BIOLOGY

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Предназначено для слушателей подготовительного отделения иностранных учащихся, обучающихся на английском языке.

INTRODUCTION

Biology is a system of Sciences studying living matter. The subjects it study are the origin and the development of life on Earth, the basic properties of living matter, the structure and vital processes of living organisms (bacteria, plants, fungi, animals and humans), transmission patterns of genetic information, structure and evolution of the biosphere, the problems of environmental protection.

At the preparatory Department, foreign students study the structure and vital processes of the human body (Anatomy and Physiology); the structure and vital processes of bacteria, protists and animals (Zoology); chemical composition, structure, functions, substance and energy exchange of cells (Cytology); heredity and variation (Genetics).

Insight into these aspects of biology is necessary for successful studying many disciplines of medical university. So, Cytology, Genetics, Ecology, Parasitology and Comparative anatomy are given in more detail in the medical universities.

The basic knowledge gained at the pre-University level is the basis for studying Anatomy, Physiology, Histology, General hygiene, Microbiology and other disciplines, which are indispensable for the insight into vital functions of healthy and sick people (preventive and clinical disciplines). Academician I. V. Davydovsky called biology «the theoretical basis of medicine». Consequently, the level of training of the applicant in biology is necessary not only for admission to the medical University, but also to further successful training.

Requirements for applicants during the entry exam:
– to possess the basic biological concepts, biological laws and theories;
– know and understand basic patterns that occur in nature;
– know the structure and vital processes of bacteria, protists, animals and humans;
– be able to find out a causal connections between the structure and functions of cell organelles, structures and functions of tissues, organ and organ systems.
– be able to solve problems on subjects: Chargaff’s rules, monohybrid, dihybrid crossing, genetic linkage and chromosomal crossing-over, sex linked inheritance, make and analyze pedigrees.
PROGRAM MATERIAL

Section 1. Cytology

Cell as a basic structural and functional unit of living things. Unicellular and multicellular organisms. Sizes and shapes of cells. The main statements of the cell theory.


Structure and functions of the cell membrane and cell envelope. Types of substance passing into the cell.

Main organelles of the cell (ER, ribosomes, Golgi complex, mitochondria, lysosomes, plastids, centrosomes), the peculiarities of their structure and function. Metabolism of the cell. Assimilation and dissimilation as two sides of metabolism. Autotrophic and heterotrophic, aerobic and anaerobic cells.


Meiosis and its characteristics. The concept of chromosomal conjugation and crossing-over, haploid and diploid chromosome complement. Changes of the genetic material content.

Section 2. Genetics

Genetics as a science. Basic concepts of genetics: gene, genotype, phenotype; allelic, dominant and recessive genes; homo- and heterozygotes; alternative characters. Structure and functions of nucleic acids (DNA and RNA). Functions of genes. Protein synthesis in the cell. The concept of transcription and translation.

The concept of monohybrid crosses. Law of hybrid uniformity and law of segregation, their cytological basis.

Dihybrid cross. Law of independent assortment, its cytological basis.


Genetics of sex. The concept of autosomes and heterochromosomes. Inheritance of sex-linked characters.


**Section 3. Human Anatomy**

Biology as a science. Basic properties of living things.

- Structure, growth and joint types of bones. The concept of bone tissue.

Muscular system. Structure and functions of striated and smooth muscle tissues. Neural regulation of muscle work.

- Internal environment of the body: interstitial fluid, lymph and blood; their composition and significance. The composition of blood. Circulatory system.
- Structural features of arteries, capillaries and veins. General and pulmonary circulations (main blood vessels).


- Digestive system. Structure and functions of the digestive system (oral cavity, pharynx, esophagus, stomach, intestine, digestive glands — liver and pancreas).


- Structure and functions of skin. Derivatives of skin.

- Structure and functions of the spinal cord. Structure of a neuron.

- Structure and functions of the brain. Structure and function of brain portions (medulla oblongata, cerebellum, midbrain, interbrain and endbrain). Cerebral cortex, its lobes and areas.


**Section 4. Zoology**


Characteristics of the phylum Arthropods. Peculiarities of the structure and vital activities.

Characteristics of the class Arachnida by the example of a garden spider. Significance of arachnids.

Characteristics of the class Insects. The significance of insects.

Characteristics of the phylum Chordates.

Features of the structure and vital activity of a lancelet.

Characteristics of the class Fishes. Features of the structure and vital activity of fishes, their significance.

Characteristics of the class Amphibians. Features of their structure, development and vital activity, their significance.

Characteristics of the class Reptiles. Features of their structure, development and vital activity, their significance.

Characteristics of the class Mammals. Features of their structure, development and vital activity, their significance. Concepts of Yinotheria (Prototheria), marsupial and placental mammals.

Section 1. CYTOLOGY

1. BIOLOGY AS A SCIENCE. BASIC PROPERTIES OF LIVING MATTER

Biology and its objects of study. Commonly, Biology is known as the science studying living matter. This word derives from Greek «βίος» — life and «λόγος» — science. According to the definition made by American scientist John Bernal, life is functioning of proteins and nucleic acids. Biology has various objects of study: bacteria, protists, plants, fungi, animals and human.

Properties and characters of living matter. All the nature consists of inanimate objects (such as water or stone) and living organisms. Living organisms have properties that differ them from inanimate objects.

These essential properties of living matter are:
1. Self-regulation — the ability of organisms to adjust their vital activity to changes of the environment.
2. Self-renewal — the ability of organisms to restore injured, lost or worn out structural and functional elements.
3. Self-reproduction — the ability of organisms to create new individuals of their kind.

These properties determine the characters (signs) of living matter:
1. Exchange of substances and energy between the environment and the organism is the main condition of life. Part of energy dissipates in any chemical reaction occurring in the cell, so maintaining normal metabolism (all reactions in the body) requires inflow of new energy. Living organisms feed, drink and breathe to receive substances they need from the environment and remove metabolic wastes they produce.
2. Reproduction is creation of new individuals of a species by already existing ones. Living organisms age and die. New young organisms replace them.
3. Heredity is associated with reproduction. Due to heredity parental traits are transmitted to new generations. Heredity is also defined as similarity of children and parents.
4. Variability is getting new traits by individuals. That can adapt them to changes of environmental conditions. Hereditary variability is defined as unlikeness or difference of children and parents.
5. Growth is increasing the size, mass and volume of an organism during individual development of the organism.
6. Ontogenesis is individual development of an individual that starts from being a zygote and ends with death of the organism. In reproduction each organism receives genetic information from parents. This information is realized during ontogenesis.
7. Phylogenesis is historical development of species or evolution of the specie.
8. Irritability is capability of the body (or organs, cells) to respond to actions of the environment. For example, constriction of the pupil is the response of the
human eye to bright light. Such response of organisms that have a nervous system is reflex while the response of unicellular organisms (that consist of one cell) is taxis.

9. Homeostasis is capability of the body to maintain the constancy of its internal environment (constant concentration of solutes in the blood, pH and etc.).

10. Integrity means that the organism is functionally indivisible and should be considered as a single unit.

11. Discretion but is composed of various parts and can be considered as many structural and functional unit.

All living organisms consist of cells, i.e. cells are structural, functional and genetic units of living matter. Cells of all organisms have a similar structure. They are made of an envelope, nucleus and cytoplasm (which includes hyaloplasm, organelles and inclusions). Shapes, sizes and functions of various cells are different.

Organization levels of living matter:
1. Molecular-genetic level. The elementary unit of this level is a gene.
2. Cellular level. Its elementary unit the cell which is a structural and functional and genetic unit of living matter. All vital processes take place there. Any cell contains genetic information determining the development of the whole organism.
3. Tissue level. A group of cells that have identical structure and perform identical functions form a tissue.
4. Organism level. The organism is an elementary unit of life. This level is characterized by processes of ontogenesis (individual development), its nervous and humoral control.
5. Population-specious level. A group of individuals of one species, occupying a definite territory for a long time, freely crossing and relatively isolated from other groups of individuals of the same species, form a population. The population is an elementary unit of evolution.
6. Biospheric-biogeocenotic level. Biogeocenosis includes all populations of different species living on definite residential territory and are historically related with each other. There is a constant exchange of substances, energy and information between populations and the environment. All biocenosis compose the biosphere — an area of the planet occupied by living organisms.

2. A CELL AS A UNIT OF LIVING MATTER. CHEMICAL COMPOSITION OF CELLS

Cytology (Greek κύτος — cell, λόγος — science) is defined as a science studying the structure, chemical composition and functions of cells, their reproduction, development and interaction in a multicellular organism.

The first view of cells was done due to invention of a microscope. The cell was first described by English physicist and microscopist Robert Hooke in 1665. He examined thin slices of cork with the microscope (fig. 1) and found there boxy partitions that resembled the cells in a monastery.
In 1831, Robert Brown discovered the nucleus in plant cell. In 1838, Matthias Schleiden proposed that any structural element of plants is composed of cells or the cells products. In 1839, Theodor Schwann, proposed the same for animals.

**These discoveries formed the basis of the Cell Theory:**

1. The cell is an elementary structural, functional and genetic unit of all living organisms. It is an open self-regulating system, through which flows of substances, energy and information pass.

2. All cells have similar structure, chemical composition and processes of vital activity.

3. Cells of a multicellular organism differentiate and form tissues to perform various functions.

4. «Omnis cellula e cellula» — new cells form due to the division of mother cells — the phrase of Rudolf Virchow that completed this theory in 1858.

All living organisms are composed of cells, and all cells arise from other cells. Cell is a structural, functional and genetic unit of living things.

Some species includes unicellular organisms which consist of only one cell (amoeba, infusoria). Their cell performs functions of entire organism. Other organisms consist of the great number of cells and thus are multicellular.

Cell sizes varies from several micrometers to 100 micrometers. There are some giant cells such as eggs of birds. Shape of the cell depends on its function: a nerve cell (neuron) have long processes to conduct nerve impulse, muscle cell is elongated because it changes the length during contraction.

**Substances of the cell.** All cells contains various organic and inorganic substances with different chemical elements. Elements that are in large amounts in the cell are macroelements (oxygen, carbon, hydrogen, nitrogen, phosphorus, sulfur, sodium, potassium, magnesium, calcium, chlorine) and vice versa, in small amounts — microelements (copper, iodine, zinc, cobalt, fluorine etc.).

**Inorganic substances** of the cell are water and minerals. Water (H₂O) is vital for all living organisms, and it is no exaggeration to say that life could not exist without it. Amount of water vary in living organisms from 60 to 95 % and depend on type of the cell (10 % — teeth, 20 % — bone, 70 % — nerve tissue, 90 % — embryo).

**Importance of water:**

1. All biochemical reactions take place in water.
2. Polar molecules of water dissolve ions (such as sodium) and another polar molecules (such as sugars) while large non-polar molecules (such as fats) cannot be dissolved.

3. Forms shells around the macromolecules and inhibits their agglutination.
4. Provides transport of substances in the cell.
5. Participates in many chemical reactions.

Minerals in the cells contained in the form of positive-charged cations \( (K^+, Na^+, Ca^{2+}, Mg^{2+}, NH_4^+) \) and negative-charged anions \( (Cl^-, H_2PO_4^{2-}, HCO_3^-, SO_4^{2-}) \). Minerals are important for proper fluid balance, muscle contraction, conduction of nerve impulses, and building bones and teeth (tabl. 1).

<table>
<thead>
<tr>
<th>Mineral</th>
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<tbody>
<tr>
<td>Calcium</td>
<td>Bone strength, blood clotting</td>
<td>Potassium</td>
<td>Water balance, muscle functioning</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Formation of HCl in the stomach</td>
<td>Sodium</td>
<td>Water balance, nerve function</td>
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<td>Magnesium</td>
<td>Component of many enzymes</td>
<td>Sulfur</td>
<td>Components of many proteins</td>
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<tr>
<td>Phosphorus</td>
<td>Bone and tooth formation</td>
<td>Iron</td>
<td>Gas exchange</td>
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**Table 1**

**Organic substances** of the cell are proteins, carbohydrates, lipids, nucleic acids, ATP, hormones, vitamins.

**Proteins** are linear chains of amino acids connected to one another with peptide bonds.

Such substance that is made of many structural elements is called a bio-polymer while these elements are monomers. Proteins have a complex structure and high molecular weight. The sequence of amino acids in the protein is determined by the sequence of nucleotides in the DNA (deoxyribonucleic acid) of the gene that codes for that protein.

Proteins are tangled chains of amino acids. **There are four levels of protein structure:**
- Primary — a linear sequence of amino acids linked to one another with peptide bonds (fig. 2, a);
- Secondary — due to formation of hydrogen bonds between amino acids, the linear chain is spiralized (\( \alpha \)-helix) or forms wrinkled loops (\( \beta \)-sheet) (fig. 2, b);
- Tertiary — the three-dimensional structure of a single polypeptide chain maintained by disulfide, ionic, hydrogen bonds and hydrophobic-hydrophilic interactions (fig. 2, c);
- Quaternary — two or more polypeptides bind to each other via ionic, hydrogen bonds and hydrophobic-hydrophilic interactions (fig. 2, d).

**Functions of proteins:**
1. Structural. Proteins are structural parts of the membranes and cell organelles. Cartilages, tendons, hairs, nails consist of keratin and collagen.
3. Catalytic. All enzymes catalyzing biochemical reactions are proteins.
5. Motor, or contractile. Myosin and actin are involved in muscle contraction.
6. Energetic. Proteins can be a source of energy.

**Fig. 2.** Protein structure

**Carbohydrates** consist of carbon, hydrogen, and oxygen. They are products of photosynthesis. Simple sugars are also called monosaccharides. They have various number of carbon atoms. Sugars with five carbon atoms are pentoses, with six — hexoses. Pentoses (ribose and deoxyribose) are part of nucleic acids (DNA, RNA) and ATP. Hexoses (glucose, fructose) are contained in the cells of plant fruits, blood of animals and etc. Monosaccharides are well soluble in water and have a sweet taste. Disaccharides are sugars composed of two monosaccharides. They are maltose (malt sugar), lactose (milk sugar) and sucrose (cane sugar). Polysaccharides are composed of a large number of simple sugars. Polysaccharides are water-insoluble. Examples of polysaccharides are starch, glycogen (animal starch), cellulose, and chitin. Starch and glycogen are similar energy-storage molecules found in plants and animals, respectively.

**Functions of carbohydrates:**
1. Energetic. Carbohydrates is a basic source of energy in the cells.
2. Structural. They are parts of cell membranes and another structures.
3. Storage of energy (starch, glycogen).

**Lipids** are organic water-insoluble compounds. Their most known group is fats which are esters of alcohol glycerol and fatty acids. Some fatty acids have double bonds (C = C) in their molecules and are called unsaturated. Fatty acids that have no double bonds (C–C) are saturated. Animal fats (butter) contain residues of saturated fatty acids, so they are solid. Lipids of vegetable oils (olive oil) contain residues of unsaturated fatty acids, so they are liquid. Lipids may form complex chemical compounds with proteins (lipoproteins), carbohydrates (glycolipids) and phosphoric acid residues (phospholipids).

**Functions of lipids:**
1. Structural. Lipids are basic elements of biological membranes.
2. Energetic. Lipids are the source of energy in the cell.
3. Thermoregulatory. They retain heat and help to maintain constant body temperature.
4. Storage function (subcutaneous fat).

### 3. Cell Wall. Delivery of Substances Into the Cell

**Basic cell parts are an envelope, cytoplasm and nucleus.** Cytoplasm consists of organelles and colloidal solution of proteins and other chemicals (fig. 3).

![Cell structure](image)

*Fig. 3. Cell structure*

All cells are covered with a cell envelope. Its basic part is plasma membrane (plasmalemma) with 7–10 nm thickness. The membrane is composed of lipids and proteins. Lipids are basic components of the membrane, they compose 20–80 % of its mass. Most common of them are phospholipids, lecithin and cho-
lesterol. Such lipid molecule has two ends: the hydrophilic one (water-soluble) and the hydrophobic (water-insoluble). Hydrophobic ends of lipids are directed towards each other (inside the membrane), hydrophilic ones — to the outside.

Plasma membrane (fig. 4) contains proteins which are embedded in the «lipid sea». There are 3 types of membrane proteins according to their position in the lipid bilayer. Those molecules which penetrate both layers of lipids are called integral. Those which are immersed into one layer are semi-integral. Proteins laying on the surface of lipids are peripheral ones.

The third component of an plasma membrane is glycocalyx which is a receptor apparatus. It is formed by glycoproteins (carbohydrates + proteins) and glycolipids (carbohydrates + lipids) on the surface of the cell. These receptors recognize certain chemicals. The membrane of plant cells is covered with cell wall that is made of cellulose.

Properties of the plasma membrane:
- plasticity — the membrane stretches and constricts in cellular movements;
- self-locking — the membrane is able to restore immediately after impairment; this property is necessary to form vesicles and vacuoles;
- semi-permeability — the membrane selectively passes molecules.

Functions of the plasma membrane:
- structural — membranes are structural parts of most of cell organelles (except for ribosomes and centrosomes);
- barrier — separating the inside of the cell from environment and protection from external factors;
- transport — cell receives essential substance through the membrane;
- receptor — glycocalyx receives signals and recognizes substances;
- metabolic — there are membrane-bound enzymes;
- division of cell cytoplasm into sections.

The membrane regulates the exchange of substances between the cell and the environment. There are 2 types of transport of substances: active and passive. Active transport follows against the concentration gradient and thus requires energy. In case of passive transport substances go down the concentration gradient and this does not require energy.

Passive transport occurs by diffusion. Diffusion is the movement of solute molecules through the membrane. It can be simple if molecules pass the mem-
brane directly or facilitated if transport proteins participate in it. Diffusion of through the membrane is osmosis. Small molecules can pass into the cell by filtration, diffusion, through pores or by solution in lipids.

**Active transport** requires ATP molecules and special transport proteins. An example of such transport is sodium-potassium pump. The concentration of potassium in the cell is higher than on the outside. Potassium ions enter the cell while sodium ions are removed from cell.

**Endocytosis** is participation of the membrane in catching particles or molecules and transporting them into the cell. It is possible due to modifying architectonics (outlines) of the membrane in order to surround and «swallow» a particle. Endocytosis of hard particles is called phagocytosis while transport of fluids is pinocytosis. Examples of phagocytosis and pinocytosis are leukocytes engulfing bacteria, nutrition of amoeba.

**Exocytosis** excretion of substances from the cell that goes in the same mechanism as endocytosis. Elimination of undigested food remains from the amoeba is an example of such transport.

4. **Cell organelles. Cell metabolism**

**Organelles** are differentiated areas of the cytoplasm that have constant structure and perform specific functions. There are organelles of general and special purpose. Organelles of general purpose are observed in almost all cells of plants and animals. They are of two types: membrane-enclosed (also known as membrane-bound) organelles and non-membrane-bound ones. Membrane-bound organelles are covered with membrane (endoplasmic reticulum, Golgi apparatus, mitochondria, lysosomes, plastids). Non-membrane-bound organelles have no membranes (ribosomes and centrosomes).

Organelles of special purpose are only in specialized cells. Examples are myofibrils of muscle cells or cilia, flagella, pseudopodia of protists.

Cells have anabolic and catabolic systems. The **anabolic system** performs synthesis of complex chemical compounds (assimilation). Organelles of this system are endoplasmic reticulum, Golgi complex, ribosomes. Organelles of the **catabolic system** which carries splitting processes (dissimilation) are lysosomes and mitochondria.

**Endoplasmic reticulum (ER)** is composed (fig. 5) of channels located throughout the whole cell and connected with a perinuclear space and the cavities of a Golgi complex. The wall of the channels consists of plasma membrane. There are rough endoplasmic reticulum with ribosomes its surface and smooth ER without ribosomes. Rough one participates in biosynthesis of proteins that are later transported into the Golgi complex. Carbohydrates (glycogen) and lipids (cholesterol) are synthesized on membranes of a smooth ER. It also participates in synthesis of steroid hormones, excretion of chlorine ions (epithelial cells of the stomach) and detoxifying harmful substances (hepatic cells). ER
channels divide the cell cytoplasm into sections where various biochemical reactions take place. This function of the ER is called compartmentalization.

The functions of the endoplasmic reticulum:
2. Transport of substances.
3. Connection of all cell organelles and the nucleus and cytoplasm.

Golgi complex (Golgi body) is composed of vesicles, tubes, sacs. Its basic elements are dictyosomes (fig. 6). Dictyosomes are piles of 10–15 plasma membranes that dilatations at ends. These dilatations form vesicles that separate and transform into lysosomes and vacuoles. Some of them excrete secretions from the cell.

 Functions of the Golgi complex:
1. Formation of complex compounds such as lipoproteins, glycoproteins;
2. Sorting out and packing substances synthesized in ER into vesicles;
3. Secretion of substances;
4. Formation of plasma membrane;
5. Formation of lysosomes, glyoxysomes and vacuoles.

Ribosomes are spherical bodies. They may stay freely in the cytoplasm, on the external nuclear membrane, on ER channels. Ribosomes are composed of two subunits: (the small and large ones). Subunits are made of ribonucleic acid (RNA) and protein (fig. 7). Function of ribosomes is arranging protein molecules.

Lysosomes are organelles performing catabolic reactions. There are primary and secondary chromosomes (fig. 8). Primary ones are formed in Golgi
complex. They look like spherical bodies covered with plasma membrane and contain 30–40 various hydrolytic enzymes. Secondary lysosomes are primary lysosome which are fused with phagosome. Breaking down of substances takes place here. Lysosomes are able to digest particles and parts of injured or worn out organelles.

**Mitochondria** have shape of rods, filaments and granules. Their number is different in cells with different activity. Size of the mitochondrion is from 0.5 to 7 micrometers. There are ribosomes, various RNA and circular molecules of DNA in its internal matrix (fig. 9). A wall of the mitochondrion consists of internal and external membranes. Folds of the internal membrane form cristae enclosing the internal matrix. The space between mitochondrion’s membranes is filled with the external matrix. Mitochondria have 3 main enzyme systems: enzymes of Krebs cycle (also known as citric acid cycle) in the internal matrix, enzymes of tissue respiration on the internal membrane and in the external matrix, enzymes of oxidative phosphorylation in ATP-somes (on cristae). Mitochondria have an autonomous system for protein biosynthesis. **Function of mitochondria** is ATP synthesis.

Plant cells contain plastids. The most important are **chloroplasts**. Each chloroplast has an outer membrane, an inner membrane, a liquid material called the stroma (fig. 10), and a network of flattened membranes called thylakoids that stack on one another to form structures called grana. Chloroplasts contain the green pigment chlorophyll to perform photosynthesis. Photosynthesis is usage of the sun’s energy to convert carbon dioxide and water into sugars.

**Functions of chloroplasts:**
2. Release of free oxygen.

**Centrioles** are barrel-shaped rings composed of nine microtubule triplets (fig. 11). Microtubules help to move chromosomes during cell division. Before that they are doubled and diverge to the cell’s poles. Centrioles are present only in animal cells. Function of centrioles is formation of microtubules during cell division and the formation of flagella and cilia.
Metabolism (exchange of substances and energy) is the main property of the living. Metabolism takes place in all cells of the body. Metabolism consists of assimilation and dissimilation.

Assimilation is a sum of all reactions during which complex organic compounds are made from simple substances. For example: photosynthesis, synthesis of proteins, fats. These reactions require energy. This energy is obtained during the reactions of dissimilation.

Dissimilation is a sum of all reactions during which complex organic compounds are split into simple substances and release energy. This energy is used for the reactions of assimilation.

According to the type of assimilation, organisms are autotrophs and heterotrophs. Autotrophic organisms form complex organic compounds such as $C_6H_{12}O_6$ during photosynthesis from simple substances such as $CO_2$ and $H_2O$. This group includes plants and some protists. Heterotrophs feed on ready-made organic substances. They are animals, fungi and some protists. Assimilation and dissimilation are closely related. Synthesis reaction cannot proceed without energy, and energy is released only in the splitting of organic compounds. Energy is also needed for active transport of substances through the membrane for cell division and movement. The energy in the cells is stored in ATP molecules.

According to the type of dissimilation all organisms are anaerobic or aerobic. Cells of aerobic organisms require $O_2$ for splitting of organic substances. Anaerobic organisms split organic compounds without oxygen.

5. THE STRUCTURE OF NUCLEUS AND CHROMOSOMES

A nucleus (Latin — nucleus; Greek κάρυον — karyon) is the cell structure that contains basic genetic information. It was first described in 1831 by R. Brown. The cell can have one or several nucleus though some cells such as human erythrocytes don’t have nuclei. The shape of the nucleus depends on the shape and functions of the cell (fig. 12).
Any cell nucleus consists of the nuclear envelope (karyolemma), nuclear matrix (karyoplasm), the nucleolus (one or several) and chromatin.

The membrane of an interphase nucleus (karyolemma) is double: it consists of an external and internal membranes. A space between them is called perinuclear space. The membranes are perforated with pores. When the cell is active, the majority of pores are open. Substances flow through them to the nucleus and back to the cytoplasm. The external membrane is linked with canals of endoplasmic reticulum and carries ribosomes.

Karyolymph of the nucleus is a colloid jelly-like solution which contains proteins, lipids, carbohydrates, RNA, nucleotides and other substances.

Nucleolus is a temporary structure of the nucleus. It is composed of proteins and RNA. Its function is assembling ribosome subunits. Nucleoli disappear when the cell begin division and restores when the division is finished.

The nucleus stores chromatin which is chromosomes of the interphase. Chromatin consists of DNA and proteins. It located in the nucleus in the form of little bodies or thin filaments. DNA together with protein form desoxyribonucleoprotein (DNP). During cell division, the chromosomes are formed from chromatin.

**Functions of the nucleus:**
1. Stores hereditary information of the cell;
2. Takes part in the cell division;
3. Regulates metabolic processes in the cell.

Chromosomes (Greek — χρώμα — color, σώμα — body) are tightly packed chromatin. A metaphase chromosome consists of 2 chromatids linked with a centromere (primary constriction). Each chromatid includes one DNA molecule together with proteins-histones. Centromere divides the chromosome into 2 arms. Some chromosomes have also secondary constrictions on the arm that separates a satellite. Such chromosomes are called satellite chromosomes. Terminal segments of chromosomes are telomeres, they prevent adhesion of chromosomes.

**Types of chromosomes according to the position of centromere** (fig. 13):
1. Metacentric — the centromere is in the middle; the length of arms is same.
2. Submetacentric — the centromere is near the center, the arms have different length.
3. Acrocentric — the centromere is far from the center, one arm is very short, and the other is very long.
Karyotype is the set of chromosomes of the cell. Each species have specific number of chromosomes i.e. specific karyotype.

**There are 4 rules of chromosomes of all organisms:**

1. The rule of a constant number. All species have constant number of chromosomes. (46 in human, 78 in dogs, 8 in Drosophila).
   
   2. The rule of pairing. Every chromosome in a diploid set has a pair — other chromosome of identical shape and size.

3. The rule of individuality. Chromosomes of different pairs have different shape, structure and size.

4. The rule of continuity. New chromosomes are made as result of copying of other chromosomes.

Function of chromosomes: storing, reproduction and transmission of genetic information, during reproduction of cells and organisms.

6. CELL PROLIFERATION. MITOSIS

Reproduction is the ability of organisms to create new individuals of their kind. It is essential property of living matter. All cells of the organism (except for sex cells) are called somatic cells. They divide by mitosis. Due to the pairing of chromosomes, somatic cells have a double chromosome set. Such set is called diploid and is denoted as $2n$.

The content of genetic material in the cell is denoted with $n$ — the number of haploid chromosome sets, $chr$ — the number of chromatids in each chromosome.

Period between two mitosis of the cell is called **interphase**. It includes three periods:

1. Pre-synthetic period (also known as post-mitotic or $G_1$). The con-
tent of genetic material is 2n lchr. During this period, the cell grows, performs its functions, accumulates ATP, synthesize RNA, proteins, DNA nucleotides. The period lasts 12 hours but sometimes may take several months (fig. 14).

2. Synthetic period (S). The content of genetic material becomes 2n 2chr. During this period replication of DNA molecules occurs and each chromatid is copied. Centrioles duplicate. RNA, ATP and proteins-histones are synthesized. The cell continues performing its functions. The duration of the period is up to 8 hours.

3. Post-synthetic (pre-mitotic, $G_2$). The content of genetic material is 2n2chr. Cell accumulates energy (ATP) and synthesize RNA, nuclear proteins and proteins tubulines. Tubulines are proteins that form the division spindle. By the end of the period all synthetic processes become slower, the cytoplasm viscosity changes.

The main cause of mitosis is changing of the nuclear-cytoplasmic ratio (1/6–1/8 – 1/69–1/89).

**Mitosis** is the basic method of cell reproduction. Mitosis has four stages: a prophase, metaphase, anaphase and telophase (fig. 15).

![Prophase](image1) ![Metaphase](image2) ![Anaphase](image3) ![Telophase](image4)

*Fig. 15. State of mitosis*

1. **Prophase.** The content of genetic material is 2n2chr. It starts with spiralization of chromatin. Long filaments of chromatin shorten and thicken to transform into chromosomes. Centrioles diverge to cell poles and threads of the division spindle are formed. The volume of the nucleus increase and nucleoli and nuclear envelope dissolve.

2. **Metaphase.** Chromosomes are at the equator of the cell. The content of genetic material is 2n2chr. They form a metapase plate. Threads of the division spindle attach to centromeres of chromosomes.

3. **Anaphase.** Threads of the division spindle constrict. The content of genetic material at each pole is 2n1chr. In the region of centromeres, chromosomes separate into two chromatids. These chromatids are now called daughter chromosomes.

4. **Telophase.** The content of genetic material of each new cell is 2n1chr. Chromosomes despiralize and lose their clear outlines. Nucleoli restores and nuclear envelope is formed. The final stage of mitosis is division of the cytoplasm between daughter cells (cytokinesis). Vesicles of the endoplasmic reticulum form the cell membrane. Two cells are formed.
The significance of mitosis:
Such division sustains the constancy of the chromosome number, provides genetic succession in cell populations. Mitosis provides equal distribution of chromosomes and genetic information between daughter cells.

7. MEIOSIS

Meiosis is the cell reproduction that consists of two specialized cell divisions. Unlike mitosis, meiosis produces 4 haploid cells. In all animals, specialized cells in the reproductive organs undergo meiosis to produce haploid gametes (sperm and egg), which then fuse during sexual reproduction to create new diploid zygote. For example, human gametes are haploid and contain twenty-three different chromosomes. All other cells in the human body are diploid and contain forty-six chromosomes: two versions of each chromosome. Fusion of gametes restores the diploid chromosome set normal for the organism, and it mixes maternal and paternal genes to give new random combinations of traits.

Meiosis consists of two divisions — meiosis I and meiosis II. As a result of meiosis I chromosome number is halved. Therefore, the first meiotic division is called reductional. In meiosis II haploid cells is preserved, and this division is called the equational division. Each division has four phases: prophase I, prophase II, metaphase I, metaphase II, anaphase I, anaphase II, telophase I, and telophase II (fig. 16).

Meiosis I:
1. Prophase of meiosis I is complicated. There are processes of conjugation and crossing over. Conjugation is a connection of homologous chromosomes throughout their length. Crossing over is exchange of identical segments of homologous chromosomes. Conjugation and crossing over results in recombination of genes in the chromosomes. Complexes of homologous chromosomes formed after conjugation are bivalents. The content of the genetic material 1n(biv)4chr: 1n(biv) — haploid set of bivalents, 4chr — each bivalent contains four chromatids.
2. **Metaphase** of meiosis I: bivalents are located along the equator of the cell; chromosomes are clearly seen; genetic material — $ln_{biv}4chr$.

3. **Anaphase** of meiosis I: bivalents separate into homologous chromosomes. Filaments of the division spindle constrict and pull chromosomes (but not chromatids!) to cell poles. Each chromosome still contains 2 chromatids. The content of genetic material at each cell pole is $ln2chr$. During this phase the reduction (decrease) of the number of chromosomes occurs — a diploid complement of chromosomes becomes a haploid one.

4. **Telophase** of meiosis I: cytokinesis takes place, and two-daughter haploid cells with content of genetic material $ln2chr$ are formed; unlike mitosis in this phase, despiralization of chromosomes does not occur.

Thus, overall, the first division of meiosis provides two major mechanisms for new genetic combinations:
- cutting apart and pasting together various segments of homologous chromosomes to build unique hybrid chromosomes;
- independent assortment of maternal and paternal chromosomes.

After meiosis I comes **interkinesis** — a short interval between two divisions. DNA replication does not occur. Interkinesis is followed by meiosis II.

**Meiosis II is similar to mitosis:**
1. **Prophase** of meiosis II. Spiralization of chromosomes does not occur (it is already done in meiosis 1). Chromosome set is $ln2chr$.
2. **Metaphase** of meiosis II. Chromosomes are on the equator of the cell. Chromosome set doesn’t change ($ln2chr$).
3. **Anaphase** of meiosis II. Chromatids (but not chromosomes!) diverge to cell poles. Chromosome set at each cell pole is $ln1chr$.
4. **Telophase** of meiosis II is similar to that of mitosis. Each daughter cell gets a complement of genetic information $ln1chr$.

The result of meiosis is formation of 4 haploid cells (gametes) from one diploid mother cell.

**The significance of meiosis:**
- it is a mechanism of gamete formation;
- it sustains the constancy of the number of chromosomes;
- provides combinative variation.

**Differences between mitosis and meiosis:**
- mitosis takes place in somatic cells, meiosis takes place only in the cells of gonads;
- meiosis consists of two divisions; between divisions DNA synthesis does not occur;
- in the prophase of meiosis I occur conjugation and crossing over;
- a diploid mother cell which divided by meiosis form 4 haploid cells; by mitosis — 2 diploid cells.
Section 2. GENETICS

1. GENETICS AS A SCIENCE. STRUCTURE AND FUNCTIONS OF NUCLEIC ACIDS.

SYNTHESIS OF PROTEINS IN CELLS

Genetics is the biological discipline studying heredity and variation. Heredity is the passing parental traits to their offspring (from parents to children). It makes an organism or cell to acquire characteristics of its parent. Variations exhibited in individuals through heredity and cause species to evolve.

Variation in alleles of genes — genetic variation — occurs both within and among populations. Genetic variation is important because it provides the genetic material for natural selection. Genetic variation is brought about by mutation, which is a permanent change in the chemical structure of a gene — a segment of DNA that code for a protein and is responsible for one or several traits.

Genetics studies the molecular structure and functions of genes, gene behavior in context of a cell or organism, patterns of inheritance from parent to offspring, and gene distribution, variation and change in populations. Given that genes are universal to living organisms, genetics can be applied to the study of all living systems, from viruses and bacteria, through plants and domestic animals, to humans (as in medical genetics).

Nucleic acids are DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). These acids were first described 1870 by Friderich Misher as macromolecules in nucleus. He named them nucleic acids.

The structure of a DNA molecule was decoded in 1953 by James Watson, Francis Krik and Maurice Wilkinson.

The nucleic acids are biopolymers. Their monomers are nucleotides. A nucleotide consists of 3 parts: a nitrogenous base, 5-carbon sugar (or pentose) and residue of the phosphoric acid (phosphate). Nitrogenous bases are of types: adenine (A), guanine (G), cytosine (C), thymine (T), uracyl (U). Adenine and guanine are purine bases while cytosine, thymine and uracyl are pyrimidine ones. Five-carbon sugars are deoxyribose (in DNA) and ribose (in RNA). The DNA molecule consists of two strands which are coiled in a double helix. Each strand is a polymer of nucleotides. A DNA nucleotide always contains one of four nitrogenous bases (adenine, guanine, cytosine or thymine), deoxyribose and a residue of the phosphoric acid (fig. 17).

The nucleotides are linked by phosphodiester bonds between deoxyribose of one nucleotide and the phosphoric acid residue of the other one.

Opposite nitrogenous bases of two strands are bound according to the principle of complementarity: adenine is bound to thymine with two hydrogen bonds; guanine to cytosine with 3 hydrogen bonds (A=T, G≡C).

The complementarity property of nitrogenous bases is expressed in Chargaf’s rules:

1. In a DNA molecule, the number of purine bases is always equal to the number of pyrimidine bases: A + G = C + T;
2. In a DNA molecule, the amount of adenine is equal to the amount of thymine (A = T), the amount of guanine is equal to the amount of cytosine (G = C).

Apart from the nucleus, DNA is found in mitochondria and plastids. Properties of DNA are replication (self-reproduction) and repair (restoration of the structure after impairment of the molecule).

**Replication** occurs in the synthetic period of interphase. DNA polymerase is the enzyme that play main role in this process. The segment of DNA where replication occurs is called the replication fork. Enzymes break the hydrogen bonds between the nitrogenous bases of the two strands, uncoil and separate them. On both strands, DNA polymerases assemble new strands of DNA according to the principle of complementarity. The new chain of DNA molecule repeats the old location of nucleotides (maternal). Two new DNA molecules are formed. After replication, each DNA molecule contains one maternal chain and the second newly synthesized daughter chain. This principle is called semi-conservative synthesis.

DNA functions are storing and transmitting genetic information during multiplication of cells and organisms.

The RNA molecule is a polynucleotide consisting of one sequence. In comparison with a DNA, it includes uracil instead of thymine and sugar ribose instead of deoxyribose. In some viruses, RNA has two strands.

**The cell has 3 types of RNA.** They are in the nucleus, cytoplasm, mitochondria and plastids. 3–4 % of the whole RNA compose the messenger RNA (mRNA). It «records» the genetic information from DNA and transmit it into ribosomes where protein molecules are assembled. The ribosomal RNA (rRNA) com-
poses 80–85 % of the whole RNA. It is included into ribosomes and provides es-

special spatial relations between mRNA and rRNA. The transport RNA (tRNA) com-

prises 10–20 % of the whole RNA (fig. 18). It transports amino acids from the cytoplas
m to ribosomes.

**Genetic code.** The unit of heredity and variation is a gene. The gene is a section of the DNA mole-
cule that carries the information about the structure of the polypeptide (protein).

Recording of genetic information as a nucleotide sequence in DNA and mRNA is genetic code. Each nucleotide triplet codes for a definite amino acid. Such coding triplet is called a codon and is an elementary functional unit of the gene.

**Properties of the genetic code:**

– **tripletness** — one amino-acid is coded by three nucleotides which form a codon (triplet);
– **universality** — definite codon code for same amino acid in all organisms;
– **no overlapping** — one nucleotide is included only in one triplet and cannot be read in both adjacent codons;
– **degeneration, or redundancy** — one amino acid can be coded by several triplets (there are 20 amino acids, by 64 possible triplets);
– **continuity** — there are no disjunctive symbols between codons;
– **single direction** (mRNA synthesis occurs in the direction from 5’ end to the 3’ end);
– **presence of codons-terminators** (they determine the end of protein biosynthesis).
– **co-linearity** — nucleotide sequence in nucleic acids corresponds to amino acid sequence in proteins

Protein biosynthesis is an enzymic process, where nucleic acids play the main role. First of all, on one of DNA sequences (coding one), mRNA is synthesized according to the complementarity principle. RNA-polymerase repeats the order of nucleotides of the DNA molecule. This process of re-writing is called **transcription.** The mRNA leaves the nucleus through pores and enters the cytoplasm. It goes to ribosomes.

**The process of translation** takes place in ribosomes which attach to the mRNA (fig. 19) and has 3 steps. The complex of ribosomes, united by one mRNA, is called a polysome. A nucleotide sequence of mRNA is read by the ribosome: the order of its codons determines the order of amino acids in the polypeptide. The beginning of translation is initiation (small subunit connects to

![Fig. 19. Protein synthesis in the ribo-](image-url)
mRNA, first tRNA with amino acid attaches to the first codon and large subunit comes), the end of translation is termination (ribosome dissociates). A ribosome has two sites (aminoacyl and peptidyl or A and P) where two mRNA codons are placed simultaneously. The formation of peptide bonds between amino acids is elongation. The transport RNA (tRNA) has a specific structure: one end of the molecule contains a nucleotide triplet which is called an anti-codon and corresponds to a definite amino acid. A definite amino acid joins proper tRNA due to enzyme amino-acyl-tRNA-synthetase and ATP. The amino acid with its t-RNA forms a complex: amino-acyl-tRNA. Recognition (recognizing of its own amino acid by tRNA) occurs in the cytoplasm.

**Elongation** is performed by ribosomes. An amino-acyl-tRNA comes to the A-site and if its anticodon matches to the mRNA codon then amino-acyl-tRNA forms a temporary bond with an mRNA codon. A peptide bond sets between the first and second amino acids, the ribosome moves by one triplet, and the amino-acyl-tRNA passes into the P-site. The second tRNA with the amino acid can come to the A-site. The ribosome moves by one triplet, the released tRNA leaves the ribosome. The second tRNA passes into the peptidyl site. The process repeats many times. Termination of polypeptide synthesis is determined by one of three stop-codons: UAA, UAG, UGA.


Basic regularities of heredity were discovered by **Gregor Mendel** in 1865 year (fig. 20). He carried out experiment on pea plants with different traits: red or white flowers, yellow or green seeds.

Traits (characters) that exclude each other (cannot exist together in one individual) are called alternative traits. Genes that responsible for alternative characters are called allelic genes. Allelic genes are situated in the same loci of homologous chromosomes. The sum of all genes of an individual that were got from its parents is genotype.

The organism that has same allelic genes in the genotype (AA or aa) is a **homozygote**. Homozygotic organisms form only one type of gametes and thus there no segregation of traits in their offspring (if both patents are homozygotes).

**Heterozygotic** organism have different allelic genes — the dominant and the recessive ones (Aa or Bb). Heterozygotes form several types of gametes. There is segregation of characters in their descendants.

The number of types of gametes is calculated by formula: \( N = 2^n \). \( N \) — the number of types of gametes, \( n \) — the number of traits that are in heterozy-
gous state. For example, a heterozygote AA form only one type of gametes — A \( (2^0 = 1) \); a heterozygote Aa form two types of gametes — A and a \( (2^1 = 2) \).

Allelic genes are situated in homologous chromosomes. Chromosomes diverge during meiosis and only one gene of a pair gets to the gamete. The sum of all traits and properties of an organism that are determined by the genotype and the environment is the phenotype.

A character that suppress the other character of the pair is dominant. Gene that is responsible for this character is the dominant gene. Such character manifests in both homozygous (AA) and heterozygous (Aa) states (for example, yellow seeds of pea).

The character which manifests only in homozygous state (aa) and is always suppressed by the dominant gene is recessive (green seeds).

Mendel crossed the of pea plants. The method of crossing is called hybridological method.

If the organisms are analyzed on only one pair of traits, the cross is called monohybrid. Mendel denoted the traits of pea:


Mendel used pure lines of pea (i.e. homozygotes) which had alternative traits. He crossed homozygous plants of pea which had yellow seeds with plants having green seeds.

\[ P. \quad \text{AA (yellow)} \times \text{aa (green)}; \]

\[ G. \quad \text{A} \quad \text{a} \]

\[ F₁. \quad \text{Aa} \quad 100 \% \text{ yellow} \]

The result of the first experiment is heterozygous plants with yellow seeds. According to the results of the cross, Mendel formulated his first law — the Law of Hybrid Uniformity: if homozygous individuals differing in one pair of alternative characters are crossed and analyzed, uniformity of offspring individuals on phenotype and genotype is observed.

Later on, Medel crossed these hybrids.

\[ P. (F₁) \quad \text{Aa (yellow)} \times \text{Aa (yellow)}; \]

\[ G. \quad \text{Aa} \quad \text{Aa} \]

\[ F₂. \quad \text{AA}, \ 2\text{Aa}, \ \text{aa}. \]

Phenotypic segregation ratio is \( 3 : 1 \) \( (75 \% : 25 \%) \) \( (3 \text{ yellow} : 1 \text{ green}) \).

Genotypic segregation ratio is \( 1 : 2: 1 \) \( (25 \% \text{ AA} : 50 \% \text{ Aa} : 25 \% \text{ aa}) \).

Mendel got 3 groups of individuals with yellow seeds and 1 group with green ones. There was homo– and heterozygotes among the plants with yellow seeds. On the ground of the experiment, Mendel formulated his second law — the Law of Segregation: if heterozygous individuals are crossed and analyzed
on one pair of alternative characters, segregation ratios of characters are 3:1 for phenotype and 1:2:1 for genotype are observed in offspring individuals.

3. DIHYBRID CROSS. THE LAW OF INDEPENDENT ASSORTMENT

A cross when organisms are analyzed on two pairs of alternative traits is dihybrid. If more than two pairs of traits are analyzed, then the cross is called polyyybrid.

Mendel crossed homozygous plants with yellow smooth (dominant traits) and green wrinkled seeds (recessive traits).

A — yellow seeds, a — green seeds
B — smooth seeds, b — wrinkled seeds

P.  

\[
\begin{array}{c}
AABB \\
\text{AABB} \\
\end{array}
\]

\text{x}  

\[
\begin{array}{c}
ahh \\
hh \\
\end{array}
\]

G.  

\[
\begin{array}{c}
AB \\
\text{AB} \\
ab \\
\text{ab} \\
\end{array}
\]

F₁.  

\[
\begin{array}{c}
AaBb - 100 \% \text{ yellow smooth.} \\
\end{array}
\]

Then Mendel crossed the hybrids

P. (F₁).AaBb  \text{x}  AaBb  

G.  

\[
\begin{array}{c}
\text{AaBb} \\
\text{AaBb} \\
\text{AaBb} \\
\text{AaBb} \\
\end{array}
\]

The law of hybrid uniformity still works in the first cross: all hybrids are uniform heterozygotes with yellow smooth seeds. Crossing these hybrids confirmed the law of segregation.

To write genotypes of all hybrids of the cross, Punnett square is used.

In the second generation, there are 9 groups of individuals with yellow smooth seeds (A–B–), 3 groups with yellow wrinkled ones (A–bb), 3 groups with green smooth ones (aaB–), and 1 group of plants with green wrinkled seeds (aabb).

Phenotypic segregation ratio in F₂ is 9 : 3 : 3 : 1 = (3 : 1)².

If we count all phenotypes in the square considering only one trait, the segregation ratio would be:

12 yellow : 4 green — 3 : 1.

In this cross, random combination of genes occurred and, consequently, individuals with new combination of traits appeared (green smooth and yellow wrinkled seeds).

On the ground of these data Mendel formulated his third law — the Law of Independent Assortment: if heterozygotes are crossed and analyzed in several pairs of alternative characters, independent assortment of gametes and genes is observed in the second generation and consequently independent inheritance of traits.

Independent assortment of traits is possible due to:

– random divergence and combination of chromosomes during meiosis;
random combination of gametes in fertilization.

Cytogenetic basis of the Mendel’s laws is explained by the hypothesis of purity of gametes: Genes of a hybrid do not mix and are in pure allelic state. During meiosis, chromosomes diverge and only one gene of an allelic pair gets to a gamete. Each chromosome carries its own genes to the gamete. Chromosomes are combined randomly during meiosis.

**Significance of Mendel’s laws:**
- The laws are universal. They explain mechanisms of inheritance for all living organisms.
- The laws are statistic: they are shown up in large groups of individuals and allow to predict the probability of a definite trait in offspring.

### 4. Genetic linkage. The chromosome theory of inheritance

According to genetic investigations, the number of individual’s genes is many times more than the number of its chromosomes. Consequently, each chromosome contains many genes. The group of genes which are in one and the same chromosome are inherited together and called linked genes. The group of genes of a pair of homologous chromosomes is called a linkage group.

In 1911 year **Thomas Morgan** (fig. 21) described the genetic linkage — joint transmission of several genes from parents to offspring. He carried experiments on fruit flies (Drosophila melanogaster). They are convenient for experiments because:
- they have just a few chromosomes (8);
- they give many offspring;
- early sexual maturity and quick alternation of generations;
- it is possible to use hybridological method (crossing).

Morgan studied inheritance of the body color and the length of wings:
- B — grey body, b — black body, V — normal (long) wings, v — vestigial (short) wings.

In the first experiment Morgan crossed homozygous flies which have grey body and normal wings (dominant traits) with black vestigial-winged flies (recessive traits). All hybrids of the first generation were uniform and had dominant traits:

<table>
<thead>
<tr>
<th>P.</th>
<th>BBVV</th>
<th>x</th>
<th>bbvv</th>
</tr>
</thead>
<tbody>
<tr>
<td>G.</td>
<td>BV</td>
<td></td>
<td>bv</td>
</tr>
<tr>
<td>F₁.</td>
<td>BbVv — 100 % grey long-winged.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

That confirmed the first Mendel’s law.

*Fig. 21. Thomas Morgan*
In the second experiment Morgan crossed recessive female and di-heterozygous male Drosophilae. He expected to get phenotypic segregation 1:1:1:1, i.e. per 25% of different phenotypes.

However, he got two types of flies (50/50%) which have parental traits. There were no individuals with new combinations of the traits.

Morgan supposed that genes of the body color and the length of wings are situated in the one and the same chromosome and therefore are inherited together.

During the meiosis the chromosome containing the genes BV gets to one gamete while the chromosome carrying genes bv to the other one. That explains why di-heterozygous male Drosophila form not 4, but only 2 type of gametes.

That is how Thomas Morgan discovered the genetic linkage — joint inheritance of traits which are determined by genes situated in the one and the same chromosome.

Genetic linkage in the male Drosophila is complete and characters are always inherited together.

In the third experiment Morgan crossed di-heterozygous female and recessive male Drosophilae.

\[
P. \ bbvv \times \ BbVv \\
G. \ \begin{array}{ccc}BV & bv \end{array} \begin{array}{ccc}bv & BV \end{array} \\
F_1. \ BbVv, \ BbVv, \ bbVv, \ bbVV \\
\begin{array}{cccc}41.5 \% & 8.5 \% & 8.5 \% & 41.5 \% \end{array}
\]

According to the Mendel’s laws the number of flies with different phenotypes should be equal: per 25%. But there were only 83% of flies with 2 types of parental traits and 17% with 2 new combinations of characters.

There was partial combining of parental traits. Genetic linkage was partial (incomplete) due to crossing-over. Crossing over is the process when homologous chromosome exchange their same segments. It occurs in the prophase of meiosis I.

According to the results of these experiments Morgan formulated the **Chromosome Theory of Inheritance:**

1. Genes are situated in chromosomes in a linear order in definite loci. Allelic genes are in identical loci of homologous chromosomes.
2. All genes of one chromosome pair compose a linkage group and are inherited together. The number of linkage groups is equal to the number of pairs of homologous chromosomes.
3. Crossing-over (exchange of allelic genes) is possible between homologous chromosomes.
4. The percentage of crossing-over between two genes depends on the distance between these genes in the chromosome.

5. 1% of crossing-over is equal to 1 centimorgan — a unit of the distance between genes called to honor T. Morgan.

5. **Genetics of sex**

*Sex* is the complex of all morphological, physiological, biochemical and other characters of the organism that provide reproduction. Reproduction is the ability of organisms to create new individuals of their kind.

*Sex dimorphism* is the sum of all morphological, physiological, biochemical and other differences that differ males and females of a species.

**Primary sex characters** are the organs that take direct part in reproduction (internal and external sex organs). They are formed during the embryonic development.

**Secondary sex characters** develop under the action of sex hormones and appear during puberty (facial hair, voice quality, body constitution and etc.).

**Hyman karyotype** includes 46 chromosomes (23 pairs). There are autosomes and sex chromosomes. Autosomes are chromosomes of pairs which are same in males and females (human has 22 pairs of autosomes).

Autosomal genes determine many characters such as hair color, skin color, height and other. Unlike autosomes, chromosomes of the 23rd pair are different. They are called heterochromosomes.

Sex chromosomes of a woman are two homologous X-chromosomes. In a man they are non-homologous X-chromosome and Y-chromosome (fig. 22).

The sex which has same sex chromosomes (XX) is homogametic, the sex with different heterochromosomes is heterogametic (XY).

In Drosophilae, human an all mammals female sex is homogametic and male sex is heterogametic.

Apart from homologous regions containing allelic genes, heterochromosomes have non-homologous regions which contain non-allelic genes.

Characters that are determined by genes situated in the non-homologous region of sex chromosomes are linked with sex.

**Genes of X-linked** characters are in the non-homologous region of the X-chromosome (genes of hemophilia and color blindness), **Y-linked (holandric)** are in the non-homologous region of the Y-chromosome (skin membranes between fingers, hairs in ears).
Mendel demonstrated that sex of the organism is inherited in the same way as the other traits. If we denote male and female genotypes with sex chromosomes (X and Y) then we can see that the sex is inherited with segregation ratio 1 : 1.

Sex of a baby is determined at the moment of fertilization. If an ovum is fertilized by a sperm containing the X-chromosome, the sex of future baby is female.

If the sperm that fertilize the ovum carries the Y-chromosome, then the sex of the baby would be male.

\[
P. \quad \begin{array}{ccc}
XX \\
X \\
Y
\end{array} \\nG. \quad \begin{array}{ccc}
X \\
X \\
Y
\end{array} \\
F_{1.} \quad \begin{array}{ccc}
XX \\
XY
\end{array}
\]

Probabilities of formation of male and female zygotes are equal — 50/50 %.

6. Variation

**Variation** is the property of living organisms to get new characters during their development and become different in comparison with their parents. All the diversity of living organisms is possible only due to variation. This property helps organisms continue existence in changes of environmental conditions. Variation is the source of the matter for evolution.

The phenotype of the organism is based on its genotype and is formed under the action of the environment. Various environmental factors «switch on» different genes and therefore one organism may get different phenotypes in different environments. New characters may also develop when the environment affects genetic material of the individual.

**There are two types of variation:**
1. Phenotypic (non-hereditary) variation;
2. Genotypic (hereditary) variation.

Phenotypic (modificatory) variation is changes of the phenotype without changes of the genotype. Modifications are organism's adaptations to the environment. For example, animals which live in cold climate have thicker coat; plant leaves that are under and above the water have different shape. In modifications, the genotype of the individual does not change. Consequently they are not inherited.

**Properties of modifications:**
- not inherited;
- reversible (not constant) — can disappear in changes of the environmental conditions (suntan);
- massive involvement — similar modifications appear in all organisms that are exposed to the same factor (suntan);
- adaptability — modifications adapt the organism to some environmental conditions and are useful for the organism (storage of fat tissue);
- modifications are not matter for the natural selection;
- predictable.

The limits of modificatory variation are determined by the reaction norm (reaction range). It is wide if the character changes within wide limits (volume of cow’s milk, body mass) and narrow if it changes insignificantly (fat content of milk).

**Hereditary variation** is also called genotypic. Genotypic variation consists in changes of the phenotype caused by changes of the genotype. There are two types of this variation: combinative and mutational.

**Combinative variation** is the result of combining parental genes in children. The structure of these genes does not change. New gene combinations cause appearance of organisms with new phenotypes. For example, Mendel got plants with green seeds from plants with yellow seeds.

**Mechanisms of combinative variation:**
1. Independent assortment of chromosomes and chromatids during meiosis;
2. Gene recombination during crossing-over;
3. Random combination of gametes in fertilization.

Combinative variation provides adaptation of species to changing environmental conditions.

Mutational variation (mutations) is changes of genetic material under the influence of environmental factors.

**Properties of mutations:**
- are inherited;
- irreversible (constant);
- non-adaptive;
- individual;
- the matter for the natural selection.

Environmental factors that cause mutations are called mutagens. They are:
1. Physical — ultraviolet rays, radiation, temperature, humidity, etc.
2. Chemical — chemicals, hormones, enzymes, conserving agents, drugs.

**Mutations cause changes in the genetic material:**
1. Mutagens can change the structure of a gene. Such mutations are called gene mutations. They result in metabolic diseases such as hemophilia, phenylketonuria, daltonism (color blindness), albinism.
2. Mutagens can change the structure of a chromosome. Such mutations are called chromosome mutations. They lead to malformations (development defects) of organs and organ systems (for example, underdevelopment of a larynx, heart defects).
3. Mutagens can change the number of chromosomes. Such mutations are genome mutations. They cause chromosomal diseases such as Down syndrome (extra 21st chromosome).
7. **Human Genetics**

Human as well as another organisms is the study object of genetics. Human genetics study normal human karyotype and its changes in various genome diseases, causes, prophylaxis and treatment of hereditary diseases. Human is complicated genetic object.

**There are difficulties of studying human genetics:**
- it is not possible to use hybridological method (experiments on human are unacceptable);
- many chromosomes (46) and genes (about 30 000);
- late sexual maturity (12–16 years);
- small number of children;
- long alternation of generation;
- it is not possible to make same environment for all people.

**Nevertheless, there are some advantages of studying human genetics:**
- great number of individuals;
- international co-operation of scientists;
- human is well-studied clinically;
- there are a lot of methods of studying human genetics.

**Private methods of human genetics are:**
1. Genealogical;
2. Cytogenetic;

**Genealogical method** is based on drawing up pedigrees (family tree, genealogy). This method allows to reveal:
1. Whether or not the character is hereditary.
2. The inheritance type (dominant or recessive, sex-linked or autosomal).
3. Probability of giving birth to a sick child in a family.

**There are special symbols (fig. 23). which are used for making family trees.**

- ○ female (without the character)
- □ male (without the character)
- △ sex is not known (without the character)
- ● female (have the character)
- ○ ○ female and male probands
- □ □ marriage (parents)
- ○ ○ children (siblings)

*Fig. 23. Symbols used in the genealogical method*
Types of inheritance are:

1. **Autosomal-dominant.** Its characteristics are:
   - sick persons are in every generation;
   - sick children only in families of sick parents;
   - equal number of sick men and women;
   - probability of inheritance is 100% if one parent is sick homozygote; 75% if parents are heterozygous; 50% if one parent is sick heterozygote and the second one is healthy.

   Characters which are inherited in such type are polydactylia (6 fingers), freckles and other.

2. **Autosomal-recessive.** Its characteristics are:
   - sick persons are not in every generation;
   - sick children are possible in families of healthy parents;
   - equal number of sick men and women;
   - probability of sick children increase in consanguineous marriages;
   - probability of inheritance is 25% if parents are heterozygous; 50% if one parent is a sick homozygote and the second one is heterozygous.

   Red hair, albinism are inherited in such type.

3. **X-linked dominant type** of inheritance is similar to the autosomal dominant type, except for the fact that man can transmit the character only to his daughters (to all of them) because sons get his Y-chromosome.

4. **X-linked recessive type** of inheritance is similar to the autosomal recessive type, except for the fact that most of sick persons are men.

   It is type of inheritance of daltonism and hemophilia.

5. **Holandric type** of inheritance (by the Y-chromosome):
   - only men are sick;
   - all sons of a sick man are sick.

   Ear hairs, skin membranes between toes are inherited in this type.

   **Cytogenetic method** studies human karyotype in cells of blood or epithelium under the microscope. This method reveals the number of chromosomes and their structure. This method is used for making the diagnosis of genome and chromosome mutations. It is also possible to find out the genetic sex of the organism.

   **Biochemical methods** can reveal the concentration of enzymes, amino acids and various metabolic products in healthy and sick persons. They help to confirm the diagnoses of metabolic diseases.

8. **Human hereditary diseases**

   At the present day, there are known more than 4000 hereditary diseases. Medical genetics is the discipline that studies hereditary diseases. These diseases are caused by changes of the genotype (mutations).

   Genome and chromosome mutations cause human chromosome disorders such as Down, Shereshevsky-Turner, Klinefelter, X-trisomy, cat’s cry syndromes.
**Down’s syndrome** (47, XX, 21+; 47, XY, 21+) is caused by trisomy on 21\(^{st}\) chromosome. Trisomy is a genome mutation when there are 3 homologous chromosomes instead of 2 (47 chromosomes in a diploid set). Symptoms of the Down syndrome: intellectual disability (mental retardation), inward slant of the eyes, low-set ears, open mouth, reduced vitility.

**Shereshevsky–Turner syndrome** (45, X0) is caused by the absence of the second sex chromosome (monosomy on the 23\(^{rd}\) pair). Phenotype is female. Symptoms: low height, short neck, underdeveloped primary and secondary sex characters, sterility.

**Klinefelter syndrome** (47, XXY) is caused by presence of extra X-chromosome in male genotype (XXY instead XY). Such people have female body constitution, tall height, long extremities, underdeveloped primary and secondary sex characters, low intellect.

**X-trisomy syndrome** (47, XXX) is caused by the change of the number of chromosomes (extra X-chromosome) in females. Such women have male body constitution, tall height, reduced intelligence.

**Cat's cry (cri du chat) syndrome** (46, XX, 5p–; 46, XY, 5p–) is caused by loss of the segment of 5\(^{th}\) chromosome’s short arm. Due to the under development of the larynx newborns have specific sound of cry: it resembles cat’s meowing. Other symptoms are arrested mental and physical development, deformed low-set ears.

Gene mutations cause metabolic diseases. Hereditary diseases caused by mutations of autosomal genes are albinism and phenylketonuria.

**Albinism** is the disease caused by disturbance of amino acid exchange. Transformation of the amino acid thyrosine into a pigment melanin is impaired. Symptoms of albinism are milky-white skin, white hairs, red pupils (due to absence of the pigment in the retina). Such people are very sensitive to ultraviolet rays.

**Phenylketonuria** is also the disease caused by disturbance of amino acid exchange. The amino acid phenylalanine is not transformed into thyrosine and is transformed into phenylpyruvic acid. This acid accumulates in the organism. Sick children get increased neural irritability, muscle tone, mental retardation.

Hereditary diseases caused by mutation of the genes situated in the sex chromosomes are hemophilia and daltonism.

**Hemophilia** is the impairment of blood clotting. Daltonism (color blindness) is disturbance of color distinguishing. These diseases usually affect boys.

Medical genetic counselling (genetic consultation) is a medical discipline that strive to prevent birth of children with hereditary diseases.

**Aims of genetic counselling:**
- prophylaxis of hereditary diseases, consulting families and sick persons with hereditary disorders;
- defining the genetic risk (probability to give birth to a sick child) in a family;
- prenatal diagnostics of hereditary disorders and congenital malformations.
Section 3: HUMAN ANATOMY

1. SCIENCES OF HUMAN. OVERVIEW OF THE HUMAN BODY

There are several medical sciences of human:

**Anatomy** is the science that studies the external and internal structure of the human body, its organs and organ systems.

**Physiology** is the science that studies the functioning and its regulation of the human organism, various tissues, organs and organ systems.

**Hygiene** is the medical science that studies conditions of human life and work to maintain human health and prevent diseases.

The human body consists of cells which form tissues. Tissue is a group of cells and intercellular substances which have the same origin, structure and functions. The human body is composed of **epithelial, connective, muscle and nerve tissues** — four types (fig. 24).

![Tissues of the human body](image)

**Fig. 24. Tissues of the human body**

1. **Epithelial tissue (epithelium)** covers the body, internal organs, majority of glands; it lines the cavities of the body. It has high level of regeneration due to mitosis. Epithelial cells are always attached to underlying layer of connective tissue. The cells are tightly packed — there are little volume intercellular substance (or it is absent).

   Types of epithelium: a single-layer (simple) and stratified epithelium. According to the type of cells in the superficial layer: squamous, cuboidal, and columnar.

   **Functions of epithelial tissue are:**
   - protective (barrier);
   - metabolic (absorption and excretion of substances);
   - secretory (gland cells of skin).

2. **Connective tissue** forms the skeleton, subcutaneous fat, blood, lymph. It is an important element of all internal organs. The ability to regenerate is high.
The cells of the tissue are widely spaced and thus leave much space for a high volume of non-living intercellular substance (intercellular matrix).

**There are several types of connective tissue:**
- hard (bone, cartilage);
- dense fibrous (ligaments, tendons);
- loose fibrous (the dermis of the skin);
- adipose (subcutaneous fat);
- liquid (blood, lymph).

**Functions of connective tissue are:**
- trophic (nutritional) participates in exchange of substances and energy;
- protective — participates in immune reactions and phagocytosis;
- mechanical — forms bones, cartilage, ligaments and tendons;
- hematopoietic (red bone marrow make blood cells);
- regenerative.

3. **Muscle tissue** forms skeletal (striated) muscles and muscles of internal organs (such as wall of blood vessels). There are two essential properties of the muscle tissue: excitability and contractility. Excitability is the ability to perceive stimuli and respond to them. Contractility is the ability to change the length.

**There are three types of muscle tissue:**
- smooth muscles work involuntary, have low and slow contraction, are in internal organs;
- striated muscles are multinucleate, voluntarily controlled; form skeletal muscles;
- cardiac cells are not multinucleate, but they are striated.

Muscle tissue performs motor function.

4. **Nervous tissue** forms the brain and spinal cord, ganglia, nerves. It consists of nerve cells — neurons which have two types of cytoplasmic processes (extensions): dendrites and axones. Cells of neuroglia are in between of neurons. Neuroglia performs nutritional, support and protective functions.

Nervous tissue has two essential properties: excitability and conductivity. Excitability is the ability to perceive stimuli and respond to them. Conductivity is the ability to transmit nerve impulse. The space or gap between processes of two neurons is called a synapse.

**Functions of the nervous tissue are:**
- receptor — perceives stimuli;
- conductive — transmits nerve impulses.

Tissues form organs (fig. 25). The organ is a body part which has a constant shape, structure, location and performs a specific function (e.g., heart, lungs, stomach).

Organs have many various forms and are composed of several tissues. The stomach consists of epithelial, connective, nervous and smooth muscle tissues. Bones are mostly composed of osseous tissue though they include nerves, connective tissue in their cavities, muscle and epithelial tissue in their blood vessels.
Organs that are responsible for the same functions are grouped into organ systems. These systems are widely studied by Anatomy. An organ system is a group of organs that have common origin and work together to perform a certain task. There are:

1. **Skeletal system.** Skeleton (together with cartilage, ligaments and tendons) supports and protects the body and its organs.

2. **Muscular system.** It includes skeletal muscles and allows the body to manipulate the environment, provides locomotion, maintains posture, and produces heat.

Skeletal and muscular systems are often classified together as musculo-skeletal (locomotor) system.

3. **Integumentary system** includes skin, hair, fat, nails and exocrine glands of the skin.

4. **Nervous system.** Includes the brain, spinal cord, nerves, and ganglions. The nervous system allows perceiving, comprehending, and responding to the environmental signals.

5. **Circulatory (cardiovascular) system.** Its organs are heart and blood vessels. The function is pumping blood through the body to supply it with oxygen and nutrition and remove metabolic wastes.
6. **Respiratory system.** Includes the pharynx, larynx, bronchi, and lungs.

7. **Digestive (gastrointestinal) system.** Digestive glands, mouth, esophagus, stomach, intestines perform mechanical and chemical processing of food.

8. **Reproductive system** includes the sex organs, such as ovaries, fallopian tubes, uterus, vagina, mammary glands, testes, vas deferens, seminal vesicles and prostate that provide human reproduction.

9. **Urinary system.** Its organs are kidneys, ureters, urinary bladder and urethra. The system is necessary for the fluid and electrolyte balance and excretion of urine.

Reproductive and urinary systems are considered sometimes as genitourinary system.

10. **Endocrine system.** Provides chemical communication within the body using hormones made by endocrine glands such as the hypothalamus, pituitary gland, pineal body or pineal gland, thyroid, parathyroid and adrenal glands.

11. **Lymphatic system.** It is a network of lymphatic vessels and nodes involved in the transfer of lymph between tissues and the blood stream.

These systems form the **human body.** The body consists of body parts: head, neck, trunk, upper limbs (arms), lower limbs (legs).

The human body has thoracic and abdominal cavities which are separated by the diaphragm. In the abdominal cavity is the stomach, intestines, liver, kidneys and reproductive organs are situated. The heart, largest vessels, lungs, trachea and esophagus are located in the thoracic cavity.

### 2. **Structure, Connection and Growth of Bones**

Bones together with muscles comprise the human musculoskeletal system. **Chemical composition of bone:** 50% water, 12.5% protein (ossein) 21.8% of inorganic salts (phosphates, calcium) and 15.7% of carbohydrates and fats. Organic substances of the bone are proteins, fats, carbohydrates. They make bone soft and plastic. Inorganic substances are water, phosphate and calcium carbonate. They make bones hard and strong.

The bone is made of bone tissue (hard connective tissue) which consists of bone cells and intercellular substance. Intercellular substance consists of collagen fibers and main substance. **Bone cells are of 3 types:**

- osteocytes are mature bone cells which exchange substances;
- osteoblasts are bone cells that divide to form new osteocytes;
- osteoclasts are cells of the bone that break down old osteocytes.

**According to the shape, bones are:**

- tubular (also known as long bones): thighbone, humeral bone (upper arm), phalanges and etc.
- flat: bones of the skull, sternum (breastbone), scapula (shoulder blade), ribs and etc. Flat bones contains red bone marrow which form blood cells.
irregular (mixed): zygomatic, mandible and etc. Such bones have characteristics of both previous groups.

A long (tubular) bone (fig. 26) consists of a diaphysis (body) and two epiphysis (heads).

There is a cartilage that provides bone growth in length between the diaphysis and epiphysis.

Bone heads consist of spongy bone substance and contain red bone marrow which produces blood cells. The heads are covered with cartilage (dense connective tissue).

The diaphysis has a cavity which is filled with adipose tissue — yellow bone marrow. The surface of the diaphysis is covered with periosteum.

Periosteum contains nerves and blood vessels; it is a connective tissue. Periosteum provides bone grows in thickness due to division of its cells (osteoblasts).

Most of bones are connected to each other. There are three types of bone connections:

- Immovable — synarthrosis is a connection that allows very little or no movement. It is possible in two ways: sutures (connection of skull bones) and accretion — fusion of bones (pelvis and sacrum, sacral vertebrae).
— **Semi movable** — amphiarthrosis is a connection that allows slight mobility. Semi movable connection is the connection by cartilage (the sternum and ribs, vertebrae of the spine).

— **Movable** — diarthrosis is freely movable connection. Movable connection of bones is called the joint (or articulation).

  *Each joint consists of* articular surfaces of the bones, joint capsule, joint cavity and synovial fluid (fig. 27). Joint connects several bones. The convex articular surface of one bone is called a head (sometimes ball), The concave articular surface of the other bone is depression (socket). Articular surfaces of bones are covered with smooth cartilage which facilitates the movement of the bones.

Articular surfaces of the bones are covered with the joint capsule. The cavity inside the capsule is called the joint cavity. It is filled with synovial fluid that reduces friction to increase the mobility of bones.

Joints are between the thigh bone and shin, between the bones of the shoulder and forearm. Examples of joints: knee, hip, shoulder, elbow and others. Joints are fixed with ligaments.

### 3. **Structure of the skeleton**

The skeleton is a passive part of the locomotor system. The human skeleton consists of more than 200 bones.

**Bones of the skeleton are grouped in 3 divisions:** head skeleton (skull); axial skeleton (skeleton of the trunk); appendicular skeleton (skeleton of limbs).

The skeleton of the head is skull. It has two sections: the neurocranium (cerebral cranium) which encloses the brain and viscerocranium (facial cranium). **Eight bones comprise the neurocranium** (fig. 28):

- 2 parietal bones;
- 2 temporal bones;
- frontal bone;
- occipital bone;
- ethmoid bone;
- sphenoid bone.

**Fourteen bones and the hyoid bone form the viscerocranium** (fig. 29):

- 2 maxillae (bones of the upper jaw);
- 2 zygomatic bones (cheekbones);
- 2 nasal bones;
- 2 lacrimal bones;
- 2 palate bones;
- 2 inferior nasal conchae;
- mandible (lower jaw);
- vomer;
- hyoid (sublingual) bone.

All bones of the skull are connected via interlocking sutures (except for the mandible which is connected with a joint).

Fig. 28. Bones of the neurocranium

Fig. 29. Bones of the viscerocranium

Fig. 30. Human vertebral column

The axial skeleton forms the spine and thorax. The spine is composed of 33–34 vertebrae and has 5 regions (fig. 30):
- cervical region (7 vertebrae);
- thoracic region (12 vertebrae);
- lumbar region (5 vertebrae);
– sacrum (a bone composed of 5 vertebrae which are fused together);
– coccygeal (4–5 vertebrae that are fused and form coccyx).

Each vertebra consists of a body, arch, and several processes. Between the vertebral bodies, intervertebral cartilaginous discs are situated. There is a hole between the vertebral body and vertebral arch. The holes of vertebrae form a vertebral canal for the spinal cord.

The first cervical vertebra is also known as the atlas. It has no body. The second one is the axis. It extends up into the atlas and allows the head to rotate from side to side on its axis.

Human spine forms four physiological curves. An anteriorly convex region of the spine is called lordosis. Human spine has cervical and lumbar lordoses. The anteriorly concave region is kyphosis. There are thoracic and sacral kyphoses. These physiological curves reduce shocks when walking, jumping and running and increase the size of the chest and pelvis.

Each of twelve thoracic vertebrae has a pair of ribs, i.e. human have 12 pairs of ribs. Thoracic vertebrae, ribs and sternum form the chest (thoracic cage). There are 3 groups of ribs (fig. 31):
– True (vertebrosternal) ribs (1–7 pairs) — their front ends are attached to the sternum through cartilage.
– False (vertebrochondral) ribs (8–10 pairs) their front end joins the cartilage of the previous rib.
– Floating ribs (11–12) pairs are not connected with the sternum and other ribs. Their front ends freely lay in the tissues.

Chest contains the heart, great vessels, lungs, trachea, and esophagus. It is involved in the respiratory movements.

The appendicular skeleton includes bones of girdles and limbs.

The pectoral girdle includes two scapulae and two clavicles.

Upper limb consists of the upper arm, forearm and palm. The bone of the upper arm is the humerus; the forearm includes radius and ulna. Bones of the palm are divided into 3 groups. Eight bones of the wrist (carpals) form the carpus. Distal to the carpals are the five metacarpals. Distal to the metacarpals are the fourteen bones of phalanges.

The pelvic girdle consists of two pelvic (coxal) bones which are grown to the sacrum.
The lower extremity consists of the upper leg, lower leg and foot. The bone of the upper leg is the femur. Bones of the lower leg are tibia and fibula. There are three groups of bones in the foot: the tarsus, the metatarsus, and the phalanges.

Functions of the human skeleton: it supports the body, protects underlying organs, and provides mobility of body parts. In addition, blood cells are formed in bones and takes part in calcium balance.

4. Muscular system

The other part of musculoskeletal system is muscles. Muscles are an active part of the system. Human have more than 600 skeletal muscles (together account for about 40 percent of a person’s weight). Muscles are composed of muscle tissue. There are smooth and striated muscle tissue, the striated tissue of the heart has special structure (table 2).

**Table 2**

<table>
<thead>
<tr>
<th>Smooth muscle tissue</th>
<th>Striated skeletal muscle tissue</th>
<th>Cardiac striated muscle tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Involuntarily controlled</td>
<td>Voluntary controlled</td>
<td>Involuntary controlled</td>
</tr>
<tr>
<td>Located in the internal organs such as walls of the stomach, intestines and blood vessels</td>
<td>Forms the skeletal muscles, muscles of oral cavity, tongue, pharynx, upper esophagus, larynx, facial muscles and the diaphragm</td>
<td>The only organ made of this tissue is the heart</td>
</tr>
<tr>
<td>Consists of separate cells (length of such cell is approximately 0.1 millimeter), which have myofibrils (contractile fibers) and a single nucleus</td>
<td>Consists of long muscle fibers (length 10–12 cm); each fiber contains cytoplasm, a large number of nuclei and myofibrils — special organelles with light and dark areas (disks)</td>
<td>Branching chains of cells which have one or two nuclei. Length of the cell is approximately 0.1 millimeter while chains they form are much longer</td>
</tr>
<tr>
<td>Contracts slowly and runs continuously</td>
<td>Contracts quickly and easily get tired</td>
<td>Runs continuously and does not get tired</td>
</tr>
</tbody>
</table>

Muscles contain contractile proteins actin and myosin. Muscles have the blood vessels, nerves and nervous terminations (receptors).
Fibers of striated muscles form bundles. Such bundle is a skeletal muscle. The skeletal muscle is covered with a capsule of connective tissue. Each muscle consists of the body (muscle belly) and tendon. These tendons are attached to the bones of the skeleton. Though the second end of a mimic muscle is attached to the skin.

**According to the shape, the skeletal muscles are:**
- long (muscles of limbs) and short (intercostal muscles);
- wide (muscles of abdomen);
- thick and thin (deep muscles of the back);
- biceps, triceps.

**According to the function, skeletal muscles are:**
- flexors — located in front of joint (biceps);
- extensors — located behind the joint (triceps);
- adductors — located medially from the joint;
- abductors — located outside from the joint;
- rotators are situated inwardly and outwardly.

**According to the location, skeletal muscles are:**
- muscles of the head (chewing, mimic);
- muscles of the neck;
- chest muscles;
- abdominal muscles;
- back muscles;
- muscles of the limbs and girdles.

The muscle work is contraction. It requires energy which is received from ATP. Muscle work has a reflex character. Reflex is a response of the body to stimulation with participation of the nervous system. Excitation (impulse) appears in the muscle as a response to the stimulation. Stimulation from the receptors is transmitted through the sensory neurons to intercalary neurons of the spinal cord and then, from the spinal cord to the muscle, impulse is transmitted through the motor neurons (fig. 32). This makes the muscle contract.

The path of the nerve impulse during this process is called a reflex arc. Reflex arc consists of receptor, sensory (afferent) neuron, interneuron, motor (efferent) neuron, and muscle (effector).

**Skeletal muscles are innervated by the somatic nervous system.** It provides fast response to stimulation of the muscles. In addition, the muscles are innervated by the autonomic nervous system that promotes working capacity.
The central nervous system (CNS) have important role in the regulation of muscle activity: the midbrain regulates tonus of muscles and cerebellum provides balance and coordination.

**Functions of muscles:**
- shape the body (together with the skeleton);
- provide posture and movement of the body;
- provide breathing, eye movements, chewing, swallowing, facial expressions;
- participate in the formation of speech;
- provide joint stability and heat production.

5. **INTERNAL ENVIRONMENT OF THE BODY. BLOOD AND ITS FUNCTIONS**

In 1878, a French physiologist Claude Bernard introduced the concept of the **internal environment of the body**.
All cells of the body require the supply of nutrients and O₂ and the removal of waste products. The connection between the respiratory, digestive, urinary organ systems and all the cells of the body is provided by means of internal environment of the body (blood, interstitial fluid, lymph).

**Interstitial fluid** is the fluid found in the intercellular spaces composed of water, amino acids, sugars, fatty acids, coenzymes, hormones, neurotransmitters, salts, and cellular products. In the organism of an adult its volume is approximately 20 liters. The fluid bathes and surrounds the cells of the body, and provides a means of delivering materials to the cells, intercellular communication, and removal of metabolic wastes. Interstitial fluid is formed by filtration through capillaries.

**Lymph** is a milky white liquid. Its chemical composition is similar to blood plasma, but contain less proteins. Its origin is interstitial fluid. Lymph moves through the lymphatic vessels (fig. 33). In the course of the lymphatic vessels, lymph nodes are located. Lymphocytes are arrived into the lymph from the lymphatic nodes.

*Fig. 33. Lymphatic vessels and organs of immune system*
The largest lymph vessels form the thoracic and right lymphatic ducts that empty into vessels joining the superior vena cava. About 1–3 liters of lymph returns to blood per day.

Functions of lymph are distribution of water in the body (prevent edema) protection of the organism (immune response).

**Blood** is a liquid connective tissue which is the main part of human internal environment. Its volume in the body is approximately 5–6 liters so it constitutes 7–8 % of body weight.

Blood consists of the liquid intercellular substance (blood plasma) (fig. 34) and formed elements (blood cells) (fig. 35).

**Plasma** is a colorless liquid which contains water (90–92 %), minerals (calcium, potassium, sodium) and organic substances (fats, proteins, carbohydrates).

There are 3 main types of blood cells: erythrocytes, leukocytes and platelets.

**Erythrocytes** are red blood cells (RBC). Erythrocytes has a shape of biconcave disc 7–8 µm in diameter (fig. 36). They have no nucleus — it is extruded from the cells as they matures. All the erythrocyte is filled with hemo-
globin — a protein able to hold oxygen and carry it to cells. Due to hemoglobin, blood is red. The erythrocyte can change its shape to an amazing extent, without breaking, to squeeze through the capillaries.

Erythrocytes are produced in the red bone marrow. The average RBC circulates for approximately 120 days before being destroyed in the liver, bone marrow, or spleen. The iron from hemoglobin is recycled. One ml of blood contains 4–5 million erythrocytes.

The function of red blood cells is transport: they bring \(O_2\) from lungs to tissues and organs and take \(CO_2\) from tissues and organs to the lungs.

In the arterial blood, hemoglobin binds with \(O_2\) to form oxyhemoglobin. In venous blood, hemoglobin binds to \(CO_2\) and forms karbhemoglobin. Carbon monoxide (CO) tightly bound hemoglobin to form carboxyhemoglobin and can be dangerous for human. Even its concentration in the air (to 0.1 %) is life threatening.

**Leukocytes (white blood cells)** have non-constant shape. Unlike erythrocytes, they have the nucleus. Leukocytes can move due to pseudopodia they form. Sizes of leukocytes are 6–25 micrometers. There are approximately 6–8 thousand of white blood cells in one milliliter of blood of a healthy man. Leukocytes are produced in the red bone marrow and maturate in spleen, lymph nodes. They live 2–4 days and are destroyed in the spleen and lymph nodes. There are several types of leukocytes: basophils, eosinophils, neutrophils, monocytes, lymphocytes.

The main function of white blood cells is to protect the organism from bacteria, viruses, foreign proteins, foreign bodies. This is due to their ability to phagocytosis. In addition, some lymphocytes form protective proteins — antibodies.

**Thrombocytes (platelets).** One milliliter of blood contains 180–320 thousand platelets. Like erythrocytes, they do not have a nucleus. Their shape is irregular, sizes are of 2–5 micrometers (fig. 37). Thrombocytes are formed in the bone marrow by special cells. Life span is 8–11 days. Destruction of platelets occurs in the spleen.

Function of thrombocytes is participating in blood coagulation (clotting) to protect the body from blood loss during bleedings.

Functions of blood are transport, protection and regulation.

*Transport function consists in carrying the following:*
- oxygen (\(O_2\)) and carbon dioxide (\(CO_2\)), between the lungs and rest of the body;
- nutrients from the digestive tract and storages to the rest of the body;
– waste products to be detoxified or removed by the liver and kidneys;
– hormones from the glands in which they are produced to their target cells;
– heat to the skin so as to help regulate body temperature.

**Protective function is the role of the blood in inflammation:**
– leukocytes (white blood cells) destroy invading microorganisms and cancer cells;
– antibodies and other proteins destroy pathogenic substances;
– platelet factors initiate blood clotting and help minimize blood loss.

**Regulative function of the blood is its control of:**
– pH by interacting with acids and bases;
– water balance by transferring water to and from tissues.

6. **Circulatory system. Structure and functioning of the heart**

Circulatory (cardiovascular) system is the system which circulates blood. Its structural components are the heart and blood vessels.

The heart is a muscular organ which is the central organ of the circulatory system. It is located in the thoracic cavity (at the left) in a sac called a pericardium. The pericardium consists of connective and epithelial tissues. It secretes a fluid that reduces friction during heart beating. Therefore, the function of the pericardium is to protect the heart.

Weight of the heart 200–300 grams. The wall of the heart consists of 3 layers:
– endocardium is the inner layer made of epithelial tissue;
– myocardium is the thickest middle layer which consists of cardiac striated muscle tissue;
– epicardium is the outer layer that consists of connective tissue covered with epithelium.

The human heart has four chambers: left and right atria and left and right ventricles (fig. 38). There are openings with cuspid valves between the atria and ventricles. The valve between the left atrium and the left ventricle is bicuspid (has two cusps). It is also known as mitral valve. Between the right atrium and right ventricle is the tricuspid valve (has three cusps). Blood must flow always from the atrium to the ventricle and tendon threads that connects valves with the ventricular muscle do not allow reverse movement of blood from the ventricle into the atrium. Due to these tendons the valves can open only to the ventricles.

Each chamber is connected with large blood vessels:
– 2 vena cava enters the right atrium;
– 4 pulmonary veins come to the left atrium;
– pulmonary trunk begins from the right ventricle, and then divide into 2 pulmonary arteries;
– aorta begins from the left ventricle.
The heart muscle is fed with blood due to two coronary arteries which follow from the aorta.

There are semilunar valves in the beginnings of the pulmonary trunk and aorta. Semilunar valves do not allow the blood return from these vessels back to the ventricles.

The work of the heart is its contraction. It works rhythmically and do 70–75 beats per minute. **Cardiac cycle consists of three phases:**

1. **Atrial systole** (contraction of the atria) — 0.1 sec. Both atria contract and blood they contained is pumped to the ventricles.

2. **Ventricular systole** (contraction of the ventricles) — 0.3 sec. Ventricles contract and eject their blood to the vessels (aorta and pulmonary trunk).

3. **Diastole** (total relaxation) — 0.4 sec. During this period, atrium and ventricles are relaxed (fig. 39).
Systole of the atria and ventricles and the general pause is a cardiac cycle. One cardiac cycle lasts approximately 0.8 seconds (at rest). During the cardiac cycle, the atria work 0.1 seconds and are relaxed 0.7 seconds. Ventricles work 0.3 seconds and rest 0.5 seconds. Therefore, the heart does not get tired and works all life.

The work of the heart is regulated by the autonomic (vegetative) nervous system. The sympathetic nervous system enhances and accelerates the heartbeat. The parasympathetic nervous system slows the heart.

There are biologically active substances such as hormones and ions which regulate heart functioning.

Regulation of the heart with participation of hormones is called humoral regulation. Epinephrine (adrenal hormone) and calcium ions enhance the heart function. Acetylcholine and potassium ions depress the heart activity.

7. STRUCTURE OF VESSELS. CIRCULATION

Heart contracts to pump the blood to the blood vessels. There are three types of blood vessels (fig. 40) in the circulatory system: arteries, capillaries and veins.

**Fig. 40. Blood vessels**

**Arteries** are the vessels that carry blood from the heart to the organs and tissues. The largest artery in the human body is the aorta (2.5 cm diameter). In arteries, the blood moves under great pressure. Arterial wall has three layers: the outer one is made of the connective tissue; the middle layer consists of smooth muscles and elastic fibers; the inner one is epithelial tissue. Such walls are strong and elastic. Large arteries split into smaller arteries. Small arteries split into arterioles. Arterioles are split into capillaries.

**Capillaries** are the smallest blood vessels which connect the small arteries and veins. Their wall consists of a single layer of epithelial cells. Diameter of capillaries is about 7 micrometers and wall thickness is about 1 micrometer, length 0.2–0.7 mm. The total cross-sectional area of all capillaries of the body is 6300 m².
Exchange of substances and gases occurs through the capillary walls:

– \( \text{O}_2 \) and nutrients go from the blood to the tissue;
– various metabolites (including metabolic wastes) and \( \text{CO}_2 \) from the cells and tissue enters the capillaries.

**Veins** are the vessels that carry blood from the organs and tissues to the heart. On the analogy of arteries, the wall of veins has three layers: the layer of connective tissue, of muscle tissue, of epithelial tissue. Vein wall is thinner than the arterial wall. The blood pressure in the veins is much smaller than in arteries and even negative in the vena cava. To prevent reverse blood flow, veins have semilunar valves.

The movement of blood through the vessels is called circulation. Vessels in the human body form systemic (greater) and pulmonary (lesser) circulation.

**The systemic circulation** (fig. 41) begins in the left ventricle and ends in the right atrium. The left side of the heart contains arterial (oxygenated) blood.

Arterial blood contains nutrients and a lot of oxygen. During the contraction of the left ventricle, blood is pumped into the aorta and then through arteries to organs. Arteries of the organs branch into capillaries. Oxygen and nutrients pass into the tissue through the capillary walls while metabolites and carbon dioxide are absorbed.

![Fig. 41. Pulmonary and systemic circulations](image)

Capillary blood is collected in small veins which unite into two large veins — the superior vena cava and inferior vena cava. These veins carry venous blood into the right atrium. The right side of the heart contains venous (deoxygenated) blood. Venous blood contains a lot of metabolites and \( \text{CO}_2 \). There is arterial blood in all the arteries of the systemic circulation, and venous blood in all the veins.
The pulmonary circulation starts from the right ventricle and ends in the left atrium. From the right ventricle, venous blood is pumped in the pulmonary trunk which split into two pulmonary arteries carrying blood to two lungs. In the lungs, arteries branches into smaller arteries, then into capillaries. Capillaries surround the alveoli, where gas exchange takes place: exit of carbon dioxide and absorption of oxygen.

Arterial blood comes back to the heart by the four pulmonary veins and gets to the left atrium. There is venous blood in all arteries of the pulmonary circulation and arterial blood in the veins.

8. Respiratory system. Structure of respiratory organs

Breath (respiration) is a process that provides the gas exchange between the organism and the environment. As a result, oxygen enters into the cells and carbon dioxide is removed.

The respiratory system is the organ system which provide the exchange of gases between the organism and the environment. It consists of respiratory tract (airways) and respiratory organs (lungs).

The respiratory tract includes the nasal cavity, nasopharynx, larynx, trachea, bronchi, bronchioles. Air passes through the nostrils and enters the nasal cavity.

The nasal cavity is divided into the right and left halves by an osteochondral partition. Each half has three nasal passages (meatuses). The canal of lacrimal gland is open into the lower nasal passage. Epithelial membrane of the nasal cavity contains cilia, glands and many blood vessels. Epithelial cilia and mucus of the glands clean the air of dust and hold microbes; blood warms air. In the nasal cavity, there are olfactory receptors perceiving various odors.

Air goes from the nasal cavity into the nasopharynx through the internal openings (choanae), then into the larynx.

The larynx consists of cartilage and muscles (fig. 42) and its cavity is covered by mucous membrane (mucosa).

![Fig. 42. Anatomy of the larynx](image-url)
The epiglottic cartilage (epiglottis) closes the cavity of the larynx during swallowing. There are 9 cartilages in the larynx:

- thyroid cartilage, cricoid cartilage and epiglottis (unpaired cartilages);
- 2 arytenoid, 2 corniculate and 2 cuneiform cartilages (paired cartilages).

There is a vocal apparatus in the larynx. It consists of a vocal cords and glottis. The vocal cords are stretched from the arytenoid cartilage to the thyroid cartilage. Between the vocal cords is the glottis. Voice occur as a result of vibrations of the vocal cords during expiration.

At the level VI–VII cervical vertebrae, the larynx proceeds into the trachea — a tube which consists of 16–20 cartilaginous semirings. Its length is approximately 10–13 centimeters.

The end of the trachea divides into two bronchi which consist of cartilaginous rings. The bronchi enters the right and left lungs. In the lungs, the bronchi branch out to form the bronchial tree. These smaller bronchi splits into branches called bronchioles. The walls of the bronchioles have muscle fibers. At the ends of the bronchioles are the alveoli (pulmonary vesicles). Alveolar diameter is 0.2–0.3 mm. Their walls consist of a single layer of epithelial cells. Lungs contains 300–400 million alveoli. In the alveoli gas exchange occurs — they are surrounded by blood capillaries.

**Lungs** (fig. 43) are in the chest cavity. Each lung has an apex and the base. Bronchi, blood vessels and nerves enters the lungs via the lungs roots on the inner surface. Lungs consists of lobes: the right lung has three lobes, the left — 2 lobes. A serous membrane pleura covers the lungs.

*The pleura* consists of two layers: the external (parietal), which lines the chest, and internal (visceral) covering the lungs. Between the layers there is a pleural cavity filled with pleural fluid.

Inhaled air with O$_2$ enters the alveoli. **Gas exchange** occurs according to the diffusion law. Gases go from the region of higher pressure to the region of lower pressure. Oxygen from the alveoli enters the blood and bind with the protein hemoglobin while carbon dioxide come out of blood to the alveoli and then removed from the body with exhaled air through the bronchioles, bronchi, trachea, larynx. During the gas exchange taking place in the lungs blood becomes arterial (oxygenated).

Arterial blood leaves lungs and through the pulmonary veins enters left atrium of the heart. It is then pumped into the left ventricle and then into the aorta. Through the arteries of the systemic circulation, blood goes to the internal organs and tissues. Gas exchange occurs between arterial blood and cells of in-
ternal organs: oxygen goes from the blood to the cells while carbon dioxide goes from the cells to the blood and bind with hemoglobin to form carbaeminohemoglobin (carbaminohemoglobin). Blood becomes venous (deoxygennated).

Venous blood is collected into upper and lower cava veins from the veins of the systemic circulation and then flows into the right atrium, right ventricle. The ventricle pumps the blood into the pulmonary trunk, pulmonary arteries and alveolar capillaries of the lungs.

Gas exchange in the lungs is possible due to breathing movements — inhalation and exhalation. An adult makes 16–18 breaths per minute. Intercostal muscles, chest muscles and diaphragm are involved in the respiratory movements.

**During the inhalation,** contraction of external intercostal muscles and diaphragm occurs. Intercostal muscles lift the ribs to increase the volume of the chest and thus the volume of the lungs. The pressure in the lungs becomes lower than the atmospheric pressure. This makes the air go to the lungs through the airways. **During exhalation** external intercostal muscles and diaphragm relax. The ribs are omitted and the volume of the thorax and lungs decreases. This increase the pressure in alveoli and makes the air leave the lungs.

The medulla oblongata provides the *nervous regulation* of respiration (the respiratory center is situated there). Inhalation reflexly causes exhalation and vice versa. *Humoral regulation* of respiration is associated with the concentration of carbon dioxide in the blood. Increasing the concentration of carbon dioxide increases the excitability of the respiratory center and causes rapid breathing.

The **main function** of the respiratory system is a gas exchange between the organism and environment.

9. **Alimentary (digestive) system. Structure of digestive organs**

**Digestive system** is the system which process food to turn it into energy and useful substances. It includes the digestive tract (alimentary canal) and digestive glands. The digestive system processes food mechanically and chemically. Chemical processing occurs under the action of enzymes made by digestive glands. Mechanical processing takes place by means of teeth and muscles of the digestive canal.

**Regions of the alimentary canal** are mouth, pharynx, esophagus, stomach, small intestine and the large intestine which ends with the anus. **Digestive glands** are salivary gland, pancreas, liver, glands of the stomach and intestine (fig. 44).

**The oral cavity** is formed by lips, cheeks, palate, tongue and muscles of the mouth bottom. There are teeth on the upper and lower jaws. In adults, there are 32 teeth: 8 incisors, 4 canines, 8 premolars and 12 molars (fig. 45). A **tooth** consists of a crown, neck and root. Teeth are laid during embryonic development. In 5–6th month after the birth, baby teeth (milk teeth) are well developed; since 6 years, they are replaced by permanent (secondary) teeth.
Fig. 44. Anatomy of the digestive system

There is a cavity inside of the tooth. It contains a pulp which consists of loose connective tissue, blood vessels and nerves. Basis of the tooth is formed by a dentin, which is covered by enamel on the crown. On the neck and root, dentin
is covered with cementum. The shape of each tooth type corresponds to the way it masticate and handles food.

In the oral cavity, there is a tongue — a muscular organ covered with a mucous membrane. The tongue consists of a root, body and apex. In the mucosa there are taste buds. The apex of the tongue has are the receptors that perceive sweet, the sides of the tongue perceive sour and salty, the root of the tongue — bitter. The tongue manipulates food in the mouth, determines the taste and the food temperature, participates in the swallowing and formation of sounds.

There are three pairs of salivary glands: parotid, submandibular and sublingual. Their ducts are open in the oral cavity. They secrete saliva which moistens food and contains digestive enzymes.

**Functions of the oral cavity are:**
- breaking food into small particles by mastication, mixing it with saliva;
- beginning chemical processing;
- determining the taste of food;
- formation of food bolus and swallowing.

**Ingestion (swallowing)** is a reflex act. During swallowing, muscles of the pharynx contract, the epiglottis closes the entrance to the larynx and food moves into the esophagus. Swallowing center is located in the medulla oblongata.

**The esophagus** is a muscular tube that links the pharynx with the stomach. Its length is about 25 centimeters. Contraction of esophageal muscles pushes food into stomach.

**The stomach** is a muscular organ located in the upper left quadrant of the abdomen below the diaphragm. Its volume is 1.5–2 liters. The stomach is divided into the fundic, cardiac, body, and pyloric regions.

There are lesser and greater curvatures are on the right and left sides, respectively, of the stomach.

The wall of the stomach consists of three layers: connective tissue (outer), muscle tissue (middle), epithelial tissue (internal).

The gastric mucosa (inner layer) forms folds (rugae). The muscles of the stomach wall are composed of three layers: longitudinal, circular and oblique.

**There are three groups of glands in the gastric mucosa:**
- chief glands secrete enzymes pepsin and chymosin;
- parietal glands secrete hydrochloric acid;
- mucous neck cells secrete mucus.

**The small intestine** (fig. 46) consists of the duodenum, jejunum and ileum. Its total length is 5–7 meters. The length of the duodenum is 25–30 centimeters. Ducts of the pancreas and liver are open into the duodenum.

The wall of the small intestine has three layers: mucous, muscular and serous. To increase the surface of the intestinal wall, mucosa forms about 30 million small finger-like projections called villi.

The villus contains blood and lymph vessels and is covered with a simple epithelium. Its function is absorbing nutrients.
The mucosa contains glands that secrete intestinal juices. Smooth muscles of the intestinal wall have two layers: the inner (circular) and external (longitudinal). Their contraction propels food along the intestine.

**The liver** (fig. 47) is the largest gland in the body — its weight is about 1.5–2 kg. It is located in the upper right quadrant of the abdominal cavity below the diaphragm. The liver consists of four lobes.

A porta hepatitis (latine «liver gate») is located on the bottom of the liver in the center. Vessels, nerves and bile ducts enter the liver here.

**The gallbladder** (biliary vesicle, cholecyst) is a pear-shaped sac attached to the bottom surface of the liver which is a storage reservoir for bile. Its volume is 40–70 ml.

Bile is a yellowish-green fluid produced by liver cells. Main components of bile are water, bile salts, bile pigments, and cholesterol.

Bile salts act as emulsifying agents in the digestion and absorption of fats. The liver of an adult produces approximately 500–1200 ml of bile per day.

Bile is produced continuously and stored in the gallbladder. When eating, it is released in the duodenum through the bile duct and enters the small intestine.

**Functions of the liver are:**
- protective (barrier) — cleaning the blood of toxic substances;
- production of bile;
- synthesis of blood proteins;
- storage of glycogen;
- participation in metabolism of proteins, fats and carbohydrates.

**The pancreas** is the digestive gland which produces pancreatic juice. It is situated in the abdominal cavity behind stomach. The length 12–15 cm (fig. 48).
The pancreas consists of a head, body, and tail. The pancreatic juice produced by pancreatic cells contains the enzymes. It is released into the duodenum while eating.

The terminal segment of the small intestine enters the large intestine. The length of the large intestine is 1.5–2 m, diameter of 4–8 cm. It consists of the cecum, colon (ascending, transverse, descending and sigmoid colon), rectum and anal canal (fig. 49). Muscular layer of the colon is larger than that of the small intestine. On the border of the small and large intestines is the appendix. The mucosa of the large intestine has a large number of goblet cells but does not have any villi.

Functions of the large intestine are the absorption of water and electrolytes and the elimination of feces from the organism.

10. Enzymes. Changes of nutrients in the mouth, stomach and intestine

Enzymes are proteins that catalyze biochemical reactions and speed them up. They are biologically active substances. During the splitting organic substances in the digestive canal, enzymes work as catalysts. Digestive enzymes are produced by the salivary glands, stomach, pancreas, and intestine.

Properties of digestive enzymes:
1. Specificity. Each enzyme breaks down certain nutrients.
   - Proteases such as pepsin, chymosin, trypsin, chymotrypsin, enterokinase, aminopeptidase, carboxypeptidase can break down only proteins.
   - Lipases are enzymes that break down fats.
– Amylases such as amylase, maltase, lactase break down carbohydrates.
– Nucleic acids are broken down by nucleases.

2. *Function in certain chemical environment.* An enzyme of gastric juice pepsin is active only in acidic environment. Intestinal enzymes require an alkaline environment.

3. *Function at a specific temperature.* The optimal temperature for enzymes is 36–37 °C. If the temperature changes, enzymes reduce their activity. This disturbs digestion.

4. *High reactivity.* A small amount of enzymes splits high volume of compound.

**Digestion begins in the mouth.**
Saliva is the fluid secreted by the salivary glands. 99% of its mass is water; the rest is mineral salts and organic substances. Saliva contains the bactericidal enzyme lysozyme. The volume of saliva produced by an adult during one day depends on the food and is 500–1500 ml.

*Salivary enzymes are:*
– ptyalin (amylase);
– maltase.
These enzymes break starch into monosaccharaides (ptyalin into maltose and maltase into glucose). Salivary enzymes require weakly alkaline environment for working.

**In the stomach,** digestion occurs under the action of gastric juice. This juice contains hydrochloric acid (HCl) and *enzymes:*
– pepsin that breaks down complex proteins into simple;
– chymosin that curdle milk proteins;
– lipase that acts on the emulsified fats (milk).
These enzymes are active only in the acidic environment. Digestion in the stomach lasts approximately 5–6 hours.

Gastric secretion is controlled by *neural and humoral regulation.* Humoral regulation of gastric juice is provided by hormone gastrin, which is released into the blood by the gastric mucosa. The center providing digestion is situates in the medulla oblongata.

Substances that are absorbed in the stomach are glucose, water, dissolved salts, and some drugs.

Further digestion of nutrients occurs in the small intestine. **Pancreatic juice** and bile are secreted into the duodenum. Pancreatic juice is alkaline. It contains *enzymes:*
– trypsin and chymotrypsin that break polypeptides into amino acids;
– lipase that breaks down fats into glycerol and fatty acids;
– amylase and maltase that break down carbohydrates to glucose;
– nucleases break down nucleic acid into nucleotides.

**Bile** does not contain enzymes. **Functions of bile:**
– emulsifying fats — breaks them up into small drops;
– activates intestinal enzymes;
– facilitate the absorption of fats and fat-soluble vitamins;
– stimulate the contraction of the smooth muscle of the intestinal wall;
– kills microorganisms.

**Intestinal juice** is secreted by the glands of mucosa of the small intestine. It is alkaline. The volume of the juice released per day is 2 about liters.

Intestinal juice contains 22 enzymes:
– proteases such as enterokinase, aminopeptidase, carboxypeptidase break down proteins;
– amylolytic enzymes such as amylase, maltase, lactase break down carbohydrates;
– lipase breaks down fats;
– nuclease digests nucleic acids.

In this region of the intestine digestion is finished.

Various substances are absorbed in the small intestine. Glucose and amino acids are absorbed into the blood vessels of villi. Glycerol and fatty acid are absorbed by villi, transformed into fats, then enters the lymphatic vessels.

Absorption continues in the **large intestine**. Water, mineral salts and toxic substances are absorbed there. Toxic substances detoxified in the liver.

There are numerous bacteria in the large intestine. They break down cellulose and synthesize vitamins (B, K). The large intestine forms stool that is excreted through the anus.

**11. Excretory system. Structure and function of kidneys.**

**Structure and function of skin**

The prior function of the excretory system is maintaining normal volume and composition of body fluids. To perform it, body excretes waste products such as ammonia, uric acid, urea, water, various salts. This is done mostly by the urinary system. Apart from the urinary system, excretion of metabolic wastes is performed by skin, respiratory and digestive systems.

**The organs of the urinary system** are two kidneys, two ureters, an urinary bladder and urethra (fig. 50).

**The kidneys** are the organs that filter the blood, remove the wastes and excrete them with urine. They are the primary organs of the urinary system.

Kidneys are located one on each side of the vertebral column. Each
A kidney of an adult has length about 10 cm and weight of 150 grams. It is roughly bean-shaped with an indentation called the hilum, on the medial side. An ureter, renal arteries and veins, nerves, lymphatic vessels enters the hilum. Each kidney is covered by a capsule of connective tissue.

The outer reddish region next to the capsule is the renal cortex. It surrounds a darker reddish-brown region called the renal medulla. There are renal corpuscles of nephrons in the renal cortex and tubules of the nephron in the renal medulla (fig. 51).

**Fig. 51. Anatomy of the kidney**

The renal medulla consists of 15–20 renal pyramids, which look striated because they contain straight tubular structures and blood vessels. Pyramids are open into the renal pelvis — the central region of the kidney.

The structural and functional unit of the kidney is a **nephron** (fig. 52).

**Fig. 52. Structure of the nephron**
Each kidney contains over a million nephrons. The nephron consists of two parts: a renal corpuscle and a renal tubule. The tubule consists of one layer of epithelial cells. The renal corpuscle consists of a cluster of capillaries, called the glomerulus, surrounded by a double-layered epithelial cup, called the glomerular capsule. The capsule is situated in the renal cortex. The proximal convoluted tubule comes from the capsule and goes to the renal medulla. In the medulla, it forms a loop of Henle (the middle part of the tubule). The loop turns to the renal cortex, and there forms a distal convoluted tubule which runs into collecting ducts. The collecting ducts are open into the renal pelvis.

**The ureter** is a small tube that carries urine from the renal pelvis to the urinary bladder. Its length is about 25 cm.

**The urinary bladder** is a hollow muscular sac collecting urine. Its volume is about 700–750 ml.

**The urethra** is a thin-walled tube where through urine is excreted from the bottom of the urinary bladder to the outside.

Urine containing metabolites is produced by the kidneys. Its formation occurs in two stages:

1. **Filtration** (formation of primary urine) goes in the capsule of the nephron. Primary urine is formed during filtration of blood plasma of blood capillaries in the capsule. Approximately 150–180 liters of primary urine is formed in the organism per day. Composition of the primary urine is similar to blood plasma, but has no proteins. Primary urine contains waste products and a large number of substances essential for the body (glucose, amino acids, and mineral salts).

2. **Reabsorption** (formation of secondary urine) occurs in the tubules of the nephron. It contains urea, uric acid, ammonia, sulfate etc. From the capsule of the nephron, primary urine flows into convoluted tubule where reabsorption of water, glucose, amino acids, ions, sodium, and potassium into the blood occurs. Due to reabsorption, the volume of secondary urine per day is 1.5 liters.

Urine formation is regulated by the nervous system and hormones. Micturition center is located in the spinal cord.

**Functions of kidneys:**
- maintaining the volume of body fluids;
- maintaining homeostasis;
- participating in control of the acid-alkaline balance;
- regulating the blood pressure;
- regulating the metabolism of carbohydrates and proteins;
- secretion of biologically active substances (angiotensin, erythropoietin, prostaglandins, renin).

**Skin** is the integument of the human body. The area of the skin of an adult is 1.5–1.6 m².

**Skin consists of three layers** (fig. 53):
1. **Epidermis** is the outermost layer of the skin composed of squamous cells. This layer is characterized into two distinct types: thick skin and thin skin.
2. *Dermis* is the thickest layer of skin that lies beneath and supports the epidermis.

3. *Hypodermis* (subcutaneous tissue) lowermost layer of the body integument that helps to insulate the body and cushion internal organs.

\[\text{Fig. 53. Structure of the skin}\]

Other components of the skin are hair, nails, sweat glands, oil glands, blood vessels, lymph vessels, nerves and muscles.

**The epidermis** is formed by epithelial tissue. Its thickness is 0.07–2.5 mm. The outer layer of the epidermis is the stratum corneum (keratinocytes), the internal one is the basal layer (consists of basal cells and melanocytes). The stratum corneum consists of dead cells. Basal layer is below the stratum corneum. It consists of living cells. These cells constantly divide to produce new cells that are pushed upward to the layers above. Basal cells become new keratinocytes, which replace the older ones that die and are shed. Within the basal layer are melanin-producing cells known as melanocytes. Melanin is a pigment that helps to protect the skin from harmful ultraviolet solar radiation. The epidermis has sensory nerve terminals (receptors). Derivatives of stratum corneum are nails.

**The dermis** is the thickest layer of skin (0.5 to 5 mm). There are papillary and reticular layers in the dermis. The papillary layer consists of loose fibrous connective tissue and form protrusions into the epidermis. It contains blood and lymph vessels, receptors, fibers that give strength and elasticity to the skin. Under the papillary layer is a reticular layer. It contains sebaceous (oil) glands, sweat glands, hair follicles.

**Sweat glands** regulate body temperature by transporting water to the skin’s surface where it can evaporate to cool down the skin. Such gland consists of a body and excretory duct which opens on the surface of the skin. The human organism have 2–3 million sweat glands. A lot of them are on the face and hands. Sweat glands secrete sweat. Sweat contains \(\text{H}_2\text{O}\), ammonia, urea, mineral salts.
Sebaceous (oil) glands secret oil that helps to waterproof the skin and protect it against microbes. They are attached to hair follicles.

Hairs are derivatives of skin. A hair consists of a hair bulb, root and stem. Hair follicles are tube-shaped cavities that enclose the hair root and provide nourishment to the hair. Vessels and nerves enters the hair follicle. Muscles attached to the hair follicle raises the hair.

The hypodermis is composed of fat and loose connective tissues; this layer of the skin insulates the body and cushions and protects internal organs from injury.

Functions of the skin:
- protection of the organism from the harmful mechanical, chemical, microbiological external factors;
- thermoregulation;
- metabolic (involved in metabolism of vitamin D, urea, water and salt balance);
- it is the organ responsible for the sense of touch (due to tactile, thermal and pain receptors).

12. NERVOUS SYSTEM. STRUCTURE AND FUNCTION OF THE SPINAL CORD

Nervous system regulates the body's responses to internal and external stimuli. Functions of the nervous system are:
- regulates the functioning of all organs and systems;
- connects the body with the environment;
- unites parts of the body into a single unit;
- is the center of all mental activity including thought, learning, and memory.

The nervous system is formed by nerve tissue. Nerve tissue is composed of neurons and neuroglia. Neuron (fig. 54) is a nerve cell. It has processes that project from the cell body — dendrites and axons. Dendrites are usually (but not always), short and branching. This increases their area to receive signals from other neurons. Dendrites are afferent processes because they transmit impulses to the cell body. The number of dendrites of the neuron varies. There is only one axon that projects from each cell body. It is usually elongated and it is called an efferent process because it carries impulses away from the cell body.
Anatomically, the nervous system is divided into the central (CNS) and peripheral (PNS). The central nervous system includes a brain and spinal cord (fig. 55). The peripheral nervous system consists of ganglia, nerves and nerve endings.

Ganglion is a group of neurons that are outside the central nervous system. In the organs and tissues, nerves form receptors (nerve endings).

Nervous system by physiological action is divided into somatic and autonomic (vegetative). The autonomic nervous system regulates the function of internal organs: heart, blood vessels, stomach, liver, lungs and kidneys. It can be sympathetic and parasympathetic. The somatic nervous system innervates skeletal muscle, skin, bones, and organs of sense.

Body and dendrites of neurons are located in the brain and spinal cord, ganglia and form gray matter. Axons of neurons form the white matter of the brain and spinal cord and nerves.

**The spinal cord** is situated in the spinal (vertebral) canal. The cord is covered with three membranes: external (dura), medium (arachnoid) and internal (pia). The space between the arachnoid and pia is filled with cerebrospinal fluid. There are longitudinal grooves on the front and rear surfaces of the spinal cord. They divide the spinal cord into the right and left halves. The length of the spinal
cord is 41–45 cm, diameter is approximately 1 cm. In the cross section, the spinal cord appears oval in shape and has two layers (fig. 56).

Gray matter is situated in the center. It has the shape of a butterfly. In its center there is the spinal canal (the central canal of the spinal cord), which contains cerebrospinal fluid. Gray matter has anterior and posterior horns, and in the thoracic region, in addition, lateral horn. Axons of sensory neurons enter posterior horns and transmit excitation into the spinal cord. The bodies of sensory neurons are in the spinal ganglia (fig. 57).

![Fig. 57. Scheme of the reflex arc](image)

There are intercalary (association) neurons in the posterior horns that trigger excitation to motor neurons. The bodies of the motor neurons are located in the anterior horns. Long processes (axons) leave them to form the front (motor) roots. Excitation is transferred to the working organ through these roots.

The second layer of the spinal cord is made of white matter, which is disposed around the gray matter. It is formed by the axons of neurons. The nerve fibers of the white matter form spinal tracts. They connect the spinal cord to the brain. There are ascending (sensory) spinal tracts and descending (motor) tracts. The ascending tract transfers excitation to the brain, the descending — from the brain to the organs.

The spinal cord has 31 pairs of spinal nerves.

Each nerve has two roots: anterior and posterior. Dorsal roots composed of processes of afferent (sensory) neurons. Ventral (anterior) roots contain processes of centrifugal (efferent, motor) neurons. The anterior and posterior roots form a mixed spinal nerve. Spinal nerves come out of the spinal canal through the intervertebral foramina. The spinal cord has two thickening (cervical and lumbar), which are the point where the spinal nerves comes to the upper and lower extremities.

**Functions of the spinal cord:**

− conductive. The spinal cord conducts impulses from the receptors to the brain (by sensitive tracts) and from the brain to all parts of the body (by motor tracts);
reflex. The spinal cord has centers of sweating, pupil dilatation, diaphragm contractions, micturation, elimination of feces from the intestine and sexual function.

The spinal cord is controlled by the brain.

13. STRUCTURE AND FUNCTION OF THE BRAIN

The brain is situated in neurocranium of the skull. Weight of adult’s brain is 1300–1500 grams. Twelve pairs of cranial (cerebral) nerves come out of the brain. The brain consists of five regions: the telencephalon, diencephalon (together they are forebrain), mesencephalon, metencephalon and medulla oblongata (together they are hindbrain) (fig. 58). Like the spinal cord, the brain is covered with three membranes: dura mater (consists of connective tissue and has a protective function), arachnoid (contains nerves and blood vessels), pia mater (rich in blood vessels). Between the arachnoid and pia is the cerebrospinal fluid.

The medulla oblongata (myelencephalon) connects the brain and spinal cord. It is made of white matter with immersed nuclei of gray matter. The fourth cerebral ventricle is situated there.

Functions of the medulla oblongata are:

– conductive. Conduction of impulses from the spinal cord into the over-lying parts of the brain and vice versa;
– reflex. The medulla contains centers of the vital functions such as breathing, heartbeat, tone of vessels, protective reflexes (cough, sneeze, blink, vomiting) and digestive reflexes (sucking, salivary secretion, secretion of gastric juice, etc.).

The metencephalon includes the pons and cerebellum.

The cerebellum is situated above the medulla oblongata. It consists of two hemispheres, which are connected by the vermis (Latin for worm). Hemispheres covered with cortex (consists of gray matter) which has gyriuses. The pons controls eye movement, muscle contraction that provides facial expressions.

Function of the metencephalon are:

– conduction of impulses from the medulla oblongata into the overlying parts of the brain and vice versa;
– reflex. It contains the coordination centers of movements, balance and body posture, regulation of muscle tone.

The midbrain (mesencephalon) is between the diencephalon and the cerebel-lum. It consists of quadrigemina (Latin for four-hills) and cerebral peduncles (Latin for legs of a brain). In its center a narrow canal passes. It connects the 4th and 3rd cerebral ventricles.
The functions of the midbrain:
- conducts impulses from the metencephalon to the diencephalon, from the cerebral cortex to the medulla oblongata and the spinal cord;
- reflex. Here are the centers of: regulation of muscle tone and posture, innervation of the eye muscles, subcortical centers of vision (upper hills) and hearing (lower hills).

The interbrain (diencephalon) is situated above the midbrain below the hemispheres of the endbrain. It consists of the thalamus and hypothalamus. There is the third cerebral ventricle. The hypothalamus releases neurohormones that regulate the pituitary gland. The pituitary gland regulates the other endocrine glands.

The functions of the diencephalon:
- conducts excitation from the lower parts of the brain to the cerebral hemispheres and back;
- reflex. The thalamus contains subcortical centers of all kinds of sensitivity (centers of sight, hearing, touch, taste). There are centers of the regulation of sleep and wakefulness, emotions and mental activity. The hypothalamus contains the centers which regulate metabolism, homeostasis, and activity of cardiovascular system, centers of digestion, thirst, hunger, and body temperature.

The endbrain (telencephalon) includes the cerebral hemispheres (about 80% of the mass of the brain) and the corpus callosum. First and second cerebral ventricles are situated there.

Cerebral hemispheres are covered with the cortex made of gray matter. The thickness of the cortex is approximately 2–4 mm. It consists of 14 billion nerve cells that form six layers. Under the cerebral cortex there is white matter where the bodies of neurons (subcortical nuclei) are situated. The cortex has sulci (fissures) and gyriuses (folds). They increase the area of the cortex, which is 2000–2500 cm². Three deep sulci divide the cortex into the frontal, temporal, parietal and occipital lobes (fig. 59). The lobes of the cortex contain different zones: the visual area is in the occipital lobe, the area of skin-muscular sense is in the parietal lobe, auditory area is located in the temporal lobe.

Fig. 59. Lobes of the cerebral cortex
**The functions of the cerebral cortex are:**
- regulation of all the regions of the brain and spinal cord;
- analysis of the information received by the sense organs;
- it is the center of conditioned reflexes;
- it is responsible for learning, thinking, memory and speech.

14. **SENSORY ORGANS. STRUCTURE AND FUNCTIONS OF THE VISUAL ORGAN**

**Sense organs** are organs which receive signals from the environment and transmit them to the central nervous system. Sense organs help to orient in the environment. Human has the organs of sight, hearing, smell, touch, taste and equilibrium.

An analyzer is a system that receives, transmits and analyzes information about the external and internal environment of the body.

**The analyzer consists of 3 parts:**
1. *The peripheral* part is receptors of sense organ;
2. *The conducting* part is the nerves which transmit excitation (pulse) from a sense organ to the cerebral cortex;
3. *The central* part is the area of the cerebral cortex, which analyzes received information.

**The organ of vision** consists of eyes and auxiliary apparatus: eyebrows, eyelashes, eyelids, lachrymal glands, eye muscles. The auxiliary apparatus protects the eyes from dust, snow, mechanical and chemical damage. The eyeball is situated in the orbit of the skull. Eye wall has *three membranes*:
- external — fibrous tunica (sclera, cornea);
- medial — vascular tunic (choroid, ciliary body, iris);
- internal — reticular (retina).

The front transparent part of the *fibrous tunica is the cornea*; the rest of the tunica forms the dense part called *the sclera*.

**Vascular membrane** has many blood vessels. The inner side of the choroid contains pigment cells. Its front part forms the *iris* which contains a pigment that stains eyes in different colors — blue, brown, black. Between the cornea and the iris there is *the anterior chamber* of the eye, which is filled with fluid. The round hole in the iris is *pupil*. There is a transparent biconvex *lens* behind the pupil. Behind the lens is *vitreous body*. Between the iris and the lens is *posterior chamber* of the eye which is filled with fluid.

Image of the object focuses on the retina. **The retina** contains two kinds of photoreceptors — *rods and cones*. There is about 7 million cones and 130 million rods in the retina (fig. 60). The rods contain visual pigment rhodopsin and perceive twilight. The cones have pigment iodopsin and perceive daylight and colors in bright light.

In the opposite of the pupil, retina has a *yellow spot (macula)*. The macula is a region of the retina which has a lot of receptors (cones). Near yellow spot,
there is a region that has no photoreceptors. This area is called the blind spot. Blind spot is a point where the optic nerve exits the retina (fig. 6.1.)

Transparent structures of the eye through which light rays pass are an optical system of the eye. The system includes the cornea, fluid of anterior chamber, pupil, fluid of posterior chamber, lens, and vitreous. The main structures of the optical system are the cornea and lens.

**The mechanism of sight:**
1. Light rays pass through the cornea, anterior chamber, pupil, posterior chamber, lens, vitreous body and fall on the retina.
2. Photoreceptors of the retina perceive visual stimuli.
3. The optic nerve conduct the impulse from receptors into visual area of the cortex (the occipital lobe) which analyze visual stimuli.
4. A person can see things around.

![Fig. 60. Structure of the retina](image)

![Fig. 61. Anatomy of the eye](image)
If the rays cannot be focused on the surface of the retina, vision impairments:

**Myopia (near-sightedness).** Light rays are focused in front of the retina. A person can see well only close situated objects;

**Hyperopia (longsightedness).** Light rays are focused behind the retina. A person can see well only far objects.

The sight provides orientation, reading, writing, drawing and etc.

15. **STRUCTURE AND FUNCTIONS OF THE HEARING ORGAN**

It is commonly known that the organ detecting sound is an ear, but it also provides balance and body position. **The organ of hearing** consists of three parts: the external, middle and inner ears (fig. 62). Receptors of hearing organ are the peripheral part of the auditory analyzer.

**The outer ear** includes the auricle, external auditory canal, and ear-drum. The auricle consists of cartilage covered with skin and collects sound. The external auditory canal is a tube with length approximately of 30 millimeters. There are glands that secrete earwax which retains dust and bacteria. The eardrum is a thin membrane that perceives sound waves. It also separates the external ear from the middle one.

**The middle ear** consists of the tympanic cavity. Its volume is about 1 cm³. There are 3 auditory ossicles (ear bones). Tympanic cavity of the middle ear is connected with the nasopharynx by the Eustachian (acoustic) tube. The acoustic tube equalizes pressure on both sides of the eardrum. The auditory ossicles are malleus, incus and stapes. They are connected to each other. Stapes is connected to the membrane of the oval window of the inner ear.

**The inner ear** is located in the temporal bone of the skull. It contains the organ of hearing (the cochlea) and the organ of equilibrium. **Cochlea** is spirally twisted bony canal. The bone canal have two membranes (fig. 63) which divide it into three ducts (scalae):

1. The vestibular duct is divided by the vestibular membrane. It is filled with perilymph.

![Fig. 62. Anatomy of the ear](image)
2. The tympanic duct is divided by the basilar membrane. It is filled with *perilymph*.

3. The cochlear (membranous) duct is between the vestibular and basilar membranes. It is filled with *endolymph* and contains the *organ of Corti* which perceives the sound.

![Anatomy of the cochlea](image)

*Fig. 63. Anatomy of the cochlea*

The basilar membrane is composed of fibers of different lengths. There are long fibers at its top and short ones at the base. Auditory receptors are located on the basilar membrane. One of their ends is fixed to the membrane and the other free and ends with hairs. Ends of the auditory nerve begins in the fixed ends of the receptors. There is the tectorial membrane over the basilar membrane.

**The mechanism of sound perception:**

1. Sound waves are collected by auricle. They pass through the external auditory canal and cause vibrations of the eardrum;

2. Vibrations of the eardrum are conducted by ossicles: malleus → incus → stapes.
3. The ossicles increase the intensity of sound up to 20 times;  
4. Vibrations of stapes are transmitted to the membrane of the oval window;  
5. Vibrations of the membrane of the oval window cause fluctuations of perilymph and endolymph;  
6. Fluctuations of the endolymph make tectorial membrane oscillate;  
7. The tectorial membrane irritate hearing receptors of the basilar membrane. Nerve impulse appears in the receptors;  
8. The auditory nerve conduct the impulse to the temporal lobe of the cerebral cortex where center of the hearing is situated;  
9. The temporal lobe of the cerebral cortex analyze the acoustic signal. 
Hearing organ allows orientation in the environment and communication with other people, hearing music, speech and etc.

16. REPRODUCTIVE SYSTEM. STRUCTURE AND FORMATION OF GAMETES

Reproduction is the property of organisms to create new individuals of their kind. Due to reproduction new generations can replace old ones. Reproduction thus provides the continuity of life and is essential for survival of the species. 

Functions of the reproductive system are: 
– production of gametes (ova and sperms);  
– providing meeting of these gametes;  
– nutrition of a developing embryo and fetus;  
– production of hormones.

A reproductive system consists of internal and external genital organs (fig. 64).

Male internal genital organs are testes and their epididymides (singular – epididymis), the vasa deferens with the seminal vesicles and prostate gland.

Male external genitalia are penis and scrotum.

The testes are male sex glands. They are located in the scrotum. Testes produce sperms and male sex hormones (testosterone). Their size is about 3–5 cm, weight is 15–30 g.

Female internal genital organs are 2 ovaries, fallopian tubes, uterus and vagina.

Female external genitalia are labia majora, labia minora, the clitoris (fig. 65).

Ovaries are female sex glands forming female gametes (ova) and female hormones (estrogens). They are located in the abdominal cavity. They maturate in 12–15 years. The length of the ovary is 3–4 cm, weight is 6–7 grams.

Fallopian tubes have a length of 10–12 centimeters, fertilization occurs there. Uterus is a muscular hollow organ where the fetus develops.
Fig. 64. Male reproductive system

Fig. 65. Female reproductive system
The process of formation of gametes is called gametogenesis (table 3). The gametogenesis of female gametes is called oogenesis.

**Table 3**

<table>
<thead>
<tr>
<th>Genetic information</th>
<th>Cells names</th>
<th>Spermatogenesis</th>
<th>Ovogenesis</th>
<th>Cells names</th>
<th>Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>2n2chr</td>
<td>Spermatogonia</td>
<td><img src="image" alt="Spermatogonia Diagram" /></td>
<td></td>
<td>Ovogonia</td>
<td>Proliferation (mitosis)</td>
</tr>
<tr>
<td>2n2chr</td>
<td>Primary spermatocytes</td>
<td><img src="image" alt="Primary Spermatocytes Diagram" /></td>
<td>Primary ovocytes</td>
<td>Growth</td>
<td></td>
</tr>
<tr>
<td>1n2chr 1n1chr</td>
<td>Secondary spermatocytes</td>
<td><img src="image" alt="Secondary Spermatocytes Diagram" /></td>
<td>Secondary ovocytes</td>
<td>Maturation (meiosis)</td>
<td></td>
</tr>
<tr>
<td>1n1chr</td>
<td>Spermatides</td>
<td><img src="image" alt="Spermatides Diagram" /></td>
<td>Transformation</td>
<td>Ovum</td>
<td></td>
</tr>
<tr>
<td>1n1chr</td>
<td>Spermatozoa</td>
<td><img src="image" alt="Spermatozoa Diagram" /></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Formation of oocyte takes place once a month from puberty (12–13 years) and up to 45–50 years old. **Oogenesis consists of periods:**

1. During the period of proliferation diploid oogonia (set of chromosomes is 2n2chr) divide by mitosis to multiply.
2. During the period of growth oogonia accumulates nutrients, grow and transform into primary oocytes (set of chromosomes is 2n2chr).
3. During the period of maturation primary oocytes begin meiosis. After first meiotic division the primary oocyte divides into two haploid cells (set of chromosomes is 1n2chr) a large secondary oocyte and a small polar body. During the second meiotic division, the secondary oocyte form the ovum (set of chromosomes is 1n1chr) and a new polar body.

The human ovum has a spherical shape, its size is about 0.13 mm (fig. 66). It contains a nucleus with haploid set of chromosomes, cytoplasm with organelles and nutrients (yolk). The egg cell is immobile. It is covered with two layers (primary and secondary).

The formation of male gametes is spermatogenesis. Formation of sperms occurs since the puberty to old age.

**Spermatogenesis includes the following periods:**

1. During the period of proliferation diploid spermatogonia multiply by mitosis. Chromosome set doesn’t change (2n2chr).
2. During the period of growth spermatogonia transform into primary spermatocytes (2n2chr).
3. During the period of maturation the primary spermatocytes divide by meiosis. After the first meiotic division each primary spermatocyte form 2 haploid secondary spermatocytes (1n2chr). After the second meiotic division, each secondary spermatocytes divide into 2 spermatids (1n1chr). Consequently, each primary spermatocyte form four spermatids;

4. During the period transformation (formation) the spermatocytes transform into the spermatozoons (sperms). Chromosome set does not change and is 1n1chr.

Spermatozoa consist of a head, neck (midpiece) and tail (fig. 67). The head contains the haploid nucleus and an acrosome (modified Golgi apparatus). The neck contains the cell center and the mitochondria. Sperms are much smaller than egg cells, their length are 55 micrometers (head is about 5 micrometers).

![Spermatozoon](image)

Fig. 67. Spermatozoon

Egg cell and sperm, fuse during fertilization to transform into a zygote. The zygote contains a diploid set of chromosomes (2n). In the mother’s body, the zygote begins development into the embryo and fetus. This development goes in the uterus.
Section 4: ZOOLOGY

1. THE CONCEPT OF PROKARYOTES AND EUKARYOTES. BACTERIA

There are two huge groups of living organisms: prokaryotes and eukaryotes. **Bacteria** refer to the first group. Their cells do not have nuclei and membrane-enclosed organelles; fission by mitosis or meiosis is not possible for them. The second group is eukaryotes. It includes plants and animals. Such cells have nuclei and membrane-enclosed organelles; they are able to divide by mitosis and meiosis.

Bacteria are tiny unicellular (consist of only one cell) organisms. Their sizes are from 0.2 to 13 micrometers. Bacteria are seen only under a microscope with high magnification.

**Living conditions** of bacteria. Optimal conditions necessary for them are the temperature +35 °C – +40 °C, presence of water, nutritive substances and for most of bacteria oxygen.

**Abundance of bacteria.** Bacteria live everywhere. Their most concentration is found in the soil to the depth of about 3 kilometers. Bacteria are also observed in the water, in the air at an altitude of about 12 kilometers; they are in living and dead animals and plants.

**Structure of bacteria.** According to the shape (fig. 68), bacteria are: bacilli (shape of rods), cocci (shape of spheres), vibrions (shape of commas) and spirilla (shape of spirals).

There are mobile and immobile forms of bacteria. Their organs of movement are one or several flagella which can be attached to one side of the cell or cover all its surface.

From the outside, mucous capsule, cell wall and plasma membrane cover the cell of a bacterium (fig. 69). The capsule is a protective covering.

Fig. 68. Types of bacteria according

Fig. 69. Anatomy of the bacterial cell to their shape
Bacterial cytoplasm contains only nucleoid. It is a circular DNA molecule that is attached to the plasma membrane by special proteins. It is a genetic apparatus of the cell. None of bacteria has membrane-enclosed organelles. Functions of mitochondria, Golgi complex and endoplasmic reticulum are performed by mesosomes which are invaginations of the plasma membrane. A lot of ribosomes are found in the cytoplasm of bacteria. These organelles make proteins.

According to feeding type (assimilation), bacteria are autotrophic and heterotrophic. The autotrophic ones synthesize organic compounds from non-organic substances for themselves. They can use energy of the sun (such bacteria are photosynthetic) or energy of chemical reactions (such bacteria are chemosynthetic).

Bacteria that use ready-made organic compounds are heterotrophic bacteria. For instance, lactic-acid bacteria transform sugars into the lactic acid. Other kind of heterotrophs are bacteria-parasites. They feed on organic compounds of living organisms.

According to dissimilation, bacteria are aerobes and anaerobes. Aerobic bacteria (an example is tubercle bacillus) require oxygen for living while anaerobic ones live only in mediums without oxygen (examples are drumstick bacillus and lactic-acid bacteria).

Reproduction of bacteria occurs asexually: the cell divide into two. In favorable environmental conditions, a bacterium can divide every 20–30 minutes and produce more than 600 million new bacteria in one day. There is a sexual process called conjugation in some bacteria. During this process, two bacteria stay close to each other and form a cytoplasmic bridge. Through that bridge, some DNA goes from the one cell to the other. When the process is done bacteria diverge. Conjugation renews the genetic information of the bacterial cell.

If environmental conditions are unfavorable, some bacteria transform into spores. At that process the cytoplasm shrink and the cell covers with a hard shell. The spore is the dormant form of a bacterium. Bacteria can stay in such form for many years. Spores are transmitted by wind, water or animals. In favorable conditions bacteria come out of the shell to give rise to new cells.

Significance of bacteria. Significance of bacteria in the nature is great. They clean up the environment from decaying corpses and remains of animals and plants. Chemosynthetic bacteria enrich the soil with minerals. Human found the way to use bacteria for making food: kefir, sour creme, cheese, butter, vine and etc; in chemical industry they are used for synthesis of alcohols, acetone, acetic acid and other chemicals; in medicine bacteria are the source of antibiotics, vitamins, enzymes, hormones.

Many bacteria are unuseful or even harmful for human. They spoil food, damage books in libraries, cause diseases of human, animals and plants. Parasitic bacteria are pathogenic agents of cholera, plague, tuberculosis, tonsillitis and a vast number of other diseases. Such ones are known as malignant
(pathogenic) bacteria. Human can be infected by the contact with sick persons, by water and food containing bacteria or their spores.

There are methods of controlling the diseases elaborated such as illuminating the hospital wards with ultraviolet rays. Surgical instruments and bandage material are processed with solution of hydrogen peroxide or with high temperature. To prevent infection, control of water and food purity is performed. Important factor to prevent diseases is vaccination.

2. Kingdom Protists. Parasitic protists

The science Taxonomy (Systematics) studies the classification of living organisms. Units of taxonomy are taxons (for example species, phylum, kingdom). The smallest unit of biological classification is species (fig. 70). For example, Homo sapiens — a reasonable man. The largest taxonomy unit is a kingdom, the next lesser taxon is phylum.

The kingdom of single-celled eukaryotic organisms is called the kingdom Protista.

This kingdom includes phylums:
1. Sarcomastigophora (for example Amoeba, Euglena, Giardia);
2. Ciliata (for example Paramecium caudatum);
3. Apicomplexa (for example Malaria parasite).

Many protists such as amoeba (fig. 71), euglena (fig. 72), ciliates are free-living. They are in the soil and water. Their body is composed of just one cell which performs the functions of the whole organism. Such cells can reach 2–3 mm in size. The shape of the body is changeable in amoeba and constant in euglena and ciliates.

Fig. 70. Taxonomic units

Fig. 71. Amoeba

Fig. 72. Euglena
The integument is various: the amoeba is covered only with the plasma membrane, euglena and ciliates have a special thin layer supporting the cell membrane called pellicle. Like all eukaryotic cells, protists have organelles — parts of the cytoplasm which function like organs of multicellular organisms. The cytoplasm of protists has two layers. The outer layer is dense and homogeneous. It is called ectoplasm. The inner one is liquid and granular, it is endoplasm. The endoplasm contains various organelles.

Locomotion is performed by specific organelles. The amoeba uses pseudopodia which are extensions of the cytoplasm. The locomotor organ of the Euglena is flagellum. Ciliates are covered with hair-like organelles called cilia. The cilia are used for locomotion and feeding.

Like most of eukaryotic cells, the cell of euglena and amoeba contain one nucleus. However, ciliates have two nuclei: the large one is called macronucleus, the small one is micronucleus. The macronucleus is a vegetative nucleus — it regulates cell metabolism. The micronucleus is generative and involved in the sexual process.

According to the feeding type, protists are autotrophs and heterotrophs. The euglena is both autotrophic (has a green pigment chlorophyll) and heterotrophic. Amoebae and ciliates are heterotrophs. The amoeba feeds by phagocytosis. It surrounds food particles with pseudopodia. They interlock and the food particle enters the cytoplasm and form a vacuole. Digestion occurs in the digestive vacuoles. Such vacuoles contain enzymes and digested food particles. Undigested remains of food are excreted by exocytosis. Being the most complicated protists, ciliates «swallow» food particles with water through the oral groove and the mouth opening. Remains of food are excreted through the anal pore.

Some protists (fig. 73) have organelles that help them to excrete water and liquid metabolic products — contractile vacuoles. Berating of protists goes by the all body surface.

Reproduction of protists is asexual. It occurs by mitosis or amitosis. Ciliates also have conjugation — sexual process which «updates» their genetic information. It is called conjugation. During the conjugation two ciliates connect with mouth openings and exchange the parts of micronuclei.

If the environmental conditions become unfavorable, protists form cysts: the cell shrinks, drops or draws-in their locomotion organelles, stops feeding and covers with a dense shell. The shell protects the body from drying out, low temperature, the action of toxic substances. Cysts are also help protists to spread on.
The capability of protists to respond on various external influences is called *irritability*. The form of irritability in protists is taxis. For example negative chemotaxis is observed when ciliates leave the water droplets with high concentration of salts; positive phototaxis is movement of euglena to the light.

**Many protists are parasites.** Organisms, which live in another organisms of plants, human and animals, eat their organic substances and do them harm are called parasites. The person or an animal where the parasite lives is called the host of a parasite. Parasites cause diseases of the host.

Many parasitic protists have no digestive vacuoles and absorb ready-made nutrients through the plasma membrane. Metabolic products are also excreted through the membrane.

*Giardia* belongs to the phylum Sarcomastigophora. It is pear-shaped, has two nuclei and eight flagella. Giardia's cysts enter the body with water or dirty fruits and vegetables. In the human body, giardia lives in gallbladder and duodenum and causes their inflammation. The disease it cause is called *giardiasis*.

*Entamoeba histolytica* also belongs to the phylum Sarcomastigophora and causes *amoebic dysentery* in humans. Cysts of amoebae are transmitted through contaminated food and water. This is the way amoeba enter the body. The parasite destroys the intestinal wall and small blood vessels. The common symptom of amoebic dysentery is diarrhea with blood. Amoebae spread by forming invasive cysts with four nuclei, which can be found in stools. These cysts can get to another organism and cause the disease.

*Malaria parasite* (*genus Plasmodium*) belongs to phylum Apicomplexa. The malaria parasite causes *malaria*. The disease is transmitted by the bite of an infected female Anopheles mosquito. This bite introduces the parasites from the mosquito's saliva into a human’s blood. Then parasite travels to the liver where a high number of plasmodia is formed. Such asexual reproduction of plasmodia is called *schizogony*. Then the plasmodium leaves the liver and enters red blood cells.

Schizogony occurs again in erythrocytes. During this reproduction, malaria parasites destroy red blood cells and liver cells. Their metabolic products are toxic for a human. The main symptom of malaria is fever. Fever a symptom associated with increased body temperature above the normal. Malaria is a serious disease which can even end up with death.

There are special diagnostic methods for these diseases. Microscopy is the most common method used to detect the malaria parasite. A blood sample is taken for the diagnosis of malaria. The malaria parasites can be seen under the microscope.

**The significance of protists.** All protists participate in the circulation of substances in the nature, they are food for animals. They decompose organic substances and purify the environment.

As parasitic protists cause human diseases, they have medical significance.
3. Characteristics of the Phylum Platyhelminthes (Flatworms)

About 18,000 species are described. Free-living flatworms live in water and soil; parasites are in the human and animal organisms.

The phylum Platyhelminthes has the following classes:

1. Turbellarians. For example, planaria. They are free-living.
2. Flukes (Trematoda). Examples are a liver fluke (lat. Fasciola hepatica) and cat liver fluke (lat. Opisthorchis felineus). All flukes are parasites.
3. Tapeworms (Cestoda). The class includes a pork tapeworm (lat. Taenia solium), beef tapeworm (lat. Taeniarhynchus saginatus). Tapeworms are parasites.

Body sizes of flatworms are from 1 millimeter to 20 meters in length. Bodies can have shapes of leaves or tapes. They have bilateral (double-sided) symmetry.

Flatworms develop form 3 germ layers — ectoderm, entoderm and mesoderm.

The body of flatworms is covered with the dermo-muscular wall (skin-muscular sac). It’s outer layer is simple epithelium. Below this layer, 3 layers of smooth muscles (circular, diagonal and longitudinal) are situated. Locomotion (movement) of flatworms is provided by contraction of muscles. In turbellarians cilia also participate in locomotion.

The parasitic flatworms have suckers and hooks — special organs which help them to attach to the host’s body.

Internal anatomy. Flatworms have no body cavity (fig. 74). The space between organs is filled with connective tissue which develops from the third germinal layer (mesoderm). It performs structural function, participates in metabolism and regeneration.

Flatworms have digestive, excretory, reproductive and nervous systems (fig. 75).
The digestive system consists of foregut and midgut. The foregut includes mouth and pharynx. Digestion and absorption of nutrients occur in the midgut. Flatworms have no hindgut with excretory opening and regurgitate undigested material through the mouth. A planaria has a muscular pharynx in the anterior region of the digestive system. The muscular pharynx is able to turn out from the mouth to «swallow» food. Tapeworms are parasites which have no digestive system.

The excretory organs are protonephridia. They begin in the parenchima with star-shaped cells with cilia. These cells collect liquid metabolic products. Short channels extend from the star-shaped cells and open into a general excretory duct that ends with excretory opening.

Flatworms have no circulatory and respiratory systems. Gas exchange goes through body surface. Transport of gases, nutrients and dissimilation products are performed by parenchyma.

The nervous system consists of two cerebral ganglia and several nerve cords which extend along the body. Flatworms have organs sensitive to light, touch and organs of chemical senses.

Reproduction is sexual or asexual. Flatworms are hermaphrodites. They have male and female gonads (spermsaries and ovaries). Eggs develop inside the body. Special glands feed these eggs and secrete substances forming their capsules. There is a complex system of channels containing eggs and their excretion.
Turbellarians multiply asexually by fragmentation. Sexual reproduction is more common and is more perspective because it increases gene diversity and, consequently, the survivability of the species.

Free-living worms such as planarians have direct development. Young planarians leave eggs which are laid in cocoons. Parasitic flatworms are characterized by high fertility and complex life cycles. During such life cycle, larvae develops and change hosts.

**The significance of flatworms:** flatworms are the components of ecosystems. They are food for larger animals. Flukes and tapeworms cause parasitic diseases of humans and animals and have a medical significance.

### 4. CHARACTERISTICS OF THE CLASS TREPATODA (FLUKES)

Parasitic worms of any phylum and class which cause diseases are called helminthes. The diseases caused by helmints are helminthiases (helminthoses).

There are about 3000 flukes. All of them are parasites of animals and humans.

In this chapter, anatomy of flukes is considered by an example of a liver fluke (lat. Fasciola hepatica).

**The Fasciola hepatica** (fig. 76) has leaf-shaped body which can reach 3–5 cm in length. There are oral and ventral suckers on the abdominal surface.

The Fasciola hepatica lives in the liver ducts of many mammals, especially ruminants and humans. It attaches to the wall of the bileduct by suckers.

All the organs of the liver fluke develop from three germ layers — ectoderm, entoderm and mesoderm.

The outer layer of the *dermo-muscular body wall* is tegument. It protects the Fasciola hepatica from the action of host enzymes. Below the cuticle are three layers of smooth muscles (circular, diagonal and longitudinal). The space between organs is filled with *parenchyma*.

**The digestive system** consists of a foregut (mouth and pharynx) and midgut. Two branches of the midgut are strongly branched. Flukes have no hindgut with an anal opening and regurgitate undigested remains of food through the mouth.

**The excretory organs** are protonephridia. *Circulatory and respiratory systems are absent.*

**The nervous system** consists of two cerebral ganglia and several nerve cords. Nerve cords extend along the body. Flukes have organs sensitive to *light and chemical substances.*

**Reproductive system.** Flukes are hermaphrodites. They have complex life cycles. The life cycle (fig. 77) of a liver fluke includes two hosts and several stages of larvae. The organism where sexual reproduction of mature fluke occurs
is called the principal host. The principal hosts of the liver fluke are cattle or human.

The principal host excretes the fluke eggs from the intestine to the environment. If eggs get to water, they continue their development. A larva with cilia — *miracidium* — comes out of the egg. The miracidium has to get into the intermediate host — a freshwater snail. In the intermediate host the parasite reproduce asexually.

The miracidium passes through several stages of development in the body of the snail. Mobile larva with a tail comes out from the snail in the water. It is called *cercaria*. Cercaria attaches to water plants and covers with a dense shell. It transforms into a dormant larva called *adulescaria*. The adulescaria are swallowed by the cattle or sometimes humans during drinking unboiled water from reservoir, and also eating the vegetables and fruit which are washed up with this water. In the duodenum, the adulescaria transforms into the *fluke* and gets to the liver. Then the Fasciola hepatica destroys the bile ducts and liver tissue. This cause inflammation in the liver and impair the bile excretion.

![Life cycle of the Fasciola hepatica](image)

The disease caused by the liver fluke is called *fascioliasis* or *fasciolosis*. It refers to helminthiasis. Methods of prevention the disease are prophylaxis.

**The prophylaxis of fascioliasis includes measures:**
1. Do not drink water from open reservoirs and do not wash vegetables with such water.
2. Elimination of the intermediate hosts (snails).
3. Prevent the pollution of reservoirs with human and animal feces.
4. Revelation and treatment of affected persons.
Beside the Fasciola hepatica, there are many other flukes: a lung fluke which parasitizes in the airways and lungs of human; a cat liver fluke lives in the human liver; blood flukes parasitize in the large veins of the abdominal cavity.

5. Characteristics of the class Cestoidea (Tapeworms)

Approximately 1800 tapeworms are described. All tapeworms are parasites of animals and human. The majority of tapeworms live in the digestive system.

External anatomy. As is seen from the name of the class, tapeworms have a tape-like body shape. Its length is from 1 mm to 10–18 m. The body consists of a scolex (head), neck, and strobila (segmental body). Tapeworms have suckers and hooks on the head. These organs are used for attachment to the host’s body.

Flatworms have the dermo-muscular body wall without body cavity. Its external layer is tegument which protects the parasite from digestive system of the host.

Internal anatomy. Tapeworms have no circulatory, respiratory and digestive systems.

Nutrients are absorbed from the host’s intestine by the body surface (tegument) with help of microvilli. The microvilli are outgrowths of the outer layer of the body wall.

The excretory organs are protonephridia.

The nervous system and sense organs are poorly developed.

Tapeworms are hermaphrodites. They have complex life cycles, several larval stages and several hosts (principal and intermediate).

A representative of tapeworms is a beef tapeworm (lat. Taeniarhynchus saginatus).

External and internal anatomy of the Taeniarhynchus saginatus. An adult worm is normally 10 meters in length. The scolex has four suckers without hooks (fig. 78). The cervix (neck) is the tapeworm’s growth zone which forms new segments. The parasite grows all its life. Segments of the middle of the body contain both male and female reproductive systems. Such segments are called immature, or hermaphroditic. Segments of the rear part of the body are mature and contain uterus with a large amount of eggs.

The life cycle is complex (fig. 79).

The principal host of the beef tapeworm is human. Mature segments with eggs separate from the worm’s body and are excreted with feces. Cattle is the intermediate host which swallows the eggs with contaminated grass. In the intestines, a larva with hooks called oncosphere leaves the egg. With hooks it perforates the intestinal wall and get to the blood vessels. The larvae can move to all parts of the body by the circulatory system, and finally settle in skeletal muscles. Inside skeletal muscles the second larval stage is formed. It is called the measles (also finn).
Measle looks like a bubble. Inside the measle the head of a young beef tapeworm is screwed. Humans can be infected by eating undercooked meat with measles. In the human intestine adult stage of beef tapeworm is formed of measles.

Taeniarhynchus saginatus absorbs nutrients in the human body; its suckers destroy the intestinal mucosa; metabolic products of tapeworm are toxic for humans. All of these changes in the human body lead to the development of the disease. The group of diseases caused by tapeworms is called cestodoses.

Prophylaxis of cestodosis:
1. Strong heat of beef meat;
2. Identification and treatment of affected persons.

There are also many other tapeworms. A pork tapeworm (Taenia solium), a broad tapeworm (Diphyllobothrium latum), a dwarf tapeworm (Hymenolepis nana) can parasite in the small intestine of human.

6. CHARACTERISTICS OF THE PHYLUM NEMATHELMINTHES (ROUNDWORMS)

The number of species is about 15 500.

Phylum Roundworms has five classes. The most considerable one is Nematoda.

Habitat: water, soil, the human body, animals and plants. The way of living: free-living and parasitic forms.

External anatomy. Bodies of roundworms are not divided into parts (segments). They have round body shape in cross section (fig. 80). This gave the name to the class. The length of the body is from a few millimeters to several meters.

On the front end of the body the mouth opening and sense organs are situated. On the ventral side of the body is an excretory opening. The ventral body
side of female worms has a genital opening which is approximately in the middle. Anus is located on the rear end of the body.

Roundworms have *dermo-muscular body wall*. It’s external layer is cuticle. Tegument protects the parasite from digestion in the host and carries out functions of an external skeleton. Under the cuticle is epithelial tissue called hypodermis. There is a single layer of longitudinal muscle cells under the hypodermis. Contractions of the longitudinal muscles bend the body and cause its serpentine movements.

**Internal anatomy.** Body cavity is primary (*pseudocoel*). It is filled with fluid, which is under high pressure. Fluid performs the function of hydrostatic skeleton and transport substances, participates in metabolism. *Roundworms have no circulatory and respiratory systems.*

The digestive system (fig. 81) consists of three region: foregut (mouth, pharynx and esophagus), midgut and hindgut which ends with the anus. In some species the mouth is surrounded by cuticular lips, others have cuticular outgrowths — teeth.

The esophagus has the expansion — bulbus. Digestion is mostly cavernous. Free-living roundworms feed on decaying organic matter and small invertebrates. Intestinal parasites feed on tissues and fluids of the internal environment of the host. Undigested food is removed through the anus.

The excretory system is represented by 1–2 skin glands similar to protonephridia. There are large cells and channels extending from them. Channels end blindly in both ends of the body but have excretory opening on the anterior ventral body surface. In addition, liquid products of metabolism are neutralized by phagocytic cells, which are found along the excretory channels.

The nervous system consists of two cerebral ganglia, circular nerve ring surrounding the pharynx and 4 nerve cords. Dorsal and ventral nerve cords are developed better. Roundworms have *organs sensitive* to touch and organs of chemical senses.
Reproductive system. Most roundworms have separate sexes. Sexual dimorphism is expressed: males are smaller than females, and the rear end of the male body is screwed on the ventral side. The reproductive system has the form of tubes.

The male reproductive system is unpaired and consists of spermaries, seminal duct and ejaculatory duct. The female reproductive system is paired and consists of two ovaries, two oviducts, two uteri and one unpaired vagina.

Reproduction is sexual, insemination is internal. Development is indirect (with metamorphosis). It often occurs without a change of hosts and the larva develops in soil or water. Development is accompanied by molting. Some species tend to viviparity. Parasitic roundworms are characterized by complex life cycles.

Significance of roundworms: They are components of ecosystems and are food for many other organisms. They participate in soil formation, many of them are causative agents of parasitic diseases.

A human ascaris (lat. Ascaris lumbricoides) refers to roundworms. The length of a female is about 40 centimeters; of a male is about 25. Alive parasites are white-pink. Their bodies are cylindrical and sharpened at ends. Sexually mature individuals live in the small intestine.

Life cycle. A fertilized female lays up to 250 000 eggs per day. They are excreted from the body and get into the soil. A larva develops in the egg in 2–3 weeks in favorable conditions (temperature is 20–25 °C, humidity and oxygen). Such eggs get into the host organism with unwashed vegetables, fruit and water. Larvae comes out of eggs in the small intestine, perforate its wall and get into blood vessels. They pass through the liver, right atrium and right ventricle. Then they are carried into the lung capillaries with the flow of blood. Larvae get into alveoli through the capillary walls; ascend into bronchioles, bronchi, trachea and get into the pharynx where they are swallowed. In 3 month, they transform into sexually mature forms in the small intestine. Larvae migration lasts about 2 weeks. Life span of the mature ascaris is about 1 year.

Ascaris cause the disease ascariasis (ascaridosis). These parasites consume nutrition from the host organism. The larvae injure the intestine wall, blood vessels and respiratory tract and excrete toxic metabolic products.

Prophylaxis of ascariasis:
1. Observance of individual hygiene.
2. Washing the vegetables and fruits.
3. Protecting food from flies and cockroaches.
4. Preventing pollution of the soil and water with feaces;
5. Revealing and treatment of infected persons.

There is a number of other parasitic roundworms such as pinworms, guinea worms, filariae. Diseases caused by roundworms are called nematodoses.
7. Characteristics of the Phylum Arthropoda

The phylum Arthropoda is the most numerous one in the whole nature. More than 1.5 millions of species belong to arthropods.

Habitat of arthropods are land, air, soil and water. The phylum includes free-living species and parasites of human, animals and plants.

The phylum Arthropoda consists of three classes:
1. Crustaceans (crawfishes, langoustes and prawns);
2. Arachnids (spiders, scorpions, ticks and mites);
3. Insects (flies, butterflies, beetles, mosquitoes and others).

Most of arthropods have bodies made of segments. Normal body sizes are from 0.1 mm to 1 m; Segments form body regions:
- three: head, thorax, abdomen (insects);
- two: cephalothorax, abdomen (crawfishes (fig. 82) and spiders).

Bodies of ticks (and mites) are solid and do not have regions.

Body coverings. Arthropods are covered with organic compound chitin. It is an exoskeleton that protects and supports the arthropod’s body. Striated muscles are also attached to chitinous exoskeleton.
Arthropods periodically undergo moulting when they cast off their old chitin to replace it with a new one. Growth of their bodies is possible only in this periods.

**Organs of locomotion.** All arthropods have segmented appendages (consist of segments) that are immovable and attached to the body with joints. They perform various functions: feeding, protection from enemies and locomotion. Arthropods of different classes have different number of walking legs: crustaceans have 5 pairs, arachnids have 4 and insects — 3.

**Internal anatomy.** Arthropods have mixed body cavity that is formed by association of primary and secondary body cavities. Such cavity is called *mixocoel*. It is filled with fluid called hemolymph. It is colorless liquid which perform both functions of blood and interstitial fluid.

A **digestive system** consists of 3 parts: front, middle and posterior. The front one is made of a mouth opening, pharynx, esophagus, sometimes crop, stomach. The middle part includes the midgut (middle gut). The posterior part of the system is composed of a hindgut and anal opening. There is a complex apparatus at the beginning of the forepart of the digestive system — mouthparts. It should be noted that arthropods have well-developed digestive glands (salivary ones and a liver).

An **excretory system** is represented by modified metanephridia (green and coxal glands) or Malpighian tubules (outgrowths of the gut). Insects have a corpus adiposum (fat body) which is the organ of the excretory system that accumulates unnecessary substances and store nutrients.

A **circulatory system** of arthropods consists of a heart and vessels. The heart is located at the dorsal side of the body (fig. 83). Hemolymph (blood of arthropods) is colorless or blue. As soon as the circulatory system is open, hemolymph passes from the heart to the body cavity and then is collected.

![Fig. 83. Anatomy of the spider](image-url)
Respiratory organs of arthropods are various: aquatic ones breathe with gills while the terrestrial ones use book lungs or trachea.

A nervous system includes a cerebral ganglion («the brain»), circumpharyngeal nerve ring and ventral nerve cord. All sense organs are developed in arthropods: sight, smell, tactile sense, taste, hearing, equilibrium.

Reproductive system. Arthropods have separate sexes. Males and females are different in body sizes and color. Such distinction between different genders of one species is sexual dimorphism.

Reproduction of arthropods is sexual. Development is direct or indirect (with metamorphosis). Direct development is observed when individuals which hatch from eggs are similar to adults. It is typical for spiders. Indirect development is characterized by transitional stages between the egg and the adult. Metamorphosis of the indirect development can be of two types: complete or incomplete. The first type consists of 4 stages: egg, larva, pupa, adult. Such metamorphosis is characteristic of flies, butterflies and mosquitoes. The second one, the incomplete metamorphosis, includes just 3 stages: egg, larva and adult — the stage of pupa is absent. Bugs and lice develop suchlike.

8. Characteristic of the class Arachnida

The class Arachnida (arachnids) includes about 75 thousand species. Arachnids are terrestrial animals. Most of species are free-living, some of them are parasites of human and animals.

The class includes spiders, scorpions, ticks and mites (the name for some arachnids belonging to the same subclass with ticks — i.e. mites can be considered as a kind of ticks). Body sizes are from 0.3 mm (itch mite) to 30 cm (bird spider).

External anatomy. Bodies consist of two regions: a cephalothorax and an abdomen. The cephalothorax carries 6 pairs of appendages, two of them are near the mouth opening. The first pair is chelicerae («jaw») and the second pair is pedipalps (tentaculites). At the tips of chelicerae the ducts of venomous glands are opened and spiders paralyze their prey with venom. Holding the prey is performed by pedipalps which are also organs of taste and touch. Pedipalps of scorpions are transformed into long chelae. The other 4 pairs of arachnids’ appendages are long and thin walking legs with little claws.

Abdomen is not segmented and does not have any appendages, but there are respiratory, reproductive and anal openings. There are also spinning glands inside of the abdomen where spider silk is synthesized. Spiders use it to weave a web for hunting, a nest and a cocoon.

Body covering. The body of the spider is covered with cuticle which is saturated with chitin. It is an exoskeleton that protects and supports the body. Below the cuticle, hypodermis and striated muscles are found.
Internal anatomy (fig. 84).

Fig. 84. Internal anatomy of the spider

A digestive system includes front, middle and posterior parts. Arachnids eat other organisms (predators), host’s blood (parasites) or plant juices. Digestion goes internally-externally. Splitting of nutrition begins after injecting the digestive enzymes of salivary glands into the prey. Muscular pharynx and suctorial stomach help the spider to suck in fluid food. Ducts of the liver are opened into the midgut. The process of digestion finishes here. Undigested remains of food go through the hindgut and are excreted through the anal opening.

Excretory organs of arachnids are coxal glands and Malpighian tubules. Coxal glands are open outwards near the walking appendages while the Malpighian tubules are open into the alimentary canal at the point between the midgut and hindgut.

A circulatory system is open. The tubule-shaped heart is at the dorsal side of the abdomen. Blood (hemolymph) flows from the heart to the body cavity where it bathes the respiratory organs. Being enriched with oxygen hemolymph runs into the vessels and comes back to the heart.

A respiratory system of arthropods includes book lungs and trachea. Book lungs are respiratory organs that lay in the anterior of the abdomen. Trachea are tubules found in its posterior side; they are open outwards by openings called spiracles.

A nervous system consists of a cerebral ganglion, ventral nerve cord and nerves. Sensory organs: simple eyes situated on the cephalothorax; there are also organs of smell and chemical sense.

Reproductive system. Arachnids have sexual reproduction and separate sexes. Fertilization is internal. Gonads (sex glands) are pair, they are located in the abdomen. Development of spiders is direct: female lays eggs to the cocoon made of spider silk and little spiders hatch from it in spring. Scorpions are viviparous. Ticks develop with metamorphosis.
There are many ticks in the nature. They are small arachnids with body sizes no more than 0.3–0.5 cm, but after feeding with blood they can dilate to 1 cm. Ticks live in the soil and bird nests, they are parasites of human, animals and plants. A tick body has no regions, chelicerae and pedipalps transform into a proboscis. Their anatomy is simplified: many ticks have no circulatory system and no eyes. Ticks eat plant juices or host’s blood. Their reproduction is sexual, development goes with incomplete metamorphosis.

**Ticks are significant for medicine.** Ticks of the families Ixodidae and Argasidae feed on blood of animals or human and can transmit encephalitis or typhus. *Iitch mites* live in the human skin.

Their sizes are about 0.3 mm. Females gnaw through the skin forming ways where they move and lay eggs. This causes severe itching. This disease is called scabies. First of all, mites inhabit skin between fingers and at the bottom of the abdomen, then they spread across the whole body. Preventing the disease is possible by observing the hygiene rules: do not use someone else’s dress, gloves, shoes, bedclothes.

**Significance of arachnids:**

Spiders play important role in the nature eating pests and another insects. Some venomous spiders are dangerous for human; many ticks are parasites and transmitters of infections; some mites are pathogenic agents of diseases.

9. **Characteristics of the class Insecta**

**The class Insecta** includes about 1 million species.

Habitat. Insect inhabit land, soil and air.

Way of life: Most of species are free-living, some of them are parasites of human and animals.

Bodies have sizes from 1–2 mm to 30 cm. *Body covering* of insects is chitin, There are hypodermis and striated muscles below the cuticle. During moulting the old chitinous covering is cast off to be replaced with a new one. Insect bodies grow only at such periods. *Body regions* are head, thorax and abdomen. The head carries a pair of antennae, eyes and mouthparts.

*Organs of locomotion* are 3 pair of segmental appendages at the abdominal side of the thorax and one or two pairs of wings at it’s dorsal side. Some parasitic insects such as lice and fleas do not have wings.

**Internal anatomy** (fig. 85).

*Digestive system* includes front, middle and posterior parts. Foregut begins with mouth opening surrounded by mouth parts which include upper and lower labia (lips), a pair of maxillae (lower jaw) and a pair of mandibles (upper jaw). The structure of mouthparts depend on manner of feeding: beetles feeding on solid food have chewing mouthparts (chewing insects), mosquitoes feeding on blood have piercing and sucking mouthparts (piercing and sucking insects). Ducts of salivary glands are open into the oral cavity (mouth). It is followed by
a pharynx, esophagus, stomach, gut and anal opening. Since insects have no liver, digestive enzymes are released by the wall of the midgut. Digestion and absorption of nutrition also occurs in the midgut.

Excretory organs are Malpighian tubules and a corpus adiposum (fat body). The Malpighian tubules are open into the digestive canal between the midgut and hindgut. The fat body accumulates dissimilation products.

A circulatory system is open. The heart having the shape of a tubule lays in the abdomen at the dorsal side above the gut. Colorless blood of insects is called hemolymph. It delivers nutrition to organs and tissues, participates in excretion of metabolic wastes and performs protective function.

A respiratory system of insects is represented by trachea. They are branching tubules bringing oxygen to all organs and tissues. Openings of trachea are situated at the sides of the abdomen and thorax and called spiracles.

A nervous system of insects is complex. It composed of suprapharyngeal ganglion, ventral nerve cord and nerves. Suprapharyngeal ganglion is often called «the brain» which is responsible for complex behavior of insects. It consist of 3 regions forebrain, midbrain and hindbrain. Hindbrain innervates mouthparts, midbrain antennae, forebrain − eyes.

Insects have developed sense organs. Organs of sight are compound eyes (also known as facet eyes) on the head. Such eyes are made of many little eyes. Besides, the head carries antennae performing functions of touch and smell organs. Some insects have also hearing organs.

Reproductive system. Insects have sexual reproduction and are of separate sexes. Pair reproductive glands are in the abdomen. Development goes with incomplete or complete metamorphosis. The first one is characteristic of cockroaches and grasshoppers, the second one is typical for beetles and butterflies.
Significance of insects:
In the nature insects are necessary origin of food for other animals; the great number of them are pollinators of flowering plants. A number of them exterminate other injurious insects. Human use insects for scientific researches and as origin of medicine (bee venom, propolis). It is even possible to obtain some food products from insects (honey).

Insects-parasites have medical significance. Many insects are venomous (bees and wasps). Some of them cause human diseases (lice), flea are carriers of plague patogenes, mosquitoes belonging to the genus Anopheles of malaria parasites.

10. CHARACTERISTICS OF THE PHYLM CHORDATA

The phylum Chordata includes approximately 50 000 species. Chordates are widely spread around the whole world. Varies species have different sizes, morphology and way of life. The considerable number of them is predators.

Chordates have complex anatomy and behavior. The bodies have bilateral symmetry. All their organ systems are developed from 3 germ layers: entoderm, mesoderm and ectoderm. Body cavity is secondary, it is also known as coelom.

General anatomic peculiarities.
All chordates have skin covering. Its outer layer is epidermis that is epithelial tissue, the inner layer is dermis made of connective tissue.

All chordates have a notochord in embryos and larvae which serve as axial skeleton. In adult animals it is replaced with a spine.

Above the notochord, a nerve tube is situated. Its cavity is neurocoel. Nerve tube is the origin of the brain and spinal cord. Chordates have developed sensory organs: sight, smell, taste, hearing, touch.

Below the notochord, the alimentary tube (digestive tube) is found. It consists of 3 parts: front, middle and posterior. The forepart of the tube has gill clefts (gill slits) which give rise to gills breathing organs of aquatic animals. Terrestrial animals have gill slits only during embryonic development and occlude later on. Adult ones breathe with lungs.

Circulatory system is closed and composed of one or two circulations (fig. 86). The heart is situated at the ventral side below the alimentary tube.

![Fig. 86. Anatomy of the lancelet](image-url)
Excretory organs are nephridia or kidneys. There are two types of kidneys: mesonephric (primordial) kidneys and pelvic (definite) kidneys.

Reproductive system. Reproduction of chordates is sexual. Most of them have separate sexes. Development can be direct or indirect.

Systematic of chordates: The phylum is divided into two subphylums: acranials (includes the class Lancelets) and cranials (includes classes cartilaginous fishes, bony fishes, amphibians, reptiles, birds and mammals).

Acranials means «have no skull». The subphylum is represented by the class lancelets which have no skull and brain. These animals inhabit the sand of a reservoir’s bottom.

External anatomy. A lancelet have streamline body shape, it’s length is approximately 4–8 cm. There are head, truncal and caudal body regions. Body covering is skin consisting of single-layer epidermis and jelly-like dermis. Skin has glands producing mucus. Due to the absence of pigment cells, body coverings are transparent. Skin creases form fins that are organs of locomotion. There are segmented muscles that lay in the body as two tapes.

Internal anatomy. The notochord is the axial skeleton.

Nervous system is a nerve tube lying above the notochord with a neurocoel inside. There is an olfactory pit (nasal fossa) at the front end of the tube. It is a chemical sense organ. Light is precept by photosensible cells of the tube.

Feeding of the lancelet is passive: tentacles surrounding the mouth make the water flow; this flow carries food particles to the mouth. Food pass the pharynx and get to the gut where it is digested. Undigested remains are excreted through the anal opening.

Pharyngeal wall has about 100–150 pairs of gill slits. Breathing of the lancelet goes at the same tame as feeding. Gas exchange occurs in the vessels of gill slits.

Excretory organs are tube-shaped nephridia lying segmentally alongside of the pharynx.

Circulatory system is closed; pulsing ventral aorta substitutes the heart. Blood is colorless due to the absence of respiratory pigments.

Reproductive system. Reproduction of lancelets is sexual, they have separate sexes. There are 25 pairs of gonads alongside of the pharynx. Fertilization (external) and development occur in the water. A zygote transform into a larva. Its development is indirect and goes with metamorphosis.

At the end of 19th century russian biologist A. Kovalevsky defined similarities of lancelets with vertebrates and invertebrates:

Similarities of lancelets with invertebrates: bilateral symmetry; 3 germ layers; single-layer epithelium; segmental localization of muscles, gonads and nephridia; low differentiation of the digestive system; passive feeding; absence of the brain and heart.

Similarities of lancelets with vertebrates: notochord; nerve tube above the notochord; alimentary tube below the notochord; gill slits; the central pulsing blood vessel is in the abdominal side.
11. Characteristics of the class Bony fishes

About 25,000 species belong to the class Bony fishes.

**External anatomy.** A body of a fish consists of the head, trunk and tail. Its shape is streamline. Organs of locomotion are fins. There are paired and unpaired fins. Pectoral (breast) and ventral (abdominal, pelvic) fins are paired. Their function is turning the body and maintaining its equilibrium. Dorsal (back), anal (proctal) and caudal are unpaired. They provide body stability and locomotion (fig. 87).

Body covering is skin covered with scales. It consists of multilayer epidermis and dermis. Simple unicellular glands produce mucus which helps the fish to move in the water and protect from agents of diseases.

**Internal anatomy.**

A skeleton is made of bone and cartilaginous tissues. It supports the body and organs. Two massive tapes of fish muscles are also attached to the bones. There are skeletons of the head, trunk and fins. The head one is skull which grows together with the spine and form immobile static connection. The skull consists of a neurocranium and visceral cranium. The neurocranium protects the brain and sense organs while the visceral cranium is associated with digestive and respiratory organ systems. The trunk skeleton is the spine. It consists of vertebrae and includes trunk and caudal regions. Truncal vertebrae have ribs.

![Fig. 87. External anatomy of the fish](image)

**Digestive system** includes mouth, pharynx, esophagus, stomach, intestine (small and large) and anus (fig. 88). There are jaws equipped with teeth in the oral cavity. The wall of the pharynx has gill slits. Fish have digestive glands such as a liver with a gallbladder and pancreas.

Especial organ of fishes is a *swim bladder*. It is an outgrowth of the esophagus which is filled with gases. Fishes increase the volume of gases to rise upward and decrease it to sink to the bottom.
**Excretory organs** of fishes are two mesonephric kidneys situated in the dorsal side of the body cavity. They form urine which passes to the urinary bladder through ureters and then excreted from the body through the urethra.

**Circulatory system** is closed. There is only one circulation. A heart consists of one atrium and one ventricle and is thus two-chamber. It is filled with venous (unoxgenated) blood.

**Respiratory organs** of fishes are gills where gas exchange occurs. Fishes breathe with oxygen that is dissolved in the water.

A **central nervous system (CNS)** consists of the brain and the spinal cord. The brain consists of 5 regions: endbrain, interbrain, midbrain, diencephalon and medulla oblongata. The most developed one is the midbrain where centers of sight are found. Cerebellum that is responsible for complex motions is also well-developed. Fishes have all *sense organs* (sight, hearing, smell, taste and touch).

Organs of sight are eyes that have spherical lens and flat cornea. It explains why fishes can clearly recognize only closely situated objects (up to 15 m).

Hearing organ of fishes is simple. It consists only of inner ear that is not connected with the environment. Due to high density of water sound waves are conducted by skull bones and perceived by the ear.

Another especial organ of a fish is a lateral line that feels the direction of water current.

**Reproductive system.** Reproduction is sexual, fishes have separate sexes. Fertilization is external, development is indirect, occurs in water. A larva called fry comes out of the egg.

**Significance of fishes.** They and their caviar are food for human and animals; fish oil is obtained from the liver of fishes.
12. Characteristics of the class Amphibia

The class Amphibia counts about 4100 species. Amphibians are first terrestrial animals on Earth. Their development occurs in the water and adults live on the land.

There are 3 orders of the class amphibians:
1. Anura (frogs and toads);
2. Caudata (salamanders and newts);
3. Caecilians (Gymnophiona, Ichthyopsis).

Body regions are head, trunk, two pairs of limbs and sometimes tail. Limbs are five-fingered.

Body covering is skin. Its layers are epidermis and dermis. Skin of amphibians is thin; it has many blood vessels and glands producing mucus. This makes amphibians be always wet.

Amphibians have skeleton of the head, trunk and limbs. The head skeleton (skull) consists of a neurocranium and visceral cranium and is movably connected with the spine. Spine is the trunk skeleton. It consists of cervical, truncal, sacral and caudal regions (4 totally). Ribs and chest are absent.

The skeleton of a forelimb is composed of upper arm, forearm and palm. Bones of the pectoral girdle are sternum (breastbone), coracoids, clavicle (collar bone) and scapulae (shoulder blade).

The skeleton of the hind limb consists of femur (hip), tibia (shin) and foot. The pelvic girdle is made of pelvic bones.

Muscles of amphibians are located as parallel beams. The most developed of them are muscles of hind limbs, head, abdomen and oral cavity.

Digestive system includes fore, middle and hind parts (fig. 89). The first one begins from the oropharyngeal cavity with a tongue and small teeth on the upper jaw. Eyes participate in swallowing food. They are drawn-in to the oropharyngeal cavity by muscles for pushing a portion of food. Amphibians have salivary glands but the saliva has no digestive enzymes and thus just moistens the food. Digestion begins in the stomach and finishes in the small intestine. Other glands of the digestive system are the liver and pancreas. The terminal section of the gut is a cloaca through which undigested remains of food are excreted.

*Fig. 89. Internal anatomy of the frog*
Excretory organs are mesonephric kidneys. Kidneys and the urinary bladder are open into the cloaca.

Respiratory organs of larvae are gills, adult individuals breathe with lungs. Their wall is thin and has a numerous blood vessels. Other breathing organ is skin. Respiratory tracts are represented by laryngotracheal chamber with vocal apparatus. Air gets to the lungs due to contraction of muscles of the oropharyngeal cavity.

Circulatory system. A heart consists of two atria and one ventricle and is thus three-chamber. There are systemic and pulmocutaneous (lat. lungs + skin) circulations. The first one begins from the ventricle and carries blood to all organs and tissues and then to the right atrium. Blood of the pulmocutaneous circulation flows from the ventricle to the lungs and skin and then back to the left atrium. All organs receive mixed blood, except the brain that receives arterial blood.

Body temperature of amphibians depends on the environmental temperature. Such organisms are called cold-blooded (poikiloterm) animals.

Nervous system. The brain consist of 5 regions: endbrain, interbrain, midbrain, diencephalon (cerebellum) and medulla oblongata. The endbrain of amphibians is developed better then that of fishes and includes two hemispheres. Cerebellum is developed less then that of fishes. It explains simplicity of their motions and low mobility. All sense organs are developed: sight, hearing, smell, taste and touch. Eyes can see objects that are relatively far. It is done due to a biconvex lens and convex cornea. Eyes are surrounded by upper and lower lids and a nictating membrane. Lids prevent drying-out of the eyes. A hearing organ is composed of inner and middle ears. The middle ear is separated from the environment by an eardrum. There is an earbone — stapes. Olfactory function is performed by nostrils. Taste organ is a tongue. Touch organ is a skin. All larvae and aquatic adult amphibians have a lateral line.

Reproductive system. Reproduction is sexual, sexes are separate. Fertilization is external and occurs in water. Development goes with incomplete metamorphosis.

The larva of an amphibian is called tadpole and is similar to a little fish: streamline shape, fins, gills, two-chambered heart, one circulation, lateral line. That is the evidence that fish are ancestors of amphibians (fig. 90).

Significance of amphibians:
They are food for birds, reptiles and mammals. Feeding on insects, they eliminate injurious ones and pests. Some amphibians (usually frogs) are used for scientific experiments.
13. Characteristic of the class Reptilia

The class Reptilia includes approximately 7000 species. There are more frequent in regions with warm climate. As soon as development of reptiles occurs on the land, they are true terrestrial vertebrates.

Orders of the class Reptilia:
– Squamates (lizards and snakes);
– Crocodiles;
– Turtles.

External anatomy. Body regions are the head, neck, trunk, tail and also two pairs of five-fingered limbs (apart from snakes that have no limbs). Lizards are able to detach their tail in case of danger and grow it again later. This phenomenon when an individual restore its lost organs or body parts is called regeneration. Bodies of turtles are covered with a shell consisting of bony scales anchored in the dermis. Turtles have short limbs and long mobile neck.

Body covering is skin which includes epidermis and dermis. It is covered with corneous scales and has no glands. Such body covering prevent water loss and protect the animal. Since the scales hold down body growth, reptiles have to shed their skin. Later on, new skin forms. This phenomenon is moulting.

A skeleton of a reptile is composed of 3 parts: the head skeleton, trunk skeleton and the skeleton of limbs. The first one is skull which has oblong shape and consists of neurocranium and visceral cranium. It is connected with the spine movably. Reptiles are first who got hard bony palate which separate nasal and oral cavities. The spine which is a trunk skeleton consists of 5 regions: cervical, thorac-
ic, lumbar, sacral and tail. There is a chest which is made of thoracic vertebrae, ribs and breastbone.

The skeleton of a pectoral girdle is made of sternum (breastbone), coracoids bones, clavicle (collar bone) and scapulae (shoulder blade).

Forelimb includes bones of the upper arm, forearm and palm.

The pelvic girdle is composed of pelvic bones.

The skeleton of a hind limb includes femur (hip), tibia (shin) and foot. There are claws on the fingers.

The spine of snakes has only truncal and caudal regions, skeleton of limbs and girdles is absent. They also have no ribs and breastbone and thus chest.

Muscles of reptiles are more developed than those of amphibians. There are new groups of muscles: those of neck, fingers, intercostal, subcutaneous.

Internal anatomy.

Digestive system includes the oral cavity, pharynx, esophagus, stomach, small and large intestines. There is a primitive blind intestine (cecum) between the large and small ones. Jaws carry teeth to hold the prey while feeding. The terminal segment of the digestive system is a cloaca through which undigested food remains are eliminated. There are liver and pancreas (fig. 91).

Reptiles are mostly predatory animals. Their food includes small invertebrates, fishes, and birds. Turtles feed on plant food.

Organs of the excretory system are pair pelvic kidneys, ureters and urinary bladder. Urine is excreted through the cloaca.

Respiratory organs are lungs. They have more septa then those of amphibians. Air passes there through respiratory tracts: nasal cavity, larynx, trachea and two bronchi.

Circulatory system consists of a three-chambered heart and two circulations. Most of reptiles have three-chamber heart with an incomplete septa in the ventricle. Crocodiles have four-chamber heart due to the complete septa. Sys-
temic circulation starts in the ventricle. Blood passes through all organs and tissues and comes back to the right atrium of the heart. In the pulmonary circulation, blood flows from the ventricle to the lungs and back to the left atrium. All organs (except the brain and forelimbs) are feed with mixed blood. The brain is supplied with arterial blood.

*Reptiles are cold-blooded (poikiloterm)*, they cannot maintain their body temperature and have to use environmental warmth.

*Nervous system.* The brain consists of 5 regions: endbrain, interbrain, midbrain, diencephalon (cerebellum) and medulla oblongata. Cortex appeared on the hemispheres of the endbrain. Unlike in amphibians, the cerebellum is developed well. That provides their high mobility.

Reptiles have *all kinds of sense organs*. Their eyes are equipped with lids. The lens can modify its shape. A hearing organ consists of inner and middle ears, the middle one is separated from the environment by an eardrum. There is one earbone (stapes). There are touch receptors on the tongue and smell receptors in the nasal cavity.

*Reproductive system.* Reptiles have sexual reproduction and separate sexes. Fertilization is internal, development is direct. Females lay eggs to the sand.

Reptilian eggs contain much nutrient substance — yolk. Embryo develops in the aquatic environment of the egg. It is possible due to an embryonic membrane called amnion. This membrane provide protection from injures and drying-out.

*Significance of reptiles.*

Reptiles and their eggs are food for animals and human. Snake venom is used in pharmaceutical industry; skin of reptiles is used in consumer industry. Venomous snakes such as common vipers, blunt-nosed viper, cobras and rattlesnakes have medical significance.

14. **Characteristic of the class Mammalia**

The class **Mammalia** includes about 4500 species. They inhabit water, land and air. Mammals are higher vertebrates. **Subclasses of the class Mammalia are:**

1. **Subclass Prototheria (Yinotheria):** echidna, long-beaked echidna, platypus.
2. **Subclass Theria (placentals):**
   - **Infraclass marsupials:** kangaroos, koalas, possums, marsupial wolves;
   - **Infraclass placentals:** - Order insectivores: moles, hedgehogs, muskrats;
     - Order chiropterans: vampires, bats, fruit bats;
     - Order rodents: mice, rats, gophers, beavers, squirrels;
     - Order lagomorphs: hares, rabbits;
     - Order carnivores: bears, cats, dogs, wolves;
     - Order pinnipeds: seals, walruses;
     - Order cetaceans: blue whales, dolphins;
Peculiarities of mammals: hair covering, viviparity, breast-feeding, developed nervous system, complex behavior, diaphragm.

External anatomy. Bodies consists of the head, neck, trunk, tail and two pairs of limbs equipped with claws.

Body covering. Skin consists of multilayered epidermis, dermis and subcutaneous fat (subcutaneous adipose tissue). This fat tissue helps to maintain body temperature. Bodies of mammals have hair covering to protect the body and keep warmth. These hairs develop from skin alongside with claws, nails, horns, toes and various glands (sweat, lacteal, oil (sebaceous) glands).

A skeleton consists of 3 parts (skeletons of head, trunk and limbs). The first one is skull. A spine consists of 5 regions: cervical, thoracic, lumbar, sacral and caudal. The cervical one is developed well and provide high mobility of the head. All mammals have chest.

A pectoral girdle consists clavicles and scapulae (shoulder blade). Forelimb has bones of the upper arm, forearm and palm. The pelvic girdle is composed of pelvic bones.

The skeleton of hind limb includes femur (hip), tibia and fibula (shin) and foot. Limbs of mammals can have 1–2 (odd-toed, even-toed) or 5 fingers (primates).

The most developed muscles are those of the back, limbs and girdles. There is a sheet-like muscle diaphragm that divides the body cavity into two (thorax and abdominal ones).

Internal anatomy (fig. 92). Digestive system. An oral cavity is surrounded by lips. Teeth are placed in especial slots. There are various kinds of teeth: incisors, canines, premolars and molars. Milk teeth replace with permanent ones. Mammals have developed tongue and digestive glands. Alimentary tract consists of pharynx, esophagus, stomach, small and large intestines with anus. There is a cecum (blind intestine).

Excretory organs are pair of pelvic kidneys, ureters and urinary bladder. Urine is excreted through the urethra.

Circulatory system. Mammals have four-chamber heart which consists of two atria and two ventricles. The right half of the heart contains venous (unoxegenated) blood, the left one is filled with arterial (oxygenated) blood. There are two circulations. Venous and arterial blood is completely separated and all organs of mammals receive oxygenated blood. Mammals are warm-blooded (homoiothermal) animals. Their body temperature is constant and do not depends on the environment.
Respiratory system. Air passes to the nasal cavity through nostrils, then it goes to the lungs through the respiratory tracts (nasopharynx, larynx, trachea, bronchi). In the lungs bronchi branch out and form a bronchial tree.

Lungs have alveolar structure. Alveoli are little vesicle-like cavities. Gas exchange occurs there. Respiratory movements are performed by intercostal muscles and the diaphragm.

Nervous system. The brain of mammals consists of 5 regions. The volume of the endbrain is high. It is covered with well-developed cerebral cortex which is the main part of the nervous system. The cortex controls functioning of the whole organism and is responsible for complex behavior.

Hearing organ consists of inner, middle and outer ears. There are three earbones in the middle ear: malleus, incus and stapes. There are developed organs of sight, taste, smell and equilibrium.

Reproductive system. Mammals have sexual reproduction and separate sexes. Fertilization is internal. The embryo develops in the mother’s organism. It is intrauterine development. Young animals are fed with mother’s milk (breastfeeding). Most of mammals are placental. Such animals develop in the uterus. Nutrition and gas exchange are provided by the placenta which is an organ that connects organism of the fetus to the mother’s one. Parental care is observed in all mammals.

Significance of mammals:
They are origin of food and medicine. Some of them are used as transport, other ones are experimental animals. Mammals have ethic significance for humans. Medical significance consist in transmitting diseases.
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