate at which a reaction proceeds, a learner places a beaker containing concentrated nitric acid on a sensitive balance. A few pieces of copper metal are dropped into the nitric acid.

- a) Use the relevant half-reactions from the table of standard electrode potentials to derive the balanced net ionic equation for the reaction that takes place in the beaker.

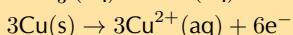
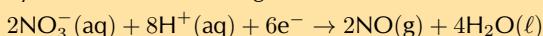
The reaction has nitric acid as a reactant, nitrogen monoxide will be a product. Find a suitable reaction on the table of standard electrode potentials:



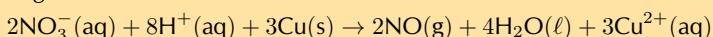
The reaction has solid copper as a reactant, so this must be the oxidation half-reaction:



We need to multiply the reduction half-reaction by 2 and the oxidation half-reaction by 3 to balance the charge:



to get:



- b) What chemical property of nitric acid is illustrated by this reaction?

Nitric acid is being reduced, and can act as an oxidising agent.

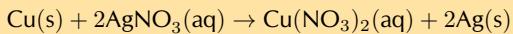
- c) List three observations that this learner would make during the investigation.

(IEB Paper 2, 2005)

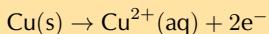
The learner would observe:

- a (brown) gas bubbling in the solution
- a colour change (the solution changing from colourless to green)
- a mass change

6. The following reaction takes place in an electrochemical cell:



- a) Give an equation for the oxidation half-reaction.

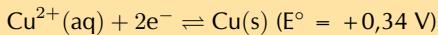


- b) Which metal is used as the anode?

Oxidation is loss at the anode. Therefore copper is the anode.

- c) Determine the EMF of the cell under standard conditions.

(IEB Paper 2, 2003)



$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(reduction)}} - E^\circ_{\text{(oxidation)}}$$

$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(silver)}} - E^\circ_{\text{(copper)}} = 0,80 - 0,34 = 0,46 \text{ V}$$

7. A galvanic cell is constructed by placing a lead rod in a porous pot containing a solution of lead nitrate. The porous pot is then placed in a large aluminium container filled with a solution of aluminium sulfate. The lead rod is then connected to the aluminium container by a copper wire and voltmeter as shown.

a) Define the term *reduction*.

Reduction is the gain of electrons by an element or ion.

b) Write balanced equations for the reactions that take place at...

- the cathode
Lead has a smaller, negative E° ($-0,13$ V) than aluminium ($-1,66$ V). Therefore lead is more likely to be reduced. Reduction is gain of electrons at the cathode.

$$\text{Pb}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Pb}(\text{s})$$
- the anode
Aluminium has a larger, negative E° ($-1,66$ V) than lead ($-0,13$ V). Therefore aluminium is more likely to be oxidised. Oxidation is loss of electrons at the anode.

$$\text{Al}(\text{s}) \rightarrow \text{Al}^{3+}(\text{aq}) + 3\text{e}^-$$

c) Write a balanced net ionic equation for the reaction which takes place in this cell.

Balance the charge by multiplying the reduction half-reaction by 3, and the oxidation half-reaction by 2:

$$3\text{Pb}^{2+}(\text{aq}) + 6\text{e}^- \rightarrow 3\text{Pb}(\text{s})$$

$$2\text{Al}(\text{s}) \rightarrow 2\text{Al}^{3+}(\text{aq}) + 6\text{e}^-$$

Therefore the overall equation is:

$$3\text{Pb}^{2+}(\text{aq}) + 2\text{Al}(\text{s}) \rightarrow 3\text{Pb}(\text{s}) + 2\text{Al}^{3+}(\text{aq})$$

d) In which direction do electrons flow in the copper wire? (Al to Pb or Pb to Al)

In a galvanic cell the anode is negative and the cathode is positive. Therefore electrons flow from the anode to the cathode. From Al to Pb.

e) What are the two functions of the porous pot?

The porous pot allows the flow of ions while also keeping the two solutions separate.

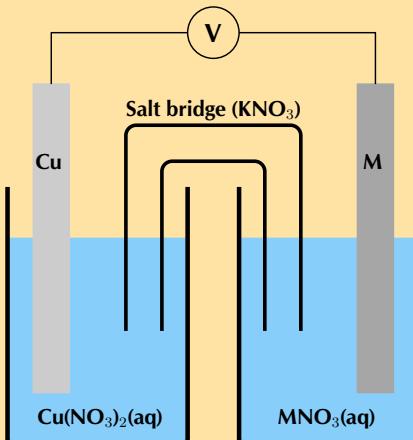
f) Calculate the EMF of this cell under standard conditions.
(IEB Paper 2, 2005)

$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(cathode)}} - E^\circ_{\text{(anode)}}$$

$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(lead)}} - E^\circ_{\text{(aluminium)}} = -0,13 - -1,66 = +1,53 \text{ V}$$

8. An electrochemical cell is made up of a copper electrode in contact with a copper nitrate solution and an electrode made of an unknown metal M in contact with a solution of MNO_3 . A salt bridge containing a KNO_3 solution joins the two half-cells. A voltmeter is connected across the electrodes. Under standard conditions the reading on the voltmeter is $+0,46$ V.

a) Sketch the electrochemical cell.



b) Write down the standard conditions which apply to this electrochemical cell.

Pressure = 101,3 kPa

Concentration = 1 mol.dm⁻³

Temperature = 298 K

c) $\text{Cu(s)} \rightarrow \text{Cu}^{2+}(\text{aq}) + 2\text{e}^-$. Identify the metal M. Show calculations.

$$E^\circ_{\text{(cell)}} = E^\circ_{\text{(reduction)}} - E^\circ_{\text{(oxidation)}}$$



We know the EMF of the cell (that is the reading on the voltmeter), we are also shown that the copper reaction is the oxidation half-reaction.

$$+0,46 = E^\circ_{\text{(reduction)}} - 0,34$$

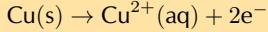
$$E^\circ_{\text{(reduction)}} = 0,46 + 0,34 = +0,80 \text{ V}$$

Now we look at the table of standard potentials to find the unknown metal. The metal is silver (Ag).

d) Use the standard electrode potentials to write down equations for the:

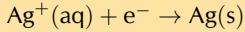
i. anode half-reaction

Oxidation is loss (of electrons) at the anode. Therefore:



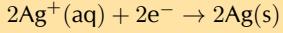
ii. cathode half-reaction

Reduction is gain (of electrons) at the cathode. Therefore:

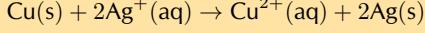


iii. overall cell reaction

To balance the charge the reduction half-reaction (silver) needs to be multiplied by 2:



Therefore:



e) What is the purpose of the salt bridge?

(IEB Paper 2, 2004)

The salt bridge acts as a transfer medium that allows ions to flow through without allowing the different solutions to mix and react. It completes the circuit and maintains the neutrality of the half-cell solutions.

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| 4b. 283Q | 4c. 283R | 4d. 283S | 5. 283T | 6. 283V | 7. 283W |
| 8. 283X | | | | | |



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The chemical industry

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14.1 Introduction

This section studies the use of resources, more specifically phosphate rock, natural gas and other gases (like nitrogen and oxygen) to produce fertilisers to sustain a food supply for people on Earth. The industrial processes that are involved in the manufacturing of fertilisers are studied. The purpose of studying this industry is to make learners aware of the impact of human activities on the environment and our responsibility to use our resources sustainably.

Prior knowledge

This section of work is done at the end of the Grade 12 year and provides an ideal opportunity to revise some of the concepts covered in redox reactions, rates and extent of reactions, acid-base reactions and balancing of equations. The prior knowledge for this chapter includes a general awareness that the chemistry that is done at school has application in industrial processes in South Africa and elsewhere. Two examples that would have been covered in the electrochemistry section, namely the production of chlorine and the recovery of aluminium metal from bauxite, can provide a useful context to study further application of chemistry in real life. These processes can be mentioned in an introductory lesson. Furthermore, this section also builds on learners' prior knowledge of the lithosphere and how we are using these resources on Earth.

CAPS allocates 6 hours for this section. A guideline for lessons is provided below. The suggested lessons can be adapted, depending on the length of the lessons at your school and how much time you have to teach the section.

- **Introduction to the importance of nutrients**

This section covers the importance of nutrients and is necessary to understand the role of fertilisers. In this lesson learners should do the concept map activity as a way of summarising the information. If necessary they should complete the concept map at home.

Learners should start on the investigation of fertiliser use in their area from this first lesson, as it is a long investigation and requires a community survey.

- **The role of fertilisers**

In this lesson the role of fertilisers should be covered. This includes an understanding of the NPK ratios and the specific nutrients found in different fertilisers.

- **The industrial preparation of fertilisers**

This section covers the industrial production of chemicals used in inorganic fertilisers. Included are processes such as the Ostwald and Contact processes. At the end of the section there is a worksheet for the learners to complete. The worksheet, as well as the answer sheet is provided in this book.

This is a long section and, if time allows, should be covered over three lessons. If necessary the worksheet can be given as homework.

- **Alternative sources of fertilisers**

In this lesson learners should understand and be able to name alternative sources of fertilisers. These are from natural sources rather than made industrially. At the end of the lesson they should complete the activity on alternative sources.

The investigation on fertiliser use in their area should be looked at. They should have designed their survey and be collecting their data.

- **Fertilisers and the environment**

Eutrophication is one of the serious effects fertilisers can have on the environment. After going through this section the learners should go through the activity on dealing with the consequences of eutrophication, discussing how best to deal with this problem.

The learners now have enough information to understand the data collected from their community. They should be working on presenting their data on the use of fertiliser in their area and should be able to interpret their findings.

- **Learners work on their investigation in class**

The learners should work on their investigation on the use of fertilisers in their area in class. They should be finishing up their report and their interpretations. This is also a good lesson for consolidation of the entire chapter by going through the end of chapter exercises in preparation for the exams.

14.2 Nutrients

The importance of nutrients

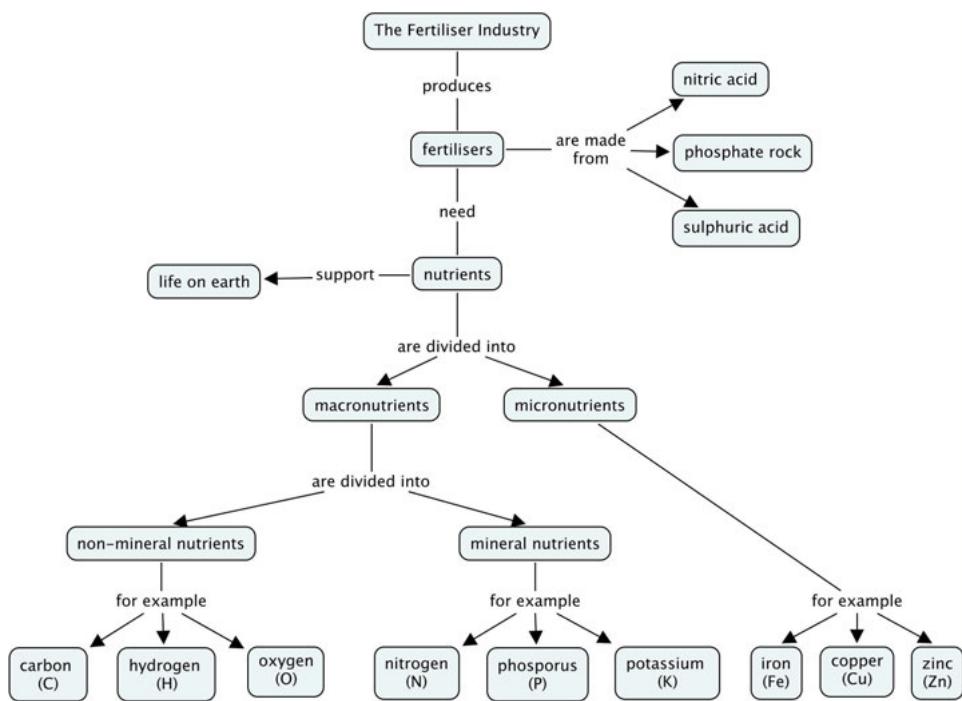
Mindmap activity: The importance of nutrients

Purpose of the activity:

- To summarise the content for study purposes
- To teach learners one method of summarising content

Time allocation: 15 - 20 minutes

The learners can extend this mindmap as they work through this chapter, or design similar ones for each of the sub-sections of this chapter. An example of the type of concept map they should create is given here:



14.3 Fertilisers

The NPK ratio

For the activity learners should work on their own.

Solutions:

1. The NPK ratio for bone meal is $4 : 21 : 1$. $4 + 21 + 1 = 26$.

21 of the 26 units are P.

Assume a 100% purity of the bone meal, so the entire 250 g is nutrients.

$$m(P) = \frac{21}{26} \times 250 \text{ g} = 201,92 \text{ g}$$

2. Assume a 100% purity of the ammonium nitrate, so the entire 200 g is NH_4NO_3 .

The NPK ratio for ammonium nitrate is 34 : 0 : 0. Therefore there is no phosphorus or potassium in the fertiliser.

$$m(\text{NH}_4\text{NO}_3) = 200 \text{ g}$$

$$M(\text{NH}_4\text{NO}_3) = (2 \times 14,0 + 4 \times 1,01 + 3 \times 16,0) \text{ g.mol}^{-1} = 80,04 \text{ g.mol}^{-1}$$

$$n(\text{NH}_4\text{NO}_3) = \frac{m \text{ (g)}}{M \text{ (g.mol}^{-1})} = \frac{200 \text{ g}}{80,04 \text{ g.mol}^{-1}} = 2,5 \text{ mol}$$

For every 1 mole of NH_4NO_3 there are 2 moles of N.

$$n(N) = 2 \times 2,5 \text{ mol} = 5 \text{ mol}$$

3. The NPK ratio for seaweed is 1 : 1 : 5. $1 + 1 + 5 = 7$.

5 of the 7 units are postassium (K).

Assume a 100% purity of the seaweed, so the entire 100 g is nutrients.

$$m(K) = \frac{5}{7} \times 100 \text{ g} = 71,4 \text{ g}$$

4. 40% of the sample is nutrients. The mass of nutrients in the sample is: $0,4 \times 100 \text{ g} = 40 \text{ g}$

The N : $\text{P}_2\text{O}_5\text{K}_2\text{O}$ ratio is 5 : 1 : 2. $5 + 1 + 2 = 8$.

2 of the 8 units are K_2O .

$$m(\text{K}_2\text{O}) = \frac{2}{8} \times 40 \text{ g} = 10 \text{ g}$$

$$M(\text{K}_2\text{O}) = (2 \times 39,1 + 16,0) \text{ g.mol}^{-1} = 94,2 \text{ g.mol}^{-1}$$

$$n(\text{K}_2\text{O}) = \frac{10 \text{ g}}{94,2 \text{ g.mol}^{-1}} = 0,106 \text{ mol}$$

For every 1 mole of K_2O there are 2 moles of K.

$$n(K) = 2 \times 0,106 \text{ mol} = 0,21 \text{ mol}$$

Exercise 14 – 1: The role of fertilisers

1. A starter fertiliser is usually used when seeds or young plants are planted.

Use Table 14.3 to answer the following questions.

- a) What is the NPK ratio of a starter fertiliser?

18:24:6

- b) Which nutrient is present in the lowest concentration?

potassium (K)

- c) Do you think an equal NPK fertiliser will be a good starter fertiliser for new plants? Explain your answer using information from Tables 14.1 - 14.4.

No. New plants need nitrogen (to boost plant growth) and phosphorus (for root growth). An equal NPK fertiliser has equal amounts of N, P and K and therefore would not promote new plant growth as much. An actual starter fertiliser contains much higher amounts of nitrogen and phosphorus (18:24:6).

2. Do you think bone meal is a good fertiliser to use for flowering plants? Explain your answer using Tables 14.1 - 14.4.

Yes. The NPK ratio of bone meal is 4 : 21 : 1. Bone meal has a high phosphorus (P) content (21 of 26 units are P). Phosphorus is good for flowering plants so a high phosphorus content would make bone meal a good fertiliser to use.

3. Determine the mass of each of the nutrient components in a 600 g bag of the fertiliser shown in Figure 14.2 (it is produced in South Africa).

The NPK mass ratio is 6 : 1 : 5 (22). $6 + 1 + 5 = 12$.

Determine the mass of the total nutrients in the fertiliser sample:

22% of the sample contains nutrients, therefore:

The mass of nutrients in the sample = $0,22 \times 600 \text{ g} = 132 \text{ g}$

6 of the 12 units are nitrogen, therefore:

$$m(N) = \frac{6}{12} \times 132 \text{ g} = 66 \text{ g}$$

1 of the 12 units is phosphorus, therefore:

$$m(P) = \frac{1}{12} \times 132 \text{ g} = 11 \text{ g}$$

5 of the 12 units are potassium, therefore:

$$m(K) = \frac{5}{12} \times 132 \text{ g} = 55 \text{ g}$$

4. You have determined that your vegetable garden will need 12 g of nitrogen. The fertiliser you have has 4:2:3 (40) written on the packet. How many grams of fertiliser will you need for your garden?

The NPK mass ratio is 4 : 2 : 3 (40). $4 + 2 + 3 = 9$.

4 of the 9 units are nitrogen and 12 g of nitrogen is needed, therefore:

$$\frac{4}{9} \times \text{total mass of nutrients required} = 12 \text{ g}.$$

$$\text{Total mass of nutrients required} = 12 \text{ g} \times \frac{9}{4} = 27 \text{ g}$$

40% of the sample contains nutrients, therefore:

40% of fertiliser required = 27 g

$$\text{Total fertiliser required} = \frac{27 \text{ g}}{0,40} = 67,5 \text{ g.}$$

5. How many moles of potassium is present in 150 g of commercial fertiliser with the N:P₂O₅:K₂O mass ratio of 1:2:5.

The N:P₂O₅:K₂O ratio is 1 : 2 : 5. $1 + 2 + 5 = 8$.

No percentage purity is given, therefore assume 100% purity. So the entire 15 g is nutrients.

5 units of the 8 units are K₂O

$$M(K_2O) = (2 \times 39,1 + 16,0) \text{ g.mol}^{-1} = 94,2 \text{ g.mol}^{-1}$$

$$m(K_2O) = \frac{5}{8} \times 150 \text{ g} = 93,75 \text{ g.}$$

$$n(K_2O) = \frac{m \text{ (g)}}{M \text{ (g.mol}^{-1})} = \frac{93,75 \text{ g}}{94,2 \text{ g.mol}^{-1}} = 0,995 \text{ mol}$$

For every 1 mole of K₂O there are 2 moles of K atoms.

Therefore, n(K) = $2 \times 0,995 \text{ mol} = 1,99 \text{ mol}$

6. More questions. Sign in at Everything Science online and click 'Practise Science'.

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1. 283Y 2. 283Z 3. 2842 4. 2843 5. 2844



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14.4 The fertiliser industry

The industrial production of fertilisers

This section is content heavy and an important sub-section in this chapter. It should be linked to rate of reactions, equilibrium and acid-base reactions done earlier in Grade 12.

Two lessons are allocated, but if three are available it would be advisable to spend this extra time on this sub-section (although the depth of information provided here is not required from the learners).

For this section a **poster**

https://vula.uct.ac.za/access/content/group/9eafe770-4c41-4742-a414-0df36366abe6/Chem%20Ind%20Resource%20Pack/html/teachers-guide/posters/F_Poster.pdf

an **animation**

<https://vula.uct.ac.za/access/content/group/9eafe770-4c41-4742-a414-0df36366abe6/Chem%20Ind%20Resource%20Pack/html/animations/Fertilisers.swf>

and accompanying **worksheet**

https://vula.uct.ac.za/access/content/group/9eafe770-4c41-4742-a414-0df36366abe6/Chem%20Ind%20Resource%20Pack/html/teachers-guide/AnimationMemos/TG_A_M_F.pdf are available.

These can be used as an introduction to the section as well as a classwork activity. Play the animation once or twice without the learners writing anything, then hand out the worksheet, and play the animation again so that learners can complete the worksheet.

The answers to the fertiliser animation worksheet are available.

Fertiliser animation worksheet memo

https://vula.uct.ac.za/access/content/group/9eafe770-4c41-4742-a414-0df36366abe6/Chem%20Ind%20Resource%20Pack/html/teachers-guide/AnimationMemos/TG_A_M_F.pdf

Images of the worksheet and the memo have also been included in the teachers guide. You may print out the worksheet for your learners.

FERTILISERS

Overview

1 Why is nitrogen important to plants?

2 In what forms can plants absorb nitrogen?

3 Complete to summarise the industrial processes:

Process	Reactants	Products of step 1	Products of step 2	Final products
Haber			not applicable	
Ostwald				
Contact				

Haber Process

4 What is the purpose of the Haber Process?

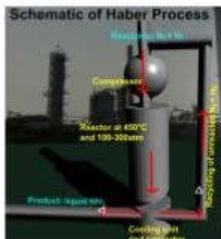
To produce _____

from _____ and _____.

5 Write a balanced equation for the Haber Process's reversible reaction:



6 Name some uses of ammonia.



7 Name two conditions which must be met for a reaction to reach equilibrium.

8 Name two characteristics of equilibrium.

9 In the Haber Process an iron oxide catalyst is usually used. Ruthenium can also be used. What does a catalyst do in a reaction, and how does it do this?

FERTILISERS

- 10 Circle the correct option (True / False) for each of the following:
- i A catalyst speeds up the Haber Process's forward reaction more than the reverse. True False
 - ii A catalyst will cause more product to be formed. True False
 - iii A catalyst will decrease the time it takes to reach equilibrium because it speeds up both forward and reverse reactions. True False
 - iv A catalyst speeds both forward and reverse reactions equally. True False

- 11 Link each element from Column A with its corresponding element in Column B.
Write the letter from A next to each item in B in the last column.

Column A	Column B	A
a dynamic equilibrium	absorbs heat	_____
b endothermic	a measure of the average kinetic energy of particles	_____
c exothermic	disturbs equilibrium, favours increased crowding: more molecules	_____
d Le Chatelier's principle	273 K and 101,3 kPa	_____
e decrease in pressure	disturbs equilibrium, favours exothermic reaction	_____
f increase in pressure	releases heat	_____
g removing heat	a state in which forward and reverse reactions occur at equal rates	_____
h adding heat	force per area, in gases related to rate of particle collisions	_____
i temperature	disturbs equilibrium, favours decreased crowding, fewer molecules	_____
j pressure	disturbs equilibrium, favours endothermic reaction	_____
k STP	when a system which is in equilibrium is disturbed, it will respond in such a way as to counteract the disturbance	_____

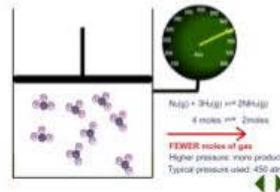
Le Chatelier: influence of pressure

Le Chatelier: Effect of pressure

- 12 Complete the explanation by filling the gaps or choosing from the options. Do this before, or after, but not during, watching the animations. Mark during re-watching.

Increased pressure

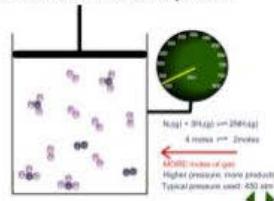
According to _____ principle, when a system which is in equilibrium is disturbed, it will respond in such a way as to _____ the disturbance. An increase in pressure [de/in]creases the crowding of gaseous molecules. The system will respond by [de/in]creasing their crowding. Crowding is decreased in gases when [fewer/more] molecules are formed. In the Haber Process the [forward/reverse] reaction makes fewer molecules than the [forward/reverse] reaction. In the forward reaction _____ molecules of ammonia are made from every _____ molecules of reactants (_____ N₂ and _____ H₂ molecules). Consequently, an increase in pressure _____ equilibrium for a while by making the [forward/reverse] reaction occur at a higher rate than the [forward/reverse] reaction. This causes [more/less] ammonia to be formed and [more/less] nitrogen and hydrogen. After a while a new dynamic equilibrium is reached. The rates of forward and reverse reactions are again _____ to one another, and the amounts of reactants and products will [change/remain constant]. However, compared to before the pressure was applied, there will now be [more/less] ammonia present at equilibrium. The equilibrium constant value, K_c, however, will be [higher than/lower than/the same as] it was in the original equilibrium.



Decreased pressure

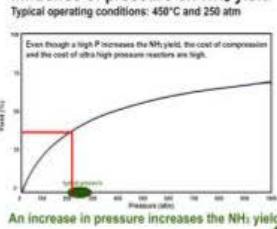
Decreasing pressure [de/in]creases the crowding of gaseous molecules. The system will respond by [de/in]creasing their crowding. Crowding can be increased by forming [fewer/more] molecules. In the Haber Process, that means that for a while the [forward/reverse] reaction will occur at a higher rate than the [forward/reverse] reaction. The reverse reaction changes every _____ molecules of ammonia into _____ molecules (_____ nitrogen and _____ hydrogen molecules). This causes the amount of ammonia present to [de/in]crease and the amount of nitrogen and hydrogen to [de/in]crease. While this is happening the system [is/is not] in equilibrium. After a while a new dynamic equilibrium will be reached, in which the rates of both forward and reverse reactions will _____ one another, and the amounts of reactants and products will remain _____. However, compared to before the pressure was decreased, there will now be [more/less] ammonia present at equilibrium. The equilibrium constant value, K_c , however, will be [higher than/lower than/the same as] it was in the original equilibrium.

Le Chatelier: influence of pressure



Optimum pressure

In the Haber Process, we want to make as much _____ as possible. We want the dynamic equilibrium to be such that a lot of [reactant/product] is formed. A(n) [de/in]crease in pressure will cause more products to form. We need as [low/high] a pressure as it is safe and economical to use. We say we need to use an _____ pressure: the pressure for which we get a good yield for a reasonable price while still being safe. Pressures between 200 and 300 atmospheres are typically used in the Haber Process.

Influence of pressure on NH₃ yield

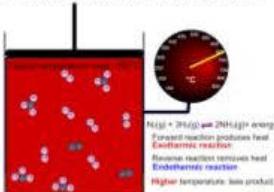
Le Chatelier: Effect of temperature

- 13 Complete the explanation by filling the gaps or choosing from the options. Do this before, or after, but not during, watching the animations.
Mark during re-watching.

Heating

Heating a reaction up increases the _____ energy of the particles, and so causes them to react more [slowly/rapidly] with one another. Additionally, heat can have an effect on disturbing the _____ of a reaction. In the Haber Process the forward reaction is [exo/endo]thermic and the reverse is [exo/endo]thermic. This means that as nitrogen and hydrogen react with one another to form ammonia, heat is [absorbed/released], but as ammonia breaks up into hydrogen and nitrogen, heat is [absorbed/released]. According to Le Chatelier's principle, when a system which is in equilibrium is disturbed, it will respond in such a way as to counteract the disturbance. So if heat is added to a system in the Haber Process, the [exo/endo]thermic [forward/reverse] reaction is favoured to [absorb/release] some of that heat and so [cool the system back down/heat the system back up]. Both the forward and reverse reactions occur at [lower/higher] rates than before the heat was added, due to the additional kinetic energy of all the particles, but the [forward/reverse] reaction will have been speeded up to a greater extent than the [forward/reverse] reaction. So for a while, the system will not be in _____

Le Chatelier: Influence of Temperature



FERTILISERS

as the [forward/reverse] reaction occurs more rapidly than the [forward/reverse] reaction. This will [in/de]crease the amount of ammonia present, and [in/de]crease the amount of hydrogen and nitrogen. After a while a new dynamic equilibrium is reached. The rates of forward and reverse reactions are again _____ to one another, and the amounts of reactants and products will remain _____. However, compared to before the heat was added, there will now be [less/more] ammonia present at equilibrium. A new equilibrium constant, K_c , [higher than/lower than/the same as] that of the original equilibrium, is reached.

Cooling

Cooling a system that is in equilibrium has two effects. Firstly, by [de/in]creasing the kinetic energy of all the molecules, it [reduces/increases] the rates of both the forward and reverse reactions. Secondly, it has the effect of disturbing the _____ by favouring the [exo/endo]thermic reaction until a new equilibrium is reached with [the same/a different] equilibrium constant.

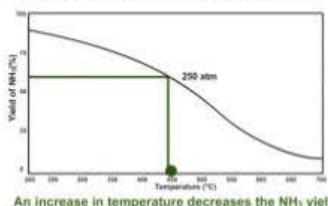
If heat is removed from a system in the Haber Process, the [exo/endo]thermic [forward/reverse] reaction is favoured to [cool the system back down/heat the system back up]. For a while, the system will not be in _____ as the [forward/reverse] reaction occurs more rapidly than the [forward/reverse] reaction. This will [in/de]crease the amount of ammonia present, and [in/de]crease the amount of hydrogen and nitrogen. After a while a new dynamic equilibrium is reached. The rates of forward and reverse reactions are again _____ to one another, and the amounts of reactants and products will remain _____. However, compared to before the system was cooled, there will now be [less/more] ammonia present at equilibrium. A new equilibrium constant, K_c , [higher than/lower than/the same as] that of the original equilibrium, is reached.

Optimum temperature

In the Haber Process, we want to get a high ammonia yield. We want a dynamic equilibrium which makes as much ammonia product as possible. Consequently, we need to use a fairly [high/low] temperature. However, this causes a problem, namely _____.

Therefore, a compromise is made, and a temperature of approximately 450°C is often used.

Influence of temperature on NH_3 yield
Typical operating conditions: 450°C and 250 atm



Units of pressure and temperature

14 Complete for units of pressure.

Name	Unit	Pressure at sea level at 0°C
	Symbol	

15 Kelvin is the SI (Standard International) unit for temperature. Complete for conversions.

Temperature in degrees Celsius (°C)	Temperature in Kelvin (K)
0	0
100	200
25	

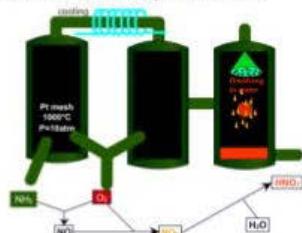
Ostwald Process

16 What is the purpose of the Ostwald Process?

To produce _____ from _____.

17 How is the product of the Ostwald Process useful for the fertiliser industry?

Ostwald Process to produce HNO₃



18 Why doesn't it matter that the platinum catalyst used is very expensive?

19 Complete.

Step 1	Step 2	Step 3
_____ + _____ ↓ catalyst _____	_____ + _____ ↓ _____	_____ + _____ ↓ _____

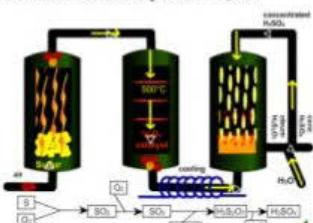
Contact Process

20 What is the purpose of the Contact Process?

To produce _____ from _____.

21 Name some uses of sulfuric acid.

Contact Process to produce H₂SO₄



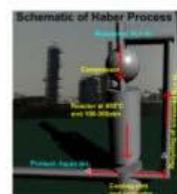
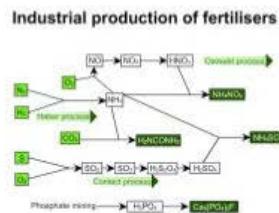
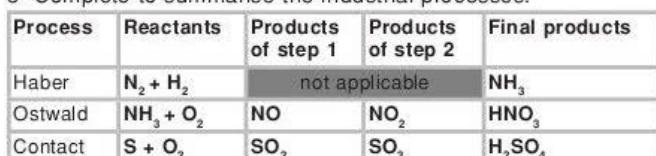
22 Complete.

Step 1	Step 2	Step 3	Step 4
_____ + _____ ↓ _____	_____ + _____ ↓ catalyst _____	_____ + _____ ↓ _____	_____ + _____ ↓ _____

FERTILISERS MEMO

Overview

- 1 Why is nitrogen important to plants? **Nitrogen is found in all proteins, and so it is an essential nutrient.**
 - 2 In what forms can plants absorb nitrogen?
Dissolved urea, nitrate, nitrite and ammonium ions.
 - 3 Complete to summarise the industrial processes.



Haber Process

- 4 What is the purpose of the Haber Process?
To produce **ammonia** (NH_3) from **nitrogen** (N_2) and **hydrogen** (H_2).
5 Write a balanced equation for the Haber Process's reversible reaction. $\text{N}_2 + 3\text{H}_2 \rightleftharpoons 2\text{NH}_3$
6 Name some uses of ammonia. **As a cleaning agent.** **As a coolant in some air conditioners.** **To manufacture nitrogen fertilisers.**
7 Name two conditions which must be met for a reaction to reach equilibrium.
- **reversible reaction** - **closed system**
8 Name two characteristics of equilibrium.
- **rates of forward and reverse reactions are equal to one another**
- **the concentrations of reactants and products remain constant**
9 In the Haber Process an iron oxide catalyst is usually used. Ruthenium can also be used. What does a catalyst do to a reaction, and how does it do this? **It speeds up a reaction by lowering its activation energy. It does this by serving as a binding site on which the reaction can occur.**
10 Circle the correct option (True / False) for each of the following.
i A catalyst speeds up the Haber Process's forward reaction more than the reverse. [True / False]
ii A catalyst will cause more product to be formed. [True / False]
iii A catalyst will decrease the time it takes to reach equilibrium because it speeds up both forward and reverse reactions. [True / False]
iv A catalyst speeds both forward and reverse reactions equally [True / False]

11 Link each element from Column A with its corresponding element in Column B.

Write the letter from A next to each item in B in the last column.

Column A	Column B	
a dynamic equilibrium	absorbs heat	A
b endothermic	a measure of the average kinetic energy of particles	b
c exothermic	disturbs equilibrium, favours increased crowding, more molecules	i
d Le Chatelier's principle	273 K and 101,3 kPa	e
e decrease in pressure	disturbs equilibrium, favours exothermic reaction	k
f increase in pressure	releases heat	g
g removing heat	a state in which forward and reverse reactions occur at equal rates	c
h adding heat	force per area, in gases related to rate of particle collisions	a
i temperature	disturbs equilibrium, favours decreased crowding, fewer molecules	j
j pressure	disturbs equilibrium, favours endothermic reaction	f
k STP	when a system which is in equilibrium is disturbed, it will respond in such a way as to counteract the disturbance	h

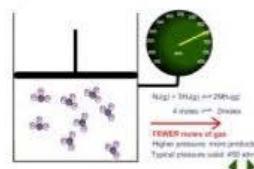
Le Chatelier: Effect of pressure

12 Complete the explanation by filling the gaps or choosing from the options. Do this before, or after, but not during, watching the animations. Mark during re-watching.

Increased pressure

According to **Le Chatelier's** principle, when a system which is in equilibrium is disturbed, it will respond in such a way as to **counteract** the disturbance. An increase in pressure [**de/in**]creases the crowding of gaseous molecules. The system will respond by [**de/in**]creasing their crowding. Crowding is decreased in gases when [**fewer/more**] molecules are formed. In the Haber Process the [**forward/reverse**] reaction makes fewer molecules than the [**forward/reverse**] reaction. In the forward reaction **2** molecules of ammonia are made from every **4** molecules of reactants (**1 N₂** and **3 H₂** molecules). Consequently, an increase in pressure **disturbs** equilibrium for a while by making the [**forward/reverse**] reaction occur at a higher rate than the [**forward/reverse**] reaction. This causes [**more/less**] ammonia to be formed and [**more/less**] nitrogen and hydrogen. After a while a new dynamic equilibrium is reached. The rates of forward and reverse reactions are again **equal** to one another, and the amounts of reactants and products will [**change/remain constant**]. However, compared to before the pressure was applied, there will now be [**more/less**] ammonia present at equilibrium. The equilibrium constant value, K_c, however, will be [higher than/lower than/**the same as**] it was in the original equilibrium.

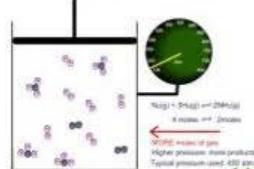
Le Chatelier: Influence of pressure



Decreased pressure

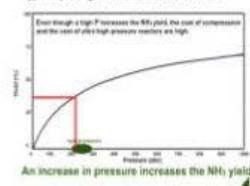
Decreasing pressure [**de/in**]creases the crowding of gaseous molecules. The system will respond by [**de/in**]creasing their crowding. Crowding can be increased by forming [**fewer/more**] molecules. In the Haber Process, that means that for a while the [**forward/reverse**] reaction will occur at a higher rate than the [**forward/reverse**] reaction. The reverse reaction changes every **2** molecules of ammonia into **4** molecules (**1** nitrogen and **3** hydrogen molecules). This causes the amount of ammonia present to [**de/in**]crease and the amount of nitrogen and hydrogen to [**de/in**]crease. While this is happening the system [**is/is not**] in equilibrium. After a while a new dynamic equilibrium will be reached, in which the rates of both forward and reverse reactions will **equal** one another, and the amounts of reactants and products will remain **constant**. However, compared to before the pressure was decreased, there will now be [**more/less**] ammonia present at equilibrium. The equilibrium constant value, K_c, however, will be [higher than/lower than/**the same as**] it was in the original equilibrium.

Le Chatelier: Influence of pressure



Optimum pressure

In the Haber Process, we want to make as much **ammonia** as possible. We want the dynamic equilibrium to be such that a lot of [**reactant/product**] is formed. A(n) [**de/in**]crease in pressure will cause more products to form. We need as [**low/high**] a pressure as it is safe and economical to use. We say we need to use an **optimal** pressure: the pressure for which we get a good yield for a reasonable price while still being safe. Pressures between **200** and **300** atmospheres are typically used in the Haber Process.

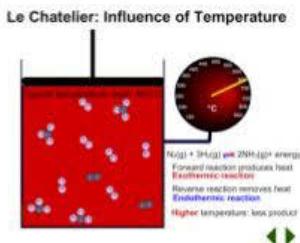
Influence of pressure on NH₃ yield
Typical operating conditions: 450°C and 250 atm

Le Chatelier: Effect of temperature

- 13 Complete the explanation by filling the gaps or choosing from the options. Do this before, or after, but not during, watching the animations. Mark during re-watching.

Heating

Heating a reaction up increases the **kinetic** energy of the particles, and so causes them to react more [slowly/**rapidly**] with one another. Additionally, heat can have an effect on disturbing the **equilibrium** of a reaction.



In the Haber Process the forward reaction is [exo/endo]thermic and the reverse is [exo/endo]thermic. This means that as nitrogen and hydrogen react with one another to form ammonia, heat is [absorbed/released], but as ammonia breaks up into hydrogen and nitrogen, heat is [absorbed/released]. According to Le Chatelier's principle, when a system which is in equilibrium is disturbed, it will respond in such a way as to counteract the disturbance. So if heat is added to a system in the Haber Process, the [exo/endo]thermic [forward/reverse] reaction is favoured to [absorb/release] some of that heat and so [cool the system back down/heat the system back up]. Both the forward and reverse reactions occur at [lower/higher] rates than before the heat was added, due to the additional kinetic energy of all the particles, but the [forward/reverse] reaction will have been speeded up to a greater extent than the [forward/reverse] reaction. So for a while, the system will not be in **equilibrium** as the [forward/reverse] reaction occurs more rapidly than the [forward/reverse] reaction. This will [in/de]crease the amount of ammonia present, and [in/de]crease the amount of hydrogen and nitrogen. After a while a new dynamic equilibrium is reached. The rates of forward and reverse reactions are again **equal** to one another, and the amounts of reactants and products will remain **constant**. However, compared to before the heat was added, there will now be [less/more] ammonia present at equilibrium. A new equilibrium constant, K_c , [higher than/lower than/the same as] that of the original equilibrium, is reached.

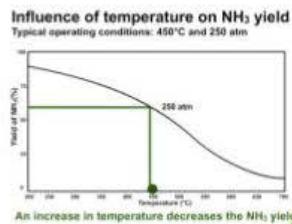
Cooling

Cooling a system that is in equilibrium has two effects. Firstly, by [de/in]creasing the kinetic energy of all the molecules, it [reduces/increases] the rates of both the forward and reverse reactions. Secondly, it has the effect of disturbing the **equilibrium** by favouring the [exo/endo]thermic reaction until a new equilibrium is reached with [the same/a different] equilibrium constant.

If heat is removed from a system in the Haber Process, the [exo/endo]thermic [forward/reverse] reaction is favoured to [cool the system back down/heat the system back up]. For a while, the system will not be in **equilibrium** as the [forward/reverse] reaction occurs more rapidly than the [forward/reverse] reaction. This will [in/de]crease the amount of ammonia present, and [in/de]crease the amount of hydrogen and nitrogen. After a while a new dynamic equilibrium is reached. The rates of forward and reverse reactions are again **equal** to one another, and the amounts of reactants and products will remain **constant**. However, compared to before the system was cooled, there will now be [less/more] ammonia present at equilibrium. A new equilibrium constant, K_c , [higher than/lower than/the same as] that of the original equilibrium, is reached.

Optimum temperature

In the Haber Process, we want to get a high ammonia yield. We want a dynamic equilibrium which makes as much ammonia product as possible. Consequently, we need to use a fairly [high/low] temperature. However, this causes a problem, namely it **causes both reactions to be slow, and so it takes a long time for equilibrium to be reached**. Therefore, a compromise is made, and a temperature of approximately 450°C is often used.

**Units of pressure and temperature**

14 Complete for units of pressure.

Unit		Pressure at sea level at 0°C
Name	Symbol	
bar	bar	1 bar
atmospheres	atm	1 atm
kilopascals	kPa	101,3 kPa
millimeters mercury	mm Hg	760 mm Hg

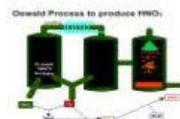
15 Kelvin is the SI (Standard International) unit for temperature. Complete for conversions.

Temperature in degrees Celsius (°C)	Temperature in Kelvin (K)
0	273
-273	0
100	373
-27	200
25	298

Ostwald Process

16 What is the purpose of the Ostwald Process?

To produce **nitric acid (HNO_3)** from **ammonia (NH_3)**.



17 How is the product of the Ostwald Process useful for the fertiliser industry?

Nitric acid can be used to make nitrate fertilisers.

18 Why doesn't it matter that the platinum catalyst used is very expensive?

It can be used over and over again because it is not used up. Catalysts speed up reactions without themselves being changed in the process.

Complete.

Step 1	Step 2	Step 3
$\text{NH}_3 + \text{O}_2$ ↓ platinum catalyst NO	$\text{NO} + \text{O}_2$ ↓ NO_2	$\text{NO}_2 + \text{H}_2\text{O}$ ↓ HNO_3

Contact Process

20 What is the purpose of the Contact Process?

To produce **sulfuric acid (H_2SO_4)** from $\text{S} + \text{O}_2$.



21 Name some uses of sulfuric acid. **manufacture of fertilisers, electrolyte in car batteries, as a dehydrating (a drying) agent**

22 Complete.

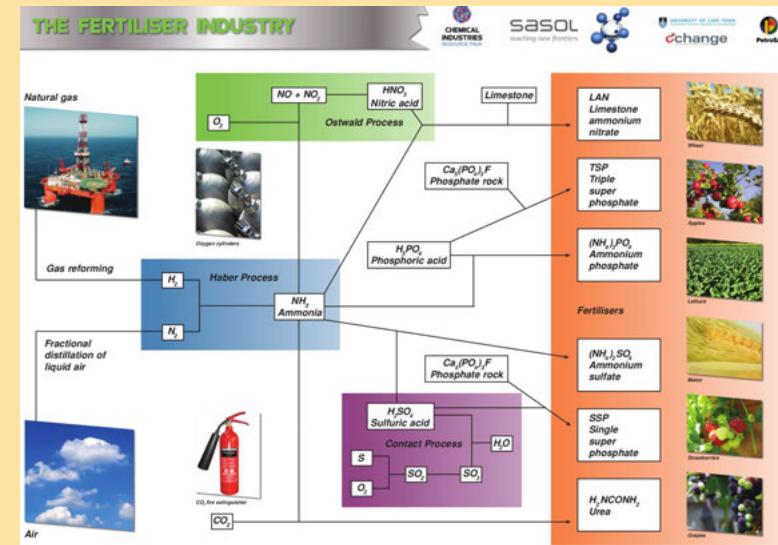
Step 1	Step 2	Step 3	Step 4
$\text{S} + \text{O}_2$ ↓ SO_2	$\text{SO}_2 + \text{O}_2$ ↓ V_2O_5 catalyst SO_3	$\text{SO}_3 + \text{H}_2\text{SO}_4$ ↓ $\text{H}_2\text{S}_2\text{O}_7$	$\text{H}_2\text{S}_2\text{O}_7$ ↓ $2\text{H}_2\text{SO}_4$

Exercise 14 – 2: The industrial production of fertilisers

1. Use the following processes to create your own mind map of the manufacturing of fertilisers:

- Fractional distillation
- Steam reforming
- Haber process
- Contact process
- Ostwald process
- you can, and should, add to this list

Include what the reactants and the products are for each process and how these link with the other processes involved.

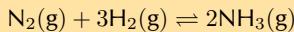


2. Research the process of fractional distillation (from old school science textbooks, from your teacher, or the internet) and write a paragraph on how this process works.

Fractional distillation is a separation method that uses the difference in boiling temperatures of the components of a mixture to separate those components. The mixture is heated to convert the components into the vapour (gas) phase. The vapour mixture is then pumped into a tall separation column (called a fractional distillation column), usually at the bottom of the column. As the vapour mixture moves up the column and cools, the different components (called fractions) condense as the temperature drops below the various boiling point temperatures. The fractions are collected using collection trays. The fractions can be removed from the mixture in this way and thus the components are separated. This process is used to separate the components of air or crude oil.

3. The reaction of hydrogen and nitrogen is an exothermic reversible reaction.

- a) Write a balanced equation for this reaction.



- b) Use your knowledge of chemical equilibrium and explain what effect the following will have on this equilibrium reaction:

- i. raising the temperature

When the **temperature** of any reaction is increased, the rate of both the forward and the reverse reactions will be increased. However, the forward reaction is exothermic. Raising the temperature would favour the reaction which would remove the excess heat. The reverse reaction will therefore be favoured more than the forward reaction. This will result in more NH_3 decomposing to form H_2 and N_2 . The overall result will be that **more reactants will be formed**.

ii. raising the pressure

Raising the **pressure** will shift the equilibrium to decrease the pressure. This would favour the reaction which produced fewer molecules. The forward reaction produces 2 moles of NH₃ (compared to the 4 moles of the reverse reaction). The forward reaction will therefore be favoured. The overall result will be that **more products will be formed**.

4. Ammonia and nitric acid react to form the compound A. Compound A is soluble in water and can be used as a fertiliser.

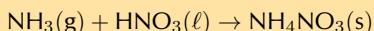
- a) Write down the name and formula for compound A.

ammonium nitrate, NH₄NO₃

- b) What type of reaction takes place to form compound A.

Acid-base reaction

- c) Write a balanced equation for the reaction to form compound A.



- d) Compound A is dissolved in water. Write a balanced ionic equation for this dissolution reaction. Include the state symbols in your equation.



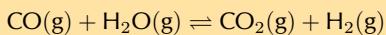
- e) Why is it important for fertilisers to be soluble in water?

So that the plants can absorb them from the soil.

- f) Compound A can also be used as an explosive. What precautions need to be taken when this compound is packaged and transported?

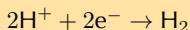
Packages need to be kept away from heat and flames.

5. The following reaction can be used to manufacture hydrogen gas. It is an exothermic redox reaction.



- a) Write down the reduction half reaction for this reaction.

Reduction is gain of electrons. H⁺ in H₂O gains an electron to become H.



- b) Which compound is the reducing agent?

Carbon monoxide or CO. CO causes H₂O to be reduced.

- c) Which compound is the oxidising agent?

Water or H₂O. H₂O causes CO to be oxidised.

- d) Identify two conditions that will ensure a high yield of hydrogen.

Remove CO₂ and H₂ (the products) from the reaction vessel. More product will therefore be formed from the same amount of reactants.

Decrease the temperature. This will favour the forward (exothermic) reaction and more product will be formed with the same amount of reactants, meaning an increased yield.

(Increasing the concentration of CO or H₂O (steam) (the reactants) will increase the amount of product formed, but not the yield. More reactants means that more product must be formed to get the same yield because the maximum yield possible has increased).

6. More questions. Sign in at Everything Science online and click 'Practise Science'.

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14.5 Alternative sources of fertilisers

Purpose of the activity:

- To work individually and as a group.
- Testing comprehension skills.
- To summarise the content for study purposes.

This activity involves the learners working on their own for 15 minutes and then forming groups of 3 - 4 to share what they have summarised in the first 15 minutes. The collaborative findings of the group are then shared with the class.

Each learner is allocated one of the sub-topics under this heading. The teachers can decide which ones they would like to include. The advantages and disadvantages of fertilisers and the next section on eutrophication could also be included. Ensure that two learners sitting next to each other do not receive the same topic. Give the learners 15 minutes (in silence on their own) to read the content in the textbook and summarise the most important facts in their own words. 1 - 2 sentences will be sufficient. Additional support might be required where learners struggle to identify the most important facts in a paragraph. Now group the learners with the same topics. Each group has 15 minutes to share with each other what they have learned and prepare a summary of their findings (3 - 4 sentences) which will be reported back to the whole class. If the lesson time at your school is short, the first section of this activity can be given as homework for this lesson so that more class time will be available for feedback. A general discussion of the section can follow.

14.6 Fertilisers and the environment

This section can be taught using the suggested class discussion.

Eutrophication

- This investigation should be handed out before this section is taught so that learners can have their results by the time this section is started.
- The last teaching lesson can be spent working on the interpretation and recommendations of their findings.
- Teachers can decide in what format they want the investigation handed in – a written report, poster, or oral presentation.

14.7 Chapter summary

Exercise 14 – 3:

1. The following extract comes from an article on fertilisers:

A world without food for its people and a world with an environment poisoned through the actions of man are two contributing factors towards a disaster scenario.

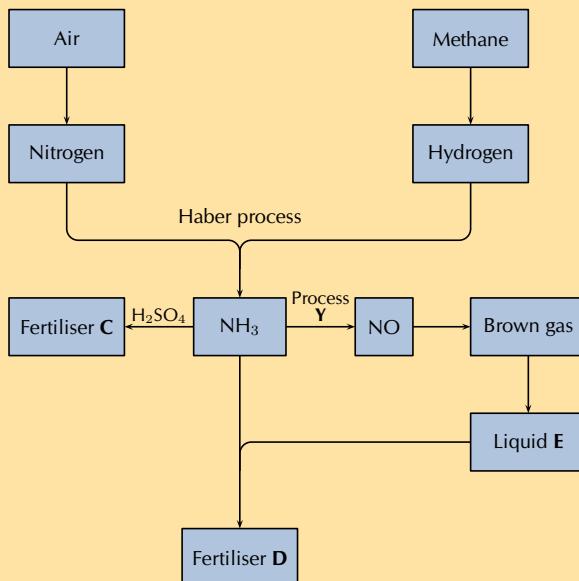
Do you agree with this statement? Write down at least three arguments to substantiate your answer.

Learners give their own opinion.

2. There is likely to be a gap between food production and demand in several parts of the world by 2020. Demand is influenced by population growth and urbanisation, as well as income levels and changes in dietary preferences.

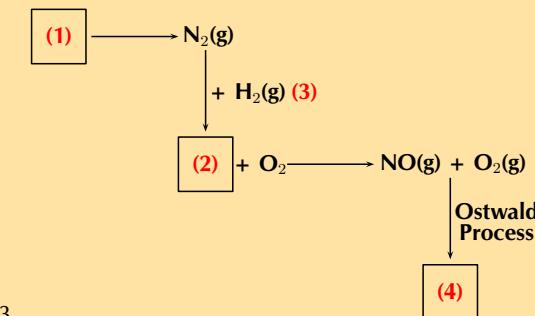
While there is an increasing world population to feed, most soils in the world used for large-scale, intensive production of crops lack the necessary nutrients for the crops. This is where fertilisers can play a role.

The flow diagram shows the main steps in the industrial preparation of two important solid fertilisers.



- How can fertilisers play a role in increasing the soil's ability to produce crops?
Fertilisers supply nutrients to the soil in a soluble form which plants can then absorb.
- Are the processes illustrated by the flow diagram above that of organic or inorganic fertilisers? Give a reason for your answer.
Inorganic fertilisers. Industrial processes are involved in the formation of these fertilisers, and they did not come from natural sources or living organisms.
- Write down the balanced chemical equation for the formation of the brown gas.
$$2\text{NO(g)} + \text{O}_2\text{(g)} \rightleftharpoons 2\text{NO}_2\text{(g)}$$
- Write down the name of process Y.
Ostwald process
- Write down the chemical formula of liquid E.
HNO₃
- Write down the chemical formulae of fertilisers C and D respectively.
C - (NH₄)₂SO₄
D - NH₄NO₃

The production of nitric acid is very important in the manufacture of fertilisers. Look at the diagram below, which shows part of the fertiliser production process, and then answer the questions that follow.



3.

- Name the process at (1).
Fractional distillation of air
- Name the gas at (2).
Ammonia

- c) Name the process at (3) that produces gas (2).
Haber process
- d) Name the immediate product at (4).
nitrogen dioxide
- e) Name the final product of the Ostwald process (product (4) + H₂O).
nitric acid
- f) Name two fertilisers that can be produced from nitric acid.
Nitrophosphates or ammonium nitrate.

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