Analytical Chemistry

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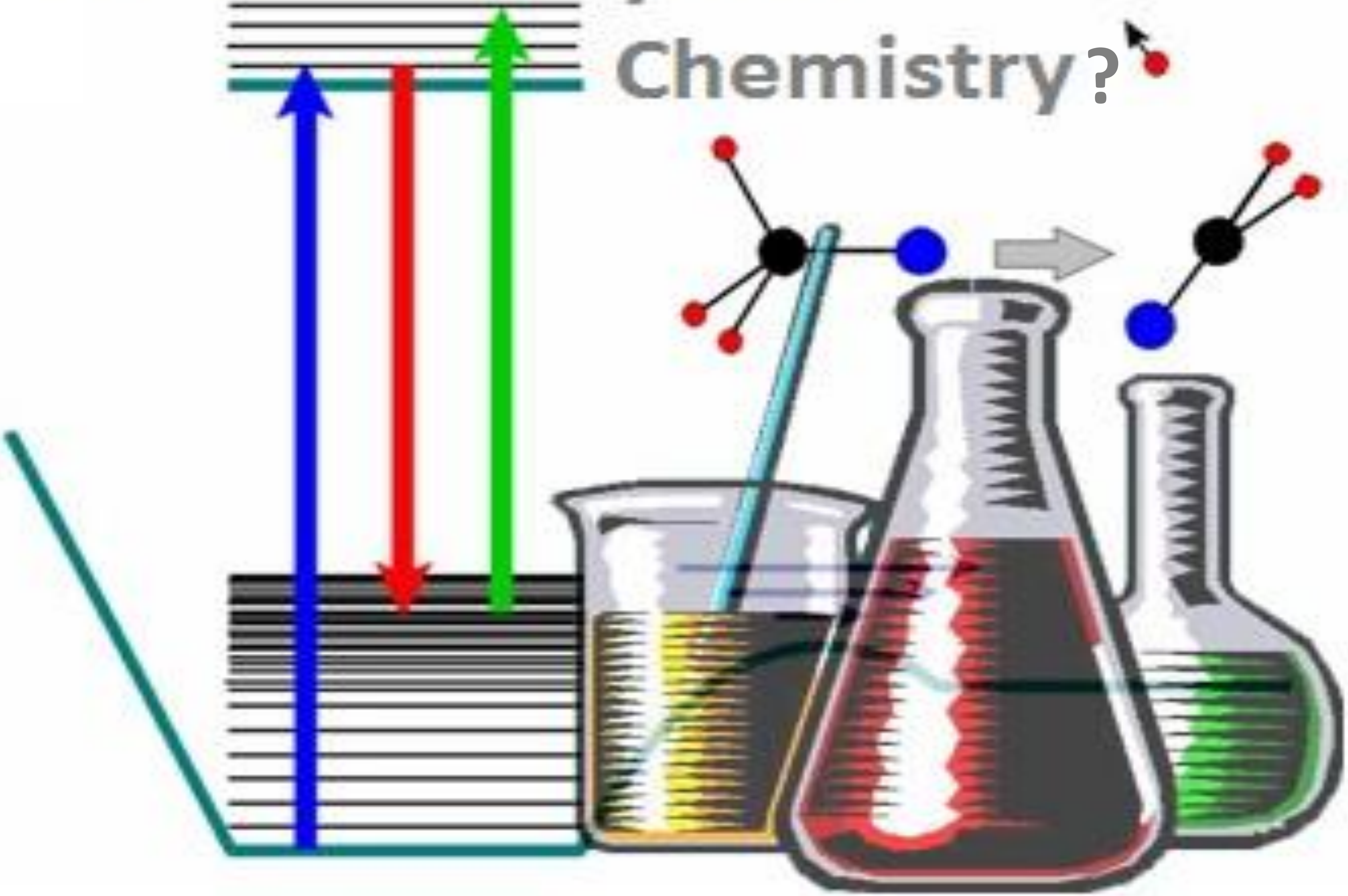
Contents

What is Analytical Chemistry?



•Analytical Chemistry :

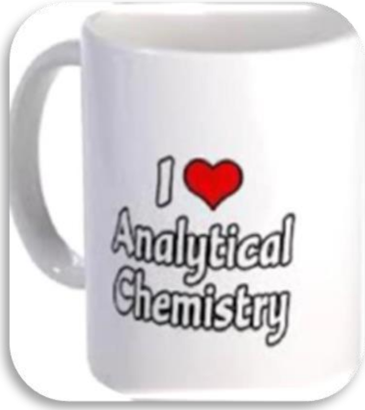
It is a Measurements science consisting of a set of powerful ideas and methods that are useful in all field of science and medicine.

“A Scientific discipline that develops and applies methods, instruments and strategies to obtain information on the composition and nature of matter in space and time”

Federation of European Chemical Societies

Is the branch of chemistry that deals with the analysis of substances (analytes) present in the sample qualitatively and quantitatively. In order to accomplish this analysis we must know the physical and chemical properties of these substances .

In other words analytical chemistry deals with the separation, Identification and determination of substances in a sample. It also includes coverage of chemical equilibrium and statistical treatment of data.



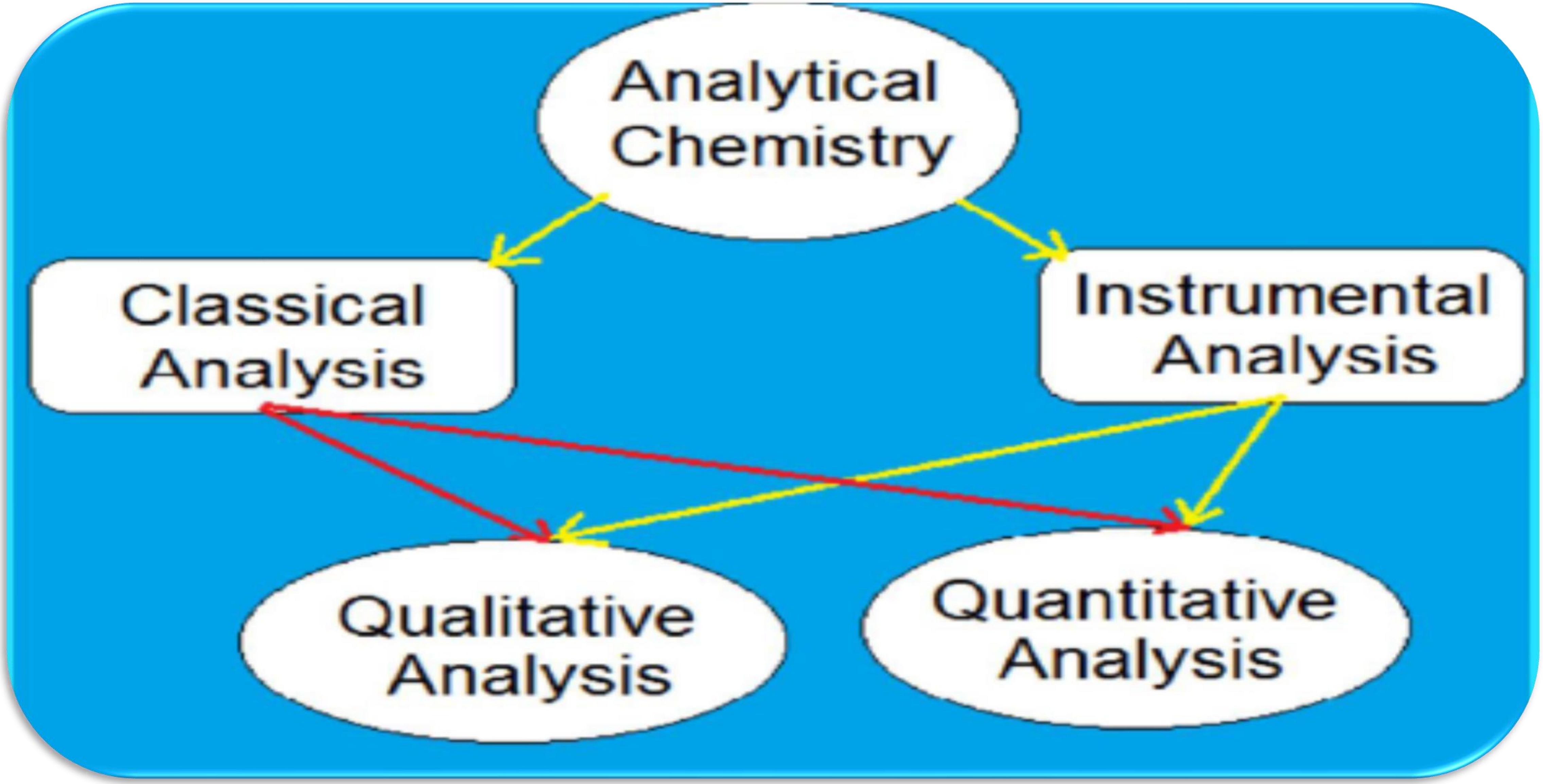
Types of Analytical Chemistry:

Analytical chemistry is concerned with the chemical characterization of matter and the answer to two important questions what is it (qualitative) and how much is it (quantitative).

Analytical chemistry answering for basic questions about a material sample:

- **What?**
- **Where?**
- **How much?**
- **What arrangement, structure or form?**

Types of Analysis:



Qualitative analysis: An analysis in which we determine the identity of the constituent species (the elements and compounds) in a sample.

Quantitative analysis: An analysis in which we determine how much of a constituent species is present in a sample.

Analytes: Are the components of a sample that are to be determined.

Classifying Analytical Techniques

A- Classical techniques

Mass, volume, and charge are the most common signals for classical techniques, and the corresponding techniques are:

1- Gravimetric techniques.
2- Volumetric techniques.
3- Coulometric techniques.

B- Instrumental techniques

1- Spectroscopic methods - measuring the interaction between the analyte and electromagnetic radiation (or the production of radiation by an analyte).

2- Electroanalytic methods - measure an electrical property (i.e., potential, current, resistance, amperes, etc.) chemically related to the amount of analyte.

The Role of Analytical Chemistry

Analytical chemistry plays a vital role in the development of science.

Plays a vital role in many research areas in chemistry, biochemistry, biology, geology, physics and the other sciences.

All branches of chemistry draw on the ideas and techniques of analytical chemistry.

Steps in chemical analysis

•Understanding the Problem (What is to be measured? Expense, time, equipment available, sensitivity, selectivity, complexity of sample)

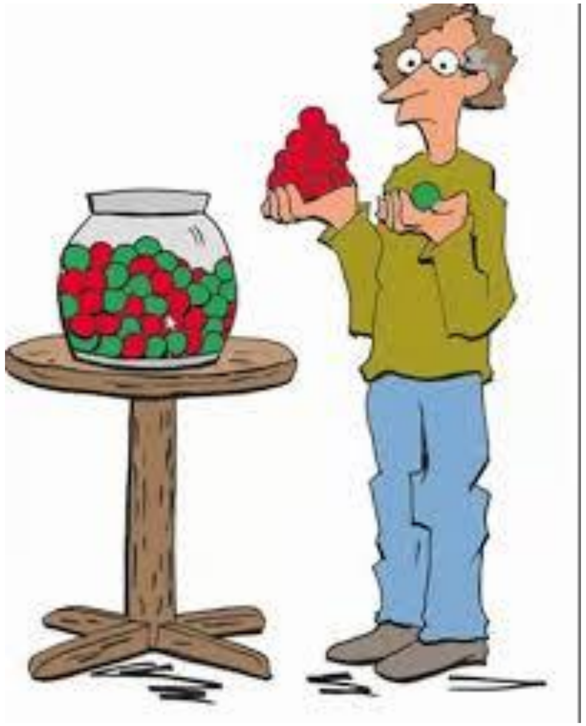
Steps in chemical analysis

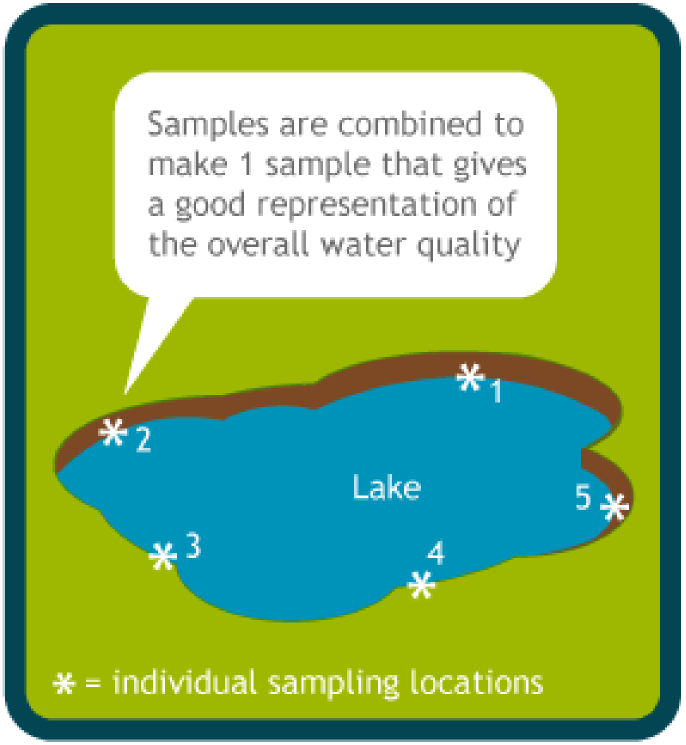
1- Formulating the question.

2- Selecting the analytical procedure.

Steps in chemical analysis

3- Sampling





Sampling: selecting representative material to analyze

Steps in chemical analysis

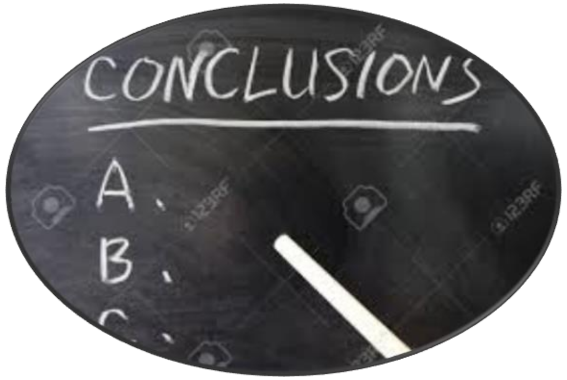
4- Sample preparation

Steps in chemical analysis

5- Analysis

6- Interpretation and reporting

7- Drawing conclusions



Sample preparation

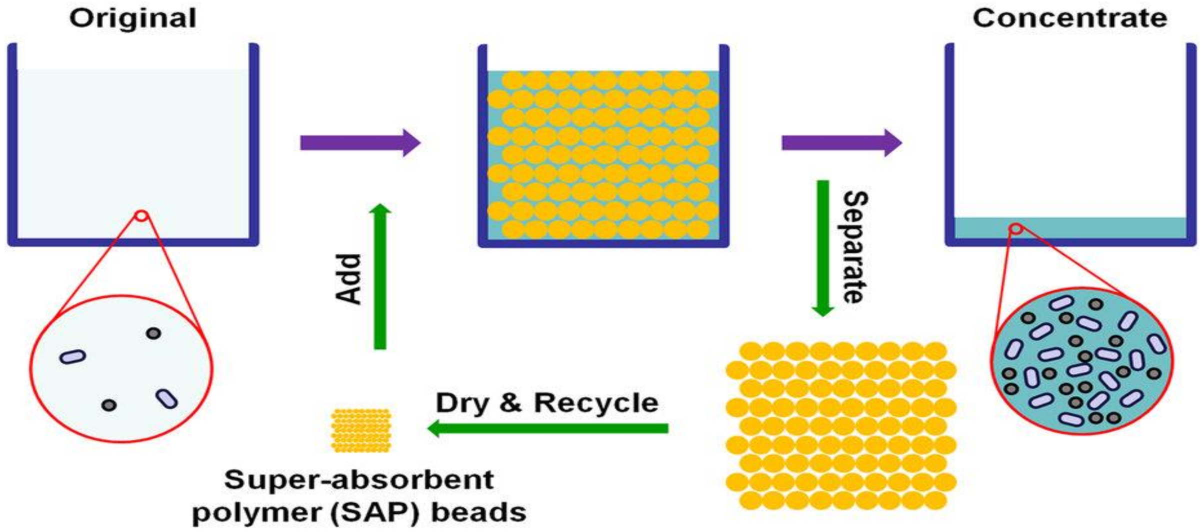
1- sample storage(e.g. temperature, moisture)

2- Grinding ,extracting analyte ,etc

Sample preparation

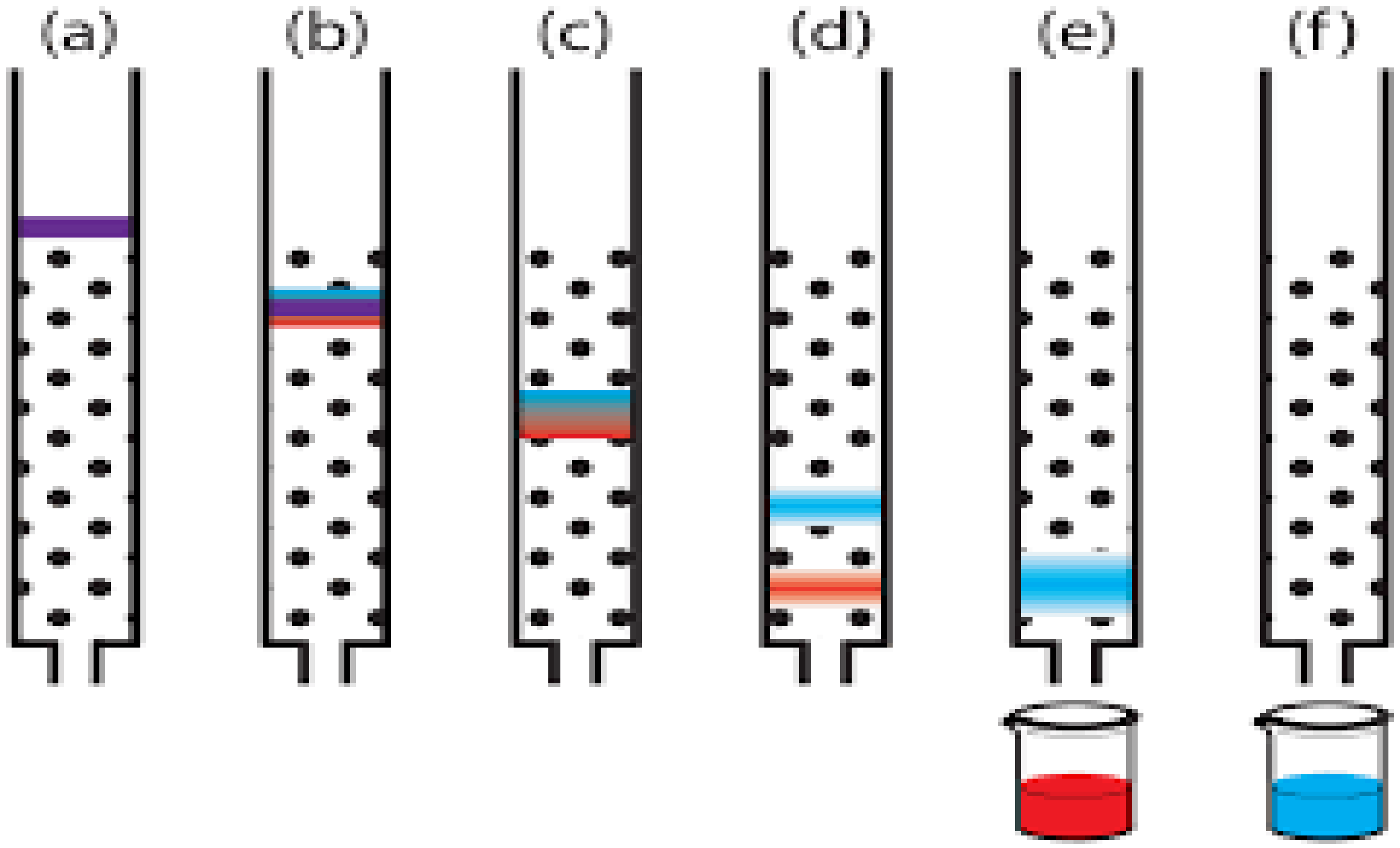
3- Dissolving sample, dispersing analyte)

4- Concentrating analyte.



Sample preparation

5- Eliminate interfering/ “mask” species (drying , ignition ,isolation).



Measurements

SI Units (*International System of Units)*

TABLE 1.2 SI Base Units

Base Quantity	Name of Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electrical current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Measurements

Prefixes used with SI Units

Prefix	Symbol	Meaning	Example
tera-	T	1,000,000,000,000, or 10^{12}	1 terameter (Tm) = 1×10^{12} m
giga-	G	1,000,000,000, or 10^{9}	1 gigameter (Gm) = 1×10^{9} m
mega-	M	1,000,000, or 10^{6}	1 megameter (Mm) = 1×10^{6} m
kilo-	k	1,000, or 10^{3}	1 kilometer (km) = 1×10^{3} m
deci-	d	1/10, or 10^{-1}	1 decimeter (dm) = 0.1 m
centi-	c	1/100, or 10^{-2}	1 centimeter (cm) = 0.01 m
milli-	m	1/1,000, or 10^{-3}	1 millimeter (mm) = 0.001 m
micro-	μ	1/1,000,000, or 10^{-6}	1 micrometer (μm) = 1×10^{-6} m
nano-	n	1/1,000,000,000, or 10^{-9}	1 nanometer (nm) = 1×10^{-9} m
pico-	p	1/1,000,000,000,000, or 10^{-12}	1 picometer (pm) = 1×10^{-12} m

Mass /amount of substance

Mass	kilogram (kg) ⟶ gram (g)
Amount of substances	moles (mol)

1 mole = 6.022×10^{23} particles (e.g. atoms, molecules, ions) .

Atomic mass = number of grams containing Avogadro's number (6.022×10^{23}) of atoms

Molecular mass = number of grams containing Avogadro's number (6.022×10^{23}) of molecules; sum of atomic masses of elements in a molecule

Solution

Solution : A homogenous mixture of two or more substances, the solute and the solvent.

A solute is what dissolves or disappears, like salt or sugar. A solvent is what does the dissolving.

Examples

- Example: Salt water
  - What is the solute?_______ Salt
  - What is the solvent?_____________ water

- Example – 70% ethanol solution.
  - Solute __________________ Water
  - Solvent___________________ ethanol
  - Why? If 70% is ethanol, then it must be the solvent. The remaining 30% is water, the solute.

Solution

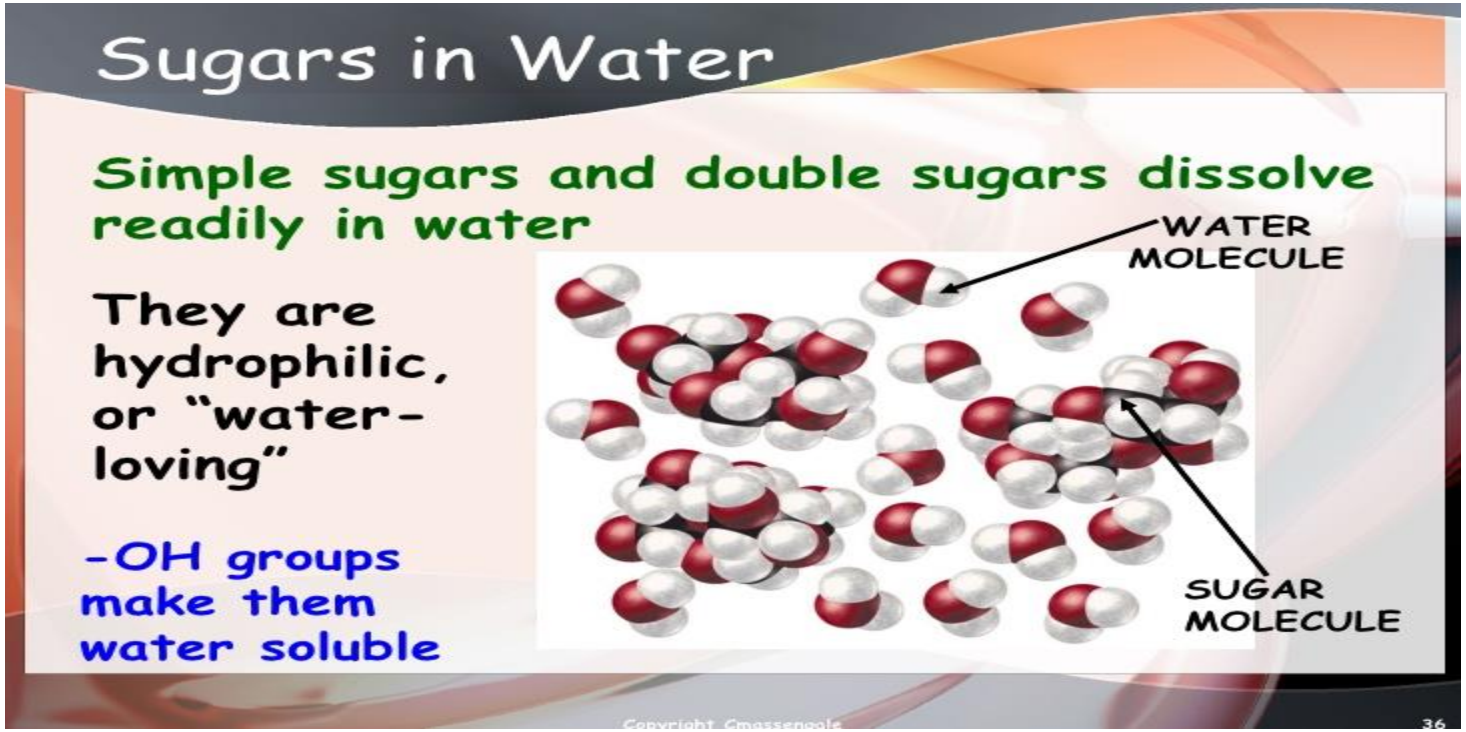
-Solutions can be electrolytes or non- electrolytes .

Solute dissolve to form

Molecules	Ions
Non-electrolytes	electrolytes

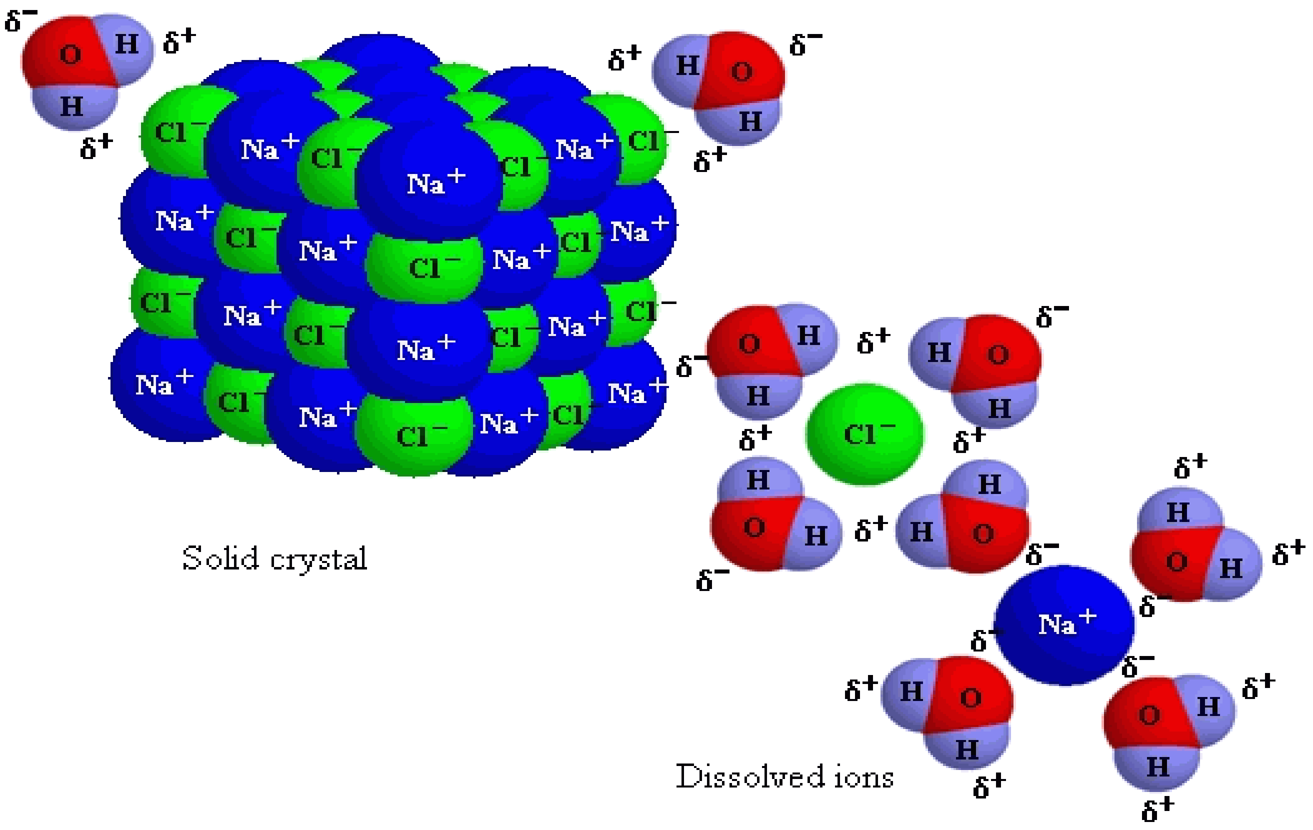
Solution

Some non-electrolytes can also dissolve in water



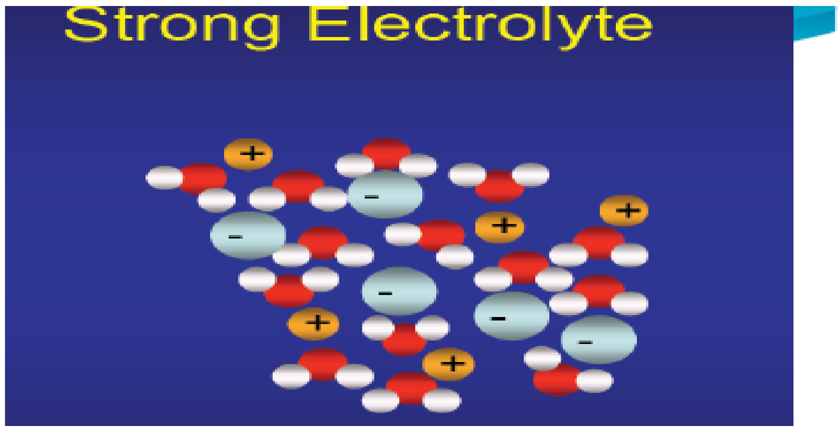
Solution

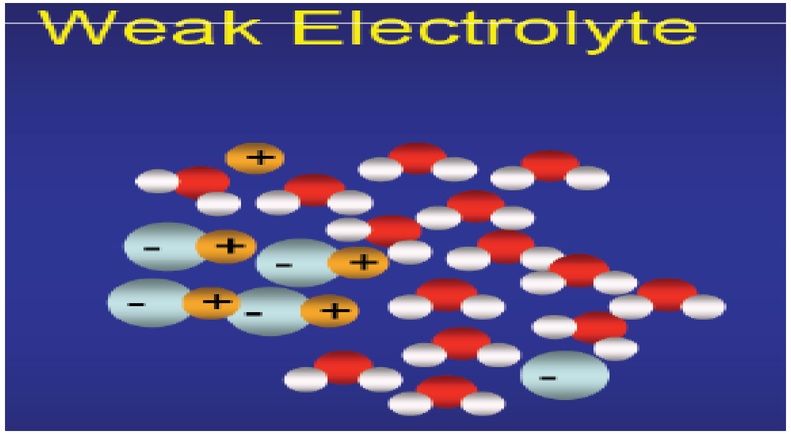
- e.g. NaCl salt

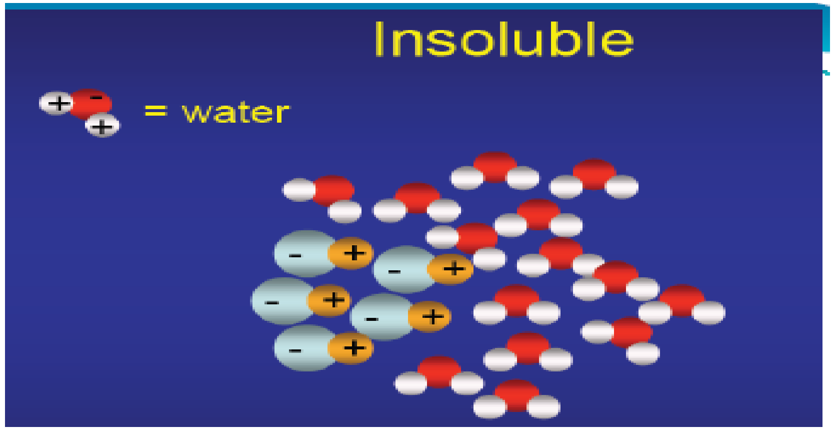


Electrolyte

Electrolytes: A substance that dissociates into ions in aqueous solution and conduct electricity.

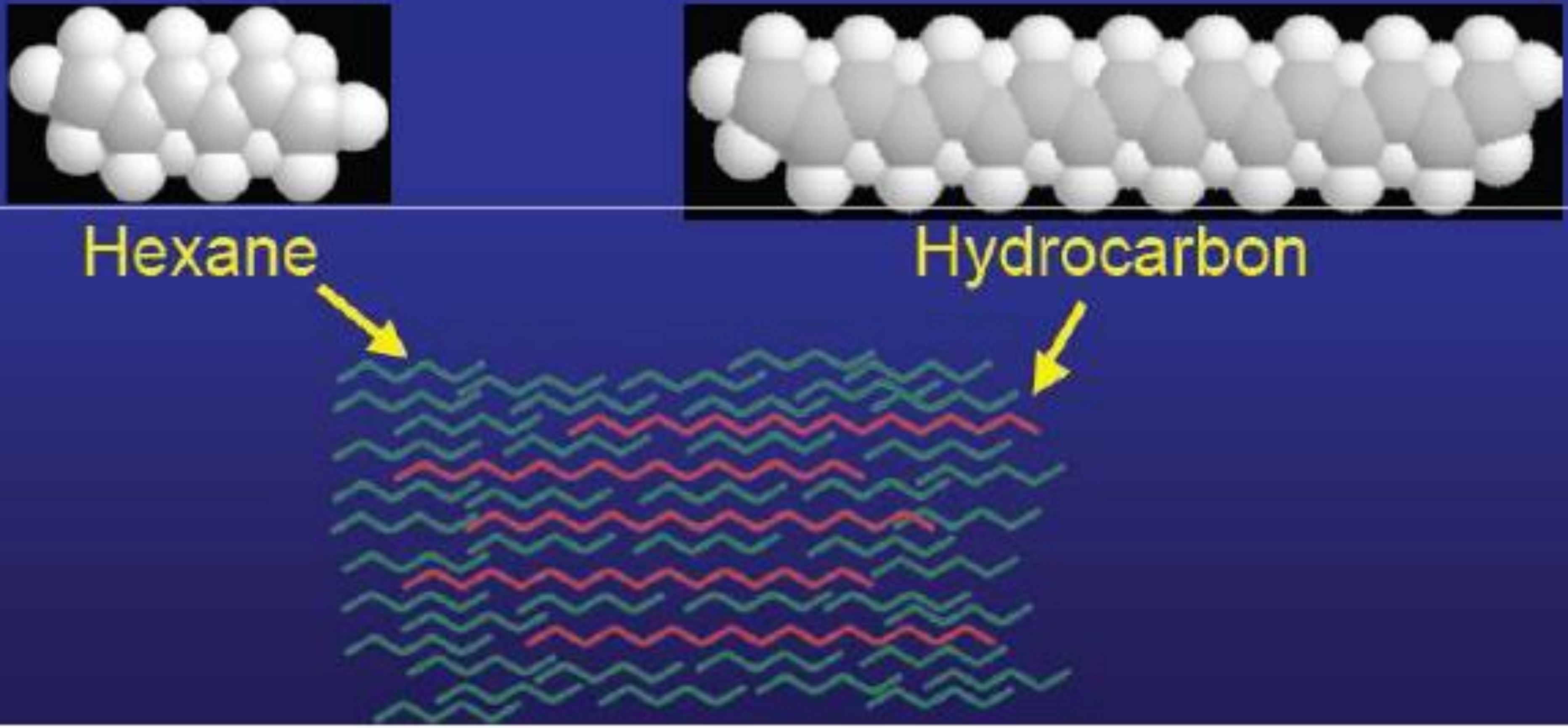




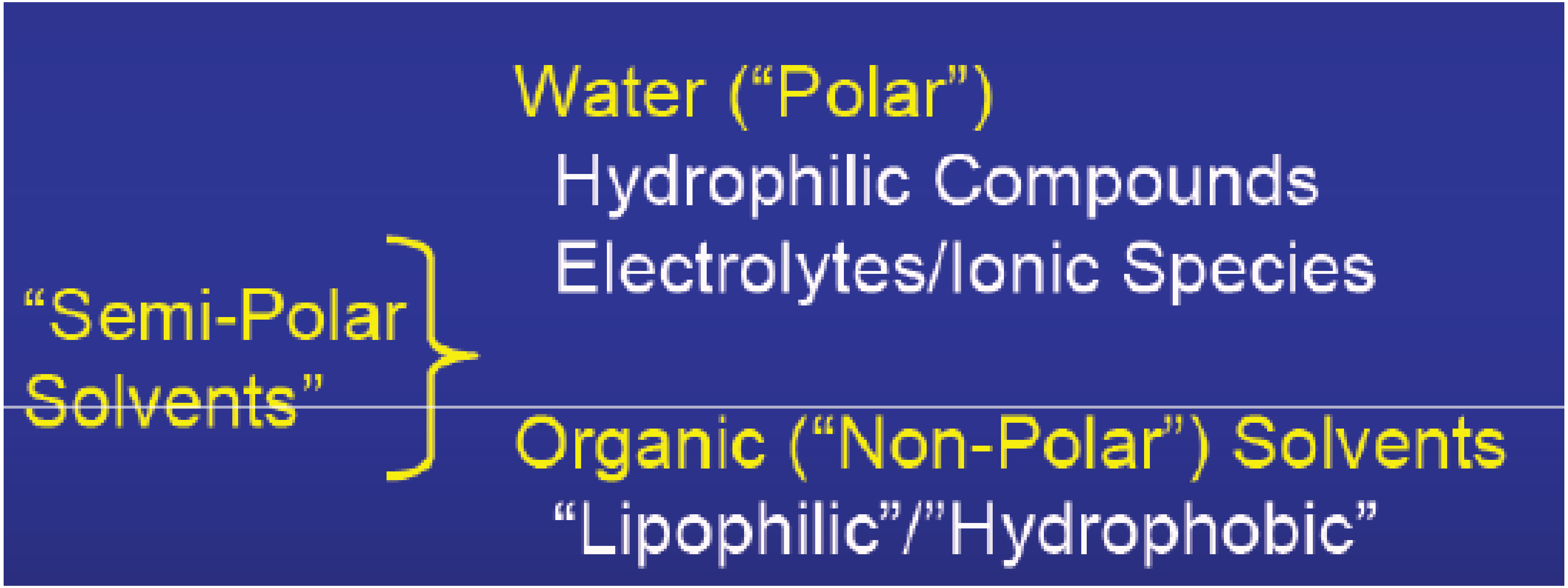


Non-Aqueous Solutions = <u>Organic</u> Solvents

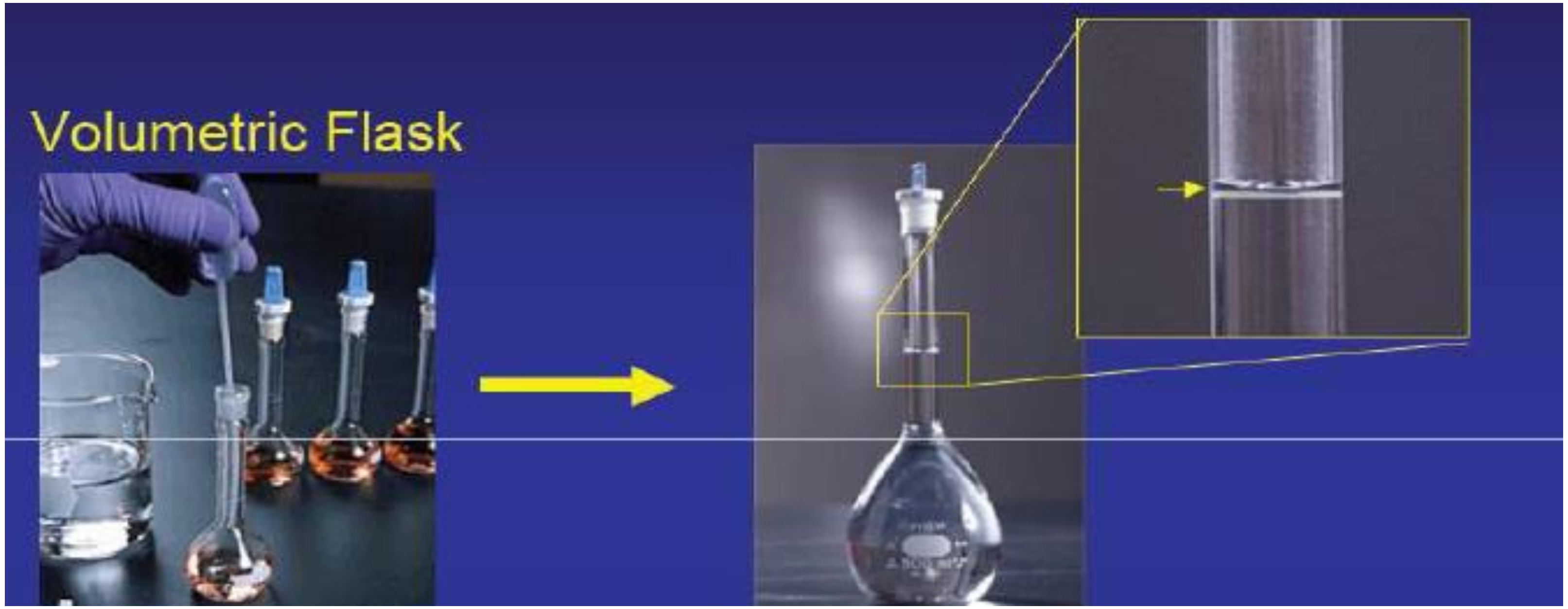
e.g. Hydrocarbon (solute) in Hexane (solvent)

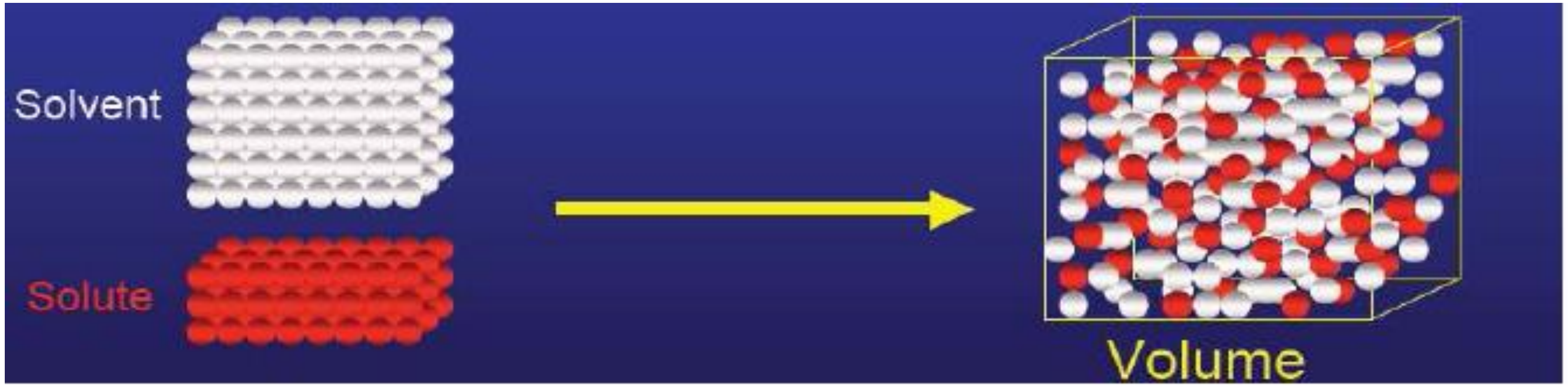


Like dissolves like



Making solutions





Applications of Analytical Chemistry

Analytical chemistry used in many fields:

1. **In medicine**, analytical chemistry is the basis for clinical laboratory tests which help physicians diagnosis disease and chart progress in recovery.
2. **In industry**, analytical chemistry provides the means of testing raw materials and for assuring the quality of finished products whose chemical composition is critical. Many household products, fuels, paints, Pharmaceutical, etc. are analyzed by the procedures developed by analytical chemists before being sold to the consumer.
3. **Environmental quality**, is often evaluated by testing for suspected contaminants using the techniques of analytical chemistry.

4. The nutritional value of food - is determined by chemical analysis for major components such as protein and carbohydrates and trace components such as vitamins and minerals. Indeed, even the calories in a food are often calculated from the chemical analysis.

5. Forensic analysis - analysis related to criminology; DNA finger printing, finger print detection; blood analysis.

6. Bioanalytical chemistry and analysis - detection and/or analysis of biological components (i.e., proteins, DNA, RNA, carbohydrates, metabolites, etc.).

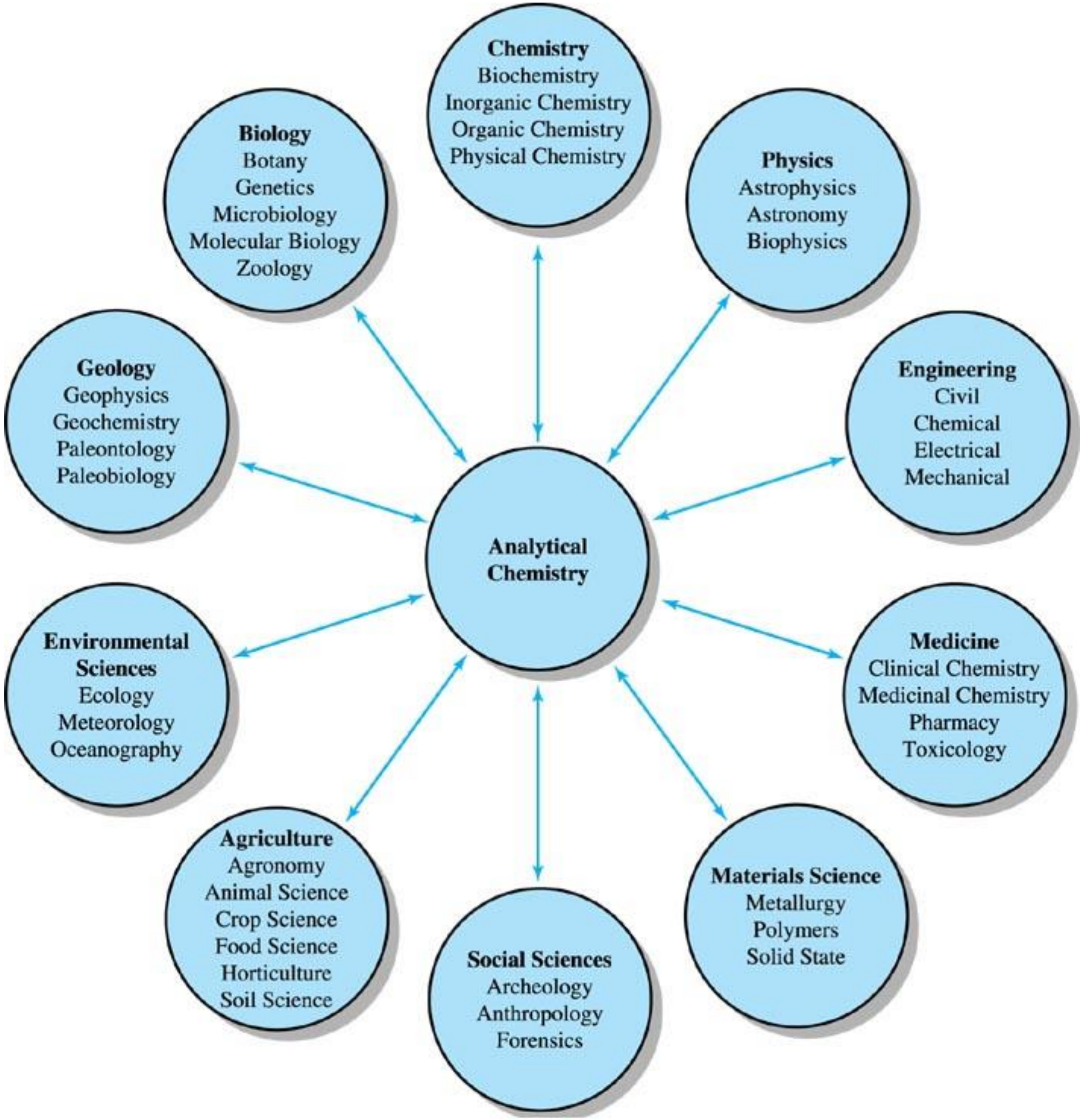
7. in pharmacy sciences:

· Pharmaceutical chemistry.
· Pharmaceutical industry (quality control).
· Analytical toxicology is concerned with the detection, identification and measurement of drugs and other foreign compounds (and their metabolites in biological and related specimens.

Natural products detection isolation, and structural determination.

All branches of chemistry draw on the ideas and techniques of analytical chemistry.

Analytical chemistry has a similar strength with respect to the many other scientific fields listed in the diagram. Chemistry is often called the central science



Units For Expressing Concentration of Solutions

Concentration is a general measurement unit stating the amount of solute present in a known amount of solution

$$\text{Concentration} = \frac{\text{amount of solute}}{\text{amount of solution}}$$

Although the terms "solute" and "solution" are often associated with liquid samples, they can be extended to gas-phase and solid-phase samples as well. The actual units for reporting concentration depend on how the amounts of solute and solution are measured.

Common Units For Reporting Concentration

Name	Units[a]	Symbol
molarity	$\frac{\text{moles solute}}{\text{liters solution}}$	M
formality	$\frac{\text{number FWs solute}}{\text{liters solution}}$	F
normality	$\frac{\text{number EWs solute}}{\text{liters solution}}$	N
molality	$\frac{\text{moles solute}}{\text{kg solvent}}$	*m*
weight %	$\frac{\text{g solute}}{\text{100 g solution}}$	% w/w
volume %	$\frac{\text{mL solute}}{\text{100 mL solution}}$	% v/v
weight-to-volume %	$\frac{\text{g solute}}{\text{100 mL solution}}$	% w/v
parts per million	$\frac{\text{g solute}}{10^6 \text{ g solution}}$	ppm
parts per billion	$\frac{\text{g solute}}{10^9 \text{ g solution}}$	ppb

[a]FW = formula weight; EW = equivalent weight.

Molarity and Formality

Both molarity and formality express concentration as moles of solute per liter of solution. There is, however, a subtle difference between molarity and formality. **Molarity** is the concentration of a particular chemical species in solution. **Formality,** on the other hand, is a substance's total concentration in solution without regard to its specific chemical form. There is no difference between a substance's molarity and formality if it dissolves without dissociating into ions. The molar concentration of a solution of glucose, for example, is the same as its formality.

For substances that ionize in solution, such as NaCl, molarity and formality are different. For example, dissolving 0.1 mol of NaCl in 1 L of water gives a solution containing 0.1 mol of Na^+ and 0.1 mol of Cl^-. The molarity of NaCl, therefore, is zero since there is essentially no undissociated NaCl in solution. The solution, instead, is 0.1 M in Na^+ and 0.1 M in Cl^-. The formality of NaCl, however, is 0.1 F because it represents the total amount of NaCl in solution. The rigorous definition of molarity, for better or worse, is largely ignored in the current literature, as it is in this text. When we state that a solution is 0.1 M NaCl we understand it to consist of Na^+ and Cl^- ions. The unit of formality is used only when it provides a clearer description of solution chemistry.

Molar concentrations are used so frequently that a symbolic notation is often used to simplify its expression in equations and writing. The use of square brackets around a species indicates that we are referring to that species' molar concentration. Thus, $[Na^+]$ is read as the "molar concentration of sodium ions."

Normality

Normality is an older unit of concentration that, although once commonly used, is frequently ignored in today's laboratories. Normality is still used in some handbooks of analytical methods, and, for this reason, it is helpful to understand its meaning. For example, normality is the concentration unit used in *Standard Methods for the Examination of Water and Wastewater*,[1] a commonly used source of analytical methods for environmental laboratories.

Normality makes use of the chemical equivalent, which is the amount of one chemical species reacting stoichiometrically with another chemical species. Note that this definition makes an equivalent, and thus normality, a function of the chemical reaction in which the species participates. Although a solution of H_2SO_4 has a fixed molarity, its normality depends on how it reacts.

Normality is the number of equivalent weights (EW) per unit volume and, like formality, is independent of speciation. An equivalent weight is defined as the ratio of a chemical species' formula weight (FW) to the number of its equivalents

$$EW = FW/n$$

Consequently, the following simple relationship exists between normality and molarity.

$$N = n \times M$$

Example

EXAMPLE 2.1

Calculate the equivalent weight and normality for a solution of 6.0 M H_3PO_4 given the following reactions:

(a) $H_3PO_4(aq) + 3OH^-(aq) \rightleftharpoons PO_4^{3-}(aq) + 3H_2O(\ell)$

(b) $H_3PO_4(aq) + 2NH_3(aq) \rightleftharpoons HPO_4^{2-}(aq) + 2NH_4^+(aq)$

(c) $H_3PO_4(aq) + F^-(aq) \rightleftharpoons H_2PO_4^-(aq) + HF(aq)$

SOLUTION

For phosphoric acid, the number of equivalents is the number of H^+ ions donated to the base. For the reactions in (a), (b), and (c) the number of equivalents are 3, 2, and 1, respectively. Thus, the calculated equivalent weights and normalities are

$$N = n \times M = 3 \times 6.0 = 18\ N$$

$$N = n \times M = 2 \times 6.0 = 12\ N$$

$$N = n \times M = 1 \times 6.0 = 6.0\ N$$

The number of **equivalents,** *n*, is based on a reaction unit, which is that part of a chemical species involved in a reaction. In a precipitation reaction, for example, the reaction unit is the charge of the cation or anion involved in the reaction; thus for the reaction

$$Pb^{2+}(aq) + 2I^{-}(aq) \rightleftharpoons PbI_2(s)$$

$n = 2$ for Pb^{2+} and $n = 1$ for I^-. In an acid–base reaction, the reaction unit is the number of H^+ ions donated by an acid or accepted by a base. For the reaction between sulfuric acid and ammonia

$$H_2SO_4(aq) + 2NH_3(aq) \rightleftharpoons 2NH_4^+(aq) + SO_4^{2-}(aq)$$

we find that $n = 2$ for H_2SO_4 and $n = 1$ for NH_3. For a complexation reaction, the reaction unit is the number of electron pairs that can be accepted by the metal or donated by the ligand. In the reaction between Ag^+ and NH_3

$$Ag^+(aq) + 2NH_3(aq) \rightleftharpoons Ag(NH_3)_2^+(aq)$$

the value of *n* for Ag^+ is 2 and that for NH_3 is 1. Finally, in an oxidation–reduction reaction the reaction unit is the number of electrons released by the reducing agent or accepted by the oxidizing agent; thus, for the reaction

THE MOLE

In chemistry, particles such as atoms, molecules, and ions are counted by the mole.

A mole: is a unit that contains 6.022×10^{23} items (PARTICLES)

A mole is the amount of substance that chemists often use to measure chemicals.

One mole of an element is its relative atomic mass in grams.

example: C = 12, so one mole of carbon atoms weighs 12g.

The number of particles in one mole of a substance is 6.022×10^{23} (Avogadro's number)

1 dozen	=	12 objects
1 mole	=	6.022×10^{23} objects

C atom + O atom → CO molecule

l mole C + l mole O → 1mole CO

(6.022×10^{23} atoms C) + (6.022×10^{23} atoms O) (6.022×10^{23} molecule CO)

Chemical quantities

of substances are

Moles

in grams is the

Molar mass

which converts

Moles to grams

Grams to moles

Atomic or molecular mass (weight) of a substance expressed in grams.

Avogadro's Number (N) = **6.022 x 10^{23}**

one mole of any element always contains Avogadro's number of atoms

Carbon	Iron
C	Fe
6.022 X 10^{23} atoms	6.022 X 10^{23} atoms
1 mole of C atoms	1 mole of Fe atoms
12.01 g of C atoms	55.78 g of Fe atoms

1 mole of an element is 6.022 X 10^{23} atoms of that element

Avogadro's Number, (N)

Avogadro's Number in 1 Mole = 6.022×10^{23} particles

Number of Particles in One-Mole Samples

Substance	Number and Types of Particles
1 mole sulphur	6.02×10^{23} sulphur atoms
1 mole Hydrogen	6.02×10^{23} Hydrogen atoms
1 mole water (H_2O)	6.02×10^{23} H_2O molecules
1 mole NaCl	6.02×10^{23} NaCl formula units
1 mole vitamin C, ($C_6H_8O_6$)	6.02×10^{23} vitamin C molecules

1 mole of a compound is 6.022×10^{23} of molecules or ions of that compound

A Mole of Particles

Contain 6.02×10^{23} particles

1 mole C = 6.02×10^{23} C atoms

1 mole H_2O = 6.02×10^{23} H_2O molecules

1 mole NaCl = 6.02×10^{23} NaCl molecules

(6.02×10^{23} Na^+ ions and

6.02×10^{23} Cl^- ions)

1 mole = 6.02×10^{23} particles

A particle could be an atom, a molecule, OR an ion!

Moles of Elements in a Formula

Sugar $C_{12}H_{22}O_{11}$

Carbon	Hydrogen	Oxygen
12 atoms C	22 atoms H	11 atoms O
12 moles C	22 moles H	11 moles O

Moles of Elements in Compounds

How many moles of each elements are present in 1 mole of caffeine ($C_8H_{10}N_4O_2$)?

Answer: (C=8, H=10, N=4, O=2)

Mole Calculations

a. How many moles of chloride ions are in 3 moles of $AlCl_3$?

Answer:

1 mole of $AlCl_3$ contains = 3 moles of Cl^- ion

3 mole of $AlCl_3$ contains = 3 x 3 = 9 moles of Cl^- particles or ion

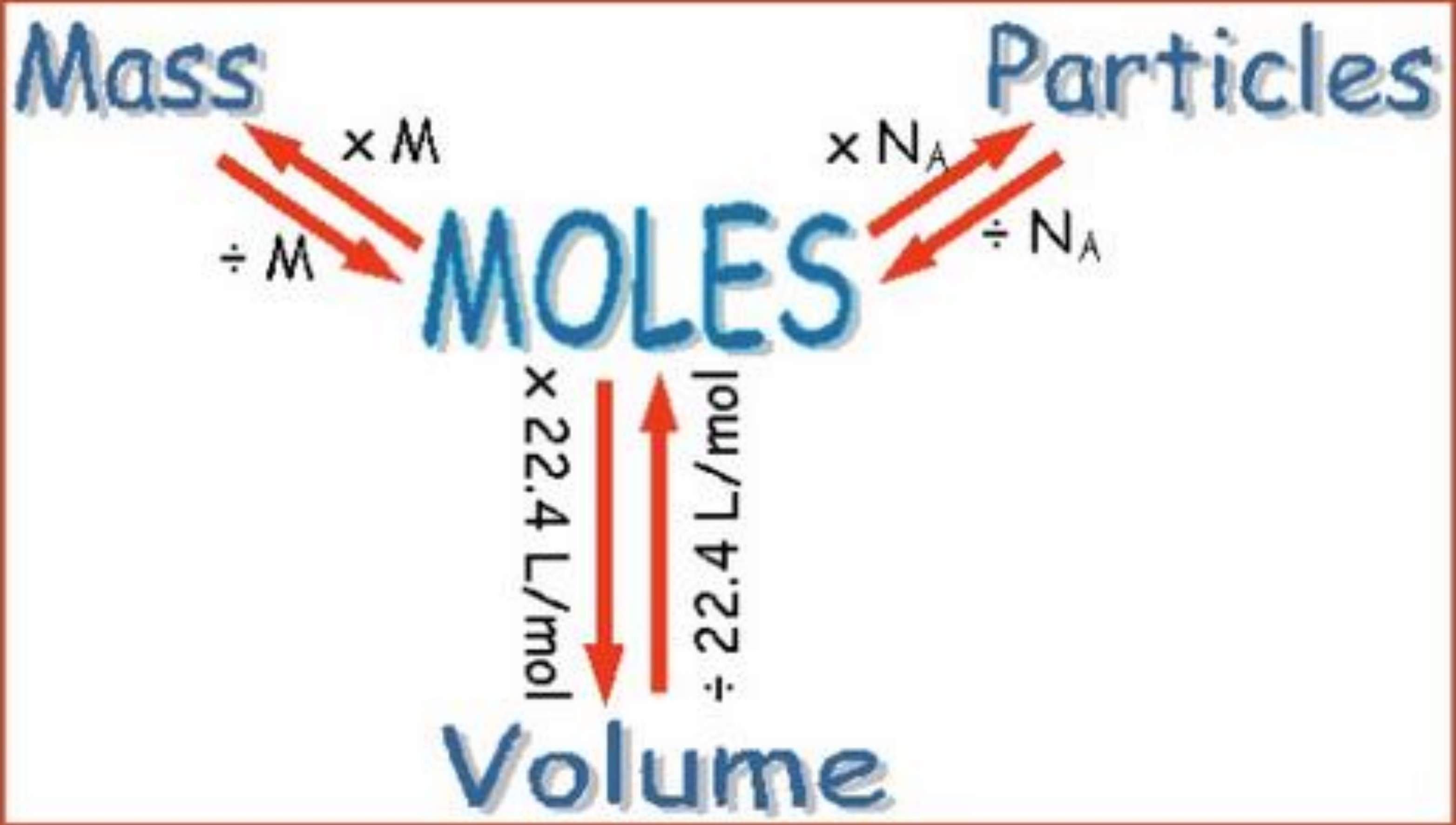
b. Find out number of moles of each element in two mole of Vitamin C (Ascorbic acid $C_6H_8O_6$)

Answer: C= 12 ; H= 16 ; O = 12 .

c. How many moles of carbon ,Hydrogen and Nitrogen are in 5 moles of quinine ($C_{20}H_{24}N_2O_2$)?

Answer: C = 100; H = 120; N = 10; O = 10 ;

Molar Volume



Calculating the Number of Moles of a Gas, Given Its Volume

Example 1 How many moles are in 50.0 L of oxygen gas at STP?

Solution.

According to Avogadro's Hypothesis, the identity of the gas does not matter when calculating volume.

Substitute into the equation.

$$n = \frac{V}{22.4\,\frac{L}{mol}} = \frac{50.0\ L}{22.4\,\frac{L}{mol}} = 2.23\ mol$$

or, **using the factor label method**

$$n = 50.0\ \cancel{L} \times \frac{1\ mol}{22.4\ \cancel{L}} = 2.23\ mol$$

Calculate Volume, Given Moles

Example 1 What is the volume, in Litres, of 2.50 moles of methane, CH_4, at STP?

Solution.

Once again, the identity of the gas is unimportant, according to Avogadro's Hypothesis, in this calculation.

Substitute into the equation.

V = *n* x 22.4 L/mol

= (2.50 mol)(22.4 L/mol) = 56.0 L

- Number of moles = $\frac{\text{mass in grams}}{\text{relative mass}}$

How many moles are present in 0.35g of ammonium hydroxide?

RMM = 14 + 4 + 16 + 1 = 35

$\therefore$ 1 mole = 35g

$\therefore$ No of moles = $\frac{0.35}{35}$ = 0.01

Find the mass of

a) 1 mole of lead (II) nitrate
b) 4.30 moles of methane
c) 0.24 moles of hydrated sodium carbonate $Na_2CO_3.10H_2O$

a) lead(II) nitrate is $Pb(NO_3)_2$

∴ 1 mole = 207 + (2x14) + (6x16) = 331g

b) Methane is CH_4

∴1 mole = 12 + (1x4) = 16g

∴ 4.30 moles = 16 x 4.30 = 68.8g

c) 1 mole of $Na_2CO_3.10H_2O$ = (2x23) + 12 + (3x16) + (10x18) = 286g

∴0.24 moles = 0.24x286 = 68.6g

1) How many moles are in 40.0 grams of water?

$$40.0 \text{ g } H_2O \times \frac{1 \text{ mole } H_2O}{18.01 \text{ g } H_2O} = 2.22 \text{ mole } H_2O$$

2) How many grams are in 3.7 moles of Na2O?

$$3.7 \text{ moles } Na_2O \times \frac{62 \text{ g } Na_2O}{1 \text{ mole } Na_2O} = 230 \text{ g } Na_2O$$

3) How many atoms are in 14 moles of cadmium?

$$14 \text{ mole Cd} \times \frac{6.022 \times 10^{23} \text{ atoms Cd}}{1 \text{ mole Cd}} = 8.4 \times 10^{23} \text{ atoms Cd}$$

4) How many moles are in 4.3 x 10^{22} molecules of H3PO4?

4.3 x 10^{22} molecules H_3PO_4 x $\frac{\text{1 mole H 3PO4}}{6.022 \times 10^{23} \text{ molecules } H_3PO_4}$ = 7.1 x 10^{-2} moles H_3PO_4

5) How many molecules are in 48.0 grams of NaOH?

48.0 molecules NaOH x $\frac{\text{1 mole NaOH}}{\text{40 g NaOH}}$ x $\frac{6.022 \times 10^{23} \text{ molecules NaOH}}{\text{1 mole NaOH}}$

= 7.23 x 10^{23} molecules NaOH

6) How many grams are in 4.63 x 10^{24} molecules of CCl4?

4.63 x 10^{24} molecules CCl_4 x $\frac{\text{1 mole CCl4}}{6.022 \times 10^{23} \text{ molecules } CCl_4}$ x $\frac{153.8 \text{ g } CCl_4}{1 \text{ mole } CCl_4}$ = 1180 g CCl_4

- Avogadros’s no = 6.022×10^{23}
- It is the number of atoms in 12g of ^{12}C
- The RAM of an element contains Avogadros number of atoms

i.e if we weigh out 12g of carbon-12 we will have 6.022×10^{23} atoms of carbon-12

and **12g of carbon-12 = 1 mole**

- Similarly the RMM of a substance contains Avogadro's number of molecules

$\therefore$ A mole of hydrogen molecules (H_2) = 2g

and contains 6.022×10^{23} molecules of hydrogen

and $2 \times 6.022 \times 10^{23}$ atoms of hydrogen

The abbreviation for moles is mol

A mole of substance is the amount of that substance that contains the same number of stated elementary units as there are atoms in 12g of ^{12}C

Stated elementary units can mean atoms, molecules ions, electrons

For example

16g (1mole) of oxygen atoms O

32g (1mole) of oxygen molecules O_2

18g (1mole) of water molecules H_2O

24g of magnesium ions Mg^{2+}

Which of the following contains the greatest number of the stated particles?

a) Molecules of hydrogen in 1g of hydrogen gas
b) Atoms of helium in 1g of helium gas
c) Atoms of beryllium in 1g of beryllium

1g of hydrogen gas = $\frac{1}{2}$ mol = 0.5mol

$\therefore$ 1g hydrogen gas contains 0.5x $6.022x10^{23}$ molecules

= 3.011x 10^{23}molecules

1g of helium gas contains $\frac{1}{4}$ mol = 0.25 mol

$\therefore$ 1g helium gas contains 0.25x
6.022x1023atoms = $1.51x10^{23}$atoms

1g beryllium contains $\frac{1}{9}$ mol = 0.11mol

$\therefore$ 1g beryllium contains 0.11x $6.022x10^{23}$ atoms

= 6.69x 10^{22} atoms

$\therefore$ 1g hydrogen gas contains the greatest number of the stated particles

How many atoms are there in 1 mol of carbon dioxide?

1 molecule of CO_2 contains 3 atoms

$\therefore$ 1 mol contains $6.022 \times 10^{23} \times 3$ atoms

$= 1.81 \times 10^{24}$ atoms

- How many hydrogen ions will 0.5 mols of sulphuric acid release on dissociation?

$$H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$$

$\therefore$ 1mol of sulphuric acid releases 2 mols of hydrogen ions

$\therefore$ 0.5 mols releases 0.5x2mols hydrogen ions

= 1mol hydrogen ions

Concentrations of solutions are measured in moles per L (or dm^3)

1000ml = 1 L 1000cm^3 = 1 dm^3

How many moles are there in 20ml of a solution of concentration 0.5mol/L?

1000ml contains 0.5mol

$\therefore$ 1ml contains $\frac{0.5}{1000}$ mol

And 20ml contains $\frac{0.5}{1000}$ x 20 mol = 0.01mol

What mass of solute must be used to prepare 750ml of 0.100M aqueous sodium carbonate from solid sodium carbonate?

RMM Na_2CO_3 = 23x2 + 12 + (16x3) = 106

∴106g = 1mol

∴ 1000ml of 0.100M solution would need 106 x 0.100 g = 10.6g

∴750ml needs $\frac{10.6 \times 750}{1000}$ g = 7.95g

Reference of Analytical Chemistry

1. www.analyticalsciences.org/index.php This is the home page of the Division of Analytical Chemistry of the American Chemical Society. There are a number of links and resources throughout this site that will take you all over the Internet to sites involving analytical chemistry.
2. http://wissen.science-and-fun.de/links/index.php?e-id=11&basis=(CH)AnalyticalChemistry. This is an analytical chemistry link center that connects to university and other sites all over the world.
3. www.nist.gov/mml/ The Materials Measurement Laboratory site of the National Institute of Standards and Technology (NIST). The national reference laboratory for measurements in the chemical, biological and materials sciences. Source of Standard Reference Materials.

4. http://www.rsc.org/Gateway/Subject/Analytical/ The Royal Society of Chemistry in Britain; the British equivalent of the ACS provides information on analytical sciences.

5. http://www.anachem.umu.se/jumpstation.htm The Analytical Chemistry Springboard. A comprehensive, annotated list of analytical chemistry resources on the Internet from Ume˚a University.

6. www.asdlib.org Analytical Sciences Digital Library (ASDL). A site of choice for listings of peer-reviewed websites dealing with pedagogy and techniques.

7. www.acdlabs.com Advanced Chemistry Development specializes in the support of analytical methods by providing various prediction and modeling tools. They also offer a demo version of structure drawing software (ChemSketch), as a free download.

8. www.asms.org The official website of the American Society for Mass Spectrometry. This site contains introductory and advanced information about the art of mass spectrometry, a common analytical technique.