Welcome to Chemistry

If anyone wishes to search out the truth of things in serious earnest, he ought not to select one special science; for all the sciences are conjoined with each other and interdependent.

*Descartes,*

*Rules for the Direction of the Mind*

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Program of course “MEDICAL CHEMISTRY”
for the first-year students of the School of Medicine

Module 1. “Acid-base equilibria and complex formation in biological liquids”.
1. Biogenic s- and p- block elements: biological role, application in medicine.
2. Biogenic d- block elements: biological role, application in medicine.
3. Chemical bonding.
5. Acid-base equilibrium in biological liquids.
7. Colligative properties of solutions.

Practice for Module 1: 5 seminars, 5 tests according to the material of seminars, 4 laboratory exercises and final test.

Module 2. “Equilibrium in biological systems at the phase interface”.
3. Electrochemical phenomena in biological processes.

Practice for Module 2: 5 seminars, 5 tests according to the material of seminars, 5 laboratory exercises and final test.
## Grades for Module 1 and 2

<table>
<thead>
<tr>
<th>Work</th>
<th>Grade</th>
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<tbody>
<tr>
<td>Laboratory exercise:</td>
<td></td>
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<tr>
<td>a) working during experiment</td>
<td>a) 5 points</td>
</tr>
<tr>
<td>b) writing of the experiment and results</td>
<td>b) 5 points</td>
</tr>
<tr>
<td>in copybook</td>
<td></td>
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<tr>
<td>Working during seminar</td>
<td>5 points</td>
</tr>
<tr>
<td>Test according to the seminar material</td>
<td>10 points = 5 problems for 2 points</td>
</tr>
<tr>
<td>Final test</td>
<td>75 points = 15 problems for 5 points</td>
</tr>
<tr>
<td>Total:</td>
<td></td>
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### For Module 1:
- 40 points = 4 lab. exercises for 10 points
- 60 points = 5 tests for 12 points
- 100 points = final test
All: up to 200 points

### For Module 2:
- 50 points = 5 lab. exercises for 10 points
- 25 points = 5 seminars for 5 points
- 50 points = 5 tests for 10 points
- 75 points = final test
All: up to 200 points

<table>
<thead>
<tr>
<th>Points</th>
<th>Traditional Grade</th>
<th>Two-level Grade</th>
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<tbody>
<tr>
<td>200 – 180</td>
<td>excellent</td>
<td>credit</td>
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<tr>
<td>179 – 150</td>
<td>good</td>
<td>credit</td>
</tr>
<tr>
<td>149 – 120</td>
<td>satisfactory</td>
<td>credit</td>
</tr>
<tr>
<td>119 – 0</td>
<td>unsatisfactory</td>
<td>not credited</td>
</tr>
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</table>
Lecture topics

- Fundamentals of chemistry.
- Classification of chemical elements.
- Classification of biogenic elements.
- Periodic law and Periodic table.
- Three important atomic properties: the atomic and ionic radii, the ionization energy, and the electron affinity.
Fundamentals of chemistry

Chemistry is the study of matter, its composition, structure and properties, and the chemical changes it undergoes.

Matter is anything that occupies space and has mass.

A substance is a form of matter that has a definite (constant) composition and distinct properties. Examples are water, ammonia, sugar, gold, oxygen, and etc.

Substances can be either elements or compounds. An element is a substance that cannot be separated into simpler substances by chemical means.

The symbols of some elements are derived from their Latin names – for example, Au from aurum (gold), Fe from ferrum (iron), and Na from natrium (sodium) – whereas most of them come from their English names.

On the basis of atomic theory, we can define an atom as the basic unit of an element that can enter into chemical combination.

Atoms actually possess internal structure; that is, they are made up of electrons, protons, and neutrons.
Fundamentals of chemistry

The atomic number (Z) is the number of protons in the nucleus of each atom of an element. As atom is a neutral particle the number of protons is equal to the number of electrons, so the atomic number also shows the number of electrons in the atom.

The mass number (A) of an atom is the total number of neutrons and protons present in the nucleus of an atom of an element. The number of neutrons in an atom is equal to the difference between the mass number and the atomic number.

A molecule is an aggregate of at least two atoms in a definite arrangement held together by chemical forces (also called chemical bonds). A molecule may contain atoms of the same element or atoms of two or more elements joined in a fixed ratio.

An ion is an atom or a group of atoms that has a net positive or negative charge. The loss of one or more electrons from a neutral atom results in a cation, an ion with a net positive charge. The acceptance of electron(s) by an atom results in an anion, a particle with a net negative charge.
Figure 1. The atom. The protons and neutrons of an atom are packed in an extremely small nucleus. Electrons are shown as ‘clouds’ around the nucleus.
Classification of chemical elements

- √ natural and artificial;
- √ metals and nonmetals;
- √ according to the structure of outer energy level (incompletely filled subshells): s-, p-, d- and f-elements;
- √ according to distribution on Earth's crust (widespread and rare). Of the 83 elements that are found in nature, 12 make up 99.7% of Earth’s crust by mass. They are, in decreasing order of natural abundance, oxygen (O), silicon (Si), aluminum (Al), iron (Fe), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), titanium (Ti), hydrogen (H), phosphorus (P), and manganese (Mn);
- √ radioactive elements (atomic nuclei are unstable), e.g. astatine (At), polonium (Po);
- √ according to importance for human and animal organisms (organogenic and biogenic).
Figure 2. Natural abundance of the elements.

(a) Natural abundance of the elements in percent by mass.

(b) Abundance of elements in the human body in percent by mass.

For example, oxygen’s abundance is 45.5 percent. This means that in a 100 g sample of Earth’s crust there are, on the average, 45.5 g of the element oxygen.
Classification of biogenic elements

- **Chemical elements essential to life forms** can be broken down into four major categories:

  1) bulk elements (H, C, N, O, P, S);
  2) macrominerals (Na, K, Mg, Ca, Cl);
  3) trace elements (Fe, Zn, Cu);
  4) ultratrace elements, comprised of nonmetals (F, I, Se, Si, As, B) and metals (Mn, Mo, Co, Cr, V, Ni, Cd, Sn, Pb, Li).

- **Biological essentiality of these elements has been defined by certain criteria:**

  1) a physiological deficiency appears when the element is removed from the diet;
  2) the deficiency is relieved by the addition of that element to the diet;
  3) a specific biological function is associated with the element.
Bioelements can be divided for physiological processes as following:

- **Elements for physiological processes in bioliquids** (C, H, O, N, P, Cl, K, Na, Ca, Mg).
- **Elements for metabolism** (Fe, Zn, Cu, Mo, Co, I).
  Of special interest are the trace elements, such as iron (Fe), copper (Cu), zinc (Zn), iodine (I), and cobalt (Co), which together make up about 0.1 percent of the body’s mass. These elements are necessary for biological functions such as growth, transport of oxygen for metabolism, and defense against disease. There is a delicate balance in the amounts of these elements in our bodies. Too much or too little over an extended period of time can lead to serious illness, retardation, or even death.

- **Elements decreasing generation and growth of microorganisms** (As, Sb, Ag).
- **Elements for regulation of redox reactions** (Mn, Cu, Cr).
Periodic law and Periodic table

Recognition of periodic regularities in physical and chemical behavior and the need to organize the large volume of available information about the structure and properties of elements and their compounds led to the development of the periodic law by Russian chemist D.I. Mendeleev.

The modern periodic law: the physical and chemical properties of elements are periodic functions of their atomic numbers.

Visual expression of the periodic law is the periodic table – a chart in which elements having similar chemical and physical properties are grouped together.

The periodic table is a handy tool that correlates the properties of the elements in a systematic way and helps us to make predictions about chemical behavior.
Periodic Table of elements: the 1-18 group designation has been recommended by the IUPAC

| Periodic Table of elements: the 1-18 group designation has been recommended by the IUPAC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1A | H | 2 | 2A | B | 3 | Li | 4 | Be | 5 | N | 6 | O | 7 | F | 8 | Ne |
| 9 | Na | 10 | Mg | 11 | Al | 12 | Si | 13 | P | 14 | S | 15 | Cl | 16 | Ar |
| 17 | K | 18 | Ca | 19 | Sc | 20 | Ti | 21 | V | 22 | Cr | 23 | Mn | 24 | Fe | 25 | Co | 26 | Ni | 27 | Cu | 28 | Zn | 29 | Ga | 30 | Ge | 31 | As | 32 | Se | 33 | Br | 34 | Kr |
| 35 | Rb | 36 | Sr | 37 | Y | 38 | Zr | 39 | Nb | 40 | Mo | 41 | Ru | 42 | Rh | 43 | Pd | 44 | Ag | 45 | Cd | 46 | In | 47 | Sn | 48 | Sb | 49 | Te | 50 | I | 51 | Xe |
| 52 | Cs | 53 | Ba | 54 | La | 55 | Hf | 56 | Ta | 57 | W | 58 | Re | 59 | Os | 60 | Ir | 61 | Pt | 62 | Au | 63 | Hg | 64 | Tl | 65 | Pb | 66 | Bi | 67 | Po | 68 | At | 69 | Rn |
| 70 | Fr | 71 | Ra | 72 | Ac | 73 | Th | 74 | Pa | 75 | U | 76 | Np | 77 | Pu | 78 | Am | 79 | Cm | 80 | Bk | 81 | Cf | 82 | Es | 83 | Fm | 84 | Md | 85 | No | 86 | Lr |

15
Periodic Table

√ In modern periodic table the elements are arranged by atomic number in horizontal rows called periods and in vertical columns known as groups or families, according to similarities in their chemical properties.

√ All elements can be divided into three categories – metals, nonmetals, and metalloids.

√ Elements are often referred collectively by their group number (Group 1A, Group 2A, and so on). However, for convenience, some element groups have been given special names.

Group 1A elements (Li, Na, K, Rb, Cs, and Fr) are called alkali metals.

Group 2A elements (Be, Mg, Ca, Sr, Ba, and Ra) are called alkaline earth metals.

Elements in Group 7A (F, Cl, Br, I, and At) are known as halogens.

Elements in Group 8A (He, Ne, Ar, Kr, Xe, and Rn) are called noble gases (or rare gases).
Three important atomic properties

The fitness of an element for a biological role is a consequence of electronic structure. We now need to understand how electronic structure affects atomic and ionic radii, and the thermodynamic ability of an atom to release or acquire electrons to form ions or chemical bonds.

**Three important atomic properties:**
- the atomic and ionic radii,
- the ionization energy,
- and the electron affinity.

These properties are of great significance in chemistry and biology, for they are controls on the number and types of chemical bonds the atom can form. Indeed, we can use these properties to reveal an important reason for the unique role of carbon in biology.
Atomic and ionic radii

The atomic radius of an element is half the distance between the centers of neighboring atoms in a solid (such as Cu) or, for nonmetals, in a homonuclear molecule (such as H₂ or S₈).

If there is one single attribute of an element that determines its chemical properties (either directly, or indirectly through the variation of other properties), then it is atomic radius.

In general, atomic radii decrease from left to right across a period and increase down each group.

The ionic radius of an element is its share of the distance between neighboring ions in an ionic solid. That is, the distance between the centers of a neighboring cation and anion is the sum of the two ionic radii.
Atomic and ionic radii

Table lists the radii of some ions that play important roles in biochemical processes.

<table>
<thead>
<tr>
<th>Ion</th>
<th>Main biochemical function</th>
<th>$r$/pm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg$^{2+}$</td>
<td>Binds to ATP, constituent of chlorophyll, control of protein folding and muscle contraction</td>
<td>72</td>
</tr>
<tr>
<td>Ca$^{2+}$</td>
<td>Component of bone and teeth, control of protein folding, hormonal action, blood clotting, and cell division</td>
<td>100</td>
</tr>
<tr>
<td>Na$^+$</td>
<td></td>
<td>102</td>
</tr>
<tr>
<td>K$^+$</td>
<td>Control of osmotic pressure, charge balance, and membrane potentials</td>
<td>138</td>
</tr>
<tr>
<td>Cl$^-$</td>
<td></td>
<td>167</td>
</tr>
</tbody>
</table>
The minimum energy necessary to remove an electron from a many-electron atom is its \textit{first ionization energy}, $I_1$. The \textit{second ionization energy}, $I_2$, is the minimum energy needed to remove a second electron (from the singly charged cation):

\[
E(g) \rightarrow E^+(g) + e^-(g) \quad I_1 = E(E^+) - E(E)
\]
\[
E^+(g) \rightarrow E^{2+}(g) + e^-(g) \quad I_2 = E(E^{2+}) - E(E^+)
\]

\textbf{The ionization energy of an element plays a central role in determining the ability of its atoms to participate in bond formation.}

After atomic radius, it is the most important property for determining an element’s chemical characteristics.
The electron affinity, $E_{ea}$, is the difference in energy between a neutral atom and its anion. It is the energy released in the process

$$E(g) + e^-(g) \rightarrow E^-(g) \quad E_{ea} = E(E) - E(E^-)$$

The electron affinity is positive if the anion has a lower energy than the neutral atom.

Further analysis of ionization energies and electron affinities can begin to tell us *why carbon is an essential building block of complex biological structures.*

Among the elements in Period 2, C has *intermediate values of the ionization energy and electron affinity*, so it can share electrons (that is, form covalent bonds) with many other elements, such as H, N, O, S, and, more importantly, other C atoms.

As a consequence, such networks as long carbon–carbon chains (as in lipids) and chains of peptide links can form readily. Because the ionization energy and electron affinity of C are neither too high nor too low, the bonds in these covalent networks are neither too strong nor too weak.

As a result, biological molecules are sufficiently stable to form viable organisms but are still susceptible to dissociation (essential to catabolism) and rearrangement (essential to anabolism).
References