1. FOUNDATION AND FUNDAMENTALS OF CHEMISTRY

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🎯 **Learning outcomes**

By the end of this chapter, Students should be able to:

- ✓ Define chemistry; matter, other key terms of chemistry
- ✓ Recognise the importance and scope of chemistry.
- ✓ Explain atom, molecule, radicals, valency, molecular formula, and empirical formula.
- ✓ Recall simple ions with their name, formula, valency, and charges
- ✓ Write the molecular formula of simple compounds
- ✓ Define and use the terms relative atomic mass, relative molecular mass, and relative formula mass.
- ✓ Write/recall the atomic masses of the first 30 elements of the periodic table
- ✓ Calculate the percentage composition of constituent elements from the molecular formula.

Introduction to chemistry | Atoms, compounds, and ions | Chemistry | Khan Academy

General Introduction to Chemistry

Chemistry is the scientific study of matter.

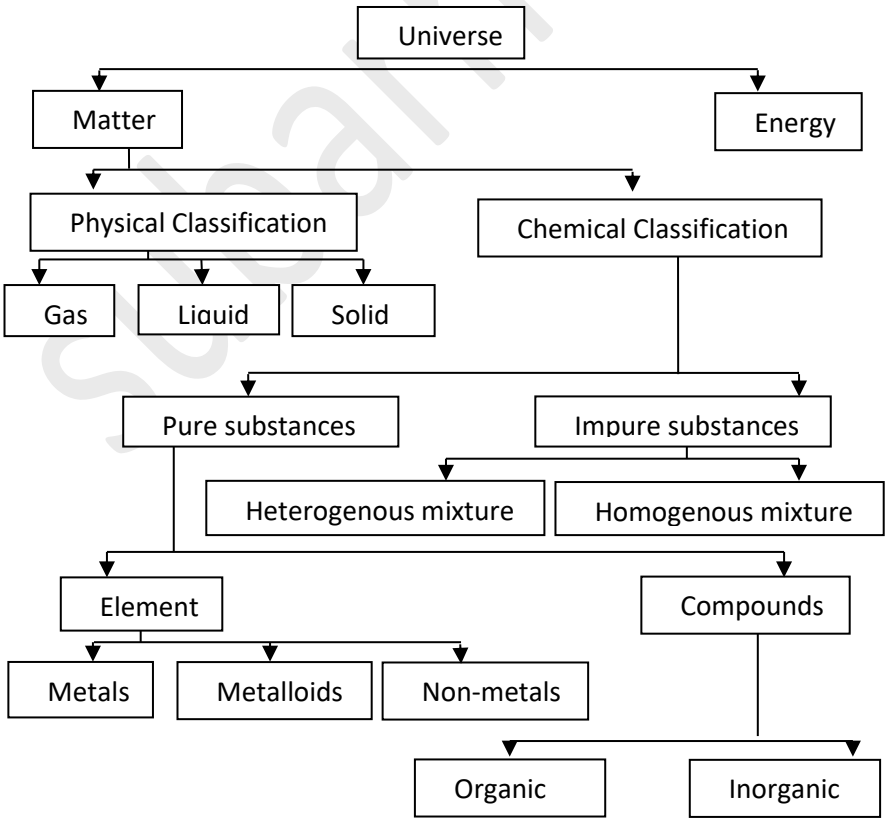
Chemistry can be defined as the *branch of science* that deals with the **study** of the ***composition***, ***properties,*** and ***transformation*** **of matter**.

Matter is anything that occupies space and has mass.

Introduction to middle school chemistry | Khan Academy

Scientific method

- Universality
- Predictability
- Objectivity
- Verifiability



Importance and Scope of Chemistry

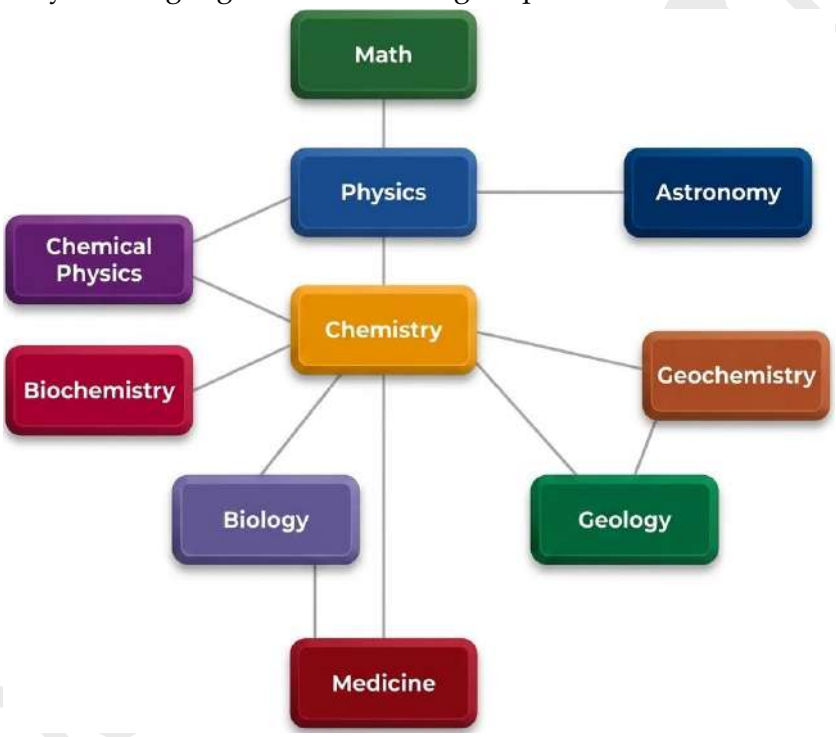
Chemistry isn't just a school subject — it's the foundation of almost every modern profession and industry. Chemistry is essential in modern daily life plus a part of the curriculum for the basics in many modern fields of professions like medicine, pharmacy, biochemistry, anatomy, engineering, food and dairy, nutrition, industries like beverages, paints, dyes, drugs, fertilisers, pesticides, and many others.

It is involved in all parts of our lives, directly or indirectly. Fulfilment of basic needs is also aided by chemistry.

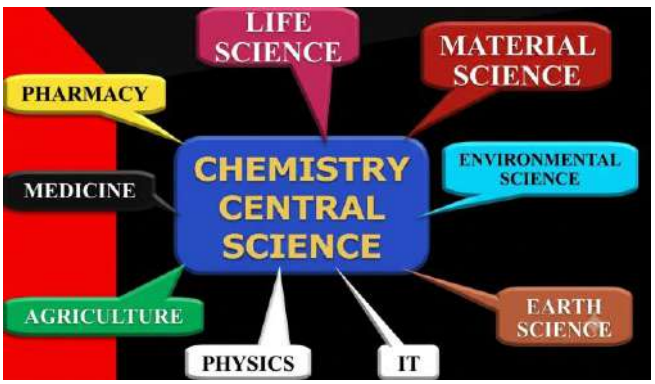
Food Shelter Cloth Health Education Security

Main branches of chemistry

Organic Chemistry – the study of carbon-containing compounds.
Inorganic Chemistry – the study of inorganic and mineral compounds.
Physical Chemistry – the study of the physical principles underlying chemical interactions.
Analytical Chemistry – the study of analysing substances and determining their composition.
Biochemistry – Chemistry of living organisms and biological processes.



The Relationships between Some of the Major Branches of Science. Chemistry lies more or less in the middle, emphasising its importance to many branches of science.



Main scopes of chemistry

Medicine & Pharmaceuticals – Drug development and disease treatment.
Agriculture – Fertilisers, pesticides, and soil testing.
Energy – Battery technology, fuels, and solar cells.
Environmental Protection – Pollution control, recycling, and waste management.
Materials Science – Development of polymers, metals, ceramics, and nanomaterials.

Assignment

Using library resources, the internet, or AI tools, write a short article or make a presentation on:
"The Importance and Scope of Chemistry"
Focus especially on how chemistry plays a role in YOUR daily life. Think about the food you eat, the medicines you take, the materials in your home, and the environment around you.

Basic Concepts of Chemistry

Atoms

An atom is the smallest, fundamental unit of an element that possesses the properties of that element. E.g., Cl represents the chlorine atom.

Or,

Atoms are the *smallest units of an element* that participate in chemical reactions.

Most atoms don't exist in a Free State in nature, except for the atoms of noble gases.

Molecule

A molecule is the smallest particle of an element or compound that has **independent existence**.
E.g., CO_2 is a molecule of the compound Carbon dioxide. Cl_2 is a molecule of the element chlorine.
It possesses all the properties of the element or compound.
Homoatomic molecule: molecules containing the atoms of the same element

Type	Examples
Monoatomic (1 atom)	He, Ne, Ar (noble gases)
Diatomic (2 atoms)	H_2, O_2, N_2, Cl_2, F_2, Br_2, I_2
Triatomic (3 atoms)	O_3 (ozone)
Tetraatomic (4 atoms)	P_4 (phosphorus)
Octaatomic (8 atoms)	S_8 (sulfur)

Heteroatomic molecules — contain atoms of two or more different elements:

- *Water: H_2O (2 hydrogen + 1 oxygen)*
- *Carbon dioxide: CO_2 (1 carbon + 2 oxygen)*
- *Sulfuric acid: H_2SO_4 (2 H + 1 S + 4 O)*

Ions/Radicals

An ion (also called a radical) is an atom or group of atoms that has gained or lost electrons, giving it an electric charge.

Type	Charge & Examples
Cation (positive ion)	Lost electrons → positive charge. e.g., Na^+, Ca^{2+}, NH_4^+, Fe^{3+}
Anion (negative ion)	Gained electrons → negative charge. e.g., Cl^-, O^{2-}, SO_4^{2-}, OH^-

In salts, the positive ion (cation) is called the basic radical, and the negative ion (anion) is called the acidic radical. **Example:** In NaCl (table salt), Na^+ is the basic radical and Cl^- is the acidic radical.

Valency

The combining capacity of an atom of an element or ion is called valency. For example, the valency of sodium in sodium chloride is 1; the valency of Mg in $MgSO_4$ is 2; the valency of carbonate (CO_3^{-2}) is 2.

Variable valency

Some elements in the periodic table, especially d-block (transition) elements, can have different valencies.

Element	Valencies (with traditional names)
Iron (Fe)	+2 (ferrous) and +3 (ferric)
Tin (Sn)	+2 (stannous) and +4 (stannic)
Mercury (Hg)	+1 (mercurous) and +2 (mercuric)
Lead (Pb)	+2 and +4
Copper (Cu)	+1 and +2

Chemical formula

The symbolic representation of a molecule of a substance is called the chemical formula, e.g., H_2O is the formula for water, and NaCl is the formula for sodium chloride.

Molecular formula

A molecular formula shows the actual number of each type of atom in one molecule of a substance.

Substance	Molecular Formula
Water	H_2O — 2 hydrogen atoms and 1 oxygen atom
Sulfuric acid	H_2SO_4 — 2 H, 1 S, 4 O atoms

List of radicals/ions:

Radicals	Formula	Radicals	Formula
Sulphate	**SO_4^{2-}**	bisulphate	HSO_4^-
Sulphite	SO_3^{2-}	bisulphite	HSO_3^-
Sulphide	S^{2-}	**hydroxide**	**OH^-**
Carbonate	**CO_3^{2-}**	**bicarbonate**	**HCO_3^-**
Nitrate	**NO_3^-**	nitrite	NO_2^-
Phosphate	PO_4^{3-}	cyanide	CN^-
Fluoride	F^-	chloride	Cl^-
Bromide	Br^-	iodide	I^-
Chromate	CrO_4^{2-}	peroxide	**O_2^{2-}**
Dichromate	$Cr_2O_7^{2-}$	permanganate	MnO_4^-
Hydride	H^-	thiosulphate	$S_2O_3^{2-}$
Hypochlorite	ClO^-	chlorate iodate	ClO_3^- IO_3^-
Perchlorate	ClO_4^-	ferricyanide	$[Fe(CN)_6]^{3-}$
Ammonium	**NH_4^+**	ferrocyanide	$[Fe(CN)_6]^{4-}$

To write the formula of a compound from its ions, use the crisscross rule: swap the valencies of the two ions to become the subscripts of the other.

Example: Calcium Sulphate
Calcium ion: Ca^{2+} (valency = 2)
Sulphate ion: SO_4^{2-} (valency = 2)
Criss-cross: $Ca_2(SO_4)_2 \rightarrow$ simplify $\rightarrow CaSO_4$
So, calcium sulphate = $CaSO_4$

Relative Atomic Mass (atomic wt., atomic mass)

Since atoms are extremely small, it is nearly impossible to measure the mass of individual atoms. Hence, the lightest element, hydrogen, was taken as the reference to express the masses of other elements.

Therefore, the atomic mass of an element may be defined as,

$$\text{Atomic mass of an element} = \frac{\text{mass of 1 atom of the element}}{\text{mass of 1 atom of hydrogen}}$$

In this scale of atomic mass, there are a few problems, like the isotope of hydrogen is not specified.

Later, the C-12 isotope was taken as a standard by IUPAC. In this C-12 scale,
"The atomic mass of an element is a number which indicates how many times one atom of the element is heavier than one-twelfth of an atom of C^{12} isotope."
Mathematically,

$$\textbf{Atomic mass of an element} = \frac{\textbf{mass of 1 atom of the element}}{\textbf{mass of } \frac{1}{12\text{th}} \textbf{ of C}-12 \textbf{ isotope}}$$

This atomic mass is not the actual mass but the relative atomic mass, sometimes called atomic weight. Since atomic mass is the ratio of two masses, it has no unit, but the atomic mass unit (amu) is used for convenience. Dalton 'D' is also the same as amu.

⚠ Common Error to Avoid
Don't confuse atomic mass with mass number!
• Mass number = total protons + neutrons in one specific atom (always a whole number)
• Relative atomic mass = average mass compared to C-12 (often a decimal, due to isotopes)

Assignment
Make a personal study card listing the first 30 elements with their name, symbol, atomic number, and atomic mass. Review it daily until you know them from memory — this knowledge is used throughout all of chemistry!

Atomic Number	Element	Symbol	Atomic Mass (amu)	Rounded off to
1	Hydrogen	H	1.008	1
2	Helium	He	4.00	4
3	Lithium	Li	6.94	7
4	Beryllium	Be	9.01	9

Atomic Number	Element	Symbol	Atomic Mass (amu)	Rounded off to
5	Boron	B	10.81	11
6	Carbon	C	12.01	12
7	Nitrogen	N	14.01	14
8	Oxygen	O	16.00	16
9	Fluorine	F	19.00	19
10	Neon	Ne	20.18	20
11	Sodium	Na	22.99	23
12	Magnesium	Mg	24.31	24
13	Aluminium	Al	26.98	27
14	Silicon	Si	28.09	28
15	Phosphorus	P	30.97	31
16	Sulfur	S	32.07	32
17	Chlorine	Cl	35.45	35.5
18	Argon	Ar	39.95	40
19	Potassium	K	39.10	39
20	Calcium	Ca	40.08	40
21	Scandium	Sc	44.96	45
22	Titanium	Ti	47.87	48
23	Vanadium	V	50.94	51
24	Chromium	Cr	51.99	52
25	Manganese	Mn	54.94	55
26	Iron	Fe	55.85	56
27	Cobalt	Co	58.93	59
28	Nickel	Ni	58.69	59
29	Copper	Cu	63.55	63.5
30	Zinc	Zn	65.38	65.5

Relative Molecular mass (weight)

Molecular mass is also defined similarly to atomic mass.

The relative molecular mass of a compound or an element is the number of times a molecule of the element is heavier than 1/12th of a C-12 isotope.

Mathematically,

$$\text{Molecular mass} = \frac{\text{mass of 1 molecule of a compound or element}}{\text{mass of } \frac{1}{12\text{th}} \text{ of C}-12 \text{ isotope}}$$

The molecular mass of a substance is calculated by summing up the mass of all the atoms present in the molecular formula.

Worked Examples

Example 1: Water (H_2O)
H = 1, O = 16
$Mr(H_2O) = (2 \times 1) + (1 \times 16) = 2 + 16 = 18$ amu

Example 2: Hydrated Copper Sulphate ($CuSO_4 \cdot 5H_2O$)
Cu = 63.5, S = 32, O = 16, H = 1
Mr = 63.5 + 32 + (4 × 16) + 5 × [(2 × 1) + 16]
= 63.5 + 32 + 64 + 5 × 18
= 63.5 + 32 + 64 + 90
= 249.5 amu

Concept of Fractional Atomic Mass (weight)

In nature, most elements exist as different isotopes. So, the atomic mass of an element is taken as an average of different isotopes of the element found in nature. This is the reason the atomic masses of most elements are fractional.

Worked Example:

Chlorine is naturally made up of 75% Cl-35 isotope and 25% Cl-37 isotope. Calculate the atomic mass of the chlorine element. [1]

Solution: The average atomic mass of Cl = $\frac{75\times35+25\times37}{100}$ = 35.5 amu

Empirical formula

The symbolic formula, which shows the simplest whole-number ratio of the number of atoms in a molecule, is called the empirical formula. The empirical formula of Ethene (C_2H_4) is CH_2, and the empirical formula of water (H_2O) is H_2O.

More examples:

Compound	Molecular formula	Empirical formula
Hydrogen peroxide	H_2O_2	HO
Benzene	C_6H_6	CH
Ethane	C_2H_6	CH_3
Glucose	$C_6H_{12}O_6$	CH_2O
Carbon dioxide	CO_2	CO_2
Butane	C_4H_{10}	C_2H_5

Percentage composition from molecular/formula weight, atomic weight, and valency

Formula
% of element = (mass of element in 1 mole of compound ÷ molar mass of compound) × 100
Or using atoms: % of element = (no. of atoms × atomic mass) ÷ Mr × 100

Worked Example: Washing Soda — $Na_2CO_3 \cdot 10H_2O$

First, calculate the molecular mass:

- *Na: 23 × 2 = 46*
- *C: 12 × 1 = 12*
- *O (in CO_3): 16 × 3 = 48 & in H_2O: 16 × 10 = 160*
- *Total Mr = 46 + 12 + 48 + 180 = 286 amu*

Now calculate each percentage:

- *% Na = (46 ÷ 286) × 100 = 16.08%*
- *% C = (12 ÷ 286) × 100 = 4.20%*
- *% O = [(48 + 160) ÷ 286] × 100 = (208 ÷ 286) × 100 = 72.73%*
- *% H = (20 ÷ 286) × 100 = 6.99%*

✓ Check: 16.08 + 4.20 + 72.73 + 6.99 ≈ 100% ✓

➢ The full symbol for an atom shows its mass number as a superscript and its atomic (proton) number as a subscript. For example, $^{12}_{6}C$ shows a carbon atom with mass number 12 and proton number 6.

Chapter Summary

🔑 **Key Definitions**
• Chemistry — the study of the composition, properties, and transformation of matter
• Matter — anything with mass that occupies space
• Atom — smallest unit of an element that retains its chemical properties
• Molecule — smallest particle of an element/compound that can exist independently
• Ion/Radical — an atom or group of atoms with a positive or negative charge
• Cation — positive ion (lost electrons); Anion — negative ion (gained electrons)
• Valency — combining capacity of an atom or ion
• Molecular formula — actual number of atoms in a molecule
• Empirical formula — simplest whole-number ratio of atoms
• Relative atomic mass — how heavy an atom is compared to 1/12 of C-12
• Relative molecular mass — sum of atomic masses of all atoms in a molecule
• Isotopes — atoms of the same element with different numbers of neutrons ✓ Isotopes = same atomic number (Z), different mass number (A)
✓ Atomic masses are fractional because of naturally occurring isotopes
✓ % composition = (element mass contribution ÷ molecular mass) × 100

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