Subject 9. Kinetic basis of biochemical processes

1. Importance:

Chemical kinetics is the basis for studying rates and mechanisms of biochemical reactions. Rates of biochemical reactions inform about enzymic activity, which is important for correct diagnosis and helps to use enzymes in treatment of diseases. Methods of chemical kinetics render it possible to measure rates of uptake and excretion of medical substances. It is important to know half life of substances to determine shelf life of medicines, accumulation of radionuclides, pesticides and other harmful substances in the environment. Methods of chemical kinetics help to choose optimal conditions for neutralization and utilization of pollutants as well as control pollution of the environment. Knowledge of theoretical basics of chemical kinetics aids students in study of biochemistry, pharmacology, hygiene.

Competences:

Be able to analyze information, make informed decisions, establish appropriate relationships to achieve objectives.

Ability to apply knowledge in practical situations.

Know the methods of application of knowledge in solving practical problems.

Use native language in professional and business communications and preparation of documents.

Know the issues of environmental conservation and ways to save the environment.

2. Concrete aims:

Analyze effects of concentration and temperature on the reaction rate.

Explain effect of activation energy on the reaction rate.

Analyze characteristics of catalyst action and explain the mechanisms of homogeneous and heterogeneous catalysis

Explain the mechanisms of action of enzymes and analyze effects of enzyme and substrate concentrations on rates of enzymatic processes

3. Basic knowledge, skills necessary for studying the subject (interdisciplinary integration)

Previous subjects	Obtained skills

1. Chemistry and physics (school course)	To know the concepts "catalysis", "catalyst", "inhibitor", "homogeneous and heterogeneous processes".
2. Biological and bioorganic chemistry	Have knowledge about enzymes as biological catalysts of the proteinaceous nature. Classify enzymes. Know mechanism of enzymic catalysis.

4. Tasks for independent work during preparation for the class and in class.

4.1. The list of key terms, parameters, characteristics which the student is to learn while preparing for classes:

Term	Definition
1. Rate of a chemical reaction	**Rate of a chemical reaction** is equal to change of concentration of the reactants or reaction products in a unit of time.
2. The Law of mass action for rates of chemical reactions	**The Law of mass action for rates of chemical reactions**: $v = kC_A^a C_B^b = k[A]^a \times [B]^b$
3. First order reactions	**First order reactions** $v = kC^1$; $\eta = 1$
4. Second order reactions	**Second order reactions** $v = kC^2$; $\eta = 2$ $v = kC_1^1 \cdot C_2^1$; $\eta = 2$
5. Complex reactions: A. Parallel reactions	**Parallel reactions** are those, where various products are formed from one initial substance depending on conditions.
B. Consecutive reactions	**Consecutive reactions** are those where the product of the first stage is a reactant for the second stage.
C. Conjugated reactions	**Conjugated reactions** are those where one proceeds only at the same time with the other, i.e. it is induced by the other reaction.
D. Reversible reactions	**Reversible reactions** proceed at the same time in the direct and opposite direction.
E. Chain reactions	**Chain reactions** are those in which elementary acts with participation of free radicals are repeated many times.
6. Vant Hoff's rule	**Vant Hoff's rule**: at a temperature increase by 10 degrees the reaction rate increases 2-4 times.

7. Arrhenius's equation	**Arrhenius's equation:** $\ln k = \ln A - \frac{E_a}{RT}$
8. Catalysis	**Catalysis** is an increase of the reaction rate upon addition of catalysts.
9. Catalyst	**Catalyst** is a simple or complex substance that participates in a chemical reaction and changes its rate, but emerges unchanged at the end of the reaction.
10. Enzymes	**Enzymes** are substances of proteinaceous nature that are produced by cells of live organisms and considerably increase rates of biochemical processes. For example, amylase, pepsin.

4.2. Theoretical questions to the lesson:

1. Chemical kinetics as the basis for studying rates and z of biochemical reactions. The rate of chemical reactions. Effect of concentration on the reaction rate. The Law of mass action for rate of chemical reactions. The rate constant.
2. The order of a reaction. Kinetic equations of reactions of first, second and zero order. The period of halflife. Molecularity of reaction.
3. Kinetics of complex reactions: consecutive, parallel, conjugated, reversible, chain. Antioxidants. Free radical reactions in a live organism. Photochemical reactions, photosynthesis.
4. Effect of temperature on the reaction rate. The temperature coefficient. The Van't Hoff's rule. Characteristics of the temperature coefficient in biochemical processes.
5. The activation energy. The theory of active collisions. The Arrhenius' equation. The theory of the transition state.
6. Catalysis and catalysts. Properties of catalysts. Homogeneous, heterogeneous and microheterogeneous catalysis. Acid-base catalysis. Autocatalysis. Mechanism of action of catalysts. Promoters and catalytic poisons.
7. Kinetics of enzymic reactions. Enzymes as biological catalysts. Properties of enzymes: selectivity, efficiency, dependence of enzymic reactions on temperature and pH of the environment.

4.3. Situation and calculation tasks done by students in class:

1. The kinetic equation of a reaction is $v = k[A]^2 [B]$. How many times does the rate of the reaction decrease if concentrations of the reactants decrease twofold.

2. How many times does the reaction rate increase upon a 50K increase in temperature? The temperature coefficient of the reaction is 2.

3. Calculate the rate of the reaction $H_{2(g)} + I_{2(g)} = 2HI_{(g)}$, if the concentration of hydrogen is 0.5 mol/L, and the concentration of iodine is 0.2 mol/L. The rate constant of the reaction is 0.18 L/mol·s.

Contents of the subject:

1. **Chemical kinetics as the basis for studying rates and z of biochemical reactions. The rate of chemical reactions. Effect of concentration on the reaction rate. The Law of mass action for rate of chemical reactions. The rate constant.**

The rate of a chemical reaction is equal change of concentration of the reactants or reaction products in a unit of time.

Average reaction rate: $v = \pm\frac{\Delta C(x)}{\Delta\tau}$

Momentary reaction rate: $v = \pm\frac{dC}{d\tau}$

The Law of mass action for rates of chemical reactions: rate of a chemical rezction is proportional to concentrations of the reactants raised to the powers equal to coefficients in the chemical equation of the reaction.

For a reaction: $aA + вB = cC$ reaction rate: $v = kC_A^a C_B^b = k[A]^a \times [B]^b$

Rate constant of a reaction is the rate of the reaction when concentrations of the reactants are equal to one.

2. **The order of a reaction. Kinetic equations of reactions of first, second and zero order. The period of halflife. Molecularity of reaction.**

Reaction order is the sum of powers of concentrations in the kinetic equation.

First order reactions: $N_2O_5 = 2NO_2 + ½\ O_2$; $v = k[N_2O_5]^1$; $\eta = 1$.

Second order reactions: $H_2 + I_2 = 2HI$; $v = k[H_2]^1 \times [I_2]^1$; $\eta = 2$.

$2H = H_2$; $v = k[H]^2$; $\eta = 2$.

Zero order reactions: $v = kC^0$; $v = k \cdot 1$; $v = k$; $\eta = 0$.

Molecularity of the reaction is the number of particles (atoms, molecules, ions) participating in the elementary act of interaction.

Halflife period is the time during which concentrations of initial substances decrease twofold.

3. **Kinetics of complex reactions: consecutive, parallel, conjugated, reversible, chain. Antioxidants. Free radical reactions in a live organism. Photochemical reactions, photosynthesis.**

Simple reactions take place in one stage: $A \rightarrow B$ or $A + B \rightarrow C$

Complex reactions proceed in several elementary stages:

Parallel reactions are those, where various products are formed from one initial substance depending on conditions.

Consecutive reactions are those where the product of the first stage is a reactant for the second stage.

$A \rightarrow B \rightarrow C \rightarrow D$

$C + ½O_2 = CO$; $CO + ½O_2 = CO_2$

Conjugated reactions are those where one proceeds only at the same time with the other, i.e. it is induced by the other reaction.

Reversible reactions proceed at the same time in the direct and opposite direction.

$A + B \leftrightarrows C$

$2H_2 + O_2 \leftrightarrows 2\ H_2O.$

Chain reactions are those in which elementary acts with participation of free radicals are repeated many times.

$H_2 + Cl_2 \rightarrow 2HCl$

$Cl_2 \xrightarrow{h\nu} Cl\cdot + Cl\cdot$ (initiation of the chain)

Elongation of the chain: $Cl\cdot + H_2 \rightarrow HCl + H\cdot$

$H\cdot + Cl_2 \rightarrow HCl + Cl\cdot$

Termination of the chain: $Cl\cdot + Cl\cdot \rightarrow Cl_2$

$H\cdot + H\cdot \rightarrow H_2$

$Cl\cdot + H\cdot \rightarrow HCl$

Antioxidants are able to disrupt ahain oxidation and protect biomolecules from oxidative damage.

Photochemical reactions are driven by visible or ultra-violet light.

4. Effect of temperature on the reaction rate. The temperature coefficient. The Van't Hoff's rule. Characteristics of the temperature coefficient in biochemical processes.

Vant Hoff's rule: at a temperature increase by 10 degrees the reaction rate increases 2-4 times.

$$\frac{\upsilon_{T_2}}{\upsilon_{T_1}} = \gamma^{\frac{T_2 - T_1}{10}},$$

T_1 i T_2 – initial and final temperature,

$\upsilon_{T_1}\ i\ \upsilon_{T_2}$ – initial rate and rate after the temperature change,

γ – temperature coefficient of the reaction rate.

5. **The activation energy. The theory of active collisions. The Arrhenius' equation. The theory of the transition state.**

Activation energy is a difference between energy of the activated complex and the initial energies of the reactants.

Arrhenius's equation:

$$\ln k = \ln A - \frac{E_a}{RT}$$

The theory of transition state: reaction pathway through a state is energetically more favorable. Therefore chemical reactions proceed through formation of various activated complexes. Energy of formation of the activated complexes is equal to activation energy of reactants.

6. **Catalysis and catalysts. Properties of catalysts. Homogeneous, heterogeneous and microheterogeneous catalysis. Acid-base catalysis. Autocatalysis. Mechanism of action of catalysts. Promoters and catalytic poisons.**

Catalysis is an increase of the reaction rate upon addition of catalysts.

Catalyst is a simple or complex substance that participates in a chemical reaction and changes its rate, but emerges unchanged at the end of the reaction.

Homogeneous catalysis: $2SO_{2(g)} + O_{2(g)} \xrightarrow{NO, NO_2} 2SO_{3(g)}$

Heterogeneous catalysis: $2C_2H_5OH_{(l)} \xrightarrow{Na_{(s)}} C_4H_9OH_{(l)} + H_2O_{(l)}$

Mechanism of catalytic action: $A + K \rightarrow AK^*$

$$AK^* + B \rightarrow ABK^* \rightarrow AB + K$$

7. **Kinetics of enzymic reactions. Enzymes as biological catalysts. Properties of enzymes: selectivity, efficiency, dependence of enzymic reactions on temperature and pH of the environment.**

Enzymes are substances of proteinaceous nature that are produced by cells of live organisms and considerably increase rates of biochemical processes. For example, amylase, pepsin.

Properties of enzymic action:

Selectivity – an enzyme only interacts with its substrate.

Activity of enzymes and reaction rates depends on pH and temperature. At body temperature enzymes accelerate reactions in millions and billions of times.

Materials for self control:

A. Tasks for self control:

1. Choose heterogenous reactions:

1. $2CO_{(g)} + O_{2(g)} = 2CO_{2(g)}$;
2. $S_{(s)} + O_{2(g)} = SO_{2(g)}$;
3. $2Na_{(s)} + Cl_{2(g)} = 2NaCl_{(s)}$;
4. $Na_2CO_{3(s)} + SiO_{2(s)} = Na_2SiO_{3(s)} + CO_{2(g)}$.

2. Choose the correct kinetic equation for the direct reaction:

$CaCO_{3(s)} \leftrightarrows CaO_{(s)} + CO_{2(g)}$:

a) $\upsilon = k \cdot [CaCO_3]$;

b) $\upsilon = k \cdot [CaO] \cdot [CO_2]$;

c) $\upsilon = k \cdot [CO_2]$;

d) $\upsilon = k$.

3. How does activity of enzymes depend on the change of pH of the medium?

a) change of pH does not affect activity of enzymes;
b) decrease of pH increases activity of enzymes;
c) change of pH causes inactivation of enzymes;
d) change of pH can increase or decrease activity of an enzyme depending on its structure and nature.

4. Which of the following effects is caused by a significant temperature increase in activity of inorganic catalysts and enzymes?

a) activity of inorganic catalysts increases, activity of enzymes decreases;
b) activity of inorganic catalysts mostly increases, activity of enzymes ceases;
c) activities of both inorganic catalysts and enzymes increase;
d) activity of inorganic catalysts does not change, activity of enzymes first increases, than ceases.

B. Practical tasks for self control:

1. Decide, how the rate of the direct reaction changes $2NO_{(g)} + O_{2(g)} \leftrightarrows 2NO_{2(g)}$, if the volume of the reaction mixture decreases three times.

a) 9 times decrease;

b) 9 times increase;
c) 27 times decrease;
d) 27 times increase

2. The rate of a reaction decreased 27 times upon cooling of the reaction mixture from 90° to 60°C. Calculate the temperature coefficient of the reaction rate.

a) 3; b) 2; c) 4; d) 2.6; e) 3.2.

Literature

Main:

1. Medical Chemistry: textbook / V.O. Kalibabchuk, V.I. Halynska, V.I. Hryshchenko et al.; edited by Prof. V.O. Kalibabchuk – Kyiv: "Medicine", 2010 – 224 p. (P. 37 – 49).

Informational resources:

2. www. pdmu, edu.ua
https://med-chemistry.pdmu.edu.ua/

(Web page of Poltava State Medical University).