# General and Inorganic Chemistry I

## Lecture 1

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# Outline

# Informations

- Lecture (3+2 hours/week) + laboratory practice (5 hours/week)
- Lecturers:
  István Szalai (Monday 3 hours)
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  web: `nlcd.elte.hu/szalai/teaching.html`

  Szabolcs Béni (Tuesday 2 hours)
  contacts: 1085 Budapest Üllői út 26 3$^{rd}$ floor
  web:
  `scholar.semmelweis.hu/beniszabolcs/oktatasi-tevekenyseg`
- Laboratory supervisors:
  Anikó Vasanits, Katalin Perényi and Viktor Mihucz

# Informations

- Laboratory grade: average result of the three Major Tests and the short tests
- Theoretical grade: oral exam during the examination period (December-January). The registration for the exam can be made in the Neptun system. The theoretical exam covers the topics discussed during the lectures and the laboratory practices (calculations!). Those who failed in laboratory not allowed to take the theoretical exam, they must repeat the whole semester!

# Lecture notes and books

- Slides: nlcd.elte.hu/szalai/teaching.html
- en.wikibooks.org/wiki/General_Chemistry

# Chemistry

Chemistry is the science that describes matter, its properties, the changes it undergoes, and the energy changes that accompany those processes.

- Inorganic chemistry
- Organic chemistry
- Physical chemistry
- Biochemistry

- Applied Chemistry:
  Analytical chemistry, Pharmaceutical Chemistry, . . .

# Outline of the semester

- Introduction
- Structure of Atoms and Molecules
- Chemical Reactions and Equilibrium
- Thermochemistry
- Chemical Kinetics

# Lecture 1: Introduction and properties of matter

Reading:
en.wikibooks.org/wiki/General_Chemistry/Properties_of_Matter

# Matter and Energy

Matter: anything that has both mass and volume.
Mass: a measure of an object's resistance to change in motion (inertia).
$F = ma$
Volume: a measure of the amount of space occupied by an object.

States of matter:

- Gases: They occupy all parts of any vessel in which they are confined. They are capable of infinite expansion and are compressed easily. The individual particles are quite far apart.
- Liquids: The individual particles are confined to a given volume. A liquid assumes the shape of the container. They are very hard to compress.

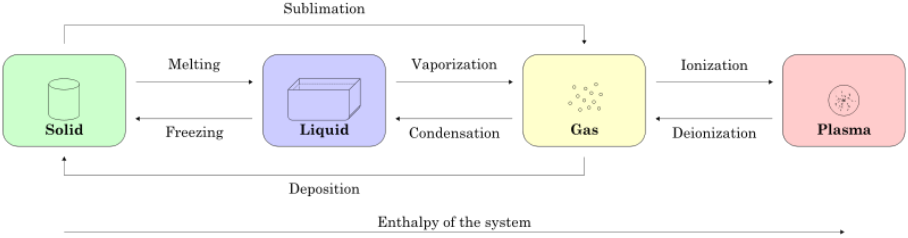
# Matter and Energy

States of matter:

- Solids: They are rigid and have definite shapes. Volumes of solids do not vary much with changes in temperature. In crystalline solids the individual particles occupy definite positions in the crystal structure.
- Plasma: Like a gas, plasma does not have definite shape or volume. Unlike gases, plasmas are electrically conductive, produce magnetic fields and electric currents, and respond strongly to electromagnetic forces. Positively charged nuclei swim in a "sea" of freely-moving disassociated electrons

# Matter and Energy

States of matter:



# Matter and Energy

Energy: is a conserved extensive property of a physical system, which cannot be observed directly but can be calculated from its state.

- Forms of energy: kinetic energy ($E_{kin} = \frac{1}{2}mv^2$), potential energy ($E_{pot} = mgh$), heat, electrical energy...
- Law of conservation of matter and energy: There is no change in the quantity of matter and energy during any chemical or physical change.
- Mass-energy equivalence is a concept formulated by Albert Einstein that explains the relationship between mass and energy.

$$E = mc^2$$

# Law of conservation of matter and energy

Chemical reaction:

$2\,H_2 + O_2 \longrightarrow 2\,H_2O$

Conservation of Matter:

$2\ \text{mol}\,H_2 + 1\ \text{mol}\,O_2 \longrightarrow 2\ \text{mol}\,H_2O$

Conservation of Mass (mass is not generally conserved):

$4\ \text{g}\,H_2 + 32\ \text{g}\,O_2 \longrightarrow 36\ \text{g}\,H_2O$

$2\,H_2 + O_2 \longrightarrow 2\,H_2O + 572000\ \text{J}\,(\text{energy})$

$m = E/c^2 = 572000\,\text{J}/(3 \times 10^8\,\text{m/s})^2 = 6,35 \times 10^{-12}\,g$

The mass associated with chemical amounts of energy is too small to measure.

# Physical Properties

A physical change occurs with no change in chemical composition. e.g.: boiling, melting, vaporization...
Physical properties altered significantly as matter undergoes physical changes.

- Extensive properties: quantity proportional to the quantity of material in the system. mass, volume, total energy
- Intensive properties: independent of the quantity of material density, pressure, temperature

# International System of units (SI Units)

| | | |
|---|---|---|
| length | meter | m |
| mass | kilogram | kg |
| time | second | s |
| electric current | ampere | A |
| temperature | Kelvin | K |
| luminous intensity | candela | cd |
| amount of substance | mole | mol |

meter: the lenght equal to the distance traveled by light in vacuum in 1/299,792,458 seconds.
mol: the amount of substance that contains as many entities (atoms or other particles) as there are atoms in 0.012 kg of pure $^{12}_{6}C$. 1 mole $= 6.022 \times 10^{23}$

# Derived Units

| | | | |
|---|---|---|---|
| area | square meter | $m^2$ | |
| volume | cubic meter | $m^3$ | |
| density | kilogram/cubic meter | $kg/m^3$ | |
| force | newton | N | $kg \times m/s^2$ |
| pressure | pascal | Pa | $N/m^2$ |
| energy | joule | J | $kg \times m^2/s^2$ |
| electric | | | |
| charge | coulomb | C | $A \times s$ |
| electric | | | |
| potential difference | volt | V | $J/(A \times s)$ |

# Derived Units

Density:

$$d = \frac{m}{V}$$

Suppose an object has a mass of $15.0\,\mathrm{g}$ and a volume of $10.0\,\mathrm{cm}^3$. What is the density?

$$d = \frac{m}{V} = \frac{15.0\,\mathrm{g}}{10.0\,\mathrm{cm}^3} = 1.50\,\mathrm{g/cm}^3$$

# SI prefixes

| | | | | | |
|---|---|---|---|---|---|
| $10^{12}$ | tera | T | $10^{-1}$ | deci | d |
| $10^{9}$ | giga | G | $10^{-2}$ | centi | c |
| $10^{6}$ | mega | M | $10^{-3}$ | milli | m |
| $10^{3}$ | kilo | k | $10^{-6}$ | micro | $\mu$ |
| $10^{2}$ | hecto | h | $10^{-9}$ | nano | n |
| $10^{1}$ | deka | da | $10^{-12}$ | pico | p |
| | | | $10^{-15}$ | femto | f |
| | | | $10^{-18}$ | atto | a |

# SI prefixes

$1\,\text{kg}=1000\,\text{g}$ ($\approx$ the mass of 1 L water)
$1\,\mu\text{g}=10^{-6}\,\text{g}=0.000001\,\text{g}$ (a typical small sand grain mass is about $3\,\mu$g)
$1\,\text{ng}=10^{-9}\,\text{g}=0.000000001\,\text{g}$ (mass of an average human cell)
$1\,\text{nm}=10^{-9}\,\text{m}=0.000000001\,\text{m}$ (a strand of human DNA is 2.5 nm in diameter)

# Measurement and significant figures

- If you repeat a particular measurement, you usually do not obtain precisely the same result, because each measurement is subject to experimental error.
- Precision refers to the closeness of the set of values obtained from identical measurements of a quantity.
- Accuracy refers to the closeness of a single measurement to its true value.
- Significant figures are those digits in a measured number (or in the result of a calculation with measured numbers) that include all certain digits plus a final digit having some uncertainty.

# Measurement and significant figures

- All digits are significant except zeros at the beginning of the number. Thus, 9.12 cm, 0.912 cm, and 0.00912 cm all contain three significant figures.
- Terminal zeros ending at the right of the decimal point are significant. Each of the following has three significant figures: 9.00 cm, 9.10 cm, 90.0 cm.

# Measurement and significant figures

- Multiplication and division. When multiplying or dividing measured quantities, give as many significant figures in the answer as there are in the measurement with the least number of significant figures.

  Suppose you want to calculate the solubility of a substance (the amount that dissolves in 100 g of water). You find that 0.0634 gram of the substance dissolves in 25.31 grams of water. The amount dissolving in 100.0 grams is

$$100.0\,\text{g of water} \times \frac{0.0634\,g}{5.31\,\text{g of water}}$$

  Performing it on a pocket calculator you get 0.250493875. The measurement 0.0634 gram has the least number of significant figures (three). Therefore, you report the answer to three significant figures, that is, 0.250 g.

# Measurement and significant figures

- Addition and subtraction. When adding or subtracting measured quantities, give the same number of decimal places in the answer as there are in the measurement with the least number of decimal places.

  Now consider the addition of 184.2 grams and 2.324 grams. On a calculator, you find that the result is 186.524. But because the quantity 184.2 grams has the least number of decimal places one, whereas 2.324 grams has three, the answer is 186.5 grams.

# Measurement and significant figures

Rounding is the procedure of dropping nonsignificant digits in a calculation result and adjusting the last digit reported. The general procedure is as follows: Look at the leftmost digit to be dropped.

- If this digit is 5 or greater, add 1 to the last digit to be retained and drop all digits farther to the right. Thus, rounding 1.2151 to three significant figures gives 1.22.
- If this digit is less than 5, simply drop it and all digits farther to the right. Rounding 1.2143 to three significant figures gives 1.21.

# Chemical properties

They are exhibited by matter as it undergoes changes in composition:

- acidity
- redox properties
- reactivity...

Chemical changes are transformations in which substances are converted into other substances. e.g..: burning, decomposition ...

$3\ Br_2(l) + 2\ Al(s) \rightarrow 2\ AlBr_3(s)$

Question: A sample of 27.0 g of aluminum yields 266.7 g of aluminum bromide. How many grams of bromine react with 15.0 g of aluminum?
Answer: 133 g

# Classification of matter

**Pure Substances:**
Fixed composition. Cannot be separated into simpler substances by physical methods.

- Elements: cannot be decomposed into simpler substances by chemical changes
- Compounds: can be decomposed into simpler substances by chemical changes, always in a definite ratio

# Classification of matter

**Mixtures:**
Variable composition. Components retain their characteristic properties. May be separated into pure substances by physical methods (e.g. distillation). Mixtures of different compositions may have widely different properties.

- Homogeneous mixtures: components are indistinguishable; have same composition throughout (e.g. solutions, alloys).
- Heterogeneous mixtures: components are distinguishable; do not have same composition throughout (e.g. muddy river water).

# Compounds

Law of definite proportions: pure compounds always consist of the same elements combined in the same proportion by mass.

| | | |
|---|---|---|
| water | 11.1 % hydrogen | 88.9 % oxygen |
| carbon dioxide | 27.3 % carbon | 72.7 % oxygen |

# Compounds

Law of Multiple Proportions: If two elements form more than one compound, in these compounds masses of one element that combine with a fixed mass of the other element are in a ratio of integer numbers.

| | N:O | |
|---|---|---|
| $N_2O$ | 1:0.57 | |
| NO | 1:1.14 | 0.57:1.14=1:2 |
| $NO_2$ | 1:2.28 | 0.57:2.28=1:4 |

# Foundations of Chemistry

Atoms: the smallest particle of an element that maintains its chemical identity.

Structure of atoms:

- The diameter of an atom is $\sim 10^{-10}$ m (0.1 nm).
- The nucleus contains protons and neutrons. The diameter of a nucleus is $\sim 10^{-15}$ m.

| Particle | Mass | Charge |
|---|---|---|
| proton | $1.672 \times 10^{-27}$ kg | $+1.602 \times 10^{-19}$ C |
| neutron | $1.675 \times 10^{-27}$ kg | none |
| electron | $9.109 \times 10^{-31}$ kg | $-1.602 \times 10^{-19}$ C |

$\frac{m(p^+)}{m(e^-)} \approx 1840$

# Foundations of Chemistry

- Atomic number ($Z$) = number of protons in the nucleus
- Mass number ($A$) = number of protons + number of neutrons
- Symbol: ${}^{A}_{Z}\mathrm{X}$, ${}^{12}_{6}\mathrm{C}$
- Isotopes: atoms for the same elements with different masses e.g ${}^{1}_{1}\mathrm{H}$, ${}^{2}_{1}\mathrm{H}$, ${}^{3}_{1}\mathrm{H}$
- Atomic mass unit: exactly 1/12 of the mass of an atom of ${}^{12}_{6}\mathrm{C}$ (1 amu $= 1.6606 \times 10^{-27}$ kg)
  On this scale the atomic weight of hydrogen is 1.00794 amu.
- Relative atomic mass: atomic weight divided by the atomic mass unit
  Relative atomic weight of hydrogen is 1.00794.

# Foundations of Chemistry

- In the molecules two or more atoms are bonded together.
- An ion is an atom or group of atoms that carries an electric charge. Ions that possess a positive charge are called cations. Those carrying negative charge are called anions.
- A radical is a group of atoms which have odd number of electrons.

# Problems

What is the volume of a C atom if its radius is 77 pm?

$$V = \frac{4}{3}R^3\pi$$

$$V = \frac{4}{3}(77 \times 10^{12} m)^3\pi$$

$$V = 1.91 \times 10^{-30}\ m^3$$

# Problems

When a mixture of aluminum powder and iron(III) oxide is ignited, it produces molten iron and aluminum oxide. In an ex- periment, 5.40 g of aluminum was mixed with 18.50 g of iron(III) oxide. At the end of the reaction, the mixture contained 11.17 g of iron, 10.20 g of aluminum oxide, and an undeter- mined amount of unreacted iron(III) oxide. No aluminum was left. What is the mass of the iron(III) oxide?
Answer: 2.53 g

# Problems

A beaker weighed 53.10 g. To the beaker was added 5.348 g of iron pellets and 56.1 g of hydrochloric acid. What was the to- tal mass of the beaker and the mixture (before reaction)? Express the answer to the correct number of significant figures.
Answer: 114.5 g

# Problems

What is the number of protons, neutrons and electrons in a $^{23}$Na atom, in 1g of Na and in 1 mol of Na?

$^{23}$Na atom: N($p^+$)=11, N($e^+$)=11, N($n^+$)=12

1g Na: N(atoms)=$\frac{1g}{23g/mol}6 \times 10^{23} = 2.61 \times 10^{22}$
N($p^+$)=$11 \times 2.61 \times 10^{22}$=$2.87 \times 10^{23}$
N($e^+$)=$11 \times 2.61 \times 10^{22}$=$2.87 \times 10^{23}$
N($n^+$)=$12 \times 2.61 \times 10^{22}$=$3.13 \times 10^{23}$

1 mol Na: N(atoms)=$6 \times 10^{23}$
N($p^+$)=$11 \times 6 \times 10^{23}$=$6.6 \times 10^{24}$
N($e^+$)=$11 \times 6 \times 10^{23}$=$6.6 \times 10^{24}$
N($n^+$)=$12 \times 6 \times 10^{23}$=$7.2 \times 10^{24}$

# Problems

What is the charge of a $Na^+$ ion and 1g of $H^+$?

$Na^+$ ion: $Q(\mathrm{Na}^+) = +1.602 \times 10^{19}\mathrm{C}$

1g $H^+$: $N = \frac{1g}{1g/mol} 6 \times 10^{23}\mathrm{mol}^{-1} = 6 \times 10^{23}$
$Q = +1.602 \times 10^{19}\mathrm{C} \times 6 \times 10^{23} = 9.612 \times 10^{4}\mathrm{C}$

# Problems

What is the atomic weight of magnesium according to the above data?

| Isotope | % Abudance | Mass (amu) |
|---|---|---|
| $^{24}$Mg | 78.99 | 23.985 |
| $^{25}$Mg | 10.00 | 24.986 |
| $^{26}$Mg | 11.01 | 25.983 |

Atomic weight of magnesium=
$0.7899 \times 23.985 + 0.1000 \times 24.986 + 0.1101 \times 25.983 = 24.30$amu

# Problems

Cocaine has the following percent composition by mass: 67.30% C, 6.93% H, 21.15% O and 4.62% N. What is the simplest formula of cocaine?

C $\frac{67.30}{12} = 5.608$
H $\frac{6.93}{1} = 6.93$
O $\frac{21.15}{16} = 1.322$
N $\frac{4.62}{14} = 0.33$

C $\frac{5.608}{0.33} = 17$
H $\frac{6.93}{0.33} = 21$
O $\frac{1.322}{0.33} = 4$
N $\frac{0.33}{0.33} = 1$

$$C_{12}H_{21}O_4N$$

# Quiz

Which one of the following is an example of a chemical change?

A. Mixing sand and sugar
B. Cutting a piece of paper into two pieces
C. Ice melting to water
D. Burning a piece of paper to form carbon dioxide and water
E. Mixing water and orange juice

# Quiz

Which of the following is an example of a solution?

A. Water
B. A combination of red and white chalk dust
C. Carbon disulfide (a chemical combination of carbon and sulfur)
D. Aluminum
E. Sugar water

# Quiz

Which of the following are substances?

A. Elements and solutions
B. Elements and compounds
C. Heterogeneous mixtures only
D. Heterogeneous mixtures and solutions
E. Elements only

# Quiz

Which one of the following is an extensive property?

A. Temperature
B. Mass
C. Taste
D. Density
E. Color

# Quiz

Which one of the following is a chemical change?

A. Iron filings are separated from sand using a magnet
B. Liquid nitrogen boils to become nitrogen gas
C. Gunpowder is exploded
D. Antifreeze is added to water in an automobile radiator
E. A shaken cola can is opened producing a spray of soda and carbon dioxide gas

# Quiz

Which of the following converts chemical energy to mechanical energy?

A. A waterwheel
B. A kerosene heater
C. A gasoline-powered automobile engine
D. A battery attached to a light bulb
E. A solar oven