Chemistry Year 1

SECTION 1

INTRODUCTION TO CHEMISTRY, SCIENTIFIC METHOD AND ATOMS

PHYSICAL CHEMISTRY

Matter and its properties

INTRODUCTION

Throughout this section, you will explore chemistry and its branches, focusing on essential topics such as the storage of chemicals and laboratory safety. You will delve into the scientific method of inquiry, as well as key historical developments in atomic theory including Bohr's model of the atom, Dalton's atomic theory, J.J Thomson's cathode ray tube experiment, and the Rutherford model of the atom. Do you wonder how an X-Ray machine works? Well, you are in luck, in this section you will study the rules for filling electrons in orbitals, as well as explore the concepts of radioactivity and properties of radioactive radiations.

At the end of this section, you should be able to:

1. Describe chemical processes around us and their applications in everyday life.
2. Discuss and explain safety rules and hazard symbols in the laboratory.
3. Explain why chemicals should be stored by compatibility and not alphabetically in the laboratory.
4. Investigate the scientific method of inquiry.
5. Identify the main postulates of Dalton's atomic theory and explain the weaknesses of the theory.
6. Describe the cathode ray experiment and alpha particle scattering experiment and identify the weaknesses of J. J. Thompson and Rutherford's models of the atom.
7. State the main postulates of Bohr's planetary theory and explain the importance of the quantum numbers to the electron structure of the atom.
8. Apply Aufbau's principle, Pauli's exclusion principle and Hund's rule of maximum multiplicity to write the electron configuration of the first thirty elements of the periodic table.

9. Describe radioactivity, and the properties of radiations and compare isotopes based on their stability as well as their applications in everyday life.

Key Ideas

- A chemical reaction is a process where substances change into new substances.
- Fermentation is a process where microorganisms convert sugars into alcohol or acids.
- Photosynthesis is the process by which green plants convert light energy (sunlight) into chemical energy.
- Respiration is the process by which cells convert glucose into energy.
- Combustion is a reaction involving the burning of fuel to release energy.
- Personal Protective Equipment (PPE) is a gear worn to protect oneself from hazards.
- A **chemical** is a substance that consists of atoms or molecules with specific properties and characteristics.
- A **fire blanket** is a safety device designed to extinguish incipient (starting) fires.
- A **fire extinguisher** is a handheld active fire protection device usually filled with a dry or wet chemical used to extinguish or control small fires.
- A **hypothesis** is a testable explanation or guesswork designed to guide experimentation and checking information.
- A **scientific theory** is a well-established explanation for experimental data.
- **Scientific method** is a way of learning that emphasises observation and experimentation.
- **Scientific law** A relationship between physical observables, often represented by a mathematical formula, tested and developed with numerous and diverse experimental observations.
- **Alpha particle** is a essentially a helium nucleus.

- **Gold foil experiment** is an experiment where alpha particles were directed at a thin sheet of gold foil to study atomic structure.
- **Deflection** is the change in direction of a particle.
- **Scattering** is the process by which particles are deflected or spread out in different directions after colliding with another particle or barrier.
- **Plum pudding model** is an early model of atomic structure proposed by J.J. Thomson.
- **Nuclear model** is the atomic model proposed by Rutherford.
- **Atomic spectra** are series of coloured bands which are formed when white light passes through a prism.
- **Continuous spectrum** is a spectrum that has no breaks or gaps between the wavelength range.
- **Line spectrum** is a spectrum that has discrete lines that can be categorised as excited atoms.
- **Radioactivity** is the emission of energy from an unstable nucleus, either in terms of particles or electromagnetic radiation.
- **Radioisotopes** are unstable elements.
- **Half-life** is the time taken for a radioisotope to reduce the number of unstable nuclei to half of the original value OR the time taken for the Activity of a radioactive substance to reduce to half of the original value.
- **Isotopes** are atoms with the same number of protons and different numbers of neutrons, e.g. a carbon atom will have 6 protons but can have 6, 7 or 8 neutrons.
- **Unstable atom** is one that has too much energy or an imbalance of protons and neutrons in its nucleus.

THE MEANING OF CHEMISTRY

Chemistry is a scientific discipline that focuses on the study of matter, its composition, structure, and properties as well as the principles governing its behaviour. It intersects with fields like physics, biology, environmental science, and engineering and is crucial in understanding and explaining the natural world. Chemistry plays a vital role in developing new technologies, materials, and drugs for various applications.

Activity 1.1: The chemistry of burning wool

Steps:

1. Use the link below to watch the video on burning of stell wool:

   https://thewonderofscience.com/phenomenon/2018/7/8/burning-steel-wool

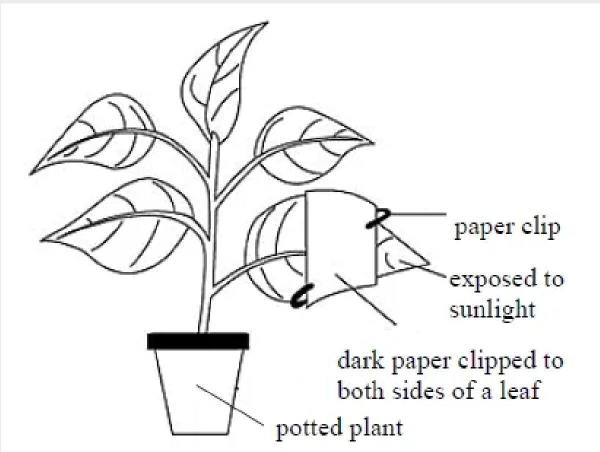
2. Now! Use the questions below to explore what role you think chemistry may play in explaining burning.
   a. What was the mass of the steel wool before burning?
   b. While the wool was burning, did you see any sparks? If so, why do you think the were sparks (***Hint: consider the components of combustion***)
   c. Did you notice a change in mass when the steel wool stopped burning? If you did notice a change, why do you think this is so.

Activity 1.2: The chemistry of photosynthesis

Materials needed: 2 green plants (potted)

Steps:

1. Label your plants A and B.
2. Place plant **A** in a dark room and plant **B** in sunlight.
3. Observe any changes to plants **A** and **B** after three (3) days.
4. Record your observations and discuss them with your colleagues.



Note: Plants convert sunlight, water, and carbon dioxide into oxygen and glucose.

Activity 1.3: The chemistry of an acid-base reaction

Materials needed: a beaker, spatula, 250 cm^3 of vinegar and baking soda reacting.

Note: For access to all apparatus, this activity should be done in the laboratory.

Steps:

1. Using a measuring cylinder, measure about 50 cm^3 of vinegar into a beaker.
2. Add 2-3 spatula full of baking soda to the vinegar solution in the beaker.
3. Observe any changes in the reactions.

Fun fact:* *Did you know that the solution of vinegar and baking soda is used in homes to clean stains?!

Note: Mixing acids like vinegar with bases like baking soda produces salt, water, and carbon dioxide gas.

Discussion:

Chemistry is the study of the substances that make up the world around us and how they interact, transform, and affect our lives. By examining processes like photosynthesis, chemical reactions (for example combustion observed in activity 1.1), and rusting we can see chemistry's fundamental role in both natural phenomena and practical applications, emphasising its importance in science and everyday life.

Activity 1.4: Distinguish among the traditional branches of chemistry

Materials needed: Internet access for research or textbooks

Steps:

1. Use the internet to find differences between the branches of chemistry.

   https://www.slideshare.net/slideshow/different-branches-of-chemistry/263492854

2. Record and discuss your observations with your friends. Let the following pointers guide your discussion.
   a. What are some of the branches you read about?
   b. Were there any similarities and or differences between any of the branches?

BRANCHES OF CHEMISTRY

1. Pure Chemistry

Pure Chemistry is the study of basic principles and theories of chemistry without considering practical use or application. It involves exploring the properties, structure, and behaviour of matter at a molecular and atomic level, analysing the interactions and transformation of substances, understanding the behaviour of atoms and molecules, discovering new compounds, and improving technologies.

Branches of Pure Chemistry

The main branches of pure chemistry are as follows.

a. **Physical Chemistry** is a branch of chemistry that combines principles from physics and chemistry to study the relationship between the physical properties of matter and its chemical composition and behaviour.

b. **Organic Chemistry** is the branch of chemistry that studies carbon-based molecules and their properties, composition, and reactions.

c. **Inorganic chemistry** is the branch of chemistry that studies non-carbon-based compounds and their properties, composition, and reactions. It includes the study of the properties of elements, their compounds and their behaviours in different conditions.

2. Applied Chemistry

Applied Chemistry is the branch of chemistry that studies the practical applications of chemical knowledge in various fields. It focuses on applying chemistry and its principles to solve real-world problems using scientific methods. It has diverse applications in food science, medicine, pharmaceuticals, material sciences, agriculture and environmental science.

THE CENTRALITY OF CHEMISTRY AS A SCIENCE DISCIPLINE

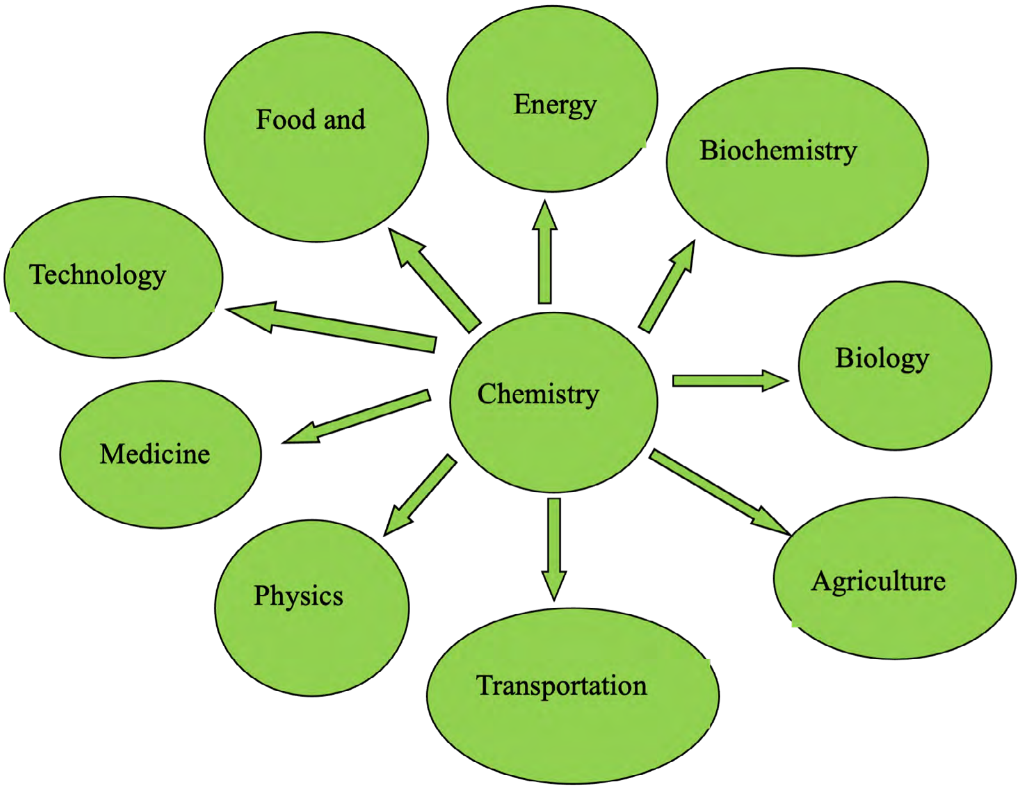


Figure 1.1: Chemistry is central to understanding your world.

Chemistry is a central scientific discipline that plays a key role in various aspects of our daily lives, from health and well-being to the environment around us. It is often called the "central science" because it is connected to other disciplines such as physics and biology. It is critical in the development of new materials in various industries, such as electronics, textiles, and construction.

Chemistry is a crucial discipline that provides a fundamental understanding of our world. Its applications are vast and include technology, medicine, industry, and environmental management, making it central to scientific progress and human development.

Chemistry thus has close relationships with various other subjects, including physics, biology, and environmental science, due to the fact that it overlaps with them in terms of content and techniques.

THE IMPACT OF CHEMISTRY ON DAILY LIVES

Activity 1.5: A flowchart to demonstrate how chemistry affects daily lives

Materials needed: Poster paper, markers, or coloured pencils, internet access, chemistry textbooks

Steps:

1. Find out different ways in which chemistry affects the following aspects of life:
   - Food and cooking
   - Health and medicine
   - Cleaning and hygiene
   - Environment and sustainability
   - Technology and industry
2. Create the flowchart:
   - In the centre of the poster paper write "Chemistry."
   - Draw branches from the central idea to the main categories identified.
   - Use markers or coloured pencils to draw arrows from "Chemistry" to the various categories.

Chemistry has an enormous impact on daily life, as it is essential for various aspects of modern life. Here are some ways in which chemistry affects daily life.

a. **Food and nutrition:** Chemistry has a significant impact on food and nutrition by improving food quality, safety, and preservation (e.g. Treatment of water at Kpong and Weija; Standardisation of products at Ghana Standards Authority). It helps us understand the composition of different foods, develops various food processing techniques, and uses chemicals as food additives to improve taste and prevent spoilage. It also provides tools and techniques for analysing food components, contaminants, and nutrients, contributing to research aimed at improving health and disease prevention.

b. **Agriculture:** Chemistry is crucial in agriculture to maximise crop yield and quality while minimising costs and environmental impact. It impacts agriculture through the development of animal feed (for example, Koudijs Gh Ltd.), fertilisers (for example, Glofert- fertiliser company in Tema, Ghana), chemical pesticides to control pests, understanding soil chemistry, genetic modifications (Ghana Atomic Energy Commission), and water management with chemicals. Chemistry has revolutionised agriculture, providing valuable insights, technologies, and solutions to enhance crop yields, control pests and diseases and improve soil and water quality.

c. **Medicine:** Chemistry has a significant impact on medicine as it contributes to the development of drugs (for example, Tobinco Pharmaceutical Ltd and Ernest Chemist.) and medical devices (for example, Intravenous Infusions PLC, Koforidua, Ghana), their production, and analysis. Chemistry plays a role in discovering new compounds and synthesising them to optimise their therapeutic use.

d. **Transportation:** Chemistry greatly affects transportation in various ways, which include fuel production (for example, Tema Oil Refinery, TOR, Ghana), vehicle material designs, lubricants and additives (for example, Ghana Oil, Goil), emissions control, and battery technologies. These chemical advancements enhance fuel efficiency, decrease emissions, and improve the transition to eco-friendly transportation methods.

e. **Energy:** Chemistry affects energy through its involvement in the production of traditional and renewable energy, energy storage solutions, the development of energy-efficient technologies, and technologies that reduce emissions from energy production. Through chemical principles, researchers can identify solutions that promote more sustainable and environmentally friendly energy production and consumption. Chemistry plays a crucial role in the production of traditional energy sources such as coal, oil (TOR), and natural gas through processes such as extraction, refining and combustion. Chemistry is also involved in the production of renewable energy sources such as solar panels (for example, Global Engineering and Drilling Ghana Ltd., East Legon) and wind turbines through the development of new materials and processes. Battery technology relies on electrochemistry.

Use the link below to observe the impacts of chemistry in daily life.

https://www.youtube.com/watch?v=L2Q2q20KaEk

CAREERS IN CHEMISTRY AND CHEMISTRY-RELATED FIELDS

There are many career opportunities in the field of chemistry and chemistry-related fields. Below are just a few examples:

1. Pharmacist
2. Medical doctor
3. Biochemist
4. Chemical engineer
5. Chemistry teacher
6. Nurse
7. Laboratory technician

Activity 1.6: Investigating careers available in chemistry and related fields

Material needed: Internet access, textbooks, any available learning resources on chemistry

Steps:

1. **Research**: Research into the following areas of chemistry and related fields:

   Pharmaceuticals and medicine, environmental science, industrial chemistry, forensic science, academic and research institutions, chemical engineering, food and agriculture

2. **Activity sheet -** Create an activity sheet with answers to the following guidelines:

   a. What are the main responsibilities and tasks associated with careers in each of these fields?
   b. What are the educational requirements and skills needed?
   c. What are some specific job titles within this field?
   d. What impact do these careers have on society and the environment?

Education and Training Required for Careers in Chemistry

The education and training required for careers in chemistry and related fields vary depending on the specific job and employer.

Some jobs in chemistry or chemistry-related fields require a minimum of a bachelor's degree, while some specialised positions may require an advanced degree. Employers often require laboratory or research experience, relevant work experience and problem-solving skills. Some routine laboratory jobs may not require a degree but would need school qualifications in chemistry.

Activity 1.7: Educational pathways and training required for various careers in chemistry and related fields

Materials needed: Internet access for research

Steps:

1. In small groups, find out the educational pathways and training required for the following careers in Chemistry:
   - Pharmacist
   - Chemical Engineer
   - Environmental Scientist
   - Forensic Scientist
   - Toxicologist
   - Biochemist
   - Food Scientist
   - Materials Scientist
2. Gather information on the following points:
   - Required high school subjects and skills
   - Necessary degrees (e.g., Bachelor's, Master's, PhD)
   - Specialised training or certifications
   - Internship or work experience opportunities
   - Continuing education and professional development
3. Discuss your findings and prepare a brief presentation.
4. Compare the educational pathways and discuss any similarities or differences.

Activity 1.8: Exploring the importance of chemistry to the Ghanaian society.

1. Work with a friend or in groups.
2. Find out on the internet, textbooks, resource persons, and chemistry-related outfits about the importance of chemistry to Ghanaian society in the field of agriculture and present your findings using PowerPoint or flipcharts.
3. Record your findings in a PowerPoint format and present them to the class.

RULES AND REGULATIONS IN THE CHEMISTRY LABORATORY

The school chemistry laboratory must be a safe place for effective learning. Given this, the following rules and regulations must be strictly observed.

1. Do not eat or drink anything in the laboratory.
2. Never taste chemicals in the laboratory.
3. Any water spilt on the floor must be wiped off immediately.
4. Do not add water to acid but rather acid to water.
5. Never walk barefoot in the laboratory.
6. Keep the laboratory clean and organised.
7. Report all accidents and spills immediately.
8. Follow proper handling and disposal procedures for chemicals.
9. Follow instructions for conducting experiments and using equipment.
10. Wear appropriate protective equipment such as a lab coat, safety goggles and gloves.
11. Know the location and use of emergency equipment such as fire extinguishers, eye wash stations, and safety showers.
12. Be aware of the potential hazards in the laboratory and take precautions to prevent accidents.

CHEMICAL HAZARDS

Chemical hazards are solids, liquids, gases, and solutions can pose potential hazards and dangers.

Depending on the chemical, the dose, the exposure route, and the duration of exposure, these hazards can have various effects on human health and the environment.

Some common chemical hazards include:

1. Explosives

These are chemicals that can rapidly release energy in the form of heat, light, gas and sound, causing physical damage and injury. Examples are dynamite, nitro-glycerine, ammonium nitrate and nitrocellulose.

2. Flammable Liquids and Gases

These are chemicals that can ignite (catch fire) or explode when exposed to heat, sparks, or flames, causing burns, fires, and explosions.

Examples are gasoline, propane, butane, ethanol, diesel, acetone, paint thinners, aerosol sprays, lubricating oils, cooking oils, and fats.

3. Corrosive Substances

These are chemicals that can destroy or damage materials such as metals, plastics, or human tissue, causing severe burns and tissue damage.

Examples are hydrochloric acid, sulphuric acid, nitric acid, sodium hydroxide, potassium hydroxide, bleach and ammonia solution.

4. Toxic Substances

These are chemicals that can harm or kill living organisms such as humans, animals, or plants by interfering with biological functions or disrupting vital organ systems.

Examples are arsenic, lead, mercury, carbon monoxide, pesticides, cyanide, benzene, chlorine gas and ammonia.

5. Oxidising Substances

These are chemicals that can accelerate and promote combustion (burning) in other materials by providing oxygen or other oxidising agents. They cause severe burns, respiratory damage, and explosions.

Examples are hydrogen peroxide, potassium permanganate, oxygen gas, chlorine gas, bleach, nitric acid, and potassium nitrate.

6. Radioactive Substances

These materials spontaneously emit radiation as a result of the decay of their atomic nuclei. Proper handling and disposal are essential, as they can pose significant hazards due to their potential for radiation exposure and contamination.

Examples of radioactive substances are uranium, radon, iodine-131 and cobalt-60.

7. Irritant Substances

These are materials that can cause irritation or inflammation when they come into contact with the skin, eyes, respiratory system, or other organs.

Irritant substances can have a range of adverse effects on humans, such as itching, pain, redness, swelling, and blistering of the skin.

Examples are ammonia, bleach, hydrochloric acid, detergents, insecticides, sodium hydroxide and gasoline.

8. Harmful Substances

These are materials that can pose a risk to the health and safety of humans or the environment. They can cause acute or chronic effects on exposure, depending on the dose, duration and mode of exposure.

Examples are lead, asbestos, pesticides, carbon monoxide, tobacco smoke, mercury, and arsenic.

9. Biohazard Substances

These are materials that can pose a threat to the health and safety of living organisms, including humans, plants, and animals. They may contain living and non-living biological agents that can cause harm, such as bacteria, viruses, toxins and biological waste.

Examples of biohazard substances include blood, bodily fluids, tissues, organs, and microorganisms.

HAZARD SYMBOLS AND THEIR MEANINGS

Hazard symbols are visual signs or markings used to indicate the potential danger or risks associated with a particular substance or product. These pictograms are usually displayed on containers or packing to help users identify and handle hazardous materials safely.

Table 1.1: Hazard Symbols

	Explanation	Symbols
1	**Harmful symbol:** The harmful symbol is used to indicate that a substance is harmful if ingested, inhaled, or absorbed through the skin. The harmful symbol as shown.	 **Figure 1.5:** *Harmful Symbol.*
2	**Irritant symbol:** The irritant symbol is used to indicate that a substance may irritate the skin, eyes or respiratory system. The irritant symbol as shown.	 **Figure 1.6:** *Irritant Symbol*
3	**Corrosive symbol:** The corrosive symbol is used to indicate that a substance is capable of causing irreversible damage to living tissues or corroding materials including metals, plastics, and other substances. The corrosive symbol as shown.	 **Figure 1.7:** *Corrosive Symbol.*
4	**Toxic symbol:** The toxic symbol is used to indicate that a substance is highly poisonous and can cause serious harm to human health or the environment. The toxic symbol shown.	 **Figure 1.8:** *Toxic Symbol*

	Explanation	Symbols
5	**Oxidising symbol:** The oxidising symbol is used to indicate that a substance is capable of promoting the combustion (burning) or ignition of other materials. The oxidising symbol as shown.	 **Figure 1.9:** *Oxidising Symbol*
6	**Flammable symbol:** The flammable symbol is used to indicate that a substance is combustible and can catch fi re easily. The symbol for flammable as shown	 **Figure 1.10:** *Flammable Symbol.*
7	**Explosive symbol:** The explosive symbol is a sign that warns people about the presence of explosives or other hazardous substances. The explosive symbol as shown.	 **Figure 1.11:** *Explosive Symbol.*
8	**Radioactive symbol:** The radioactive symbol, also known as radiation hazard symbol, is a warning symbol that is used to indicate the presence of radioactive materials or areas that emit radiation. The radiation hazard symbol is shown below.	 **Figure 1.12:** *Radioactive Symbol*
9	**Biohazard symbol:** The biohazard symbol is used to indicate the presence of biological hazards such as infectious agents, toxins, and other biohazardous materials that can cause harm to human health or the environment. The biohazard symbol is shown below.	 **Figure 1.13:** *biohazard Symbol*

PROHIBITION SIGNS

Prohibition signs are warning signs that indicate that certain activities, actions, or objects are not allowed (prohibited) in a particular area.

Table 1.2: Prohibition Signs

	Explanation	Symbol
1	**No naked flame:** It is a prohibition sign that indicates that open flames and any activity involving unprotected flames are restricted or prohibited in a certain area. The sign is intended to improve safety, guard against fire hazards, and ensure adherence to applicable legislation. Common locations include industrial settings, laboratories, fuel storage areas, construction sites, and places with flammable materials. A 'no naked flame' sign as shown.	 **Figure 1.2:** *No Naked Flame Symbol.*
2	**Danger:** 'Danger' is a term used to describe a specific situation, activity, or condition that poses a significant risk of harm, injury or damage to individuals, property or the environment. Any situation that has the potential to cause harm, injury or damage can be considered as dangerous, and it is important to respond to such situations promptly to prevent harm. A 'danger' sign as shown.	 **Figure 1.3:** *Danger Symbol.*
3	**No smoking:** 'No smoking' is a common sign that is seen in public places, workplaces, and other areas where smoking is prohibited. A 'no smoking' sign as shown.	 **Figure 1.4:** *No smoking Symbol.*

FIRST AID SIGNS

First aid signs serve as visual markers intended to designate the whereabouts of first aid facilities, equipment, or stations within a given area. Their essential function lies in enhancing workplace safety and furnishing explicit directions to individuals during emergency situations. These signs commonly employ universally acknowledged symbols, colours, and text to communicate details regarding the accessibility and position of first aid resources.

Table 1.3: First Aid Signs

	Explanation	Symbols
1	**First aid:** First aid is the immediate assistance provided to a person who has been injured or has suddenly taken ill. It involves a series of simple, life-saving techniques and procedures that can be performed by anyone with basic training. The primary objective of first aid is to preserve life, prevent the condition from worsening, and promote recovery while waiting for professional medical attention. A first aid sign is shown.	 **Figure 1.14:** *First aid Symbol*
2	**Safety Shower:** This sign is a visual cue that shows where first aid supplies and safety showers are located in a building. This sign is usually located in areas where there is a possibility of exposure to hazardous compounds that may require quick decontamination or first aid, is essential to emergency response. This sign is placed strategically in places where there is a greater chance of coming into contact with potentially harmful products, such as industrial facilities, laboratories, chemical storage areas, and other workspaces with potentially harmful materials. A safety shower sign is shown.	 **Figure 1.15:** *1. Safety Shower Symbol*

	Explanation	Symbols
3	**Eye Wash:** This sign is a visual indicator designed to identify the location of emergency eye wash stations. These stations are crucial in environments where there is a risk of exposure to hazardous substances that can cause eye injuries or irritation. The sign helps individuals quickly locate the nearest eye wash station, promoting prompt action in case of an emergency. It is strategically placed in areas where there is a risk of eye exposure to chemicals, dust, or other hazardous materials. Common locations include laboratories, manufacturing facilities, chemical storage areas, and places where workers handle potentially harmful substances. An eye wash sign is shown.	 **Figure 1.16:** *Eye Wash Symbol.*

PERSONAL PROTECTIVE EQUIPMENT (PPE)

Personal protective equipment (PPE) is any equipment or clothing worn by individuals to protect against the specific hazards in the workplace or other environments. PPE is designed to protect the wearer from potential hazards that could cause injury, illness, or death. Some of the common types of PPE include:

1. **Respirators/Gas masks:** These are devices designed to reduce the inhalation of hazardous substances such as dust, fumes, and gases.
2. **Hand gloves:** These are specialised hard-worn protective coverings that protect the skin against harmful substances or injuries.
3. **Eye protectors:** These devices include safety glasses, chemical goggles, or face shields that protect the eyes from flying particles, dust, or splashes of hazardous substances.
4. **Protective clothing:** This includes specialised clothing such as lab coats, aprons, and full-body suits that protect against chemicals, heat, and other hazardous materials.

Example of PPEs

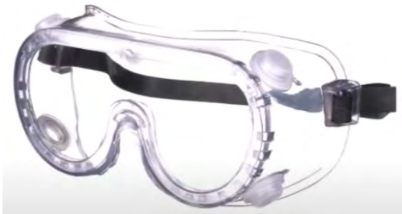
Safety earmuff

Safety helmet

Respiratory mask

Hair net

Dust mask



Safety goggle

Safety boots

Disposable Overall

Hand gloves

Lab Coat

Apron

SAFETY EQUIPMENT

Safety equipment refers to devices or clothing that are designed to protect individuals from injuries or hazards while performing activities or tasks. This includes:

1. **Eye shower station:** An eye shower station is a safety device found in workplaces where hazardous exposure is possible. It provides immediate treatment to individuals who have contact with hazardous materials or chemicals in the eye. The device consists of a basin attached to a water supply, and an injured person is instructed to flush the eyes with water directed at the eyes and not the face.
2. **Fume chamber:** A fume chamber is an enclosed space or hood designed to contain and capture hazardous fumes, dust, or vapours that may be produced during laboratory experiments or industrial processes. It is often used to protect workers from dangerous substances that may be emitted during experiments, testing, or production and to prevent contamination of the external environment.

Activity 1.9: Various practices in a chemistry laboratory.

Material needed: Internet access

Look at the images and discuss the various practices in a chemistry laboratory

a. Describe what you observed in each image.
b. Mention some of the good practices and wrong practices in the images.
c. Identify some of the personal protective equipment in the images.
d. Identify some of the laboratory glassware in the images.
e. Identify any potential hazards in a laboratory environment as seen in any of the images.

Activity 1.10: 'Dos' and 'Don'ts' in the Chemistry Laboratory

Materials Needed: Short clips demonstrating proper and improper lab behaviour.

Use the links below to watch a video on the 'Dos' and 'Don'ts in the lab.

https://www.youtube.com/watch?v=saXFQR86ziM

https://youtu.be/MEIXRLcC6RA

After watching the videos:

a. Discuss and make a list of 'dos' and 'don'ts' in the chemistry laboratory.

b. Discuss the general rules and regulations in the chemistry laboratory with a colleague. Note down the rules and regulations and let your teacher have a look at it.

Activity 1.11: Examining the assay of chemical containers or reagents, electrical gadgets, and other materials and identifying the hazard symbols on them.

Materials needed: A variety of empty chemical containers, reagent bottles, and electrical gadgets with hazard symbols printed on them; a printed sheet of common hazard symbols and their meanings.

Steps:

1. In a small group carefully observe and identify the hazard symbols on the chemical containers or reagents, and electrical gadgets. (If real items are not available, use pictures or printed images.)
2. Take note of the hazard symbols identified (e.g., flammable, corrosive, toxic)
3. Refer to the printed sheet to determine the meaning of each symbol.
4. State the precautions that should be taken when handling the item.
5. State any personal protective equipment (PPE) that might be required.
6. Present your findings to the class, explaining the symbols identified and the associated hazards and safety precautions.

Activity 1.12: The essential safety rules and regulations in the chemistry laboratory

Materials needed: A printed list of common laboratory rules and regulations

Steps:

1. Discuss the provided rules and regulations.
2. Analyse why each rule is important and what potential risks it mitigates.
3. Give examples or scenarios where each rule would be applicable.
4. Create a poster that highlights key laboratory rules and regulations.
5. Present your poster to the class.

Activity 1.13: Various prohibition signs related to laboratory safety

Materials needed: Printed examples of prohibition signs (e.g., First Aid, Danger, No Smoking, High Voltage, etc.)

Procedure:

1. Printed examples of various prohibition signs is assigned to the group.
2. Focus on specific prohibition signs (e.g., First Aid, Danger, No Smoking, High Voltage).
3. Discuss the prohibition signs related to their assigned heading.
4. Analyse the meaning of each sign and discuss why it is important in a laboratory setting.
5. Give examples or scenarios where each sign would be applicable.
6. Create a poster that highlights the prohibition signs under your assigned heading. Use drawings, symbols, and brief descriptions to make your poster informative and engaging.
7. Present your poster to the class.

Activity 1.14: Handling hazardous chemicals safely using personal protective equipment (PPE) and safety equipment.

Materials needed: Printed sheets with different types of PPE and safety equipment.

Steps:

1. Think about your experiences or knowledge of handling hazardous chemicals safely.
2. Write down your thoughts on how to use specific PPE (chemical goggles, hand gloves, aprons/laboratory coats, and respirators/gas masks) and safety equipment (eye shower station, fume hood).
3. In pairs share your ideas and discuss the following points:
4. The importance of each type of PPE and safety equipment.
5. Specific scenarios where each item would be necessary.
6. Each pair to share your ideas and discussion points with the class.
7. In a small group, discuss at least five laboratory rules and at least five hazard symbols.
8. Present your findings to the class.

STORAGE OF CHEMICALS

Chemicals in the laboratory should be stored safely and organised to prevent accidents and ensure the safety of laboratory workers. It is better to store these chemicals by compatibility rather than alphabetically.

Here are some reasons why chemicals should be stored by compatibility and not alphabetically:

1. Chemicals should be stored by compatibility in the laboratory because some chemicals can react explosively or dangerously when they come into contact with other chemicals.
2. Storing chemicals alphabetically can result in incompatible substances being stored next to each other. This can cause chemical reactions that can result in fires, explosions, toxic fumes, and other hazardous situations.
3. Storing chemicals by compatibility reduces the risk of accidents and ensures the safety of laboratory workers.

4. Storing chemicals by compatibility also helps organise their storage, making it easier to locate specific chemicals when needed.

Therefore, it is important to follow the guidelines for the storage of chemicals by compatibility to prevent harmful incidents or accidents in the laboratory.

The following guidelines can be used to store chemicals in the laboratory.

Chemical Incompatibility Chart

Table 1.4: Chemical Copatibility Chart.

	Acids Inorganic	Acids Oxidizing	Acids Organic	Alkalis Bases	Oxidizers	Poisons Inorganic	Poisons Organic	Water Reactives	Organic Solvents
Acids Inorganic			x	x		x	x	x	x
Acids Oxidizing			x	x		x	x	x	x
Acids Organic	x	x		x	x	x	x	x	
Alkalis Bases	x	x	x				x	x	x
Oxidizers			x				x	x	x
Poisons Inorganic	x	x	x				x	x	x
Poisons Organic	x	x	x	x	x	x			
Water Reactives	x	x	x	x	x	x			
Organic Solvents	X	X		X	X	X			

How to put out a Small Fire Using Fire Blanket and Fire Extinguisher

If a small fire breaks out in the laboratory, it is important to act quickly and appropriately to minimise any potential damage or injuries.

Here is how to use a fire blanket and fire extinguisher to put out a small fire in a laboratory setting:

Using a Fire Blanket

Fire blanket

1. If there is a small fire on or near a person, the person should stop, drop, and roll to smother the flames. If the fire is caused by a flammable liquid or in a pan, turn off the heat source.
2. Pull the blanket out of its bag or storage container.
3. Hold the corner of the blanket and, if possible, cover the fire starting from the base. If the fire is on a person's clothing, wrap the blanket around him or her to smother the flames.
4. Make sure the edges of the blanket create a seal with the surface around the fire to prevent the spread of flames.
5. Leave the blanket in place until the fire has completely stopped or until help arrives.

Using Fire Extinguisher


Fire extinguisher

1. Before using the fire extinguisher, pull the fire alarm and make sure everyone in the area is aware of the fire.
2. Identify the type of fire extinguisher you are using to ensure it is appropriate for the fire you are dealing with.
3. Hold the fire extinguisher in an upright position and aim it at the base of the flames.
4. Squeeze the handle or trigger to release the extinguishing agent.
5. Sweep the nozzle from side to side while aiming at the base of the flames until the fire is completely extinguished.
6. Stay alert for any re-ignition of the flames and keep the fire extinguisher aimed at the base of the flames until it is safe to put away.

Understanding the type of fire extinguisher, you have and the type of fire you are dealing with is crucial to ensure the right type of action.

Activity 1.15: Principles and practices of chemical storage and compatibility

Materials needed: Laboratory coat, gloves, safety goggles, printed checklist of storage practices and safety guidelines, notebook, pen,

Steps

1. In your groups, or with a partner, take a trip to the chemistry laboratory or chemical store near you.
2. Meet the laboratory technician or staff in charge.
3. Ask the laboratory technician or staff in charge to give you a brief overview of the storage area, highlighting key safety features and practices.
4. In small groups, explore the storage area, observing how chemicals are organised and stored.
5. Use your checklists to note specific storage practices, such as:
   - **a.** Are flammable chemicals stored away from heat sources?
   - **b.** Are corrosive substances stored in corrosion-resistant containers?
   - **c.** Are toxic chemicals clearly labelled and stored securely?
   - **d.** Is there proper segregation of incompatible chemicals?
   - **e.** Is there adequate ventilation in the storage area?
   - **f.** Are safety signs and labels clearly visible?
   - **g.** Is safety equipment such as eye wash stations and fume hoods easily accessible?
6. Discuss what you observed with the laboratory technician.
7. Find out why it is essential to store chemicals by compatibility in a laboratory setting.
8. Write a brief summary in your notebook. The write-up should include:
   - **a.** The storage practices you observed.
   - **b.** Why it is important to separate different types of chemicals?
   - **c.** How proper labelling contributes to safety.
   - **d.** What you learned about the role of safety equipment in the laboratory?

Activity 1.16: Why it is important to store chemicals based on compatibility rather than alphabetically in the laboratory.

Materials needed: Internet access, access to chemical storage guidelines, chemical compatibility charts, worksheet with questions.

Steps

1.

a. Use the link **A** below to watch the video on why chemicals should be stored on compatibility not alphabetically:

A: https://youtu.be/6EYxVqLj7NI

b. Click on link **B** below to watch a video of what happens when chemicals are not stored properly:

B: https://www.youtube.com/watch?v=ZIAyNFLRFuw

2. In small group discuss and answer the following questions:

a. What is compatible or incompatible chemicals?

b. Why might storing chemicals alphabetically be dangerous?

c. Give examples of chemical reactions that could occur if incompatible chemicals are stored together.

d. How do chemical compatibility charts help in organising a laboratory?

3. Present your findings to the class.

Activity 1.17: Putting out a small fire using a fire blanket and a fire extinguisher.

Steps

1. Discuss the following questions in your groups or with a friend:

a. What type of fire is it (paper, electrical, chemical)?

b. Which extinguishing method is appropriate (fire blanket or extinguisher)?

c. What are the steps to use each method correctly?

2. Share your pair's discussion with the larger group.

Summarise the key points, including:

a. Identifying the type of fire

b. Choosing the appropriate extinguishing method

c. Using a fire blanket to smother the fire
d. Using a fire extinguisher (e.g., PASS method: Pull, Aim, Squeeze, Sweep)

THE SCIENTIFIC METHOD OF INQUIRY

The Scientific method of inquiry is a systematic approach used by scientists to investigate and learn about the natural world around us. The scientific method involves a series of steps that are followed to ensure that scientific investigations are made in a logical, objective, and repeatable manner.

Here are the steps involved in the scientific method:

1. **Make Observations:** Scientists begin by carefully observing and recording information about a phenomenon or problem they wish to investigate, or gather prior knowledge about a certain topic or concept
2. **Formulate a Question:** Based on their observations and prior knowledge, scientists create a question or issue they want to investigate.
3. **Develop a Hypothesis:** A hypothesis is an educated guess about the answer to the question or issue that has been formulated.
4. **Conduct Experiments:** In this step, scientists design and conduct experiments to test the hypothesis.
5. **Collect and analyse Data:** Scientists record their observations and collect data from their experiments.
6. **Draw Conclusions:** Based on the results of their experiments and observations, scientists use logic to draw conclusions about their hypothesis.
7. **Communicate Results:** Finally, scientists communicate their findings through scientific papers, presentations or other means.

The scientific method allows scientists to avoid bias and to ensure that their results are valid, reliable and replicable. Through this methodical approach, scientists can discover new knowledge, solve problems and explore and understand the natural world.

Activity 1.18: Using the scientific methods of inquiry to solve a problem in the school environment or nearby community.

Materials needed: Materials needed: Notebooks, pens, and pencils, measuring tapes, rulers, or other instruments to measure physical dimensions, sample containers, Lab equipment (e.g., beakers, test tubes, microscopes) for scientific experiments, chemicals (if necessary), graph paper, calculators, Safety gear such as gloves, goggles, and lab coats, poster paper and computer. Cameras (optional, to capture visual evidence), internet (optional),

Steps

1. **State the problem**: For example, the decline in students' performance in integrated science.
2. **State your observation**: Example –
   - Data collected on recent test scores and grades showed a decline in students' performance in integrated science.
   - Feedback from parents, administrators and teachers confirmed the decline.
   - Most students could not satisfactorily answer chemistry questions in integrated science.
3. **State hypothesis**: Example – 'The decline in integrated science performance is due to a lack of understanding of fundamental concepts.
4. **Carry out experimentation**:
   a. Conduct surveys and interviews with students to understand their perception of the difficulty in integrated science.
   b. Review teaching methods and curriculum to identify any potential gaps or areas for improvement.
   c. Implement interventions, such as additional instruction sessions, interactive workshops, and changes in teaching strategies.
5. **Analysis:** Analyse data collected from the experiments conducted. This includes:
   a. Analysing survey responses to identify common challenges or misconceptions among students.
   b. Comparing the performance of students who received interventions with those who did not.
   c. Assessing changes in student attitudes and engagement with integrated science after implementing interventions.

6. **Conclude:** Based on the analysis of data, write your conclusion regarding the effectiveness of the interventions in addressing the decline in integrated science performance.
   a. If the interventions were successful, consider implementing them on a larger scale or adjusting based on feedback.
   b. If the interventions were not effective, revisit the hypothesis and consider alternative explanation for the decline in performance. This might involve further experimentation or research.

Activity 1.19: Step by step application of scientific method of enquiry in the localities.

1. Design a poster outlining the method used and share with your class for discussion.
2. Outline at least five steps involved in the scientific method of enquiry.
3. Identify at least a problem in the school environment that can be solved using the scientific method of enquiry.
4. Formulate a hypothesis to drive the investigation for at least one of the problems identified.
5. Design an experiment that can be used to solve the problem(s) identified.

DALTON'S ATOMIC THEORY

Quite a few scientists contributed to the modern model structure of the atom. We now look at a few of the most important scientific discoveries that led to the modern atomic theory. Amongst them are Dalton's Atomic Theory, J.J. Thomson's Cathode ray experiment, and Rutherford' alpha scattering experiment.

The idea that elements are made up of atoms is called the **atomic theory.**

The postulates of the Dalton's atomic theory are as follows:

a. *All elements are made up of small indivisible particles called atoms.*
b. *Atoms cannot be created or destroyed.*
c. *Atoms of the same element are identical, that is, they have the same mass and size, but atoms of different elements have different masses and sizes.*
d. *Atoms of different elements combine in simple whole number ratios to form compounds.*

The theory in its broad outline is still valid, however, some of the postulates have been modified in the light of subsequent discoveries.

Modification of the Dalton's Atomic Theory

1. **All elements are made up of small indivisible particles called atoms:** Atoms are not indivisible. This is because it was later discovered that atoms are not the smallest particles and are further broken down into subatomic particles such as protons, neutrons and electrons.
2. **Atoms cannot be created or destroyed:** This postulate is still acceptable for ordinary chemical reactions. In nuclear reactions, however, atoms of the same element are destroyed, and new ones are created.
3. **Atoms of the same element are identical, that is, they have the same mass and size, but atoms of different elements have different mass and size:** The discovery of isotopes (atoms of the same element having the same number of protons but different number of neutrons) contradicts this postulate.
4. **Atoms of different elements combine in simple whole-number ratios to form compounds:** This postulate is still acceptable for inorganic compounds, which usually contain few atoms per molecule. Carbon, however, forms very large organic compounds such as polymers, proteins, and starch, which can contain thousands of atoms. Silicon, which is inorganic, also forms very complex silicates involving a large number of atoms.

Activity 1.20: Review of the atom and its sub-atomic particles

1. What is an atom?
2. Draw a model of the atom.
3. Name the three sub-atomic particles.
4. State where each sub-atomic particle can be located.
5. What is the nucleus, and what does it contain?

Activity 1.21: To discuss the main postulates of Dalton's atomic theory.

Materials needed: Internet access, printed postulates of Dalton's atomic theory

Steps

1. In small groups, introduce the four main postulates of Dalton's atomic theory.
2. Discuss the postulates using the following questions as guides:
   a. What does each postulate mean?
   b. Give an example to illustrate each postulate.
3. Share your understanding of the postulates with the class.
4. Research and explore the limitations and contributions of Dalton's atomic theory to modern chemistry.

Activity 1.23: Constructing the atomic model.

1. Construct a model to represent the atom as a simple sphere with no internal structure.
2. Draw a diagram of the atom modelled.
3. Display the model and diagram for class discussion.

Activity 1.24: The Dalton's Atomic theory

1. In your own words, state the main postulates of Dalton's atomic theory.
2. State at least one strength and one weakness of Dalton's atomic theory.
3. Explain at least one strength and one weakness of Dalton's atomic theory.
4. How relevant is Dalton's atomic theory to the evolution of modern chemistry?

J.J. THOMSON'S CATHODE RAY EXPERIMENT

J.J. Thomson's cathode ray experiment was a series of experiments that laid the foundation for the discovery of the electron.

Thomson passed an electric current through a vacuum tube and observed a stream of negatively charged particles that travelled from the negatively charged electrode, known as the cathode, to the positively charged electrode, known as the anode. These particles were called cathode rays. The cathode ray tube used by Thomson is shown below.

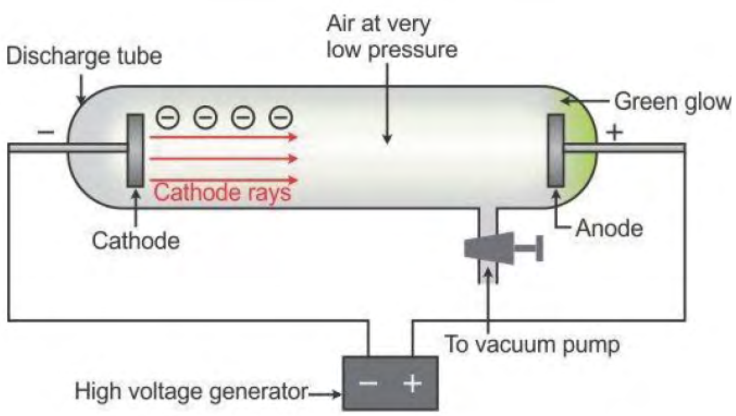


Figure 1.2: A cathode ray tube

To further study the cathode rays, Thomson conducted experiments using electrical and magnetic fields. He found that the rays were deflected by both fields, indicating that the particles that made up the ray had a negative charge. He also measured the charge-to-mass ratio of the particles and found that it was much smaller than any known atom, leading him to conclude that the cathode rays were made of particles smaller than the atoms. These particles were named as electrons.

Thomson's discovery of the electron was a major breakthrough in the understanding of the structure of matter.

J.J. Thomson's Model of the Atom

J.J. Thomson's model of the atom, also known as the 'plum pudding' model was developed on the basis of his discovery of the electron. According to this model, the atom is composed of a positively charged sphere, like a pudding, in which negatively charged electrons are embedded, like plums.

The diagram below shows Thomson's model of the atom.

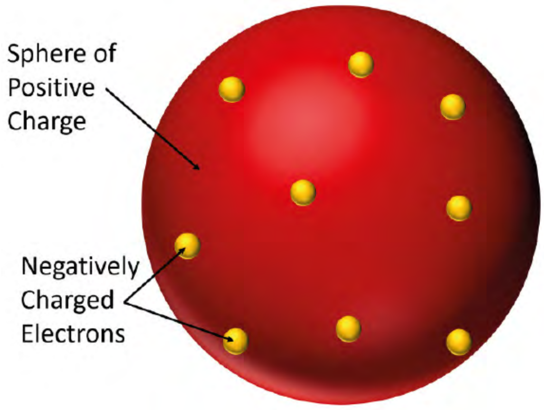


Figure 1.3: Plum Pudding Model of the Atom.

While this model was a significant step in the understanding of atomic structure, it had some weaknesses.

Some main weaknesses of J.J. Thomson's model of the atom are:

1. The model assumed that the positive and negative charges were spread evenly throughout the atom, which would produce a neutral electric charge. However, the model failed to explain the presence of a nucleus in atoms.
2. The model also did not provide any information about the number or arrangement of the electrons in an atom. Thomson's model just suggested that the electrons were dispersed throughout the atom but not in a pattern or orbit.
3. The model did not explain the atom's overall mass. The electrons are much lighter than the protons and neutrons that make up the nucleus, and it was not clear how the atom's overall mass was distributed.
4. Rutherford's discovery of the atomic nucleus disproved Thomson's model by showing that it was inaccurate in describing the atomic structure.

Despite the limitations, Thomson's model was significant in showing that atoms are not indivisible but could be further broken down into constituent particles. It also led to the development of further models for the structure of the atom, including Rutherford's model, which corrected some of the shortcomings of Thomson's model.

RUTHERFORD'S ALPHA SCATTERING EXPERIMENT

Rutherford's alpha scattering experiment was a landmark experiment aimed to investigate the structure of the atom and the nature of its constituent particles.

The experiment involved firing positively charged alpha particles at a thin gold foil and observing their trajectory as they passed through the foil. The expectation was that the alpha particles would pass straight through the foil or be slightly deflected by the atomic structure of the atoms within the foil. However, some alpha particles were scattered at very large angles, and some even scattered backwards.

The diagram below shows Rutherford's alpha scattering experiment.

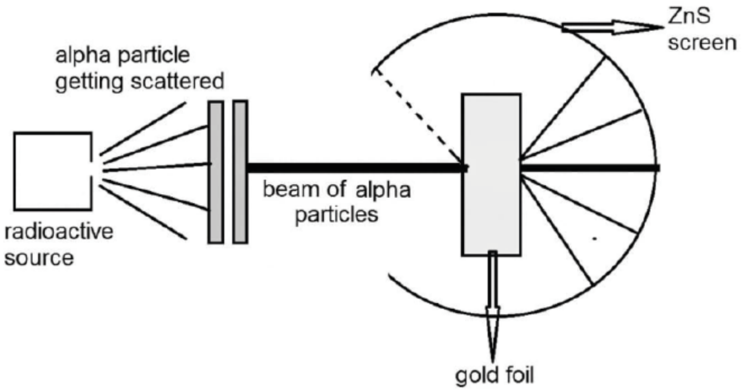


Figure 1.4: Rutherford's alpha scattering experiment.

Rutherford analysed the results of the experiment and proposed a new atomic model that showed that the atom has a small, dense, positively charged nucleus at its centre, surrounded by negatively charged electrons. He concluded that the deflected alpha particles were deflected by a strongly charged nucleus, while others passed straight through the atom's empty space.

This experiment provided evidence for the existence of the atomic nucleus and paved the way for further discoveries about the structure and behaviour of atoms.

Rutherford's Model of the Atom

Rutherford's atomic model, also known as the nuclear model, was proposed based on his famous Alpha particle scattering experiment. The model introduced the concept of a small, positively charged. nucleus in the centre of the atom, surrounded by negatively charged electrons. The electrons would orbit the nucleus in specific energy levels and paths, similar to the planets orbiting the sun.

Rutherford's model of the atom is shown below.

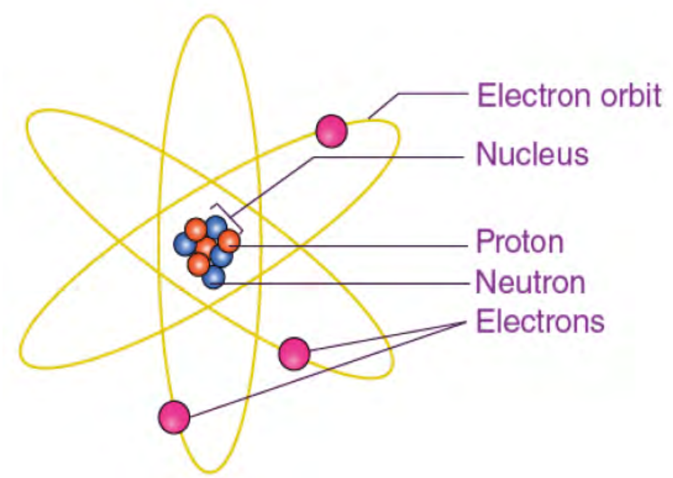


Figure 1.5: Rutherford's model of the atom.

Despite its contribution to the understanding of the structure of the atom, Rutherford's atomic model had several weaknesses, which are as follows:

1. The model is unable to explain the stability of atoms. In the model, negatively charged electrons move around the positively charged nucleus and should eventually lose energy and spiral into the nucleus, causing the atom to collapse. However, this does not happen in reality, and the model failed to explain why.
2. The model cannot account for the high energy emission spectra of atoms. According to the model, electrons must travel in specific paths and can only transition between certain energy levels, which would result in a limited spectrum of radiation. But experimental observations showed that the atoms emitted a much larger range of radiation than predicted by the model.
3. Rutherford's atomic model could not explain the existence of isotopes, atoms of elements with the same atomic number but different mass numbers. The model proposes that the number of electrons in an element is equal to its atomic number, which would also determine the number of protons in the element. However, isotopes of the same element have a different number of neutrons even though they have the same number of protons.

Despite these limitations, Rutherford's atomic model was a fundamental stepping stone towards the modern understanding of atomic structure and formed the basis of further models, including Bohr's atomic model, which built upon Rutherford's concept of a nucleus and attempted to address some of the model's weaknesses.

The Structure of the Atom

Based on the results of J.J. Thomson's cathode ray and Rutherford's alpha scattering experiments, the following structure of the atom was proposed:

The atom consists of a positively charged nucleus, which contains most of the mass of the atom. The protons are positively charged. The electrons, which have a negative charge, are located outside the nucleus.

The number of electrons in an atom is equal to the number of protons, giving an atom a neutral overall charge. The electrons are held in the shells by the electrostatic attraction to the positively charged nucleus.

The table below shows the location, charges and relative masses (amu = atomic mass units) of the subatomic particles of the atom.

Table 1.5: Subatomic Particles

Subatomic Particles			
Particle	**Charge**	**Relative Mass (AMU)**	**Location**
Proton	Positive	1	Proton
Neutron	Neutral	1	Neutron
Electron	Negative	1/1840	Outside Nucleus

Activity 1.25: Investigating the properties of cathode rays through interactive simulations.

Materials needed: A computer or tablet with internet access, simulation videos or interactive charts demonstrating cathode ray properties.

Steps:

1. Use the link below to watch the video to explore the properties of cathode rays.

   https://www.youtube.com/watch?v=vXOeehVTcRA

2. Observe and discuss the direction of deflection relative to the orientation of the magnetic field.
3. Observe and discuss the direction of deflection relative to the orientation of the electric field.

4. Discuss the concept of fluorescence when cathode rays strike certain materials, causing them to emit light or leave a visible trace.
5. Share your findings with a colleague.

Activity 1.26: Findings of Rutherford's alpha scattering experiment

Materials needed: Access to internet and computer or tablets, video of Rutherford's alpha scattering experiment

Steps

1. Watch the video (use the link below) that demonstrates Rutherford's alpha scattering experiment.

   https://www.youtube.com/watch?v=XBqHkraf8iE

2. Take notes on key aspects such as:
   a. How alpha particles were emitted towards a thin gold foil.
   b. What Rutherford expected to happen to the alpha particles.
   c. What actually happened to the alpha particles as observed on the detector screen.
3. Describe what you observed in the video.

Activity 1.27: Description of the model of the atom by J. J Thompson and Rutherford experiments.

Describe the structure of the atom based on analysis of the evidence gathered from both experiments.

Activity 1.28: Constructing J.J Thompson and Rutherford atomic models.

1. Construct a model to represent the atom using the evidence gathered from of JJ Thomson and Rutherford experiments.
2. Draw a diagram of the modelled atom.

BOHR'S PLANETARY THEORY

This lesson looks at the theories that explain how electrons behave in the atom and the effects their behaviours have on the physical and chemical nature of the atom.

Bohr's planetary theory explained the structure of an atom and the behaviour of electrons.

According to this theory, electrons orbit the nucleus in a fixed, circular orbits at specific energy levels, similar to the planets in the solar system. These energy levels were quantised. This means the electrons could only occupy specific energy states and could only transition between those levels by either absorbing or emitting a discrete amount of energy in the form of a photon. This theory also introduced the concept of ground state, where the electron orbits the nucleus at its lowest energy level, excited states, where the electron absorbs energy and jumps to higher energy levels.

Bohr's theory provided a foundation for modern atomic theory and led to further developments in the understanding of quantum mechanics.

Main Postulates of Bohr's Planetary Theory

Bohr's planetary theory of the atom was based on the following postulates:

1. Electrons move around the nucleus of an atom in fixed, circular orbits.
2. The electrons can exist only in certain allowed orbits, which correspond to specific energy levels.
3. While an electron is in a particular energy level, it does not radiate energy. This energy is only emitted when the electron jumps from one energy level to another.
4. The energy of the emitted radiation corresponds to the difference in energy between the initial and the final energy levels.
5. The size of the orbit and the energy of the electron are related. Electrons in larger orbits have more energy than those in smaller orbits.
6. Electrons can only make transitions between energy levels that correspond to a specific amount of energy, known as a quantum. These transitions produce or absorb photons that have a frequency proportional to the difference in energy.

These postulates provided a framework for understanding the behaviour of electrons within atoms.

The diagrams below show Bohr's model of the atom.

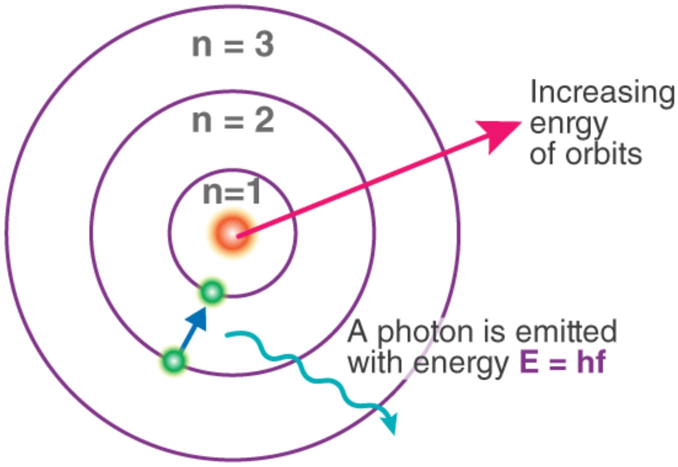


Figure 1.6: Bohr's model of the atom

Continuous and Line Spectra

Continuous spectrum

A continuous spectrum is a spectrum of electromagnetic radiation containing photons of all energy levels within a specific range. Unlike atomic spectra, which consists of only specific energy levels, a continuous spectrum contains a radiation of all energies resulting in a smooth display of colours or wavelengths.

Examples of sources of continuous spectra include a hot solid object, such as a light bulb filament, a glowing gas or plasma.

Continuous spectra are important in both astronomy and laboratory experiments, as they can be used to help identify the composition and temperature of objects emitting radiation.

Line spectrum

A line spectrum is a spectrum produced by an excited atom or molecule that contains only discrete wavelengths or colours of electromagnetic radiation. These wavelengths correspond to specific energy level transitions within the atom or molecule.

The line spectrum appears as a series of coloured lines or bands rather than a continuous spectrum, which contains radiation at all wavelengths. For example, the line spectrum of hydrogen consists of several discrete lines of colour in the visible spectrum. Each line corresponds to a specific transition between energy levels in the hydrogen atom. Similarly, each chemical element has a unique line spectrum, which can be used to identify the element based on the wavelengths of the lines observed.

Line spectra are important in many areas of science, including astronomy, chemistry and physics. Chemists use line spectra to help identify unknown substances or verify the purity of a sample.

Physicists use line spectra to study the behaviour of electrons within atoms and molecules, providing insights to the nature of matter and energy.

The diagrams below show examples of continuous and line spectra.

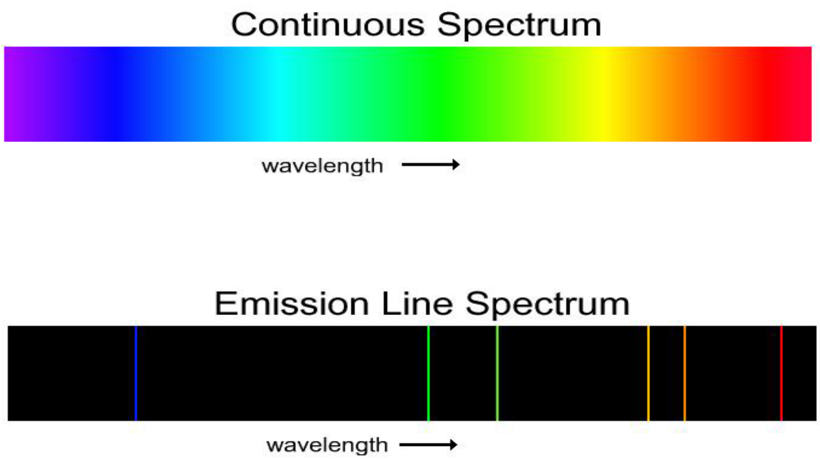


Figure 1.6: Diagram showing continuous spectrum and emission spectrum

Differences between a continuous spectrum and a line spectrum

There are several differences between a continuous spectrum and a line spectrum. These are summarised in the table below.

Table 1.6: Differences between a continuous spectrum and a line spectrum

Definition	A *continuous spectrum* contains radiation of all energies within a certain range, whereas an *emission line spectrum* contains only specific wavelengths of radiation.
Source	A (nearly) *continuous spectrum* is emitted by a hot, dense object such as a light bulb filament or a star, whereas an *emission line spectrum* is produced when an excited atom or molecule emits light.
Appearance	A *continuous spectrum* appears as a smooth display of colours or wavelengths while an *emission line spectrum* appears as a series of discrete lines or bands.
Composition	A *continuous spectrum* contains radiation of all energies, while an *emission line spectrum contains* only specific energies that correspond to the energy level transitions of the emitting atom or molecule.
Usage	*Continuous spectra* are used to identify the temperature and composition of a source emitting light while *emission line spectra* are used to identify the chemical composition of a source emitting light.
Examples	Examples of sources for *continuous spectra* include the sun (almost continuous), light bulbs, and blackbody radiators, while *emission line spectra* are typically emitted by excited atoms or molecules, such as hydrogen, helium or neon.

Relationship of the lines in the emission spectrum of hydrogen to electron energy levels

The lines in the emission spectrum of hydrogen are directly related to the electron energy levels of the hydrogen atom. When an electron in a hydrogen atom is excited, it moves from the ground state (lowest energy level) to a higher energy level. This higher energy state is not stable, and the electron will eventually return to its ground state by releasing energy in the form of a photon of light.

The energy of this photon is directly proportional to the difference between the higher and lower energy levels of the electron. Since each energy level of the electron in a hydrogen atom is fixed, the energy of the released photon is also fixed. It corresponds to specific wavelength or colour of light. Therefore, each emission line in the hydrogen spectrum corresponds to a specific energy level transition for the electron in the hydrogen atom.

The lines in the spectrum represent wavelengths of the photons emitted as the electron transitions back to a lower energy level.

The diagram below shows the relationship between the line spectrum of hydrogen and energy levels.

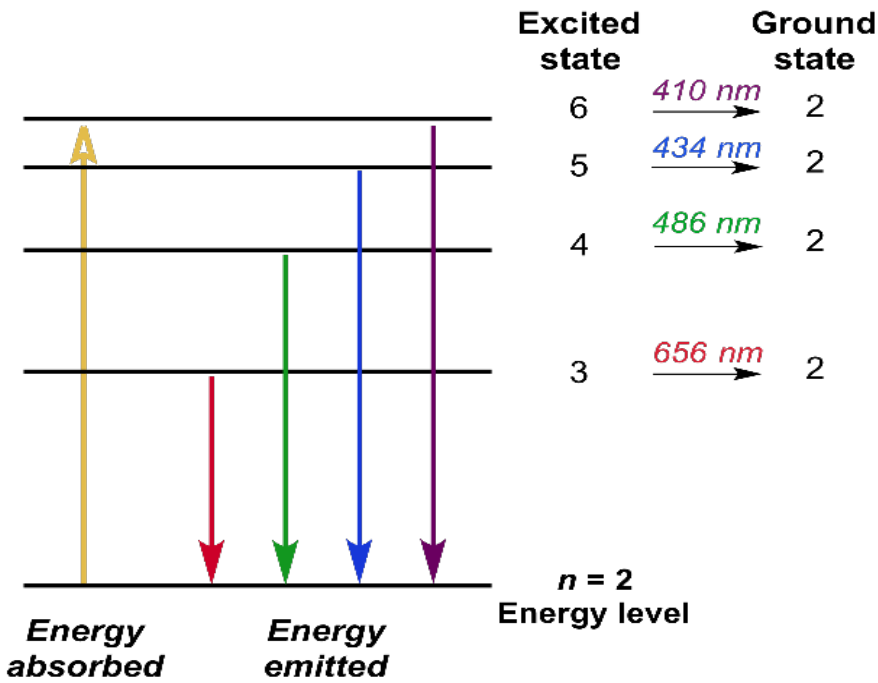


Figure 1.7: Line Spectrum of Hydrogen and Energy Levels

CONTRIBUTION OF QUANTUM THEORY TOWARDS THE DEVELOPMENT OF THE ATOMIC STRUCTURE

Quantum theory has made significant contributions toward the development of the atomic structure. Some of these contributions are:

Wave-particle duality: Quantum theory introduced the concept of wave-particle duality, which suggests that particles could exhibit both wave-like and particle-like behaviours. This theory helped scientists to understand the behaviour of electrons in atoms, as electrons exhibit wave-like behaviour in their movement around the nucleus.

Discrete energy levels: Quantum theory introduced the concept of energy levels in atoms. This means that electrons can only exist at certain energy levels around the nucleus and cannot exist anywhere in between.

Uncertainty principle: Quantum theory introduced the uncertainty principle, which states that it is impossible to know both the position and the momentum of an electron at the same time.

Quantum numbers: Quantum theory introduced the concept of quantum numbers, which describe the energy levels and positions of electrons in atoms. These quantum numbers help predict the properties of atoms and their behaviour during chemical reactions.

Electron spin: Quantum theory also introduced the concept of electron spin, which explains why two electrons in the same electron orbital have opposite spins. This concept helps scientists understand the behaviour of electrons in atoms and their contribution to the magnetic properties of materials. These concepts introduced by quantum theory have helped scientists understand the fundamental behaviour of electrons and predict their properties and behaviour during chemical reactions.

QUANTUM NUMBERS

Quantum numbers are integers or half-integers that describe the properties of electrons in an atom. There are four types: principal, momentum/azimuthal, magnetic and spin quantum numbers.

1. **Principal quantum number (n):** This quantum number determines the energy level of an electron and describes the size of the electron cloud. It can have any positive value starting from 1.
2. **Angular Momentum/Azimuthal quantum number (l):** This quantum number indicates the shape of the electron cloud or the subshell in which an electron is present. It can have value from 0 to (n-1).
3. **Magnetic quantum number (m):** This quantum number specifies the orientation of the electron cloud in space. It can have values from (-l) to (+l).
4. **Spin quantum number (s):** This quantum number describes the spin of an electron, which is a fundamental property of all particles. It can be either (+½) or (-½).

These quantum numbers play a crucial role in determining the electron configuration of an atom and understanding its behaviour. They also help us in predicting the position of electrons in an atom by providing a framework for describing energy states and orbitals.

The Importance of Quantum Numbers to the Electron Structure of the Atom

Quantum numbers play an important role in understanding the electron structure of an atom. The electron structure refers to the arrangement of electrons in an atom's different energy levels and subshells.

Here are some reasons why quantum numbers are important in this regard:

1. **Describing the electron energy levels:** The principal quantum number (n) allows us to determine the energy levels available to electrons in an atom. Each energy level corresponds to an electron shell, and the value of n determines the number of subshells and electrons that can reside in each shell.
2. **Specifying the subshells:** The angular momentum/azimuthal quantum number (l) provides information about the subshells within each shell. It determines the shape of the subshell. This helps us to predict the electron distribution more accurately.

3. **Determining the electron orientation:** The magnetic quantum number (m), indicates the orientation of the electron cloud in space. It helps us to understand spatial arrangement of electrons within subshells.
4. **Predicting electron spin:** The spin quantum number (s), describes the spin of each electron, which is important for understanding the electron configuration of an atom. Two electrons with opposite spins can occupy the same orbital, which has important consequences for the chemical and physical properties of different elements.

ORBITALS

An orbital is defined by a set of quantum numbers (n, l, m). Here are a few examples of orbitals:

a. The **s** orbital is the lowest orbital, with a spherical shape and can hold up to two electrons. The **s** orbital is shown below.

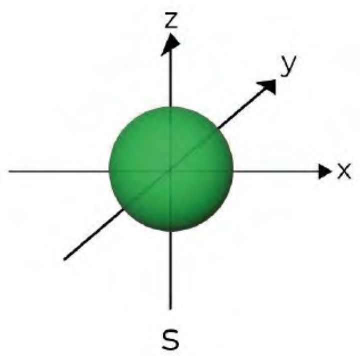
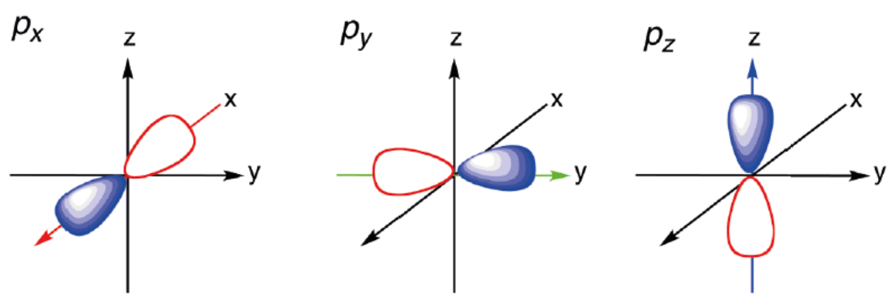


Figure 1.8: Shape of the S-orbital

b. The **p** orbitals (*px*, *py* and p z), have a dumb-bell shape and can hold up to six electrons (two in each orbital). These orbitals are found in the second and higher energy levels. The **p** orbitals are shown below:



The three p orbitals are aligned along perpendicular axes.

Figure 1.9: The three P orbitals aligned along perpendicular axes

c. The **d** orbitals have more complex shapes and can hold up to ten electrons in total (5 orbitals with 2 electrons in each orbital). These orbitals are found in the third energy level and higher.

Activity 1.29: The Bohr's planetary atomic model.

1. State Bohr's planetary model of the atom.

Activity 1.30: Illustrating the Bohr model of the atom.

Materials needed: Poster paper or large sheet of paper or cardboard, markers, coloured pencils, access to textbooks, or internet.

Steps:

1. Research and find out basic information about the Bohr model.
2. Create a large diagram of the Bohr model on paper.
3. Indicate the following in the diagram:
   - **a.** The nucleus at the centre (use different colours to draw the nucleus and the electron orbits
   - **b.** Multiple electron orbits around the nucleus
   - **c.** Electrons in the orbits
   - **d.** Labels for the energy levels

Activity 1.31: Understanding Bohr's theory and the stability of the atom through research and structured writing tasks.

Materials needed: Textbooks covering atomic theory, access to the internet for research, notebook, and pen.

Steps:

1. Use textbook and online articles to gather information about Bohr's theory. Keywords for online research: "Bohr model", "Bohr theory of the atom", "stability of the atom", "postulates of Bohr's atomic theory".
2. Take notes of the key postulates of Bohr's theory and how it explains the stability of the atom.

3. Write a brief summary of each of Bohr's postulates. The summary should cover the following postulates:

  a. Electrons orbit the nucleus in specific, fixed orbits or energy levels.

  b. Each orbit corresponds to a specific energy level.

  c. Electrons can move from one orbit to another by absorbing or emitting a quantum of energy.

  d. The angular momentum of an electron in an orbit is quantized.

3. Compose explanations of Bohr's theory and the stability of the atom in your own words.

Learner to address the following points:

  a. How Bohr's model differs from previous atomic models.

  b. How the fixed orbits prevent electrons from spiralling into the nucleus.

  c. The significance of quantized energy levels.

4. Discuss the key points and common themes found in the summaries and explanations.

Activity 1.32: The difference and similarities between continues and line spectra.

Analyse the differences and similarities between *continuous* and *line spectra* and carry out the following in your analysis:

  a. delve into the fundamental principles that govern each of the spectra.

  b. with the fundamentals principles identified present the differences and similarities between the two spectra in a tabular form.

Activity 1.33: Description of the energy levels in Bohr's planetary structures of the atom.

1. Carefully study the following diagrams illustrating the planetary structure of the atom.

a. Identify the fixed orbits and energy levels as proposed by Bohr.

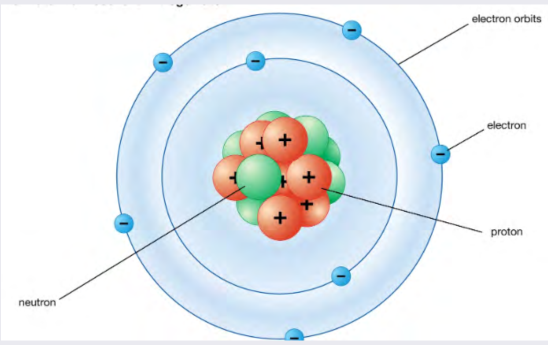


Figure 1.20

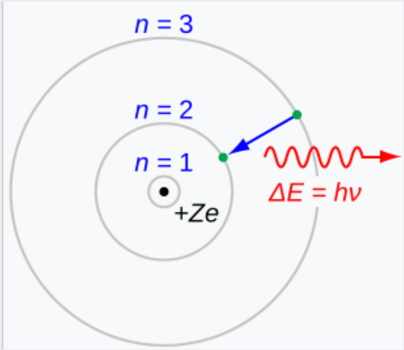


Figure 1.21

(b) Describe the meaning of the numbers in Fig. 1.21

Activity 1.34: Learning about the s, p, d and f orbitals.

Visit the following websites and given links to learn more about the s, p, d and f orbitals.

- Chemistry Steps
- Wikipedia
- https://byjus.com/chemistry/bohrs-model/
- https://byjus.com/physics/bohr-model-of-the-hydrogen-atom/
- https://www.space.com/bohr-model-atom-structure

Activity 1.35: Using physical models to illustrate the concept of quantum numbers

Materials needed: Different coloured balls or beads to represent electrons, rings of different sizes to represent energy levels (orbits), string or wire to suspend the rings at different heights, labels for principal quantum number (n), angular momentum quantum number (l), magnetic quantum number, and spin quantum number.

Steps

1. Arrange the rings or hoops on the large sheet or poster board to represent different energy levels. Suspend them at different heights using string or wire to signify increasing energy levels.
2. Label each ring with the corresponding principal quantum number (n = 1, 2, 3, ...).
3. Use the coloured balls or beads to represent electrons.
4. Place the balls on the different rings to show electrons in various energy levels.
5. Discuss how the principal quantum number (n) increases with distance from the nucleus and how energy increases with n.
6. Introduce the concept of subshells (s, p, d, f) corresponding to the angular momentum quantum number (l).
7. Use different coloured sections on each ring to represent different subshells (e.g., one section for s, three sections for p, five sections for d, and seven sections for f).
8. Place electrons in these sections to show how they occupy different subshells within an energy level.

Activity 1.36: Illustrate the relationship between quantum numbers and electron orbitals.

Materials needed: Quantum number charts, computer or tablet with internet access.

Steps

1. Identify the four types of quantum numbers (principal, angular momentum, magnetic, and spin).
2. Use the link below to watch the video on the relationship between quantum numbers.

   https://www.youtube.com/watch?v=eRIN9CPDrpo&t=234s
3. Discuss the relationship between quantum numbers and electron orbitals

Worked Example

Identify the principal quantum number (n) and the angular momentum (l) in following energy levels:

i. 2p
ii. 3d

Answer

i. In the above, the 2 in the 2p is the principal quantum number and the angular momentum is 1(that is l = 2 – 1).
ii. 3 in the 3d is the principal quantum number and the angular momentum is 2 (that is l = 3 – 1)

Activity 1.37: properties of *s* and *p* in terms of shape, orientation energy level.

Compare and contrast the properties of *s* and *p* in terms of shape, orientation energy level. Justify your reasoning with relevant examples.

Worked Example

Identify the *principal quantum number* (*n*) and the *angular momentum* (*l*) in the following energy levels:

(i) 2*p*

(ii) 3*d*

AUFBAU'S PRINCIPLE

Aufbau's principle, also known as the building-up principle, is a fundamental principle in chemistry stating that the atomic orbitals are filled with electrons in order of increasing energy. Specifically, electrons will fill lower energy atomic orbitals before moving on to higher energy levels. This principle is used to determine the electron configuration of atoms and the order in which the orbitals are filled. Electrons fill subshells in the following order: 1s, 2s, 2p, 3s, 3p, 4s, 3d.

PAULI'S EXCLUSION PRINCIPLE

Pauli's exclusion principle is a fundamental principle in quantum mechanics that states that no two electrons in an atom can have the same set of quantum numbers. In other words, if two electrons are in the same orbital, they must have opposite spins. The principle is essential in determining the structure of atoms, as it limits the number of electrons that can occupy each orbital and organises the electron configuration of atoms in the periodic table.

HUND'S RULE OF MAXIMUM MULTIPLICITY

Hund's rule of maximum multiplicity is a principle in quantum mechanics that states that within a subshell, electrons will occupy orbitals singly, with their spins parallel' before they pair up with opposite spins.

In other words, if two or more orbitals having the same amount of energy are unoccupied, then electrons will start occupying them singly, before they fill them in pairs.

This means that electron pairing in **p** and **d** orbitals cannot occur until each orbital of a given subshell contains one electron or is singly occupied.

This rule is based on the fact that, electrons in orbitals with parallel spins repel each other less than electrons with opposite spins, leading to a lower potential energy for the system. Therefore, when electrons occupy a subshell, they will make the least energetic configuration by occupying orbitals singly before pairing up.

This rule is important in determining the electronic configuration of atoms.

How to Express Electron Configuration Using s, p, d Notation

To express the electronic configuration of an atom using s, p, d notation, you first need to identify the principal quantum number of the highest energy level occupied by electrons, which is equal to the period number of the element in the periodic table. Then you assign the electrons to each subshell in the following order:

1. First, the 1s orbital is filled before any other orbital.
2. Next, the 2s orbital is filled before the 2p orbitals start to fill.

3. Then, the 3s orbital is filled before the 3p orbitals start to fill.
4. After that, the 4s orbital is filled before the 3d orbitals begin to fill.

That is, 1*s* 2s 2*p* 3*s* 3*p* 4*s* 3*d*

So, for example, the electron configuration of Carbon (C), which has 6 electrons, can be expressed in s, p and *d* notation as follows: 1*s* 2 2*s* 2 2 *p* 2.

This indicates that the first energy level (n = 1) is filled with two electrons in the 1s orbital, while the second energy level (n = 2) is filled with four electrons in the 2*s* and 2*p* orbitals, (with two electrons in the 2*s* orbital and two electrons in the 2*p* orbitals).

Electron configuration of ions and elements can be written as seen in the examples below. Writing these configurations usually follows the Aufbau's principle.

Example

Write the electron configuration for each of the following ions and elements:

i. ${}_{13}Al^{3+}$
ii. ${}_{16}S^{2-}$:
iii. ${}_{24}Cr$
iv. ${}_{29}Cu$
iii. ${}_{24}Cr$
iv. ${}_{29}Cu$

Answers

i. ${}_{13}Al^{3+}$ ${}_{13}Al^{+3}: 1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2$
ii. ${}_{16}S^{2-}$: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^2\ 3p_y^2\ 3p_z^2$
iii. ${}_{24}Cr$: $1s^2\ 2s^2 2p^6\ 3s^2\ 3p^6\ 3d^5\ 4s^1$
iv. ${}_{29}Cu$: $1s^2\ 2s^2 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^1$

How to Express Electron Configuration Using 'Electrons-in-Boxes' Method

The electron configuration of an atom can also be expressed using the 'electrons-in-boxes' method.

In this method, each orbital is represented as a box, and the electrons are represented by arrows, with the direction indicating their spin.

For example, the electron configuration of carbon (C) with 6 electrons can be represented as follows:

1s

↑↓

2s

↑↓

2p

↑	↑	

In this representation, the first energy level (n= 1) has only one orbital, the 1s orbital, with electrons represented by a pair of arrows pointing up and down. The second energy level (n=2) contains four orbitals: the 2s orbital, which has two electrons represented by arrows pointing up and down, and the three 2p orbitals, which has two electrons represented by two arrows pointing up.

Differences in Stability between Fully Filled, Half-Filled and Partially Filled Orbitals

The stability of an atom depends on the electron configuration of its orbitals. A fully filled or half-filled subshell is more stable than a partially filled subshell.

Activity 1.38: To assess prior knowledge on electron configuration.

Materials needed: Periodic table charts, paper and pen, handouts with basic questions on electron configuration.

Steps

1. In small groups answer basic questions on electron configuration. Example questions:
   a. What is an electron configuration?
   b. How are electrons arranged in an atom?
   c. What do the terms 'orbital' and 'energy level' mean?
2. Share your answers with other groups.

3. Use the periodic table to explain the order of filling orbitals (1s, 2s, 2p, 3s, etc.).

Activity 1.39: To understand the rules for writing electron configurations and how to apply these rules to different elements.

Materials needed: Access to textbooks and the internet for research, periodic table charts, paper and pen, key questions and tasks.

Steps

1. In small groups Investigate on the following principles stated in **1a** and **b**:
   a. Aufbau Principle
   b. Pauli Exclusion Principle
   c. Hund's Rule
2. Research on the rule stated in **1c**. Focus on its significance, and examples of how it is applied in writing electron configurations.
3. After your investigations and research, prepare for a group presentations. The information in your presentation should answer the following questions:
   a. What is the Aufbau principle?
   b. Why is it important in writing electron configurations?
   c. Examples of electron configurations using the Aufbau principle.
   d. What is the Pauli Exclusion Principle?
   e. Why is it important in writing electron configurations?
   f. Provide examples of electron configurations using the Pauli Exclusion Principle.
   g. What is the Hund's rule?
   h. Why is it important in writing electron configurations?
   i. Provide examples of electron configurations using the Hund's rule.

Activity 1.40: Application Activity

1. Write the electron configurations of the following using the researched rule and principles in Activity 1.38:
   a. ${}_{1}H$, ${}_{3}Li$, ${}_{6}C$, ${}_{11}Na$, ${}_{17}Cl$

b. $_{24}Cr$, $_{29}Cu$

c. $_{2}He$, $_{10}Ne$, $_{18}Ar$

2. Using the 'electron in box method' write the electron configuration of the following elements showing how the electrons occupy the orbital.

$_{13}Al$, $_{20}Ca$, $_{26}Fe$

Activity 1.41: To help learner understand the stability associated with fully filled, half-filled, and partially filled orbitals in subshells.

Materials needed: Whiteboard and markers, periodic table charts, handouts or slides with examples and key points

Steps

1. Write the electron configuration of noble gases (Neon, Argon)
2. Discuss why noble gases are inert and stable due to their fully filled orbitals.

   Note: Fully filled orbitals (e.g., s^2, p^6, d^{10}, f^{14}) are especially stable due to symmetry and maximised electron pairing. Noble gases are inert and stable due to their fully filled orbitals.
3. Write electron configuration of nitrogen and manganese.
4. Discuss why elements with half-filled orbitals tend to have extra stability

   Note: half-filled orbitals (e.g., p^3, d^5, f^7) have a special stability due to exchange energy and symmetry.
5. Write electron configuration of oxygen and iron.
6. Discuss why these configurations are less stable and often more reactive.

Activity 1.42: Filling the orbitals with electrons in box method

Visit https://www.youtube.com/watch?v=9ogq50CBgCg to watch videos or observe demonstrations of the process of filling orbitals using the *s*, *p* and *d* notations and electron-in- box method.

Activity 1.43: Application of Aufbau's principles in writing electron configuration

1. Write the electron configuration of oxygen using s, p and d notation
2. Explain the Aufbau principle and how it applies to writing of electron configurations.

RELATIVE ATOMIC MASS

Relative atomic mass is the average mass of an atom of an element, considering all its naturally occurring isotopes, relative to the mass of an atom of carbon-12, which has been assigned a mass of exactly 12.

This value is expressed in atomic mass units (amu). The relative atomic mass is determined by the abundance of each isotope of an element.

RELATIVE MOLECULAR MASS

Relative molecular mass is the sum of the relative atomic masses of all the atoms in a molecule, relative to the mass of carbon-12, which has been assigned a mass of exactly 12.

The relative molecular mass is calculated by adding up the atomic masses of all the atoms in a molecule, considering the number of atoms in each element present in a molecule.

MASS SPECTROMETER

A mass spectrometer is an instrument used for measuring the mass-to-charge ratio (m/z) of ions in a sample. It operates by generating ions from a sample and then separating the ions based on their mass-to-charge ratio (m/z) using electric and magnetic fields. The separated ions then hit a detector where they create a signal that is proportional to their abundance.

This signal is then analysed to determine the mass-to-charge ratio (m/z) of the ions and their relative abundance, providing information about the composition of the sample.

The mass spectrometer is shown below.

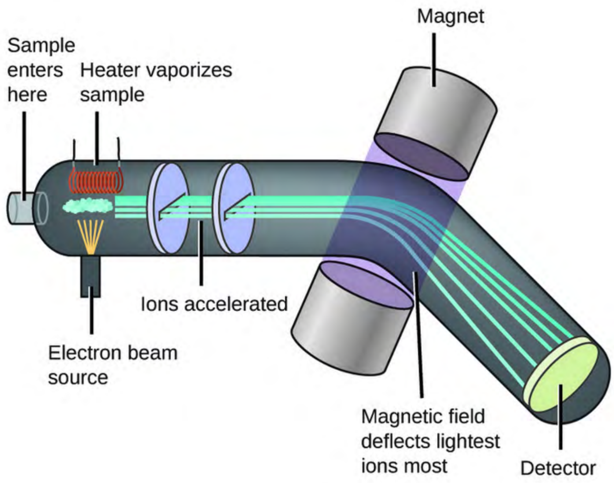


Figure 1.22: Mass spectrometer

Mass spectrometers are used in a wide variety of fields, including chemistry, biochemistry, physics, geology and environmental science, for applications such as identifying the presence of specific compounds in a sample, analysing the composition of proteins and other biomolecules, studying the isotopic composition of elements, and monitoring air and water pollution.

Parts of the Mass Spectrometer and how they Work

The five main processes which take place in the mass spectrometer are:

1. A sample of the substance is vaporised in the vaporisation chamber.
2. The vapour is ionised into positive ions in the ionisation chamber.
3. The positive ions are attracted and accelerated by an electric field.
4. The accelerated positive ions are deflected in the magnetic field and focused onto a detector according to their mass-to-charge ratio (m/z).
5. The ions generate a current or signal that is proportional to their abundances. The detector then draws a mass spectrum of the different ions.

The diagrams below show how the mass spectrometer is used.

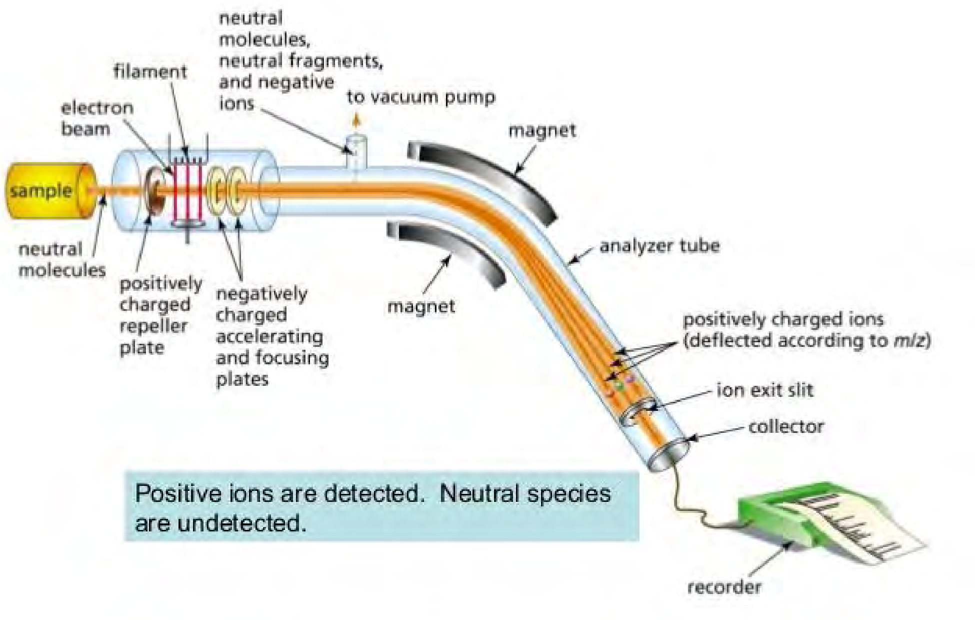


Figure 1.23: Diagram of a mass spectrometer process that takes place in it.
Source: K. Bhavyasri et al., IJSRR 2019, 8(2), 3161-3176

Mass Spectrum

A mass spectrum is a graphical representation of the ion intensities (relative abundances) as a function of their mass-to-charge ratios (m/z). Simply put, a mass spectrum is a graph of the percentage abundance versus the relative atomic masses of the ions present in the sample.

Generally, the mass spectrum shows a series of peaks, each representing an ion with a specific mass-to-charge ratio (m/z). The height of the peak is proportional to the abundance of the ion in the sample.

The mass spectrum of chlorine is shown below.

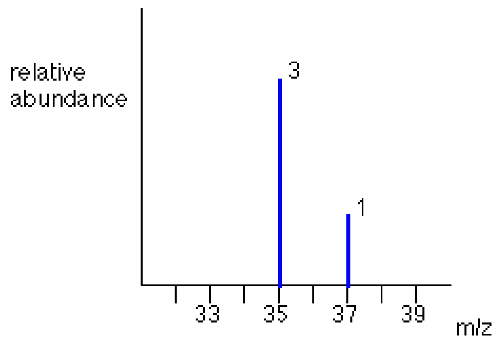


Fig 1.24: Mass spectra of Chlorine element

How to calculate the relative atomic mass of different elements

The relative atomic mass of an element can be calculated by using:

1. The mass spectrum
2. Percentage abundance data.

Generally, the relative atomic mass is calculated by using the following steps:

1. Identify the isotopes of the element and their percentage abundances. The percentage abundance refers to the amount of each isotope present in a sample, expressed as a percentage of the total number of atoms of the elements.
2. Multiply the mass of each isotope by its percentage abundance.
3. Add up the products obtained in step 2.
4. Divide the sum obtained in step 3 by 100 to obtain the relative atomic mass of the element.

Worked Example

Let us consider the element boron. Boron has two isotopes, boron-10 and boron-11 with natural abundances of approximately 20% and 80% respectively. To calculate the relative atomic mass of boron, we can use the steps as follows:

1. Boron-10 has a percentage abundance of 20% and boron-11 has a percentage abundance of 80%.
2. The relative atomic mass (A_r) of boron-10 is 10 amu and the relative atomic mass (A_r) of boron-11 is 11 amu.

   Therefore, $10 \times 20 = 200$ and $11 \times 80 = 880$
3. $200 + 880 = 1080$
4. $\frac{1080}{100} = 10.8$

   Therefore, the relative atomic mass of boron is 10.80 amu.

Worked Example

Chlorine naturally exists as two isotopes, chlorine-35 and chlorine-37. The abundance of chlorine-35 is 75% and the abundance of chlorine-37 is 25%.

Calculate the relative atomic mass of chlorine.

Answer

1. % of chlorine-35 = 75% and % of chlorine-37 = 25%
2. The A_r of chlorine-35 is 35 amu and the A_r of chlorine-37 is 37 amu.
   Therefore 75 × 35 = 2625 and 25 × 37 = 925
3. 2625 + 925 = 3550
4. $\frac{3550}{100} = 35.50$
   Therefore, the relative atomic mass of chlorine is 35.50 amu.

Activity 1.44: Operation of the mass spectrometry and it's application

1. Design a flow chart to show the operation of the mass spectrometer.
2. **(a)** Design a model to show how to calculate the relative atomic mass of different elements.

   (b) Use the information provided in table-1 to calculate the relative atomic mass of naturally occurring copper isotopes. Give your answer to 1 decimal place.

Mass number	% Abundance
63	69
65	31

3. Bromine has two main isotopes: Br-79 with an atomic mass of 78.91833 amu and a relative abundance of 50.69%, and Br-81 with an atomic mass of 80.91629 amu and a relative abundance of 49.31%. Calculate the average atomic mass of bromine.

RADIOACTIVITY

Radioactivity is the process by which unstable atomic nuclei decay, releasing energetic particles or electromagnetic radiation including alpha, beta, and gamma rays. This natural phenomenon occurs in each radioactive isotope (radionuclides) at a fixed rate, characterized by a half-life, which is the time for half of the radioactive atoms to decay into stable ones. This rate of decay is unique to each individual radioactive isotopes, e.g. Carbon-14 will have a different half-life to Uranium-235, but all carbon-14 isotopes will have the same half-life. Radioactivity has practical applications in medicine, industry, and energy production, but also poses health risks and safety concerns that require careful management.

DIFFERENCES BETWEEN NUCLEAR REACTIONS AND CHEMICAL REACTIONS

Nuclear reactions and chemical reactions are two different reactions that involve changes in the composition of matter.

The main differences between these two types of reactions are as follows:

1. **Nature of particles involved:** In a chemical reaction, the atoms of the reacting substances do not change their identities. In contrast, in a nuclear reaction, the atomic nuclei of the reacting substances undergo changes, resulting in the formation of different nuclei and subatomic particles. Chemical reactions can be summarised in the movement and arrangement of electrons within Chemical bonds, however nuclear reactions involve the nucleus of the atoms themselves.
2. **Energy changes:** Nuclear reactions involve much larger energy changes than chemical reactions. This is because nuclear reactions involve changes in the binding energies of atomic nuclei, which are much larger than the energies involved in the breaking and forming of chemical bonds.
3. **Rate of reaction:** Chemical reactions generally occur at a faster rate than nuclear reactions. This is because chemical reactions involve the interaction of electrons, which are much lighter and move much faster than atomic nuclei.
4. **Triggering factors:** Chemical reactions are triggered by factors such as temperature, pressure, and concentration, while nuclear reactions are triggered by factors such as particle bombardment and radioactive decay. In other words, chemical reactions are affected by environmental conditions such as temperature and pressure, but nuclear reactions are not.
5. **Product stability:** The products of a chemical reaction are typically more stable than the products of a nuclear reaction. This means that the products of a nuclear reaction may undergo further decay or transformation into products over time.
6. **Emission of radiation:** Nuclear reactions emit radiation such as alpha particles, beta particles, and gamma rays while chemical reactions do not.

PROPERTIES OF ALPHA, BETA AND GAMMA RADIATION

Alpha, beta, and gamma radiation are types of ionising radiation, which have different properties based on their composition and energy.

Here are the properties of each type of radiation:

Alpha Radiation

1. Consists of a helium nucleus of two protons and two neutrons.
2. Has a charge of +2 and a mass number of 4 amu.
3. Travels only a few centimetres in the air and are blocked by a sheet of paper or the dead cells on the surface of skin.
4. Has a high ionisation potential and can cause significant damage to living tissue.
5. Emitted by heavy nuclei like uranium and radium as they decay into lighter elements.
6. Symbol $^{4}_{2}He$

Beta Radiation

1. Consists of a negatively charged particle identical to a high-energy electron.
2. It has a charge of -1 and has a negligible mass.
3. Are more penetrating than alpha particles and can penetrate several millimetres of aluminium or plywood.
4. Have lower ionisation potential than alpha particles and may cause damage to living tissue.
5. Are emitted by elements with an excess of neutrons, like carbon-14.
6. Symbol $^{0}_{-1}e$

Gamma Radiation

1. Consists of high-energy photons of electromagnetic radiation.
2. Has no charge or mass.
3. Is highly penetrating and can pass through several centimetres of lead or concrete.
4. Has a lower ionisation energy potential than alpha and beta radiation but can still cause damage to living tissues by ionising atoms along their path.
5. Emitted by the nucleus of some radioactive atoms, such as Cobalt-60.
6. Symbol γ

FACTORS THAT AFFECT THE STABILITY OF NUCLEI

The stability of atomic nuclei is determined by the balance between the strong nuclear force, which holds the nucleus together and the electrostatic repulsion between protons in the nucleus.

The neutron-to-proton ratio and the binding energy per nucleon *(one of the subatomic particles of the nucleus)* are the two most important factors that determine the stability of an atomic nucleus.

Neutron-to-Proton Ratio

The neutron-to-proton ratio is the ratio of the number of neutrons to the number of protons in the nucleus. This ratio affects the stability of the nucleus because it determines the balance between the strong nuclear force and the electrostatic repulsion between protons.

When the ratio is low, meaning there are more protons than neutrons, the electrostatic forces between the protons are stronger than the strong nuclear forces holding the nucleus together, making the nucleus unstable. On the other hand, nuclei with high neutron-to-proton ratios are also unstable as there are more neutrons than protons and the strong nuclear force becomes weaker leading to decay of the nucleus.

For stability, the ratio must be equal to the values shown in the graph below. As you can see this is close to one (1) for low atomic mass isotopes but drifts away from this as the atomic mass increases.

Also shown in this diagram are the types of decay that will occur depending upon the specific isotope (it is worth noting that some of the types of decay shown here are not covered by this course e.g. beta +, neutron or proton).

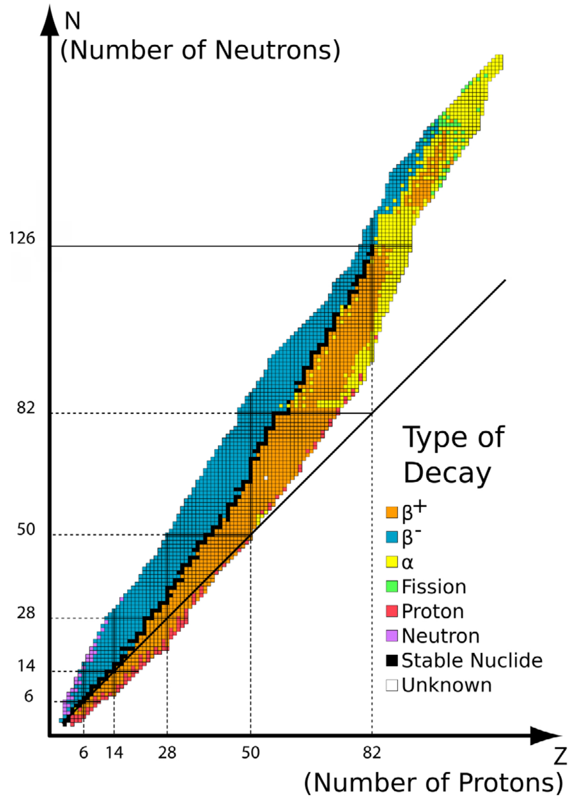


Figure 1.22: Graphical representation of neutron-to-proton ratio after decay

Binding Energy per Nucleon

The energy needed to keep the protons, neutrons, and electrons together in an atom is generally called binding energy.

The binding energy per nucleon refers to the average amount of energy required to remove a nucleon from the nucleus of an atom. It is calculated by dividing the total binding energy of a nucleus by the total number of nucleons (protons and neutrons) in the nucleus. The binding energy per nucleon reflects the strength of the strong nuclear force that holds the nucleus together.

When the binding energy per nucleon is high, the nucleus is more stable, meaning the strong nuclear force is strong enough to overcome the electrostatic repulsion between the protons. Nuclei with low binding energy per nucleon are less stable and tend to undergo radioactive decay which increases their binding energy per nucleon.

Carry out following activities (1, 2 and 3) in the laboratory.

Activity 1.45 Demonstrating radioactivity in a safe and engaging way.

Materials needed: naturally-occurring radioactive substances, Geiger counter, radioactive sources, lead, aluminium, paper, spark counter, High voltage power supply.

1. Observe the teacher (or any trained personnel invited by the teacher hold the radioactive sources in turn over the spark counter to show the presence of radiation.
2. For each source in turn, observe the teacher or trained personnel demonstrate the range and penetration power of each source.
3. For learners who may not have access any of the materials or receive a demonstration by a teacher or trained personnel, **alternatively**, you can use any of the links below to watch the video on radioactivity.

   https://www.youtube.com/watch?v=Pc3-y6Omzzw&list=PLEEC940EB121761B3

   https://www.youtube.com/watch?v=xwYSvzojFbo&list=PLEEC940EB121761B3&index=3

   https://www.youtube.com/watch?v=IUp9xa8tYs&list=PLEEC940EB121761B3&index=4

   https://www.youtube.com/watch?v=t9bKVL6hdRQ&list=PLEEC940EB121761B3&index=5

Do well to write down what you observe while watching the video(s) and compare your notes with that of your colleagues in class.

Half-life of a Nuclide

The half-life of a nuclide is the time it takes for half of the undecayed atoms in a sample of the nuclide to decay. This means that after one half-life has passed, half of the original nuclide atoms will have decayed, and the remaining half will remain.

A second half-life will have passed when a further half (i.e. half of a half) has decayed.

The half-life is a characteristic property of each radioactive nuclide and is constant for that nuclide, which means that regardless of the size of the sample, each atom has the same probability of decaying during a certain period.

Some nuclides have very short half-lives, which means they decay rapidly and are highly radioactive for only a short time, while others have very long half-lives, which means they decay slowly and can remain radioactive for thousands or millions of years.

Consider the implications of a substance which has a long half-life; why might this be beneficial and why might this not be beneficial? Discuss your thoughts with a neighbour and feedback to the class.

Consider the implications of a substance with a short half-life; why might this be beneficial and why might this not be beneficial? Discuss your thoughts with a neighbour and feedback to the class.

Half-life is an important concept in the study of nuclear chemistry and is used to calculate the amount of time needed for a given amount of radioactive material to decay to a desired amount, as well as how much of a substance will remain after a certain period of time. It is also used in radioactive dating methods to estimate the age of geological samples or archaeological artefacts.

Activity 1.46 Determination of half-life from experimental data.

Material Needed: A set of 100 dice.

1. Lay out a results table as shown below:

Number of rolls	Number of dice
0	100
1	

2. Shake all 100 dice.
3. Remove all the dice which show a number 1 or 2.
4. Count the remaining dice
5. Record this result in your table next to “number of rolls = 1”
6. Roll the remaining dice again.
7. Repeat steps 3 to 7 until all the dice have been removed.
8. Plot a graph showing how the number of dice changes as the number of rolls increases.

9. Repeat this experiment but now remove all dice which show a number of 1, 2 or 3.

a. Using observations from the activity. Discuss how this model relates to half life

b. Determine the half-life of both of your experiments (how many rolls did it take to reach 50?).

c. Discuss how the experiment could be developed to show a radionuclide with a longer half-life.

How to calculate the half-life using experimental data and calculation

To calculate the half-life of a substance a few things need to be known:

1. The initial activity or number of undecayed nuclei.
2. The final activity or number of undecayed nuclei.
3. The total time that the sample has been left for.

Worked Example

An isotope of Uranium-235 has an initial activity of 32 Bq and a final activity of 2 Bq. This sample was left for 200 years. Calculate the half-life of the sample:

Answer

Firstly, begin by halving the initial activity value:

32/2 = 16.

Next, continue the halving process until the final activity value is reached:

$\frac{16}{2} = 8.$

$\frac{8}{2} = 4.$

$\frac{4}{2} = 2.$

Then count how many times the activity has halved: 4

This process has undergone four (4) half-lives.

Finally divide the total time taken by the number of half-lives.

$\frac{200}{4} = 50$ years.

The time for one (1) half-life was 50 years.

Alternatively,

To calculate the half-life of a radioactive nuclide using experimental data, you need to measure the decay rate or the amount of radioactive material remaining at specific time intervals.

Here is how to calculate half-life using experimental data and calculation:

1. Measure the initial activity (or quantity) of the radioactive sample i.e. No.
2. Measure the activity (or quantity) of the radioactive sample at a specific time interval, Δt i.e. Nt
3. Calculate the fraction of the original material that has decayed during the time interval, Δt

   Using the formula:

   $$\text{Fraction decayed} = \frac{\text{Activity at } \Delta t}{\text{initial activity}}$$

   $$= \frac{N_t}{N_o}$$

4. Calculate the natural logarithm of the fraction decayed:

   i.e. $\text{In}\left(\frac{N_t}{N_o}\right) = \lambda\Delta t$ (λ is the decay constant of the nuclide)

5. Solve for the decay constant:

   $$\lambda = -\frac{\text{In}\left(\frac{N_t}{N_o}\right)}{\Delta t}$$

6. Calculate the half-life, $t_{1/2}$:

   i.e.

   $t_{1/2} = \frac{\text{In}2}{\lambda}$, where (*In*2) is the natural logarithm of 2, which is approximately 0.693.

   i.e.

   $$t_{\frac{1}{2}} = \frac{0.693}{\lambda}$$

Note that you can repeat this process with different time intervals, and the resulting half-lives should be consistent if the sample is homogeneous and the decay process is steady.

NB:

The expressions

$\text{In}(\frac{No}{Nt}) = \lambda\Delta t$ and

$\log\left(\frac{No}{Nt}\right) = \frac{\lambda t}{2.303}$ can also be used

Now try your hand at using equations to calculate half-life using experimental data.

Activity 1.47

Calculate the required values for each of these questions:

1. A sample of radioactive isotope **X** starts with an activity of 1000 counts per minute (cpm) and decays to 250 cpm in 60 years. What is the half-life of isotope **X**?
2. A sample of element **Y** has an initial activity of 800 counts per minute (cpm) and decays to 100 cpm in 24 years. Determine the half-life of element **Y**.
3. A sample of isotope **Z** starts with an activity of 1600 counts per minute (cpm) and decays to 100 cpm in 50 years. What is the half-life of isotope **Z**?
4. A sample of substance **W** starts with an activity of 3200 counts per minute (cpm) and decays to 200 cpm over a period of 48 years. Find the half-life of substance **W**.
5. A sample of material **Q** starts with an activity of 1600 counts per minute (cpm) and decays to 200 cpm in 21 years. Calculate the half-life of material **Q**.

Uses of radioisotopes and the principle behind each use

Radioisotopes are used in a wide range of applications, from medical diagnosis and treatment to industry and scientific research.

Here are some common uses of radioisotopes and the principle behind each use:

1. **Medical diagnosis:** Radioisotopes like technetium-99, iodine-131, and gallium-67 are commonly used in medical imaging techniques such as positron emission tomography (PET), single photon emission computed tomography (SPECT,) and computed tomography (CT) scans.

   These isotopes emit gamma rays that can be detected by special cameras to create images of internal body structures, allowing doctors to diagnose and monitor diseases such as cancer, heart disease, and neurological disorders.

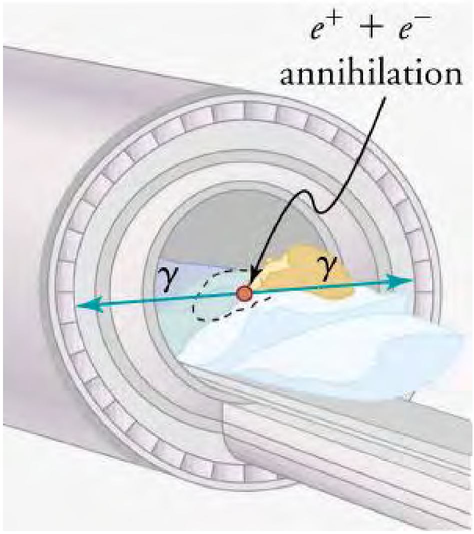


Figure 1.25: Medical diagnosis

2. **Medical treatment:** Radioisotopes can be used to treat certain types of cancer, such as thyroid cancer, by selectively targeting and destroying cancerous cells.

   Iodine-131 is used to treat thyroid cancer, while strontium-89 is used to relieve pain in bone cancer patients.

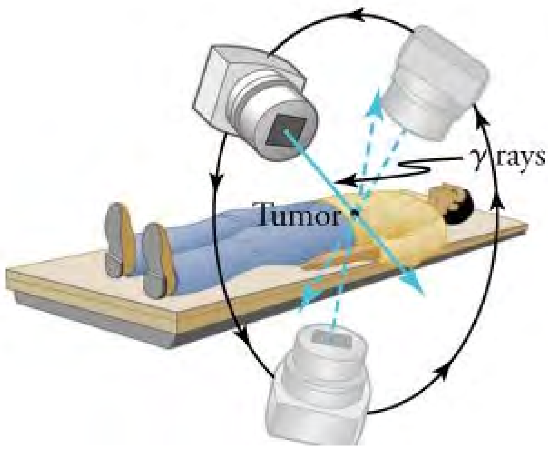


Figure 1.26: Medical treatment

3. **Industrial applications:** Radioisotopes such as cobalt-60 and iridium-192 are used to sterilise medical equipment and food products, as well as measure the thickness of materials in manufacturing processes.
4. **Agricultural applications:** Radioisotopes can be used to measure plant and soil properties, such as moisture content and nutrient uptake, to improve crop yield and quality. Radioisotopes are also used for insect and pest control.

5. **Scientific research:** Radioisotopes can be used to study various biological and chemical processes in cells, tissues, and organisms. Carbon-14 is used in dating archaeological artefacts and geological samples, while tritium (hydrogen-3) is used to label molecules and track their movement within biological systems.
6. **Source of heat energy:** Controlled nuclear fission is used to generate electricity and heat energy.

   The principle behind each use of radioisotopes is based on their unique properties, including their half-life, decay mode, and energy spectrum. For example, in medical imaging, radioisotopes that emit gamma rays are used because they can penetrate the body and be detected by specialised cameras. In cancer treatment, radioisotopes that emit beta particles or alpha particles are used because they can travel short distances and deliver a high dose of radiation to cancerous cells while sparing healthy tissue.

In industrial and agricultural applications, radioisotopes are used to measure various properties based on their ability to emit radiation or interact with other materials.

In a nutshell, the uses of radioisotopes are based on their ability to provide useful information, diagnose and treat diseases, improve quality control in manufacturing, and advance scientific research.

How to complete and balance simple nuclear reactions

Balancing a nuclear reaction involves ensuring that the total number of protons (atomic number, or proton number) and the total mass numbers (nucleon number) are the same on both sides of the equation. Additionally, the sum of the charges on each side must be equal. Example of a balanced nuclear reaction is shown below:

$$^{238}_{92}\text{U} \longrightarrow \,^{234}_{90}\text{Th} + \,^{4}_{2}\text{He}$$

Note that nuclear reactions involve the emission or capture of particles, such as alpha particles (helium nuclei) or beta particles (electrons).

These particles should be accounted for in the equation with the appropriate symbol.

Worked Example

A certain radioactive element, N, disintegrated into another element, K, when an alpha particle was released. The atomic mass and atomic number of N are 289 and 87, respectively.

a. Write the unbalanced equation

b. Balance the equation in (a) above.

c. Determine the values of x and y

d. Discuss how you balanced your nuclear equation with a friend.

Answer

1. Write out the radioactive elements and radiations involved in the form equation

$$\mathrm{N} \rightarrow \mathrm{K} + \alpha$$

2. Attach the mass numbers and atomic numbers

$$^{289}_{87}\mathrm{N} \rightarrow {}^{x}_{y}\mathrm{K} + {}^{4}_{2}\alpha$$

NB. The total atomic mass on the left-hand side is equal to that on the right side.

The total atomic number on the left-hand side is equal to that on the right side.

3. Find x and y by equating the mass numbers on the left-hand side to that on the right-hand side and the atomic numbers on the left-hand side to that on the right-hand side.

$$289 = x + 4$$

$$\therefore x = 289 - 4 = 285$$

$$87 = y + 2$$

$$\therefore y = 85$$

Hence the nuclear equation is balanced

$$^{289}_{87}\mathrm{N} \rightarrow {}^{285}_{85}\mathrm{K} + {}^{4}_{2}\alpha$$

Self-Assessment

Try to balance the following nuclear reactions using the worked example above (ask your teacher for assistance if you need it):

1. $^{232}_{690}Th \rightarrow {}^{228}_{88}Ra + X$

2. $^{14}_{6}C \rightarrow {}^{14}_{7}N + Y$

3. $^{9}_{4}Be + Z \rightarrow {}^{12}_{6}c + {}^{1}_{0}n$ $({}^{1}_{0}n = neutron)$

Risks associated with radioactivity

Radioactivity can pose several health and environmental risks.

Here are some of the risks associated with radioactivity:

1. **Radiation exposure:** Exposure to ionising radiation emitted by radioactive materials can damage the DNA in cells, leading to cellular mutations and cancer. Long-term exposure to low levels of radiation is associated with an increased risk of cancer, while high levels of radiation exposure can cause sickness and death.

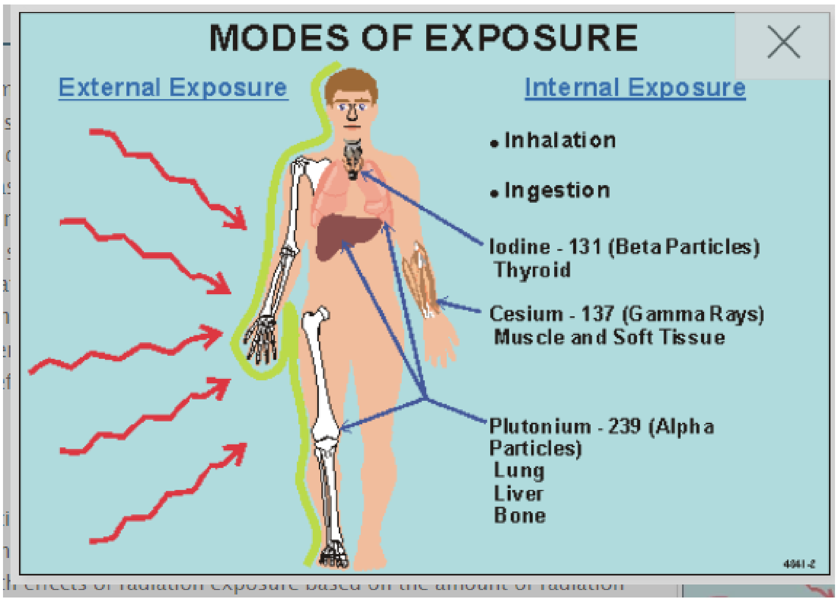


Figure 1.27: Modes of exposure

2. **Health risk to workers:** Individuals who work with or around sources of radiation, such as nuclear power plant workers and medical professionals, are at a higher risk of radiation exposure and associated health risks.

Figure 1.28: Effects of exposure to radiation

3. **Environmental risks:** Radioactive materials can contaminate soil, water, and air, leading to environmental contamination and increased radiation exposure for humans and other living organisms.

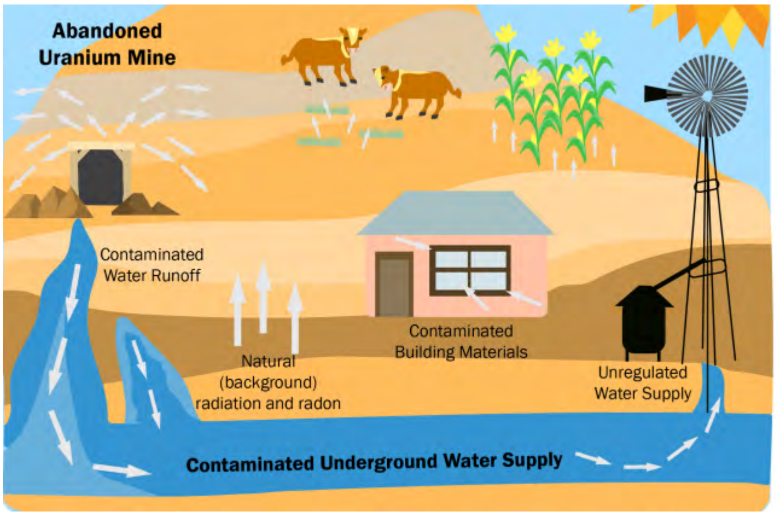


Figure 1.29: Environmental risks

4. **Nuclear accidents:** Accidents at nuclear power plants can release large amounts of radioactive materials into the environment, leading to increased radiation exposure and environmental contamination.

Figure 1.30: Nuclear accidents

5. **Nuclear weapons:** The use of nuclear weapons can release large amounts of ionising radiation, causing both immediate and long-term health effects for humans and the environment.

   To mitigate the risks associated with radioactivity, it is important to follow proper safety protocols when working with radioactive materials. This includes using protective equipment, maintaining proper monitoring and dosimetry practices, and ensuring that radioactive waste is properly disposed of and secured.

In the event of a nuclear accident or radiation release, evacuation procedures and clean-up exercise should be carried out to minimise exposure and contamination.

Fig 1.31: Nuclear weapons

Activity 1.48 Exploring the applications of radioisotopes in various fields.

Materials needed: Internet access, presentation tools (e.g., posters, PowerPoint)

1. In a group of 5 learners each, explore a different application of radioisotopes (e.g., medical imaging, cancer treatment, food irradiation, energy, carbon dating).
2. Present you findings to the class as a poster or PowerPoint, focusing on how radioisotopes are used and their benefits and risks.
3. Discuss the different applications and the importance of radioisotopes in everyday life.

Activity 1.49 The principal parts of a mass spectrometer and how they work.

Materials needed: Charts or printed images of a mass spectrometer, worksheet with questions and space for notes

1. Use a diagram or a chart of a mass spectrometer,
2. Identify the principal parts of a mass spectrometer:

3. Explain the function of the parts.

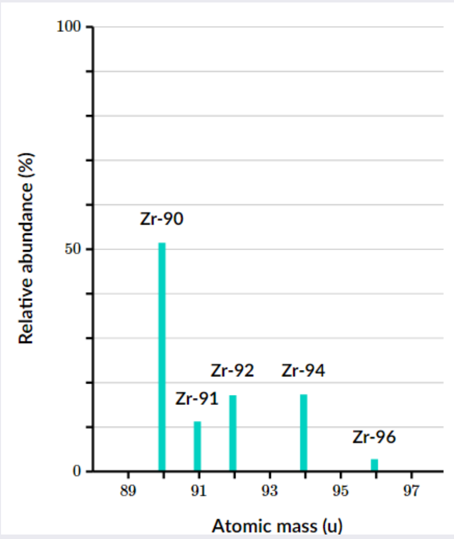
4. Explain the step-by-step process of how a mass spectrometer works following the guiding questions below:
   a. What is the purpose of the ion source in a mass spectrometer?
   b. How are ions accelerated in a mass spectrometer?
   c. What role does the magnetic field play in the deflection of ions?
   d. How does the detector measure the ions?

Activity 1.50: Identification of peaks on the mass spectrum

To learn how to identify peaks on a mass spectrum and use them to calculate the relative abundance and masses of isotopes.

Materials needed: Printed mass spectra charts and calculators

Using the given mass spectrum Identify how the x-axis (horizontal axis) and y-axis (vertical axis) represent.



1. Identify the number of peaks on the mass spectrum.

   (Each peak corresponds to an isotope, and the height (or intensity) of the peak indicates its relative abundance.)

2. **Calculating Relative Abundance:**

   $A_r = (m_1 \times a_1) + (m_2 \times a_2) + \ldots$

   Where: $m_1, m_2, \ldots, \ldots$ are the masses of the isotopes

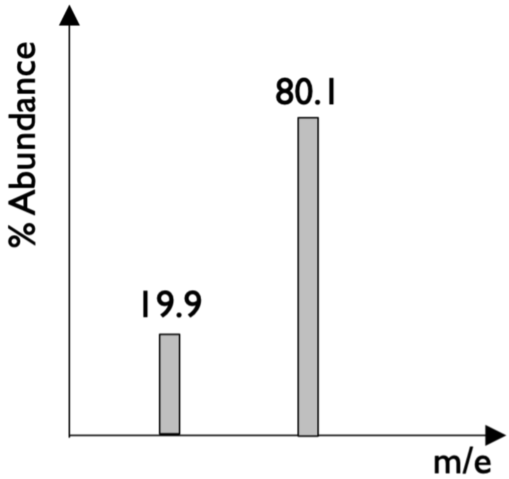
   $a_1, a_2, \ldots, \ldots$ are the abundances of the isotopes

Worked Example

Using the simple mass spectrum of boron isotopes below.

(a) Identify the percentage abundance of the boron isotopes.

(b) Calculate the relative atomic mass of boron.



Answer

a. *The peak heights show the relative abundance of the boron isotopes:*

boron-10 has a relative abundance of 19.9% and

boron-11 has a relative abundance of 80.1%

b. $(A_r(\mathrm{B}) = (m_1 \times a_1) + (m_2 \times a_2)$

$=(10 \times 0.199) + (11 \times 0.801) = 10.8$

Therefore, relative atomic mass of boron is 10.8

Review Questions

Review Questions 1.1a

1. State three careers that are related to chemistry.
2. State and explain at least three benefits of chemistry to the Ghanaian society.
3. Conduct research on the importance of chemistry to Ghanaian society in the field of agriculture and present your findings using PowerPoint or flipcharts.
4. Why is the study of chemistry important, and how does it contribute to our understanding of the natural world and address global challenges?
5. Explain why chemistry is considered the "central science".
6. What are some examples of interdisciplinary research that combine chemistry with other sciences like biology, physics, or environmental science?
7. Explain how chemistry informs and improves our daily lives, from medicine to technology to consumer products.
8. Create a flow chart showing how chemistry affects daily lives, such as in
   a. Personal care and hygiene
   b. Food and nutrition
   c. Health and medicine
   d. Technology and gadgets
   e. Environment and conservation

Review Questions 1.1b

1. State at least one (1) type of fire that can be extinguished using a carbon dioxide fire extinguisher.
2. Explain why potassium permanganate should not be stored near a bottle containing ethanol.

3. Design a chemical storage compatibility chart using the following chemicals in the laboratory: HNO_3, CH_3COOH, NaOH, H_2O_2, CH_3CH_2OH

Review Questions 1.1c

1. State at least two (2) examples of personal protective equipment used in the chemistry laboratory.
2. State the precautions to take when handling chemicals with the following hazard labels.
   a. Corrosive substance
   b. Toxic substance
3. In a certain school, the authorities are concerned about the increasing rate of accidents in the chemistry laboratory during practical sessions.
   (a) Suggest three (3) possible causes of these accidents.
   (b) Write and explain three (3) ways of curbing the problem identified.
4. State **five** wrong practices that should be avoided in the chemistry laboratory.
5. What should you do when handling chemicals in the laboratory?
6. Explain what a chemistry student should do in case of a chemical spillage in the laboratory.
7. Discuss how to handle hazardous chemicals safely using protective clothing and safety equipment. Consider the following: gloves, goggles, laboratory coats, respirators and safety showers.

Review Questions 1.2

1. What is the role of curiosity and wonder in driving scientific inquiry?
2. How does the scientific method relate to real-world problems and applications?

Review Questions 1.3a

1. How does Dalton's atomic theory help us understand the basic structure of matter?
2. Why is it important to learn about the historical development of atomic theory in science?
3. How did Dalton's theory contribute to the field of chemistry?
4. How did Dalton's atomic theory differ from earlier concepts of atoms?

Review questions 1.3b

1. Which subatomic particles did Thomson include in the plum-pudding model of the atom?
2. How did the results of Rutherford's gold foil experiment differ from his expectations?

Review Questions 1.4a

1. What was the name of Bohr's model of the atom?
2. Briefly describe how Bohr's model of the atom contributed to our understanding of the stability of the atom.
3. Evaluate the possible values of the magnetic quantum number (m) for an electron in an orbital with $l = 2$.
4. Which of the following sets of quantum numbers are not allowed in the hydrogen atom? For the sets of quantum numbers that are incorrect, state what is wrong in each set.

   (a) $n = 3, l = 2, m = 2$

   (b) $n = 4, l = 3, m = 4$

   (c) $n = 0, l = 0, m = 0$

   (d) $n = 2, l = -1, m = 1$
5. Given the quantum numbers $n = 4$, $l = 3$, determine the number of orbitals and the maximum number of electrons possible in this subshell.
6. If an electron in a hydrogen atom transitions from the $n = 3$ level to the $n = 2$ level, what are the possible values of the azimuthal quantum number l for the initial and final states?

7. Explain why an electron orbiting around the nucleus of an atom does not collapse into the nucleus, according to Bohr's model.

Review Questions 1.4b

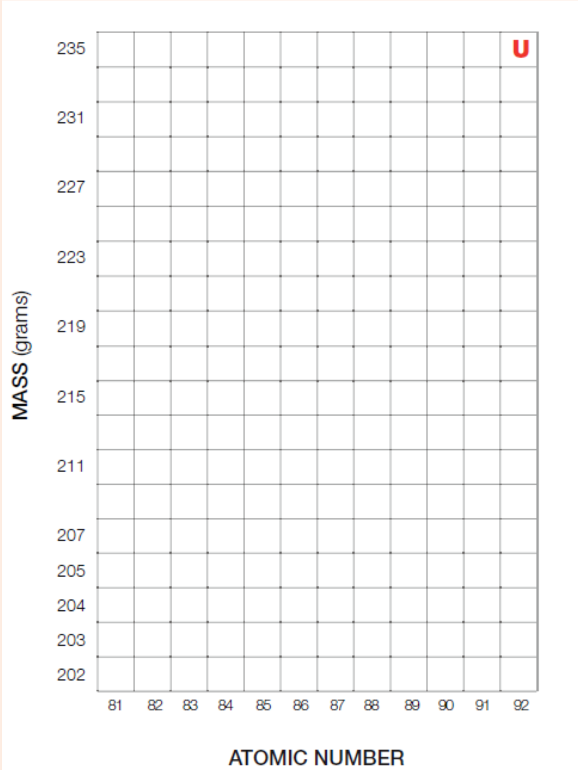
1. What is an isotope, and how do isotopes of the same element differ?
2. What happens when an atom becomes unstable and decays?
3. Explain what happens when there more neutrons than protons in the nucleus.
4. List and explain three (3) uses of radioactivity
5. Half-life of a radionuclide is 5 days. How many days will it require for a 160 g sample of this radionuclide to decay to 5 g?
6. An unknown radioactive isotope, X, decays to one-fourth of its original amount in 60 years. What is the half-life of isotope X?
7. A sample of element Y decays to 12.5% of its initial quantity in 24 years. Determine the half-life of element Y.
8. Isotope Z decays to 6.25% of its initial amount in 50 years. What is the half-life of isotope Z?
9. A sample of substance W reduces to one-sixteenth of its original amount over a period of 48 years. Find the half-life of substance W.
10. Material Q decays to one-eighth of its original mass in 21 years. Calculate the half-life of material Q.
11. A fossil contains 25% of its original Carbon-14. The half-life of Carbon-14 is 5730 years. How old is the fossil?
12. A sample of Radium-226 has decayed to one-eighth of its original amount. If the half-life of Radium-226 is 1600 years, how much time has passed since the sample started decaying?
13. A medical treatment involves Iodine-131, which has a half-life of 8 days. If a patient's body initially contains 200 mg of Iodine-131, how much time will it take for the amount to reduce to 25 mg?
14. Uranium-238 has a half-life of 4.5 billion years. If a rock originally had 60 grams of Uranium-238 and now contains 15 grams, how old is the rock?
15. Use the worksheet provided to answer questions about the types of radiation emitted in each decay process.

Complete the graph by following the sequence of alpha and beta decays that actually occurs in nature from the decay event table.

Start with U-235 and follow the steps (in order) of alpha and beta decays.

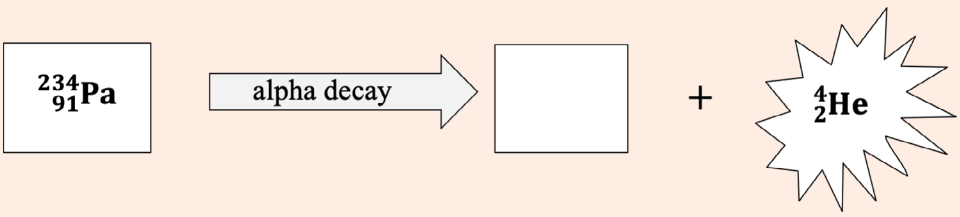
Graph the path of decays by drawing an arrow tracing the mass number per atomic number and writing the correct atomic symbol for each mass number per atomic number event.

STEP #	DECAY EVENT
1	ALPHA
2	BETA
3	ALPHA
4	ALPHA
5	BETA
6	ALPHA
7	ALPHA
8	ALPHA
9	BETA
10	ALPHA
11	BETA
12	STABLE

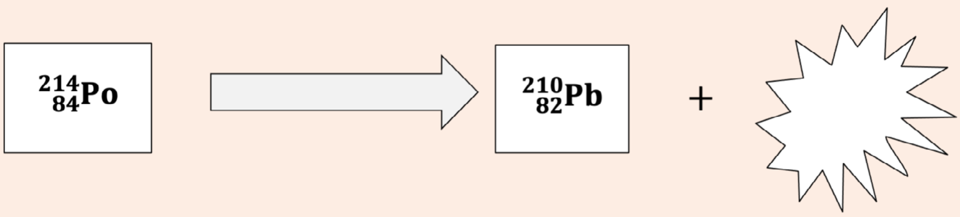


16. Fill in the blanks with the correct notation, atomic symbols, mass number, atomic number, decay type, and/or emission particles. You may use a periodic table to identify the element.

(a)



(b)



17. Using flow charts, distinguish between nuclear reactions and chemical reactions.

18. What materials can the teacher use to explain the concept of radioactivity to learners?

19. What precautions should a learner take in disposing of materials like mobile phones that can release nuclear radiations that will contaminate the environment?

Review Questions 1.4c

Calculate the relative atomic masses of the following elements:

1. Magnesium has three main isotopes: Mg-24 with an atomic mass of 23.98504 amu and a relative abundance of 78.99%, Mg-25 with an atomic mass of 24.98584 amu and a relative abundance of 10.00%, and Mg-26 with an atomic mass of 25.98259 amu and a relative abundance of 11.01%. Calculate the average atomic mass of magnesium.

2. Carbon has two main isotopes: C-12 with an atomic mass of 12.00000 amu and a relative abundance of 98.93%, C-13 with an atomic mass of 13.00335 amu and a relative abundance of 1.07%. Calculate the average atomic mass of carbon.

3. Silicon has three main isotopes: Si-28 with an atomic mass of 27.97693 amu and a relative abundance of 92.23%, Si-29 with an atomic mass of 28.97649 amu and a relative abundance of 4.67%, and Si-30 with an atomic mass of 29.97377 amu and a relative abundance of 3.10%. Calculate the average atomic mass of silicon.

Review Questions 1.5a

1. Explain the following terms:

(a) relative atomic mass **(b)** relative molecular mass

2. Below is a list of elements with their corresponding atomic masses. Use this information to answer the questions that follow.

Element Symbol	Element Name	Relative Atomic Mass
H	Hydrogen	1.01
He	Helium	4.00
Li	Lithium	6.94
Be	Beryllium	9.01
B	Boron	10.81

Element Symbol	Element Name	Relative Atomic Mass
C	Carbon	12.01
N	Nitrogen	14.01
O	Oxygen	16.00
F	Fluorine	19.00
Ne	Neon	20.18
Na	Sodium	22.99
Mg	Magnesium	24.31
Al	Aluminium	26.98
Si	Silicon	28.09
P	Phosphorus	30.97
S	Sulphur	32.07
Cl	Chlorine	35.45
K	Potassium	39.10
Ca	Calcium	40.08

(a) What is the relative atomic mass of nitrogen (N)?

(b) Which element has a relative atomic mass of 12.01?

(c) What is the relative atomic mass of sulphur (S)?

(d) Which element has the highest relative atomic mass in the table?

Review Questions 1.5b

1. Explain why the electron configuration of chromium (Cr) is different from what is expected based on the Aufbau principle

2. Analyse the relationship between electron configuration and the chemical properties of elements within a period.

3. Write the electron configuration for $_{11}$**Na** and $_{19}$**K.** Using the configuration, explain why they are considered reactive elements.

4. Using the electron configurations for ($_{18}$**Ar and** $_{10}$**Ne),** explain why they are considered to be non-reactive.

5. Explain why half and fully-filled sub-shells are more stable than those that are neither half nor fully filled.

6. The electron configurations for the elements named are shown here. Each configuration is incorrect in some way. Identify the error in each and write the correct configuration.

(a) $_{13}$Al: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3d_1^1$

(b) $_{17}$Cl: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^2\ 3p_y^2\ 4s^1$

(c) $_{10}$Ne: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^1\ 3s^1$

(d) $_{19}$K: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^2\ 3p_y^2\ 3p_z^2\ 3d_1^1$

(e) $_{7}$N: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^1$

ANSWERS TO REVIEW QUESTIONS

Answers to Review Questions 1.1a

Q. 1-2 Refer to Learner Material

3. Answers will differ

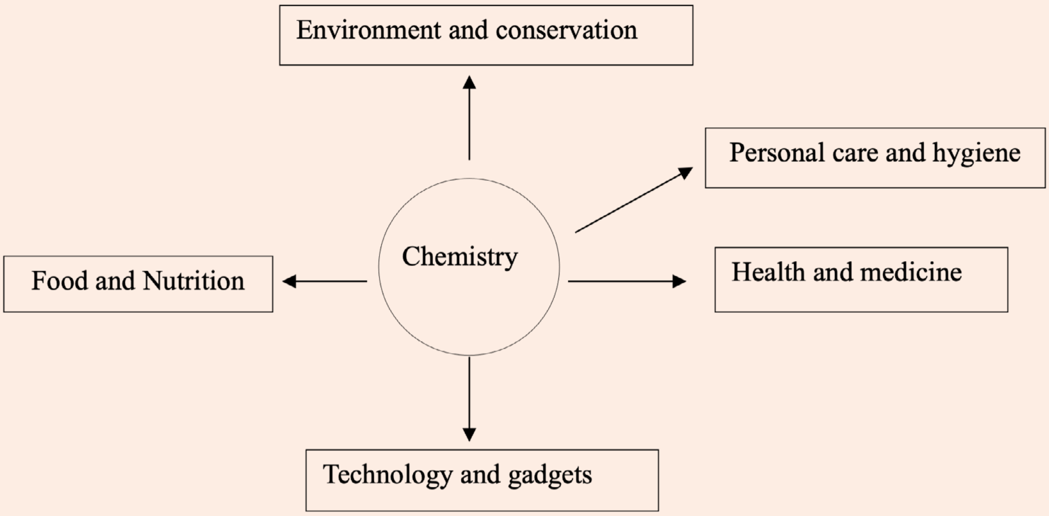
4. The study of chemistry is essential for advancing basic understanding of matter, improving quality of life, and addressing complex challenges facing society and the environment. Its interdisciplinary nature and practical applications make it a critical science with far-reaching implications for the well-being of present and future generations.

5. Chemistry is often referred to as the "central science" because it serves as a bridge between other scientific disciplines, connecting and integrating concepts from physics, biology, environmental science, materials science, and many others.

6. Examples include drug development, materials science, environmental redress, and nanotechnology).

7. Chemistry leads to developments in medicine, materials, energy, and consumer products; it improves our quality of life and addresses global challenges)

8. This flow chart demonstrates how chemistry is integral to various aspects of our daily lives, from personal care and food to health and technology.



Answers to review questions 1.1b

1. Electrical equipment, flammable liquids, gases, and fires in enclosed or confined spaces.

2. Potassium permanganate should not be stored near a bottle containing ethanol because potassium permanganate is a strong oxidising agent, and ethanol is a flammable organic compound. If they come into contact, the reaction can be highly exothermic and potentially explosive, posing a serious fire and explosion hazard

3.

Chemical	HNO_3	CH_3COOH	NaOH	H_2O_2	CH_3CH_2OH
HCl	X	√	√	√	√
HNO_3	√	√	√	√	√
CH_3COOH	√	√	√	√	√
NaOH	√	√	√	√	√
H_2O_2	√	√	√	√	X
CH_3CH_2OH	√	√	√	X	√

Answer to review questions 1.1c

1. Chemical goggles, hand gloves, nose mask

2. **(a)**

- Always wear chemical-resistant gloves, chemical goggles or face shields, and a lab coat or apron to protect your skin and eyes from splashes.
- Work in a well-ventilated area, preferably under a fume hood, to avoid inhaling harmful vapours.
- Handle the chemical carefully to avoid spills and splashes. Use proper tools like pipettes or dispensers.
- Store corrosive substances in a cool, dry place, away from incompatible materials.
- Ensure that containers are clearly labelled and tightly sealed.

- Dispose of corrosive substances according to your institution's hazardous waste disposal guidelines. Do not pour them down the drain.

(b) Toxic Substance

- Always wear gloves, chemical goggles, and a lab coat to prevent skin and eye contact.
- Use a respirator or mask if there is a risk of inhaling toxic fumes.
- Handle toxic substances in a fume hood to avoid inhaling dangerous vapours or dust.
- Use tools like tongs or spatulas to handle toxic substances. Avoid direct contact and minimise exposure.
- Store toxic substances in a secure, well-ventilated area, away from incompatible materials.
- Ensure containers are clearly labelled and kept out of reach of unauthorised personnel.
- Dispose of toxic substances following your institution's hazardous waste disposal procedures. Never pour them down the drain or throw them in regular trash.

3. **(a)** Lack of proper training, inadequate supervision and improper use of Personal Protective Equipment (PPEs).

(b) Implement comprehensive safety training programs

Enhance supervision in the laboratory

Enforce strict PPE policies:

4. Wearing open-toed shoes; not wearing gloves, tasting or smelling chemicals; not wearing safety goggles; poor labelling and storage; not following procedures; using damaged equipment (any four will do).

5. Wear appropriate protective gear, read labels carefully, and follow established protocols.

6. Neutralise the spill, contain it, and report it to the instructor or laboratory technician.

7. Handling hazardous chemicals requires proper protection to prevent exposure and injury. Wear the type of gloves, goggles, laboratory coats and respirators. Use the safety shower immediately in case of exposure to hazardous chemicals.

Answer to Review Questions 1.2

1. Curiosity and wonder are the emotional and intellectual foundations of scientific inquiry, driving scientists to explore, question, and understand the world. This leads to discoveries that advance knowledge and improve our lives.
2. The structured approach of the scientific method ensures that real-world problems are addressed systematically, with solutions grounded in empirical evidence. By utilising this method, scientists and practitioners can create reliable and effective solutions that enhance quality of life, drive technological advancements, and safeguard the environment.

Answer to review question 1.3a

1. Dalton's atomic theory lays the groundwork for understanding the structure of matter by identifying atoms as the fundamental units of all substances. It clarifies the nature of elements, the creation of compounds, and the rules that govern chemical reactions. This theoretical framework has been pivotal in the evolution of modern chemistry and remains a critical influence on how we explore and comprehend the material world.
2. Studying the history of atomic theory helps us understand how scientific ideas have changed over time. It shows us the important work of early scientists, helps us learn key concepts, encourages us to think critically, and shows how science affects our lives. This history makes science more interesting and helps us see its impact on our world.
3. Dalton's idea that everything is made of tiny building blocks called atoms helped scientists understand and develop modern chemistry.
4. Dalton's theory differed from earlier ideas (like those of Democritus) by being based on scientific evidence and experimentation. While ancient Greek philosophers speculated about atoms, Dalton provided a coherent scientific framework supported by empirical laws.

Answer to Review questions 1.3b

1. Electrons and positive charges
2. The results of Rutherford's gold foil experiment differed from his expectations in the following ways:

   Rutherford expected:

   (a) all alpha particles would pass through the gold foil.

   (b) the alpha particles would pass through the gold foil with little deflection

   Rutherford observed:

   (a) that most alpha particles passed through the gold foil, but some bounced back.

   (b) A small percentage of alpha particles were deflected at very large angles, with some even bouncing back towards the source

You will learn more about relative atomic mass and relative molecular mass in section 2

Answer to Review questions 1.4a

1. The planetary model
2. Bohr's model accounts for the stability of atoms because the electron cannot lose more energy than it has in the smallest orbit, the n=1
3. $m = -2, -1, 0, 1, 2$
4. **(b)** For $l = 3$, m, can range from -3 *to* $+3$; thus 14 is not allowed.

   (c) n cannot equal zero.

   (d) l cannot be a negative number.
5. For $n = 4$ *and* $l = 3l = 3$ (which corresponds to the f subshell):

   The magnetic quantum number m can have values $-3, -2, -1, 0, +1, +2, +3$, providing 7 possible orbitals.

   Each orbital can hold a maximum of 2 electrons, so the f subshell can hold $7 \times 2 = 14$ electrons.
6. For $n = 3$: l can be 0, 1, *or* 2 $(s, p, or\ d\ subshells)$.

   For $n = 2$: l can be 0 or 1 $(s\ or\ p\ subshells)$.

7. According to Bohr's model, electrons do not collapse into the nucleus because they move in specific orbits at specific distances, and they have just the right amount of energy to stay in those orbits without falling in.

Answer to review questions 1.4b

Q. 1-3: Refer to Learner material

4. Medical Applications

(i) Radioactivity is used in medicine for diagnosis, treatment, and research, helping to save countless lives. Examples include cancer treatment, imaging techniques like PET scans, and radioimmunotherapy.

(ii) Industrial Applications

Radioactivity is used to inspect materials, detect leaks, and sterilise medical instruments and food. It also helps to analyse the structure and composition of materials.

(iii) Energy Production

Nuclear power plants generate electricity by harnessing the energy released from radioactive decay, providing a significant source of clean energy worldwide.

5. 25 *days*

6. Half-life of isotope X is30 years

7. Half-life of isotope Y is 8 years

8. Half-life of isotope Z is12.5 years

9. Half-life of substance W is12 years

10. Half-life of material Q is 7 years

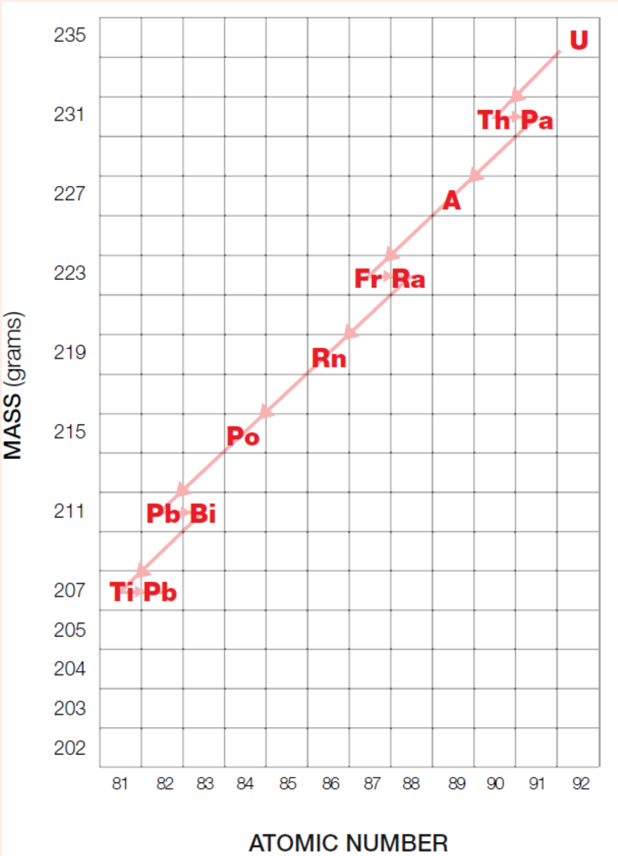
11. 11460 years

12. 4800 years

13. 24 days

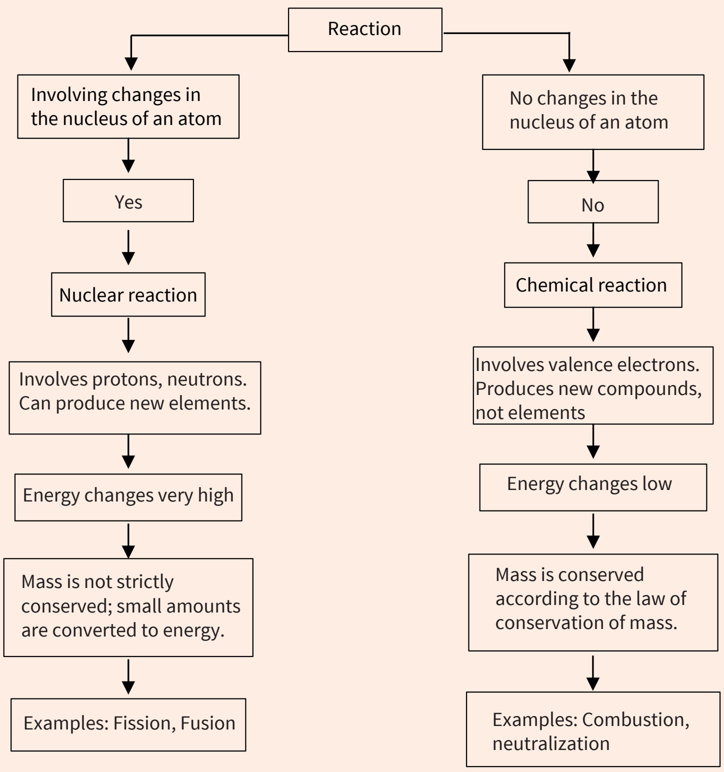
14. 9 billion years

15.



16. **(a)** $^{230}_{89}$Pa; **(b)** alpha decay, $^{4}_{2}$He

17.



18. Mobile phones, mobile phone battery, old television sets etc.

19. Recycle or properly dispose,

- Check with local authorities
- Follow manufacturer guidelines
- Do not crush or burn

Answers to Review Questions 1.4c

1. Average atomic mass of Mg is 24.305 amu

2. Average atomic mass of C is 12.011 amu

3. Average atomic mass of Si is 28.089 amu

Answers to Review Questions 1.5a

1. **Refer to learner material in this section**

2. **(a)** 14.01 **(b)** Carbon

(c) 32.07 **(d)** Calcium

Answers to Review Questions 1.5b

1. Chromium's electron configuration deviates from the Aufbau principle because the half-filled 3d subshell ($3d^5$) provides additional stability. This results in the actual configuration of $4s^13d^54s^1$ being lower in energy and more stable than the expected $4s^23d^4$ configuration.

2. The electron configuration influences the chemical properties of elements within a period by affecting their atomic radius, ionisation energy, electronegativity, and reactivity. Understanding these trends helps explain why elements exhibit certain chemical behaviours and how their properties change across a period.

3. ${}_{11}Na = 1s^2\ 2s^2\ 2p^63s^1$; ${}_{19}K = 1s^22s^22p^63s^23p^64s^1$.

They all have one electron in their outermost energy level. They easily donate this one electron during chemical reactions. This makes them highly reactive.

4. ${}_{10}Ne = 1s^22s^22p^6$; ${}_{18}Ar = 1s^22s^22p^63s^23p^6$.

They have full outer energy levels, making them very stable and unreactive.

5. Half-filled and fully-filled subshells are more stable because they have symmetrical electron distributions, which reduce repulsions and lower the overall energy of the atom.

6. **(a)** $_{13}Al$: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^1$

(b) $_{17}Cl$: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^2\ 3p_y^2\ 3p_z^1$

(c) $_{10}Ne$: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2$

(d) $_{19}K$: $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^2\ 3p_y^2\ 3p_z^2\ 4s^1$

(e) $_{7}N$: $1s^2\ 2s^2\ 2p_x^1\ 2p_y^1\ 2p_z^1$

EXTENDED READING

Basic chemistry / Karen Timberlake, William Timberlake. Sixth edition. Pearson, [2019] (Pg: 510-511)

General chemistry / Donald A. McQuarrie, Peter A. Rock. — 4th ed. / Ethan B. Gallogly. (Pg: 137, 141-158)

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REFERENCES

1. SHS Chemistry Curriculum
2. Zumdal, S,S.,& Decoste(2017). Chemistry. Cengage learning
3. Chang, R(2017). Chemistry, McGraw-Hill Education.
4. Atkins, P.W.,& de Paula J(2017). Atkins, Physical Chemistry, Oxford University Press
5. Khan Academy-Introduction to chemistry: https://www.khanacademy.org/science/chemistry/atomic-structure-and-properties/introduction-to-the-atom/v/introduction-to-chemistry
6. American chemical society. (n.d). Careers in chemistry.https://www.acs.org/careers/chemical sciences.html
7. OSHA. Personal Protective Equipment. Retrieved from https://www.osha.gov/personalprotective-equipment.
8. Laboratory Safety Institute-https:// www.labsafetyinstitute.org
9. Occupational Safety and Health Administration (OSHA)-Hazard Communication Standard. https://www.osha.gov/hazcom
10. Occupational Safety and Health Administration (OSHA)-Hazard Communication. Retrieved on December 18, 2023, from https://www.osha.gov/hazcom.
11. National Academy of Science. (1998). Teaching about the Scientific method: *A guide for schools*. National Academy Press.
12. Harrison, A.G., &Treagust, D.F., (2016). Teaching and Learning the Nature of Science and Scientific Inquiry: *An International Review of Science Education*. Springer.
13. Tro, N.J., (2017) Chemistry: A Molecular Approach. Pearson Education.
14. Encyclopaedia Britannica. https://www.britannica.com/science/atomic-theory
15. ThoughtCo. H: https: https://www.thoughtco.com/john-daltons-atomic-model-607777

16. Encyclopaedia Britannica https://www.britannica.com/science/Rutherford-atomic-model
17. Cathode ray tube experiment, "Retrieved [February 27, 2024] from Cathode Rays – Sir
18. William Crookes (wordpress.com)"
19. Plum pudding model of the atom, "Retrieved [February 27, 2024] from https://keystagewiki.com/index.php/Plum_Pudding_Model#/media/File%3APlumPuddingDiagram.png"
20. Rutherford alpha scattering experiment, "Retrieved [February 27, 2024] from Rutherford alpha scattering experiment - Search Images (bing.com) "
21. Rutherford atomic model, "Retrieved [February 28, 2024] fromhttps://cdn1.byjus.com/wpcontent/uploads/2018/07/Rutherford-Atomic-Model-and-Limitations-.png"
22. Subatomic particles displayed in a table, "Retrieved [February 27, 2024] from subatomic particles displayed in a table - Search Images (bing.com)"
23. Tro, N. J. (2017). Chemistry: A Molecular Approach. Pearson Education.
24. Encyclopaedia Britannica. https://britannica.com/science/Bohr-atomic-model
25. https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_

Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)

26. https://www.khanacademy.org/science/physics/quantum-physics
27. https://www.britannica.com/science/Pauli-exclusion-principle
28. s and p-orbital diagram. Retrieve on [February 27, 2024] from www.google.com
29. Bohr model of atom. Retrieve on [February 27, 2024] from bing.com
30. Continuous spectrum and emission spectrum. Retrieve on [February 27, 2024] from Google Search
31. Line spectrum showing H and energy level. Retrieve on [February 27, 2024] from Google Search

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