Chemistry course
ACME Faculty, EHVE course
B.Sc. Studies, I year, I semester
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Fundamental laws of chemistry

Mole

- **Mole** is a unit of matter quantity; it is used in similar context as ‘million’ or ‘thousand’ words.
- Milion of molecules is $1 \cdot 10^6$ molecules;
- Mole of molecules (atoms, particles) is $6.022 \cdot 10^{23}$
- $6.022 \cdot 10^{23}$ is called the Avogadro number (N_A);
- Atomic and molecule mass (in a molecular scale) is expressed in ‘**u**’ (units) or atomic mass units.
  Hydrogen atom weight is 1 u, water molecule weight is 18 u;
- 1 atom or molecule mole mass value in grams is equal to the given atom/molecule in ‘u’;
- Hydrogen atom mole weighs 1 g (although hydrogen molecules – H_2 - 2g). Water molecule mole weighs 18 g .
  Molecular mass of the molecule is the sum of atomic masses of which it consists.

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Avogadro’s law

- In different gases in the same volume (at the same temperature/pressure) there is the same number of gas particles (molecules or atoms in case of noble gases).
- 1 mole of every gas occupies 22.4 dm^3 (in normal conditions: T = 0˚C, p = 1013 hPa)
- ‘mole of a gas’ means ‘gas atoms’ in case of argon (Ar) BUT ‘gas molecules’ in case of nitrogen (N_2), so 1 mole will be weighing 28 g, not 14 g.
- In real gases there are deviations from this rule, but they are negligible (up to few percent at most).

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Reactions

- **Reaction** is process of new bond forming between atoms (optionally after breaking previously existing bonds).
- Substances which existed before the reaction and take part in it are called **substrates**.
- Substances which are the result of reaction are called **products**.
- *E.g.*: $A + B \rightarrow C \qquad D + E \rightarrow F + G$

  $H \rightarrow I + J \qquad K + K \rightarrow L$

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Stoichiometry

- Quantitative ratios measured (weighed) in human scale (macroscale) are the same as in the microworld (ratios between atoms, molecules).
  That means for the A_xB_y compound:

(molecules) $x \cdot m_A / y \cdot m_B = \%A/\%B$ **(macroscale)**

- <u>Law of conservation of mass</u>: mass of substrates is equal to products mass (mass of reagents is not changing).
- Mass ratio of elements in a chemical compound is constant and characteristic for a compound.

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Stoichiometry

- Molar ratio (mass ratio as well) of elements in a compound is not always (especially in organic chemistry) identifying unambiguously the compound.

E.g.: $H_2C{=}CH_2$ (2C:4H = 1:2) i $H_2C{=}CH{-}CH_3$ (3C:6H = 1:2)

- Mass ratio (and molar calculated from it) between elements of a compound can be used, although **only as one of few methods**, to confirm compound’s structure (<u>elemental analysis</u>).

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Stoichiometry of chemical equations

- Substances are reacting with each other in a certain ratio only, which is characteristic for the given reaction. Product is yielded in a certain proportion to substrates and to other products, *e.g.*:
- $2H_2+O_2 \rightarrow 2H_2O$ $3H_2+N_2 \rightarrow 2NH_3$

2 : 1 : 2	3 : 1 : 2	(molar ratio)
4g: 32g : 36g	6g : 28g : 34g	
(4+32=36	6+28=34)	

Stoichiometry of chemical equations

- As a result of Avogadro's law, volume ratio of gases is the same as their molar ratio.
- Values of molar ratio that describe stoichiometry of reagents are equal to stoichiometric coefficients of the chemical equation.
- Quantity of one reagent is determining quantity of all other reagents. That applies only to substrates that reacted, not all that have been put to the reaction mixture (*e.g.* excess) as well as products resulting from reaction (including any possible side products).

Stoichiometry of chemical equations

Example:

How many moles of oxygen is needed to fully combust 6 moles of hydrogen?

Basic reaction equation:

$2H_2+O_2 \rightarrow 2H_2O$

So to combust 6 moles of hydrogen:

$6H_2+3O_2 \rightarrow 6H_2O$

Answer: Three moles of oxygen are needed (ca. 67.2 dm^3)!

Energy of reaction

- In order for reaction to start, it has to be "beneficial" for substrates. After reaction they have to be in "better" (energetically) state than before it. Reagents' surroundings (conditions) have to be beneficial towards reaction initiation as well (proper conditions mean: temperature over certain level, pressure, presence of certain catalyst or absence of inhibitor). Often it is critical for reaction to start (required, not beneficial). Reaching such conditions often requires a lot of energy.
- Some reactions emit energy (heat), some absorb energy (heat). The latter decrease the temperature of its surroundings if not heated artificially (from outside).
- The heat (energetic) effect is characteristic for the given reaction (at the constant pressure). This effect is called the **enthalpy of reaction** (**ΔH**).

Energy of reaction

- **ΔH > 0** means that reaction is **endothermic** (absorbs energy).
- **ΔH < 0** means that reaction is **exothermic** (emits energy).
- Minimal requirements of reaction initiation mentioned earlier can be of many reasons. Among others (boundary reasons): above certain temperature one of substrates can be changing its state of matter or decomposing (explodes); below certain temperature solvent, in which reaction takes place, can be solidifying or one of substrates can be precipitating, *etc*.

Mixture and chemical compound

- **Chemical compound** has defined composition and all its atoms are connected with chemical bonds.
- **Mixture** is two or more compounds/elements mixed with each other. They can be of the same state of matter or not. Mixture composition can be changed, *e.g.* by adding some of one of the components. Atoms of different compounds are not bonded with each other, but can be (do not have to) interacting with each other.

Mixtures

- Mixture component can be of any state of matter.
- Mixtures can be **homogenous** or not - **heterogenous**.
- **Phase** is a physically uniform part of the system separated from other phases with interfacial boundary (**interphase**), at which there is nonlinear, abrupt change of properties (physical, chemical or both).
  - Oil poured on the water surface forms a mixture with a clearly visible phase boundary (both phases are liquid).
  - Mist (atmospheric phenomenon) is the mixture of microscopic water droplets (liquid phase) surrounded with water vapor (gaseous phase).
  - Water containing dissolved sugar is a two-component (neglecting impurities), but one-phase mixture (homogenous).

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Mixtures

- Mixture consist of dispersing phase and of dispersed phase.
- Mixtures can be divided into the following categories:
  - heterogeneous (dispersed phase is visible with a naked eye or a magnifying glass)
  - colloid (dispersed particles are of 1nm-500nm size).
  - homogenous = solutions (dispersed particles are below 1nm size)
- In homogenous phases dispersing phase is called a solvent, the other components are called solutes.
- Solvent has to be of the same state of matter as the final mixture (solution).

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Heterogeneous mixtures

Components of mixtures retain their both macro- and microscopic properties; they can be separated with simple physical methods, *e.g.*: filtration, segregation, centrifugation (cyclone), *etc.*


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Dispersed phase / Solvent	gas	liquid	solid
gas	-	spray (drizzle)	smoke (combustion gases with ash)
liquid	foam (soap foam)	emulsion (water with oil)	suspension (water with sand = mud)
solid	foam (styrofoam)	emulsion (composite electrolytes)	- (some alloys, composites, minerals, etc.)

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Colloids

- Mixtures that are something in between homogenous and heterogenous ones.
- We can observe Tyndall's effect in colloids.


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Dispersed phase / Solvent	gas	liquid	solid
gas	-	liquid aerosol (mist)	solid aerosol (smoke)
liquid	liquid foam (whipped cream)	emulsion (milk)	liquid sol (water with chalk)
solid	solid foam (some composites)	gel (some polymers with plasticizers)	solid sol (some alloys and composites)

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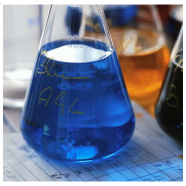
Solutions

- Components in solutions lose some of their individual properties. Solution is physically homogenous. Sample taken from any point of the solution will have the same composition and properties as the whole solution (components ratio is the same for the whole volume of a solution).
- Components of solution can be separated, *e.g.* by means of distillation, crystallization or chromatography.



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Solutions

- Dissolving is a process of mixing particles of one component (dispersed phase = solute) among particles of other component (solvent).
- Dissolving rate can be controlled through: temperature change (higher = faster dissolution), stirring (faster/more intensive = faster dissolution) and comminution (higher interfacial surface = faster dissolution).
- Solution composition can be changed by solute addition, solvent addition (dilution) or solvent evaporation (expelling/concentrating).

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Solubility

- Is a maximal concentration of a given substance in a given solvent (at given temperature and in case of gases, at given pressure).
- Solution at the peak concentration is **saturated**. Solute addition to saturated solution does not change its concentration. Equilibrium is obtained instead, at which dissolution is taking place at the same rate as crystallization of solute..
- Solubility is measured in grams of solute per 100 g of solvent (depends on temperature).

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Solubility

- **Unsaturated** solutions are solutions with concentration lower then the peak one (at given temperature).
- **Supersaturated** solutions are instable (metastable) solutions with a concentration higher than the peak one (obtained by e.g. very slow evaporation of the solvent from unsaturated solution). Upon nucleation initiation (e.g. through small solute crystal addition, etc.) very quick crystallization of the solute excess takes place.
- Solubility of liquids and solids usually increases with a temperature. Solubility of gases decreases with a temperature.

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Solubility

- Dissolution influences:
  - density change (mass increase with small volume change);
  - contraction (sum of components' volume is not equal to mixture volume - Mendeleev!);
  - melting point value decrease (pouring salt on ice-covered roads/sidewalks during winter) – eutectics;
  - boiling point value increase;
  - thermal effect (depends on mixing enthalpy) – „always pour acid into water, never the other way around";
  - dissociation/solvation.

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Concentration

- **Percentage concentration** (written as % or weight%):

$$c_p = \frac{m_{solute}}{m_{solute} + m_{solvent}} \cdot 100\%$$

- **Molar concentration** (note that denominator consists of volume of whole, final solution!):

$$c_m = \frac{n_{solute}}{V_{solution}}$$ unit: mol/dm^3 or „M"

- **Molal concentration** (used when, for instance, solvent is a mixture of solvents):

$$c_n = \frac{n_{solute}}{m_{solvent}}$$ unit: mol/kg or „*m*"

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Concentration

- What is the percentage concentration of 10 g kitchen salt (NaCl) solution in two liters of water?
- What is the molar concentration of 11.7 g kitchen salt (NaCl) solution in a liter of water (M_{NaCl} = 58.5 g/mol)?
- What is the molality of 6.84 g sucrose (which molecular mass is 342 g/mol) solution in 250 cm^3 of water?
- What is the percent concentration of copper and zinc in an alloy that consists of 30 g of copper and 120 g of zinc?

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