Step 3 Exploring matter

Here is a review of the main concepts of this step!

1 States of matter

On Earth, the most common states of matter are solids, liquids, and gases, each displaying unique particle behaviour.

Solids have a definite shape and volume. At a microscopic level, their particles are tightly packed and can only vibrate in place due to strong interparticle forces. This structure makes solids rigid and incompressible, only changing shape when broken or cut.

Liquids have a definite volume but no fixed shape. Their particles are less tightly bound than in solids, allowing them to slide past each other. This fluidity enables liquids to take the shape of their container. In the absence of gravity, like in space, liquids can float and change shape while maintaining their volume. They are also difficult to compress because the particles are still close together.

Gases have neither a definite shape nor volume. Their particles move freely and randomly due to very weak bonds, allowing gases to fill any container completely. Gases are easily compressible because their particles are spaced far apart.

Beyond these common states, there are two additional forms of matter.

Plasma forms under extremely high temperatures and is actually the most prevalent state in the universe, found in the solar corona, solar wind, nebulae, and Earth's ionosphere.

Bose-Einstein Condensate is a state achieved when materials are cooled to temperatures near absolute zero, causing particles to occupy the same space and quantum state, behaving as a single quantum entity.

2 Phase transitions

Phase transitions refer to the transformation of matter from one state to another.

When a solid is heated, its particles gain energy and start to move more freely. As a result, the substance transitions from a solid state to a liquid state, a process known as **melting**. The specific temperature at which this change occurs is called the melting point.

When a liquid is cooled, it loses energy, and its particles slow down, leading to the formation of a solid. This process is known as **freezing** or solidification. For instance, water freezes at 0°C.

Conversely, when you heat a liquid, its particles move faster and eventually break free to become a gas. This process, known as boiling, occurs at the boiling point, which is 100°C for water. During boiling, bubbles of gas form within the liquid and rise to the surface, turning the entire liquid into steam. Even before reaching the boiling point, particles at the surface of a liquid can gain enough energy to escape as gas through a process called **evaporation**.

Condensation is the reverse of this process. When a gas is cooled, its particles lose energy and slow down, coming closer together to form a liquid. For example, steam from a boiling pot of water condenses into droplets on a cool window pane.

Some substances can transition directly from a solid to a gas without passing through the liquid state, a process known as **sublimation**. An example of this is dry ice turning directly into carbon dioxide gas. The opposite of sublimation is deposition, where a gas changes directly into a solid. An example of deposition is frost forming from water vapor on cold surfaces.

3 Physical and chemical properties and phenomena

Substances have specific physical and chemical properties that influence their transformations, known as phenomena.

Physical properties are characteristics that can be observed or measured, like mass, volume, color, boiling point, and density. They describe how a substance responds to external influences and are classified as extensive (dependent on quantity) or intensive (independent of quantity).

Chemical properties describe how substances interact or transform into different substances, such as wood burning, iron rusting, and milk souring.

Physical phenomena involve changes in a substance's state or appearance without altering its composition, like melting ice or bending copper.

Chemical Phenomena involve changes that result in new substances, like iron rusting or an apple rotting.

4 Atoms: the basic units of a substance

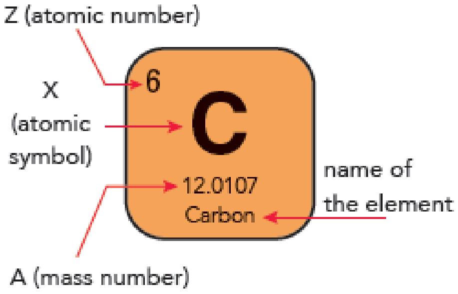
Matter is composed of atoms, the smallest units that retain the properties of an element without releasing charged particles. Atoms consist of three main subatomic particles:

- **Protons** carry a positive charge (+) and have significant mass.
- **Neutrons** carry no charge (0) and have a mass similar to protons.
- **Electrons** carry a negative charge (-) and have much smaller mass compared to protons and neutrons.

Protons and neutrons are located in the nucleus at the centre of the atom, while electrons orbit the nucleus in regions called orbitals. Despite this structure, most of an atom is empty space. Atoms are usually neutral, with equal numbers of protons and electrons. However, atoms can become charged ions if they gain or lose electrons.

Mass and atomic number

The nucleus, containing protons and neutrons, determines the mass of an atom. The sum of protons and neutrons is the mass number (A). The atomic number (Z) is the number of protons in an atom and defines the element. For instance, carbon (atomic number 6) has six protons, while oxygen (atomic number 8) has eight protons. The atomic number is represented by Z, and the mass number by A ($A = Z + N$, where N is the number of neutrons). These numbers are shown next to the chemical symbol of an element on the periodic table.



5 The periodic table

The periodic table is essential for chemists to classify elements by their characteristics. It was conceived by Dmitri Mendeleev, who first organized elements by atomic mass and later by increasing atomic number.

The table has seven horizontal rows called **periods** and eighteen vertical columns called **groups**. Elements with similar properties are in the same group. While most elements are in the main body of the table, the lanthanides and actinides are separate.

Currently, the periodic table includes 118 elements recognized by the IUPAC. It helps identify the atomic number, element name or symbol, elements in a compound, elements in the same group or period, and the relative atomic mass of an element.

6 Molecules

Molecules are formed when two or more atoms bond together in fixed ratios. They can be of two types: molecules of elements, composed of identical atoms, or molecules of compounds, composed of different atoms. Examples include water (H_2O) and glucose ($C_6H_{12}O_6$).

Molecular bonding

Atoms form molecules and compounds by bonding with each other through strong attractive forces. Covalent bonds, where atoms share electron pairs, are common in molecules.

Molecular formulae

Molecular formulae represent the composition of a substance in simplest terms. For example, the molecular formula of glucose ($C_6H_{12}O_6$) indicates it consists of 6 carbon, 12 hydrogen, and 6 oxygen atoms. The molecular weight is the sum of the weights of its constituent atoms.

Molecular structure

Molecules have diverse shapes determined by the three-dimensional arrangement of atoms, known as molecular geometry. This arrangement influences properties like reactivity, polarity, phase of matter, colour, magnetism, and biological activity.

Types of molecules

Molecules can range from simple diatomic or triatomic structures to complex polyatomic or giant covalent structures. Giant molecular structures, like graphite and diamond, have thousands of atoms held together by strong covalent bonds, resulting in high melting and boiling points and insolubility in water and organic solvents.