ЗМІСТ

Medical Chemistry: textbook

Про книгу

The textbook outlines theoretical foundations of bioenergetics and kinetics of biochemical reactions, fundamental principles of chemical equilibrium; chemical properties and biological role of biogenic elements; structure of coordination complexes. Considerable attention is given to the theory of solutions and dissolution processes, as well as to importance of pH values for assessment of the acid-base state of blood and other biological fluids. Mechanisms of electrode potentials, surface phenomena, and their role in life of the organism are described. The textbook also describes classification and fundamental properties of dispersed systems and colloidal solutions; theoretical foundations of properties of macromolecular compounds, and their role in living organisms. The textbook is intended for use by students of higher medical educational institutions studying in English.

V.Y. TSUBER
A.A. KOTVYTSKA
K.V. TYKHONOVYCH

Medical CHEMISTRY

Edited by **V.Y. TSUBER**

TEXTBOOK

RECOMMENDED
by the Academic Council of
Poltava State Medical University
as a textbook for foreign students
seeking higher education with
a master's degree, majoring
in specialties: 221 "Dentistry",
222 "Medicine" in higher education
institutions of the Ministry
of Health of Ukraine

Kyiv
AUS Medicine Publishing
2022

UDC 54:61(075.8)
LBC 24ya73
T83

Recommended by the Academic Council of Poltava State Medical University as a textbook for foreign students seeking higher education with a master's degree, majoring in specialties: 221 "Dentistry", 222 "Medicine" in higher education institutions of the Ministry of Health of Ukraine. (Excerpt from Protocol № 2 of June 23, 2021)

Authors: *V.Y. Tsuber, A.A. Kotvytska, K.V. Tykhonovych*, Poltava State Medical University.

The textbook outlines theoretical foundations of bioenergetics and kinetics of biochemical reactions, fundamental principles of chemical equilibrium; chemical properties and biological role of biogenic elements; structure of coordination complexes. Considerable attention is given to the theory of solutions and dissolution processes, as well as to importance of pH values for assessment of the acid-base state of blood and other biological fluids. Mechanisms of electrode potentials, surface phenomena, and their role in life of the organism are described. The textbook also describes classification and fundamental properties of dispersed systems and colloidal solutions; theoretical foundations of properties of macromolecular compounds, and their role in living organisms.

The textbook is intended for use by students of higher medical educational institutions studying in English.

UDC 54:61(075.8)
LBC 24ya73

Reviewers:

G.O. Syrova, Head of the Department of Medical and Bioorganic Chemistry, Doctor of Pharmaceutical Sciences, Professor (Kharkiv National Medical University);

N.V. Zaichko, Head of the Department of Biological and General Chemistry, Doctor of Medical Sciences, Professor (Vinnytsia National Pirogov Medical University);

L.G. Netyukhailo, Doctor of Medical Sciences, Professor of the Department of Biological and Bioorganic Chemistry (Poltava State Medical University);

V.G. Kostenko, Candidate of Philological Sciences, Associate Professor of the Department of Foreign Languages with Latin Language and Medical Terminology (Poltava State Medical University)

ISBN 978-617-505-895-4

Contents

Preface

Medical chemistry is a scientific discipline that has progressed rapidly over the last few decades and has become the connecting bridge of a variety of related scientific disciplines. Medical chemistry holds a key position in the curricula of medical universities, and is one of the basic preclinical science subjects for students of medicine.

Medical chemistry is an interdisciplinary science covering a particularly wide domain situated at the interface of life sciences such as biochemistry, pharmacology, molecular biology, genetics, immunology, pharmacokinetics, and toxicology on one side, and chemistry-based disciplines such as physical chemistry, colloidal chemistry, electrochemistry, inorganic chemistry on the other side.

Medical chemistry remains a challenging science which verges greatly on biochemistry and on all the physical, genetic, and chemical riddles in human physiology that are related to medicine. Medical chemistry is needed to understand fundamentals of prevention, diagnosis, and treatment of diseases, and thereby it contributes to a healthier life.

In general, international textbooks in medical chemistry are either too voluminous or focused on a single branch of chemistry, which makes them of diminished use for our students of medicine. With this textbook, we are providing students of medicine with a comprehensive yet concise guide to the chemical phenomena that are related to human metabolism and diseases. We have tried our utmost to ensure that the language used in this textbook is lucid and simple, making it an easy reading, and the text provides a systematic and in-depth study. At the same time, we have attempted to adhere to high scientific standards through incorporating most recent developments and concepts.

The text is divided into 11 chapters. Chapter 1 sets out the basic laws and principles of thermodynamics, with the emphasis on the functioning of a living organism as an open thermodynamic system. The purpose of Chapter 2 is to teach students to predict the route and outcome of biochemical processes in the body based on knowledge of chemical kinetics, as well as to elucidate the mechanism of action of enzymes as biological catalysts. Chapter 3 highlights basic principles of chemical equilibrium, which makes it possible to predict and adjust the direction of biochemical reactions and processes. Chapter 4 describes main chemical properties and biological role of biogenic elements. Chapter 5 discusses in detail the structure of coordination complexes, their role in the life of organisms, and their applications in chelation therapy. Chapter 6 deals with the theory and properties of solutions, the dissolution process, as well as applications of solution concentration calculations and volumetric analysis in medical practice. Chapter 7 offers information on acids and bases, the hydrogen index (pH), buffer systems, and their role in maintaining the acid-base homeostasis in the organism. Chapter 8 describes the mechanism of formation of electrode potentials and introduces a concept of biopotentials. Chapter 9 describes role of adsorption in heterogeneous systems, as well as applications of chromatography in medical practice and in biomedical research. Chapter 10 discusses classification and properties of dispersed systems, including colloidal solutions, which is important to understand properties of fluids and tissues in the organism. Chapter 11 highlights chemical properties of macromolecular compounds that are essential for the existence of living organisms.

There is an exceptionally close relationship between chemistry and medicine. The living organisms are wholly composed of chemical substances, and all their functions depend upon chemical reactions. Chemical processes underlie food digestion, muscle contraction, nerve impulse transmission. In other words, the human body is a complex chemical machine, and its states of health and disease essentially depend on the coordination of a variety of complex chemical reactions. This complexity of the human organism demands profound knowledge of its underlying chemistry, and we hope that the textbook will be a very useful guide to study medical chemistry.

Chapter 3

CHEMICAL EQUILIBRIUM. HETEROGENEOUS EQUILIBRIUMS IN THE ORGANISM

CHEMICAL EQUILIBRIUM

In some chemical reactions, the products of the reaction can react together to produce the original reactants. These reactions are called reversible. In a reversible reaction, the forward reaction forms the reaction products, and the reverse reaction converts them into reactants at the same time. The reaction mixture then contains reactants and products. Some examples are salt hydrolysis, esterification, formation of ammonia, etc. In the organism, examples of reversible reactions are oxygen binding to hemoglobin or the formation of the bicarbonate buffer system.

By the Law of mass action, the rate of the forward reaction decreases when concentrations of the reactants decrease. At the same time, the concentrations of the products increase, and the reverse reaction goes faster. In a closed system, at a certain point of time, the rates of the forward reaction and the reverse reaction become equal, and the system attains a state of chemical equilibrium.

Chemical equilibrium is the state when the forward reaction proceeds at the same rate as the reverse reaction.

At equilibrium, there are no net changes in concentrations of the reactants and products. Also, there are no observable changes in the properties of the system.

Kinetics of chemical equilibrium

The rate of a chemical reaction is described by the Law of mass action. According to the Law of mass action, the rate of a chemical reaction is proportional to the product of concentrations of the reactants raised to their respective stoichiometric coefficients.

Let's consider a reversible homogeneous reaction:

$$aA + bB \rightleftharpoons cC + dD.$$

With the Law of mass action, the rates of the forward and reverse reactions are as follows:

$$\upsilon_{forward} = k_+ [A]^a [B]^b;$$

$$\upsilon_{reverse} = k_- [C]^c [D]^d.$$

Here,
[A] and **[B]** are concentrations of the reactants;
[C] and **[D]** are concentrations of the products;
$\mathbf{k_+}$ is the rate constant of the forward reaction;
$\mathbf{k_-}$ is the rate constant of the reverse reaction.

At equilibrium, the rates of the forward and reverse reactions are equal:

$$\upsilon_{forward} = \upsilon_{reverse};$$

$$k_+ [A]^a [B]^b = k_- [C]^c [D]^d;$$

$$\frac{k_+}{k_-} = \frac{[C]^c [D]^d}{[A]^a [B]^b}.$$

The ratio of the constants is known as the equilibrium constant:

$$K_C = \frac{[C]^c [D]^d}{[A]^a [B]^b}.$$

The equilibrium constant is designated as K_c when it is calculated from concentrations of the reacting species. For reactions in a gaseous phase, the partial pressures of the gases are used to calculate the equilibrium constant:

$$K_P = \frac{P_C^c P_D^d}{P_A^a P_B^b}.$$

Here,
$\boldsymbol{P_A}$ and $\boldsymbol{P_B}$ are partial pressures of the gaseous reactants;
$\boldsymbol{P_C}$ and $\boldsymbol{P_D}$ are partial pressures of the gaseous products.

Equilibrium constant

Rate constants only depend on the nature of reactants and temperature and do not depend on concentrations of reactants, as the concentrations are held at one mol/L. The equilibrium constant is the ratio of the rate constants of the forward and reverse reactions; therefore, it also depends on the nature of reacting species and temperature. Likewise, the equilibrium constant does not depend on concentrations of the reactants and products, albeit for a different reason. Chemical equilibrium is a dynamic state, i.e., a change in concentration of any reacting species in a system at equilibrium causes changes of concentrations of all the other substances in the reaction, and the equilibrium constant remains stable at a given temperature.

The equilibrium constant is used to predict the extent of a reaction at given conditions (Fig. 3.1).

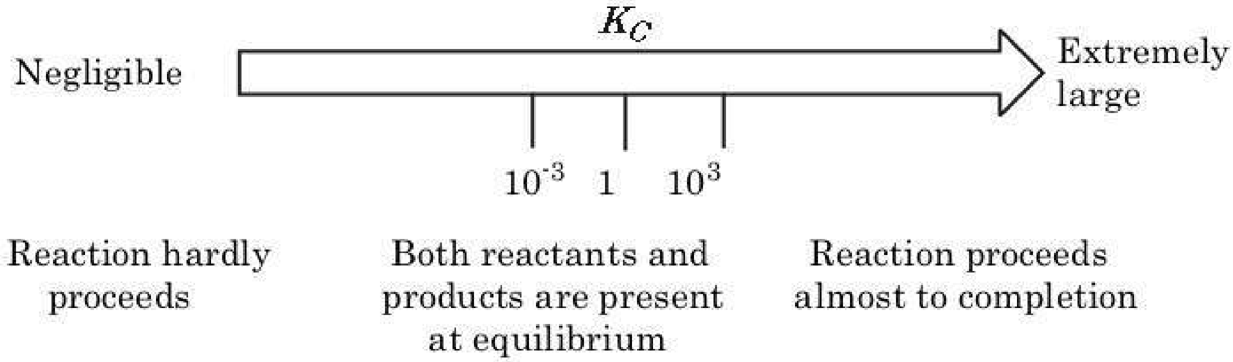

Figure 3.1. **The value of the equilibrium constant predicts the extent of a reaction**

If $K_c > 10^3$, then the products predominate over the reactants.

If $K_c < 10^{-3}$, then the reactants predominate over the products.

If $10^{-3} < K_c < 10^3$, then appreciable concentrations of both reactants and products are present.

Factors affecting chemical equilibrium. Le Chatelier's principle

The equilibrium state and equilibrium constant are not the same. For a particular reaction, the equilibrium constant has a unique value for any given temperature and is not affected by changes in other conditions. On the contrary, the equilibrium state is a dynamic state that can be perturbed by changes in concentrations, pressure, volume, or temperature. The changes lead to a shift in the equilibrium, and a new equilibrium state is eventually attained.

Le Chatelier's principle explains the effect of a change of conditions on the state of chemical equilibrium:

If a system at equilibrium is disturbed by a change of a condition, the position of equilibrium shifts to reduce the effect of the change.

The following paragraphs describe several factors that cause equilibrium shifts, along with examples of reactions that can be regulated by changing the factors.

A. Change of concentration

- The equilibrium constant does not change.
- The position of the equilibrium state shifts.
- When a reactant is added, the equilibrium state shifts to the formation of the products.
- When a product is added, the equilibrium state shifts to the formation of the reactants.

Creatine phosphate acts as a high-energy reserve in the organism. The ability of the cell to generate creatine phosphate from excess ATP during rest and its use of the stored creatine phosphate for quick generation of ATP during intense activity ensures an instant supply of energy when it is needed. In the muscle and brain, creatine phosphate donates its phosphate group to produce ATP from ADP in the first two to seven seconds of an intense muscular or neuronal effort. ATP generated in the reaction is used up by the cell, and the equilibrium shifts to the right, leading to further ATP synthesis from creatine phosphate and ADP. During a period of low effort, an increased concentration of ATP causes a shift of the equilibrium towards the formation of creatine phosphate. The reaction is catalyzed by the enzyme creatine kinase:

$$\textit{creatine phosphate} + \mathrm{ADP} \rightleftharpoons \textit{creatine} + \mathrm{ATP}.$$

B. Change of pressure

- A change of pressure only effects reactions where products or reactants are gases. The volume of a solid or liquid phase is not affected by changes in pressure.
- The equilibrium constant does not change.
- The position of the equilibrium state shifts.
- When pressure increases, the equilibrium state shifts in the direction where fewer moles of gas are produced.
- When pressure decreases, the equilibrium state shifts in the direction where more moles of gas are produced.

Sulfur trioxide is produced on an industrial scale as a precursor to sulfuric acid in the reaction:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g).$$

In the left part of the equation, there are three molecules of gas, and in the right part, there are two. An increase of pressure favors the process that causes the decrease in the number of moles of gas, and the equilibrium shifts towards the product of the reaction. A decrease in pressure shifts the equilibrium towards the formation of the reactants.

In the equation of a reversible reaction of hydrogen iodide formation, the number of molecules of gaseous substances in the left part is equal to the number of molecules of a gas in the right part:

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g).$$

In this case, a change in pressure will not cause a shift in chemical equilibrium.

C. Change of temperature

- The equilibrium constant changes.
- A change in temperature changes the rates of both the forward and reverse reactions but to different extents. Thus, the position of the equilibrium state shifts, as shown in Table 3.1.

Table 3.1. **Effect of changes of temperature on chemical equilibrium**

Forward reaction	Increase of temperature	Decrease of temperature
Exothermic (negative ΔH)	$\rightarrow$ to reactants	$\rightarrow$ to products
Endothermic (positive ΔH)	$\rightarrow$ to products	$\rightarrow$ to reactants

The formation of water in the reaction between gaseous hydrogen and oxygen is a highly exothermic process and proceeds virtually to the end at standard conditions:

$$H_2(g) + \frac{1}{2}O_2(g) = H_2O(l), \quad \Delta H^0 = -286 \text{ kJ/mol}.$$

However, a temperature higher than 1500 °C favors the reverse reaction of water dissociation into oxygen and hydrogen, and the dissociation increases with increasing temperature.

D. Addition of a catalyst

- The equilibrium constant does not change.
- The position of the equilibrium state does not shift.
- In a reversible reaction, a catalyst equally accelerates its forward and backward reactions.
- A catalyst does not change the yield of the reaction. It accelerates the attainment of the equilibrium state.
- Changes in concentrations, pressure, or temperature should be applied to increase the yield of a desired product of a reaction.

Upon combustion of a fuel in a car engine, incomplete oxidation of hydrocarbons gives rise to highly poisonous carbon monoxide CO. The toxic substance has to be rapidly neutralized to prevent harm to the environment and human health. Catalytic neutralization of exhaust gases of internal combustion engines is performed on the surface of a solid catalyst. The catalyst is an alloy containing platinum, rhodium, and palla-