Intensive online course “Integrative Life Sciences”

Biochemistry (30h lectures, 12h seminars)

Semchyshyn H., Ushakova G., Lushchak O., Abrat O.

***** Highlighted lectures are part of the Introductory course

1. ***Energy and Metabolism**. Thermodynamic bases of metabolism. The first and second laws of thermodynamics. Endergonic and exergonic reactions. Metabolic Pathways. Oxidation and reduction reactions. Redox potential. The Nernst equation. Biological oxidation. High energy phosphates.
2. ***Energy and metabolism of carbohydrates.** Biochemistry of glycogen metabolism, its regulation and cyclic AMP. Glycolysis. Fates of pyruvate under anaerobic conditions.
3. ***Aerobic cellular respiration.** General aspects. Chemistry and biological significance of oxidative decarboxylation of pyruvate and tricarboxylic acid cycle. Their regulation. Substrate-level phosphorylation. Energy balance of complete glucose oxidation.
4. **Electron transport chains.** Biological oxidation and mitochondrial electron transport chain. Chemi-osmotic theory. ATP synthase. Regulation of oxidative phosphorylation. General aspects and biological significance of non-mitochondrial electron transport chains in different species.
5. **Metabolic pathways of carbohydrates: glucose and its “relatives”.** Gluconeogenesis. Interplay between glycolysis and gluconeogenesis. Fructose and galactose metabolism. Metabolism of alcohol.
6. **Metabolic pathways of carbohydrates: pentose phosphate shunt.** General aspects, chemistry, and biological significance of hexose monophosphate pathway. Relationship between pentose phosphate pathway and glycolysis.
7. **Principles of metabolic regulation: carbohydrate metabolism.** Coordinated regulation of glycogen breakdown/synthesis, glycolysis, gluconeogenesis, and pentose phosphate pathway.
8. **Metabolic pathways of lipids: catabolism.** General aspects, chemistry, and biological significance of lipid degradation. Catabolism of triacylglycerols. The role of hormones. Oxidation of fatty acids.
9. **Metabolic pathways of lipids: anabolism.** General aspects, chemistry, biological significance, and regulation of synthesis of fatty acids and triacylglycerols.
10. **Metabolic pathways of lipids: cholesterol biosynthesis.** General aspects, chemistry, biological significance, and regulation of synthesis of cholesterol. Metabolism of ketones.
11. **Metabolic pathways of proteins: catabolism of amino acids.** General aspects, biological significance, and regulation. Pathways of amino acid degradation. Ammonia transportation, detoxication, and excretion. Urea cycle**.**
12. **Metabolic pathways of proteins: amino acid anabolism.** The pathways of amino acid synthesis. General aspects, biological significance, and regulation.
13. **Metabolic pathways of nucleotides: catabolism.** Degradation of purines and pyrimidines. General aspects, chemistry, and biological significance.
14. **Metabolic pathways of nucleotides: anabolism.** Biosynthesis of purines and pyrimidines. General aspects, chemistry, biological significance, and regulation.
15. **Integration of metabolism.** Coordination of carbohydrate, lipid, and protein metabolism. The role of vitamins.

Physiology (26h lectures, 10h seminars)

Manko V., Garaschuk O., Merlavsky V.

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1. ***Structure, properties and functions of the plasma membrane**. Transport of substances across biological membranes. Direct and indirect mechanism of action of primary messengers. Ionotropic and metabotropic receptors. The role of G-proteins in physiological signal transduction. cAMP system. Adenylate cyclase pathway of information transduction. The role of G_s- and G_i-proteins. cGMP system. Guanylate cyclase pathway of information transduction. Phosphoinositide pathway of information transduction. The role of $G_{q/11}$-proteins. Ca^{2+} as intracellular messenger. Ca^{2+}-transporting systems of plasma and intracellular membranes. Ca^{2+}-calmodulin system.
2. ***Bioelectric potentials**. Resting membrane potential. Action potential, its physiological role and mechanisms of generation. Phases of action potential upon intracellular recording. Mechanisms of action potentials propagation. Classification of nerve fibers by the rate of propagation of the action potential. Laws of action potentials conduction by nerve fibers.
3. ***Synaptic excitation transduction.** Classification of synapses. Electrical and chemical synapses. Mechanism of excitation transduction via chemical synapse. Exocytosis. General scheme and role of membrane proteins. Synaptic mediators. Properties, mechanism of action and inactivation. Fast and slow postsynaptic processes. The role of ionotropic and metabotropic receptors. Properties of excitatory and inhibitory postsynaptic potentials. Temporal and spatial summation of postsynaptic potentials. Presynaptic and postsynaptic inhibition.
4. **Muscle physiology.** Skeletal muscles. Muscle fiber. Sarcomere. Physiological properties and mechanism of skeletal muscle contraction. Slow and fast neuromotor units. Energy of muscle contraction. Work, strength and muscle fatigue. Structural features and electrophysiological properties of smooth muscle cells. Classification of smooth muscles. The mechanism of contraction and relaxation of smooth muscle. The mechanism of regulation of smooth muscle contraction involving Gq- and Gs-proteins.
5. **Sensory systems.** General description, role and mechanisms of transduction, transformation and transmission of sensory information in sensory systems. Sensory network. Classification of sensory systems and receptors. Visual sensory system. Optical system of the eye and its significance. Architecture of the receptor apparatus of the eye. Structure of retinal photoreceptors and mechanism of transduction. Architecture of receptor fields of retinal ganglion cells. Transformation of receptor potential into a sequence of action potentials. Auditory sensory system, components and functioning. Gustatory and olfactory sensory systems, components and functioning. Somatosensory system and pain sensing.
6. **Motor functions of the nervous system**. Spinal reflexes. Spinal shock and hyperreflexia. Decerebrate rigidity. Descending and ascending pathways of the spinal cord. Motor functions of the medulla oblongata and pons. The role of the substantia nigra and red nuclei of the midbrain legs in the regulation of skeletal muscle tone and phase contractions. Reflex arc and physiological significance of four-humped reflexes of the midbrain. Motor functions of the cerebellum. Disorders that occur due to removal or damage of the cerebellum. Motor functions of the basal ganglia of the cortex of the large hemispheres. Motor zones of the cortex of the large hemispheres. Cortical representation of muscles in the primary motor area. Premotor and secondary motor zones of the cortex of the large hemispheres.
7. **Functions of the autonomic nervous system. General characteristics of humoral regulation**. **Stress**. Peculiarities of the autonomic nervous system organization. Features of the vegetative reflex arc. Mediators of the autonomic nervous system and their mechanism of transduction. Comparative characteristics of the sympathetic and parasympathetic nervous systems. The role of the sympatho-adrenal system, cortisol and endogenous opiates. General characteristics of endocrine glands. Properties of hormones and their classification. Hypothalamic-pituitary connection.

8. **Blood system.** Composition, functions and physicochemical properties of blood. Structure and functions of erythrocytes. Hematopoiesis. Respiratory function of blood. Blood groups. System AB0 and Rh. General characteristics, classification and functions of leukocytes. Immunity. Nonspecific and specific mechanisms. Congenital and acquired. Allergy. Platelets. Vascular-platelet and coagulation hemostasis. The role of plasma coagulation factors. Fibrin clot retraction.
9. **Physiological properties of the heart**. Properties of the heart muscle. Automation of the heart. Regulation of heart activity. Frank-Starling's law. Electrical conduction system analysis. Propagation of excitement in the heart. Cardiac cycle. Electrocardiogram. Arterial pulse. Structure and types of vessels. Basic principles of hemodynamics. Pressure in different parts of the big circle of blood circulation. Blood pressure. Laminar and turbulent blood flow. Volumetric and linear blood flow rate. The rate of blood flow in different parts of the big circle of blood circulation. Nervous and humoral regulation of blood vessel tone.
10. **Physiology of respiration and excretion**. The main stages of respiration. Mechanism of inhalation and exhalation. The role of the respiratory muscles. Intrapleural pressure and elasticity of the lungs and their role in respiration. Surfactant. Lung volumes. The composition of inhaled, exhaled and alveolar air. Gas exchange in the lungs and tissues. Partial pressure and tension of gases. Blood gas transport. Nervous and humoral regulation of respiration. Respiratory center of the medulla oblongata. Kidneys: structure and blood supply of the nephron. Composition and properties of primary and secondary urine. The mechanism of formation of primary and secondary urine. Regulation of renal function.
11. **Physiology of digestion and absorption.** Secretion and secretory cells. Classifications of exocrine glands. Basal and stimulated secretion. The mechanism of fluid secretion. Digestion in the mouth. Regulation of salivary secretion. Swallowing. Digestion in the stomach and small intestine. Intestinal juice. Secretion and composition of pancreatic juice. Regulation of pancreatic activity. Liver. Gallbladder. Bile. Composition and functions of bile. Enterohepatic circulation of bile acids. Digestion in the colon. The role of symbiotic microorganisms. Mechanisms of absorption of nutrients, water and mineral salts in different parts of the gastrointestinal tract.
12. **Higher nervous activity**. Congenital and acquired forms of behavior. Memory formation. Forms of learning. Circadian rhythm and sleeping. Physiological fundaments of motivation and emotions. Neural fundaments of speech.
13. **Reproductive phase. Ageing.**

Biophysics (14h lectures, 8h seminars)

Shvadchak V., Muzalov I.

***** Highlighted lectures are part of the Introductory course

1. ***Structure of proteins.** Covalent, hydrogen, ionic bonds. Individual molecules and biopolymers. Diffusion and size of molecules. Primary, secondary, ternary structure of proteins. Disulfide bonds. Relationship between amino acid sequence and secondary structure. Structure prediction, MD.
2. ***DNA and RNA.** Complementarity. Helix. Hairpins. tRNA. Annealing. UV absorbance to monitor dsDNS-ssDNA transition. Atypical conformations. Viral and non-coding RNA. RNAzymes.
3. ***Membrane.** Lipid bilayer. Model membranes. Membrane phase. Structure and composition of cell membrane. Proteins and membranes. Membrane permeability. Membrane asymmetry. Transmembrane potential. Channels.
4. **Molecular machines and bioenergetics.** ATP-synthase. Bacterial flagella.
5. **Transport in cells.** Tubulin microtubules. Kinesin and dynein. Actin microfilamens and myosin.
6. **Thermodynamics.** Reversible and irreversible processes. Laws of Thermodynamics. Heat and reaction enthalpy. Entropy. ΔG. Nernst equation. Hess law. Equilibrium constants. Determining Kd and stoichiometry of protein interactions.
7. **Kinetics.** First-order reactions. Two-stage reactions. Reversible reaction rates and equilibrium constants. Second order reaction. Kinetics in complex systems. Basics of kinetic modelling. Modeling of epidemics development. Catalysis. Kinetics of fermentative reactions. Inhibition. Kinetics in studies of reaction mechanisms.

Molecular Biology (18h lectures, 8h seminars)

Lushchak V., Bayliak M., Luzhetskyy A.

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1. ***Flow of genetic information and principles of its regulation.** The basic dogma of molecular biology. The flow of genetic information in pro- and eukaryotes and basic principles of its regulation.
2. ***DNA biosynthesis – replication.** DNA replication – Initiation, elongation, termination. Formation of phosphodiester bonds. DNA replication in E. coli. Eukaryotic DNA replication. Replication at the ends of linear chromosomes.
3. ***DNA repair**. Terminology. Repair by excision in E. coli. Repair during replication. Reversible damage repair. SOS response.
4. **Transcription.** Initiation and elongation. Termination. RNA polymerase of pro- and eukaryotes, and archaebacteria. RNA processing. Ribozymes.
5. **Translation.** Activation of amino acids. Elongation of the polypeptide chain. Termination. Regulation of translation.
6. **Molecular basis of mutagenesis.** Types of mutations. Chemical modification. Radiation damage. Errors in DNA polymerase and repair systems. Double spiral stretching. Biological mutagenesis. Directed mutagenesis.
7. **Regulation of gene expression.** General principles. Repression and induction. Operons and regulons. Peculiarities of gene expression in pro- and eukaryotes. Positive and negative control. Lactose and tryptophane operons. Catabolite repression. DNA protection.
8. **Regulation of gene expression by reactive species in prokaryotes and eukaryotes.** Introduction to reactive species. Oxidative/reductive stress. Regulons of bacteria - OxyR and SoxRS. Yap1 yeast stimulon. Keap1/ Nrf2 system in animals.
9. **Regulation of gene expression in procaryotes.** General principles. Positive control. Negative control. Global regulation.

Instrumental methods (8h lectures, 8h seminars)

Shvadchak V.

1. **Fluorescence-based methods in biology.** Fluorescence principles. Fluorophores. Brightness. Solvatochromism. Protein labeling with organic dyes. Tryptophan fluorescence and other natural fluorophores. FRET and its application to study protein interactions. Fluorescence anisotropy.
2. **Methods to determine size of the molecules and low-resolution structural methods.** Electrophoresis of proteins and oligonucleotides. DLS. FCS. CD spectroscopy to determine protein structure. IR spectroscopy.
3. **High-resolution structural methods.** NMR. Spin. 13C and 15N protein labeling. NMR for protein structure analysis. Solid state NMR. ESR and free radicals. X-ray. Protein crystallization.
4. **Chromatography and mass-spectrometry.** HPLC principle, preparative and analytical applications. Types of columns. Ion exchange chromatography. Size-exclusion. Mass-spectrometry. LC-MS. ESI, MALDI and other ionization methods. Types of mass detectors. Fragmentation. LC-MS in proteomics.

Introduction to microscopy (8h lectures, no seminars)

Shvadchak V., Kovalchuk Yu. , Bondarenko N.

1. **Transmission and fluorescence microscopy.** Transmission microscopy, phase contrast. Fluorescence microscopy. Principal schemes of microscopes. Lasers. Filters. Dichroic mirrors. Channels. Digital image collection. Image resolution, microns and pixels. Confocal microscopy. Z-slices. TIRF. ImageJ (Fiji) software for image processing. Colocalization.
2. **Advanced fluorescence microscopy.** FRET and detection of interactions in microscopy. Fluorescence lifetime and FLIM. Diffraction limit. Superresulution, STORM. PALM. Application to image actin fibrils.
3. **Fluorophores.** Fluorescent proteins. Small molecule dyes. Channel crosstalk and selection of fluorophores. Membrane trackers, staining of nuclei. Photodegradation during measurements. FRAP. Light intensity and damage to cells. Caged molecules and controllable photorelease. Photoswithchable molecules.
4. **Atomic Force Microscopy. Electron microscopy.** Principle and scheme of microscopes. XY and Z resolution. Sample preparation. Scanning speed and sample damage. Application for protein unfolding. Principle. Resolution. Modes. Sample preparation.