МИНИСТЕРСТВО ЗДРАВООХРАНЕНИЯ РЕСПУБЛИКИ БЕЛАРУСЬ
БЕЛОРУССКИЙ ГОСУДАРСТВЕННЫЙ МЕДИЦИНСКИЙ УНИВЕРСИТЕТ
КАФЕДРА БИОЛОГИИ

БИОЛОГИЯ
для слушателей подготовительного отделения иностранных учащихся, обучающихся на английском языке

BIOLOGY
for English-studying international students of preparatory department

Учебно-методическое пособие

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Содержит теоретический материал по всему программному материалу для поступающих в ВУУ. Первое издание вышло в 2016 году. В данном издании уточнены некоторые теоретические вопросы. Предназначено для слушателей подготовительного отделения иностранных учащихся, обучающихся на английском языке.
INTRODUCTION

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

At the Department of Pre-University Training of BSMU, foreign students study the structure of the human body (Anatomy) and vital processes proceeding there (Physiology); the structure and vital processes of bacteria (Microbiology), 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 considered in more details in the course of Biology delivered in medical universities.

The basic knowledge gained at the pre-university level is the basis for studying Anatomy, Physiology, Histology, Hygiene, Microbiology and other disciplines, which are indispensable for the comprehension of vital functions of healthy and sick people (preventive and clinical disciplines). Academician I. V. Davydovskiy called Biology «the theoretical basis of Medicine». Consequently, the training of a student in Biology is necessary not only for admission to a 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 the nature;
- know the structure and vital processes of bacteria, protists and animals including 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.
Section 1. Cytology
Biology as a science. Basic properties of living things.
Cell as a basic structural and functional unit of living things. Unicellular and multicellular organisms. Sizes and shapes of cells. The main concepts of the Cell Theory.
Structure and functions of the cell envelope and the cell membrane. Types of transport of substances across the membrane.
Main organelles of the cell (ER, ribosomes, Golgi body, mitochondria, lysosomes, plastids, centrosomes), the peculiarities of their structure and functioning. 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 synapsis and crossing-over, haploid and diploid chromosome complements. Changes in the content of genetic material during meiosis.

Section 2. Genetics
Genetics as a science. Basic concepts of genetics: gene, genotype, phenotype; allele, dominant and recessive genes; homo- and heterozygotes; alternative characteristics. Structure and functions of nucleic acids (DNA and RNA). Functions of genes. Protein synthesis in cells. The concept of transcription and translation.
The concept of monohybrid cross. The Law of Hybrid Uniformity and The 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 characteristics.

Section 3. Human Anatomy and Physiology
Structure, growth and types of bones. The concept of bone tissue. The structure of synovial joint. Human skeleton. Parts of the human skeleton. Main bones of the head, axial and appendicular parts of the skeleton.
Muscular system. Structure and functions of striated and smooth muscle tissues. Neural regulation of muscle work.
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 neuron.
Structure and functions of the brain. Structure and function of brain regions (medulla oblongata, cerebellum, midbrain, interbrain and endbrain). Cerebral cortex, its lobes and areas.
Section 4. Microbiology and Zoology
The characteristics of the phylum Flatworms. Peculiarities of their morphology and physiology. Characteristics of the class Flukes. The anatomy and life cycle
of the liver fluke. Prevention of fascioliasis. The characteristics of the class Tape-worms. Peculiarities of anatomy and the life cycle of the beef tapeworm. Prevention the diseases caused by tapeworms.


The characteristics of the phylum Arthropods. Peculiarities of their morphology and physiology.

The characteristics of the class Arachnida through the example of a garden spider. Significance of arachnids.

The characteristics of the class Insects. Significance of insects.

The characteristics of the phylum Chordates.

Features of the morphology and physiology of a lancelet.

The characteristics of the class Bony Fishes. Features of the morphology and physiology of fishes, their significance.

The characteristics of the class Amphibians. Features of their morphology and physiology, significance.

The characteristics of the class Reptiles. Features of their morphology and physiology, their significance.

The characteristics of the class Mammals. Features of their morphology and physiology, 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. The word «Biology» derives from Greek «βίος» — life and «λόγος» — science i.e. science about life. But what is life? According to the American scientist John Bernal, life is form of functioning of proteins and nucleic acids which maintain its orderliness at the expense of the environment.

Biology studies living matter. Its objects of study are bacteria, protists, plants, fungi and animals (including human).

Properties and characteristics of living matter. All the nature consists of inanimate objects (such as water or stone) and living organisms. The difference between them consists in the essential properties of living matter:

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 elements.
3. Self-reproduction — the ability of organisms to create new individuals of their kind.

Inanimate objects do not have such properties.

These properties of living matter are the basis for the signs (characteristics) of living matter:

1. Exchange of substances and energy between the environment and organism is considered to be the main condition of life. In any chemical reaction occurring in the cell, a portion of energy dissipates. That is why maintaining normal metabolism (all reactions in the body) requires constant 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 the same species by already existing organisms. Living organisms age and die. Young organisms replace them to continue the existence of the species.
3. Heredity is associated with reproduction. It is the transmission of genetic characteristics from parents to offspring. As offspring receive parental traits, heredity is also defined as similarity of children and parents.
4. Variation is ability of organism to acquire new traits (ability to change). That can adapt them to changes of environmental conditions. Hereditary variation is defined as unlikeness or difference of children and parents.
5. Growth is increasing in the size, mass and volume of an organism during its individual development.
6. Ontogenesis is the individual development of an organism that starts from being a zygote and ends with death. In reproduction any organism receives genetic information from parents. This information is realized during ontogenesis.
7. Phylogenesis is the historical development of a species or the evolution of the species.

8. Irritability is capability of the body (or organs, cells) to respond to factors 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 nervous system is called reflex. Another example of irritability is movement of bacteria to/from a stimulus such as higher concentration of sugar. Such response of unicellular (i.e. consisting of a single cell) organisms is called 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 means that any organism is composed of various parts and can be considered as a group of structural and functional units.

   Unlike inanimate objects, all living organisms consist of one or many cells. In another words, cell is the unit of living matter. 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 gene.
   2. Cellular level. Its elementary unit is 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. A biogeocenosis (or community) includes all populations of different species living on definite residential territory which are historically related with each other. There is a constant exchange of substances, energy and information between populations and the environment. All the biocenoses compose the biosphere — an area of the planet occupied by living organisms.

2. **Cell as the unit of life. 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 cell was discovered by English physicist and microscopist Robert Hooke in 1665. He examined thin slices of cork with the microscope he constructed (fig. 1). He noticed that it consisted of boxy partitions that resembled the cells in a monastery.

In 1831, Robert Brown discovered the nucleus in a 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. Schleiden and Schwann summarized all that knowledge and formulated the first statements of the Cell Theory (1839):

1. Cell is the structural and functional unit of all living organisms.
2. Cells of animals, plants and other organisms have similar structure, chemical composition and basic processes of vital activity.
3. Multiplication of cells provides growth and development of organisms.
4. «Omnis cellula e cellula» — new cells are made by means of division of mother cells — the phrase of Rudolf Virchow that completed this theory in 1858.

There are 3 basic elements of cell (fig. 2): plasma membrane, nucleus (except some cells such as bacteria) and cytoplasm. Cytoplasm includes solution cytosol (or hyaloplasm) and organelles («organs» of cell).

Thus, cell is the structural, functional and genetic unit of living things: all living organisms are composed of cells, and all cells arise from other cells. Each cell has all the basic properties of living organisms.

Some species (Amoeba, Infusoria) include only the organisms which consist of single cell (they are called unicellular). Their cell performs functions of entire organism. Other organisms consist of the great number of cells and are called multicellular.

Common cell sizes vary from several micrometers to 100 micrometers. There are some giant cells such as eggs of birds. Shape of cell depends on its function: nerve cell (neuron) has long processes to conduct nerve impulse, muscle cell is elongated because it must change own length for contraction.

**Chemical composition of cells.** All cells contain various organic and inorganic substances consisting of different chemical elements. Elements that are in large amounts in the cell are called macroelements (oxygen, carbon, hydrogen, nitrogen, phosphorus, sulfur, sodium, potassium, magnesium, calcium, chlorine). The ele-
ments contained in large amounts are called — 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 life could not exist without it. *All the content of the cell is water solution.* Amount of water vary in living organisms from 60 to 95% and depends 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. Covers the macromolecules and inhibits their agglutination.
4. Provides transport of substances in the cell.
5. Participates in many chemical reactions.

Minerals in the cells are dissolved in water in the form of positive-charged *cations* (K⁺, Na⁺, Ca²⁺, Mg²⁺, NH₄⁺) and negative-charged *anions* (Cl⁻, H₂PO₄⁻, HCO₃⁻, SO₄²⁻). The content of cation H⁺ and its balance with the anion OH⁻ determine pH of cell’s media. The pH is the scale that specifies acidic (much H⁺ and low pH) or basic (much OH⁻ and high pH) properties of solutions.

Minerals are important for proper fluid balance, muscle contraction, conduction of nerve impulses, and building bones and teeth (table 1).

**Minerals and their functions**

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Examples of some functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>Bone strength, blood clotting, muscle contraction</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Formation of HCl in the stomach, water-electrolyte balance</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Component of many enzymes, participates in muscle relaxation</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Bone and tooth formation, phosphates are parts of many biomolecules</td>
</tr>
<tr>
<td>Potassium</td>
<td>Water-electrolyte balance, electric charge of cell membranes</td>
</tr>
<tr>
<td>Sodium</td>
<td>Water-electrolyte balance, electric charge of cell membranes</td>
</tr>
<tr>
<td>Sulfur</td>
<td>Components of many proteins</td>
</tr>
<tr>
<td>Iron</td>
<td>Transport of gases, part of proteins participating in oxidative processes</td>
</tr>
</tbody>
</table>

**Organic substances** of the cell are proteins, carbohydrates, lipids, nucleic acids, ATP, hormones, vitamins. Many organic substances of cells are made of many repeating structural units. Such molecules are called *polymers* while these repeating structural elements are their *monomers*.

**Proteins** are one of the main biomolecules of the cell as they are the molecules which can «work». Proteins are responsible for almost all functions of cells. The information about the structure of all proteins required by the cell is stored in its DNA. All proteins are polymers as they are long chains of different *amino acids* connected to one another with *peptide* bonds (fig. 3) so they are also called *polypeptides*.  

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The chain of amino acids acquires complex twisted shape. Amino acids of a protein can interact with each other and form additional bonds. **There are four levels of protein structure:**

- Primary structure of protein is a linear chain of amino acids linked to one another with peptide bonds (fig. 4, a).
- Secondary structure forms due to hydrogen bonds between amino acids. The linear chain coils into a spiral (α-helix) or forms wrinkled loops (β-sheet) (fig. 4, b);
- Tertiary structure is the three-dimensional globe of a single polypeptide chain maintained by disulfide, ionic, hydrogen bonds and hydrophobic-hydrophilic interactions (fig. 4, c);
- Quaternary structure is two or more polypeptides bind to each other via ionic, hydrogen bonds and hydrophobic-hydrophilic interactions (fig. 4, d).
Functions of proteins:
1. Catalytic. The work of many proteins is acceleration of chemical reactions (catalysis). Such proteins are called enzymes.
2. Structural. Proteins are structural parts of many cell’s and body’s structures. Cartilages, tendons, hairs, nails contain much keratin and collagen.
5. Motor, or contractile. Myosin and actin are involved in muscle contraction.
6. Energetic. Proteins can be used as a source of energy.

Carbohydrates consist of carbon, hydrogen, and oxygen. There are simple and complex sugars-polymers.

Simple sugars are called monosaccharides. They have various number of carbon atoms. Sugars with five carbon atoms are pentoses, with six — hexoses. Pentoses (ribose and deoxyribose) are parts of nucleic acids (DNA, RNA) and ATP. Hexoses (glucose, fructose) are contained in the cells of plants, blood of animals and etc. Monosaccharides are well soluble in water and have sweet taste.

Disaccharides are sugars composed of two monosaccharides (fig. 5). Examples: maltose (malt sugar), lactose (milk sugar) and sucrose (cane sugar).

Polysaccharides are long chains of simple sugars (polymers). Polysaccharides are water-insoluble. Examples: starch, glycogen (animal starch), cellulose and chitin. Starch and glycogen are energy storages of plants and animals respectively.

Functions of carbohydrates:
1. Energetic. Carbohydrates are the basic energy source of cells.
2. Storage of energy (starch and glycogen consist of glucoses).
3. Structural. They are parts of cell membranes and other structures.

Lipids are various water-insoluble organic compounds. Their most known group is fats which are esters of alcohol glycerol and fatty acids (fig. 6).

Some fatty acids contain double bonds (C=C). They are called unsaturated fatty acids. 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 and are liquid. Lipids may form complex chemical compounds with proteins (lipoproteins), carbohydrates (glycolipids) and phosphoric acid residues (phospholipids).
Fig. 6. Formation of a fat from glycerol and fatty acids: hydroxyl (–OH) groups of glycerol interact with carboxyl (–COOH) groups of the fatty acids

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

### 3. Plasma Membrane. Delivery of Substances into the Cell

**Basic cell parts are cell envelope, cytoplasm and nucleus.** Cytoplasm consists of organelles and cytosol — colloidal solution of proteins and other substances (fig. 7).

All cells are covered with cell envelope. Its basic part is plasma membrane (plasmalemma) with 7–10 nm thickness. The membrane is composed of lipids and proteins. The basic components of the membrane are lipids. They compose 20–80 % of its mass. Most common of them are phospholipids, lecithin and cholesterol. They are arranged into a double layer. Each phospholipid has two ends: the water-soluble or hydrophilic one

Fig. 7. Cytoplasm — all the contents of the cell except nucleus
and the water-insoluble *hydrophobic* one. Hydrophobic ends of lipids are directed towards each other (inside the membrane), hydrophilic ones — to the outside.

The lipids of the membrane do not form any bonds between each other. They are held together due to hydrophobic-hydrophilic interactions (fig. 8).

There are 3 types of membrane proteins according to their position in the lipid bilayer. The proteins which penetrate both lipid layers are called *integral bitopic*. Those which are immersed into one layer are *integral monotopic*. Proteins laying on the surface of lipids are *peripheral*.

The third component of plasma membrane is glycocalyx. It is formed by *glycoproteins* (carbohydrates + proteins) and *glycolipids* (carbohydrates + lipids) on the surface of the cell. Glycocalyx can interact with particular molecules and participates in cell-to-cell recognition. 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;
- selective-permeability — the membrane selectively passes molecules.

**Functions of the plasma membrane:**
- structural — membranes are structural parts of most of cell organelles (except ribosomes and centrosomes);
- barrier — separation the inside of the cell from environment and protection from external factors;
- transport — cell receives essential substance through the membrane;
- receptor — some proteins and carbohydrates of the membrane participate in transmission of chemical signals from the environment;
- metabolic — many enzymes are attached to membranes;
- compartmentalization — the division of cell cytoplasm into sections where different chemical reactions take place.

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 runs against the concentration gradient and requires energy. In case of passive transport substances go down the concentration gradient and this does not require energy (fig. 9).
The passive movement of solute through the membrane down the concentration gradient is called **diffusion**. It can be **simple** if molecules pass the membrane directly or **facilitated** if transport proteins are used. The passive transport of solvent (water) to the area of high concentration of solute is **osmosis**.

**Active transport** requires ATP molecules and special transport proteins. An example of such transport is the **sodium-potassium pump**. It pumps ions of sodium from the cell and takes the ions of potassium to the cell. That is why the concentration of potassium in the cell is higher than on the outside and the concentration of sodium is higher on the outside.

**Endocytosis** is participation of the membrane in catching molecules or even entire cells. It is possible due to modifying architectonics (outlines) of the membrane. The membrane surrounds the particle and locks, so the particle is packaged into a vesicle (fig. 10).

**Fig. 10. Endocytosis**

Endocytosis of hard particles is called **phagocytosis** while transport of fluids is **pinocytosis**. Examples of phagocytosis and pinocytosis are leukocytes engulfing bacteria, feeding of amoeba.

**Exocytosis** is 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. METABOLISM. ORGANELLES OF THE CELL

**Organelles** are the differentiated areas of the cytoplasm that have constant structure and perform specific functions (fig. 11).

There are organelles of *general and special purpose*. Organelles of general purpose are observed in almost all cells of plants and animals.

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

All organelles can be divided into 2 groups: *membrane-bound* organelles and *non-membrane-bound* ones. Membrane-bound organelles are covered with lipid bilayer with embedded proteins (endoplasmic reticulum, Golgi apparatus, mitochondria, lysosomes, plastids). The chemical composition of their membranes has some differences. Ribosomes and centrosomes are the organelles without membranes.

![Fig. 11. Organelles of the cell](image)

All organelles have specific functions in the cell. However, all of them to some extent participate in numerous chains or cycles of chemical reactions occurring in the cell. All the chemical reactions of the cell are called *metabolism*. It consists of anabolism and catabolism.

**Anabolism** (or assimilation) is the constructive part of metabolism which includes synthesis of macromolecules from simpler substances. For example: synthesis of glucose \((\text{C}_6\text{H}_{12}\text{O}_6)\) from \(\text{H}_2\text{O}\) and \(\text{CO}_2\) (photosynthesis) or synthesis of proteins from amino acids. These reactions require energy.
**Catabolism** (or dissimilation) is the part of metabolism including breakdown of complex organic compounds into simpler substances, so energy is released. For example, breakdown of glucose into H₂O and CO₂.

According to the type of assimilation, organisms are *autotrophs* and *heterotrophs*. *Autotrophic* organisms can use inorganic carbon of CO₂ to synthesize organic compounds such as glucose (plants, some protists, some bacteria).

*Heterotrophic* organisms use ready-made organic compounds as a source of carbon (for example the material of fats can be used for synthesis of carbohydrates). Examples of such organisms are animals (including human), fungi, some protists, many bacteria.

According to the type of dissimilation all organisms are *anaerobic* and *aerobic*. Cells of aerobic organisms require O₂ for breakdown of organic substances. Anaerobic organisms break down organic compounds without oxygen.

Assimilation and dissimilation are closely related. Synthesis reaction usually require energy, and the energy is released when organic compounds are broken down. Energy is also needed for active transport of substances through the membrane, changes of cell’s shape, division and other processes.

The energy in the cells is stored in ATP molecules (fig. 12). They can be created during catabolic reactions when energy is released, and then their energy is used in other reactions in the cell.

Fig. 12. ATP — the molecule which stores and releases energy when it is needed

All organelles can be divided into two groups depending on the chemical reactions they mainly perform.

The organelles of the **anabolic system** of the cell are:
- endoplasmic reticulum;
- Golgi complex;
- ribosomes;
- chloroplasts (in plants).

The organelles of the **catabolic system** of the cell are:
- lysosomes;
- mitochondria.

**Ribosomes** (fig. 13) are numerous bodies situated on the membranes of rough ER, external membrane of the nucleus and freely in the cytoplasm. Their function is *synthesis of proteins* from amino acids according to mRNA «instruct-
Ribosomes are composed of two subunits: the small and the large ones. Subunits are made up of ribonucleic acid (RNA) and proteins.

**Endoplasmic reticulum (ER)** is composed of the network of flattened membrane-enclosed sacs and tube-like structures (fig. 14). The membrane of ER is fused with the outer membrane of the nucleus. There are 2 types of ER: rough (with ribosomes on its surface) and smooth (without ribosomes).

The proteins created by the attached ribosomes pass to the inside of rough ER. There they are properly processed and directed to Golgi body in membrane enclosed vesicles. Such vesicles separate from the surface of ER.

The smooth ER synthesizes lipids (including cholesterol and phospholipids). It also participates in synthesis of steroid hormones, excretion of chlorine ions (epithelial cells of the stomach) and detoxifying harmful substances (hepatic cells). The ER is a factory where cell’s membranes are created.

**The functions of the endoplasmic reticulum:**

2. Transport of substances (in vesicles).
3. Compartmentalization.

**Golgi complex (Golgi body, Golgi apparatus)** is composed of plasma membranes in the shape of vesicles, tubes, sacs. The basic elements of the complex are dictyosomes (fig. 15). Dictyosomes are piles of several disc-like cavities (cisternae) that have 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. Sorting out and packing substances synthesized in ER;
2. Formation of complex compounds such as lipoproteins, glycoproteins;
3. Secretion of substances in vesicles;
4. Increasing the surface of the cell membrane due to secretory vesicles;
5. Formation of lysosomes.

Lysosomes (fig. 16) are organelles that look like vesicles covered with plasma membrane. They contain 30–40 various hydrolytic enzymes and perform catabolic reactions. There are primary and secondary lysosomes. Primary ones are formed by the Golgi complex. The secondary lysosomes are primary lysosomes fused with phagosomes. Breakdown of substances takes place there. Lysosomes may digest foreign particles and injured or worn out parts of the cell itself.

Mitochondria (fig. 17) have shape of rods, filaments and granules. Their number is different in cells with different activity. Size of a mitochondrion is 0.5 to 7 micrometers. Mitochondria are covered with inner and outer membranes. The inner membrane is «wrinkled» and its folds are called cristae.
The content of mitochondria bordered by the inner membrane is matrix. It contains ribosomes and circular DNA (because mitochondria originate from bacteria). The space between mitochondrion’s membranes is called perimitochondrial (or intermembrane) space.

**Plastids** are other organelles which originate from bacteria. They are present only in the cells of plants. The most important plastids are **chloroplasts** (fig. 18). A chloroplast is covered with outer and inner membranes and contains liquid material called stroma. There is a network of flattened membranes called thylakoids that stack on one another to form structures called grana in the chloroplasts. 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:** synthesis of organic compounds (photosynthesis) and release of free oxygen (side product of photosynthesis).

**Centrioles** (fig. 19) are organelles of animal cells which look like barrel-shaped rings consisting of nine microtubule triplets. Microtubules are long protein tubules inside the cell. Their network forms cytoskeleton (the «skeleton» of the cell). They also participate in transport of matter inside the cell (vesicles, chromosomes during cell division). Centrioles is the region which organizes all microtubules.

![Fig. 18. Chloroplast](image1)

![Fig. 19. Centrioles](image2)

5. **The Structure of Nucleus and Chromosomes**

**Nucleus** (Latin — nucleus; Greek κάρυον — karyon) is a compartment of the cell containing the basic genetic information. It was first described in 1831 by R. Brown. Some simple cells like bacteria do not have nucleus and store genetic information in the cytoplasm (they are prokaryotes). Eukaryotes (animals, plants, fungi, protists) can have one nucleus (or sometimes several nuclei).

Any nucleus consists of the nuclear envelope (karyolemma), nuclear matrix, karyoplasm, nucleolus (one or several) and chromatin (fig. 20).

**Karyolemma** (membrane of the nucleus) is double: it consists of external and internal membranes. The outer membrane is linked with rough ER and has ribosomes on the surface. The space between the membranes is called perinuclear (intermembrane) space. The substance exchange between the nucleus and cytoplasm occurs via pores — perforations in the nuclear envelope.
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 in the nucleus. It is mostly composed of proteins and RNA. Its function is assembling ribosome subunits. Nucleoli disappear when the cell begins division and restore when the division is finished.

Chromatin consists of DNA and proteins. This substance is chromosomes of the interphase. It is located in the nucleus in the form of little bodies or thin filaments. Chromatin is desoxyribonucleoprotein (DNA together with protein) or DNP. During the division of the cell, the chromatin condenses into chromosomes.

**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 — χρῶμα — chromo — color, σῶμα — soma — body) are tightly packed chromatin. A metaphase chromosome consists of 2 chromatids (fig. 21) linked with centromere (primary constriction). Each chromatid contains one DNA molecule linked with proteins-histones. The chromatids of a chromosome contain same copies of DNA. Centromere divides the chromosome into arms. Some chromosomes have secondary constrictions which separates the region called 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. 22):
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 has specific number of chromosomes i.e. specific karyotype.

![Classification of chromosomes](image)

**Fig. 22. Classification of chromosomes**

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

1. The rule of a constant number. All species have constant number of chromosomes in every cell. (46 in human, 78 in dogs, 8 in Drosophilae).

2. The rule of pairing. Every chromosome in a diploid set has a pair — the other chromosome of identical shape and size. Such chromosomes are homologous.

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 MULTIPLICATION. MITOSIS**

Reproduction is the ability of organisms to create new individuals of their kind. It is essential property of living matter.

The period of cell life from its «birth» to the next division (or death) is called cell cycle (fig. 23).

Each daughter cell must have its own nucleus with same copies of DNA received from the dividing mother cell. For this aim the mother cell doubles its DNA before division. During the division each chromosome will be separated into two same halves (chromatids having the same copies of DNA) for the daughter cells.

Cells which make up human body (they are called somatic cells) have 46 chromosomes. As soon as each chromosome has a pair, their chromosome set is double. Such set is called diploid and is denoted 2n. Somatic cells always have diploid set of chromosomes.
The cell cycle consists of two main stages: division and interphase. The interphase is the period between two divisions. It includes three phases:

1. **Pre-synthetic phase** (also known as post-mitotic phase or G₁). The content of genetic material is 2n 1chr (n — the number of chromosome sets, chr — the number of chromatids in each chromosome). At this phase cell grows, performs its functions. Synthesis of RNA, proteins, nucleotides ATP, and other substances occur. The phase lasts 12 hours but sometimes its duration may be several months.

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

3. **Post-synthetic phase** (pre-mitotic phase, G₂). The content of genetic material is 2n2chr. Cell prepares for division: accumulates energy (ATP) and synthesize RNA, nuclear proteins and proteins tubulins. Tubulins are proteins of microtubules that form the division spindle.

**Mitosis** (M-phase of the cell cycle) is the common division of somatic cells. Mitosis has four basic stages: prophase, metaphase, anaphase and telophase (fig. 24).

1. **Prophase** (2n2chr). It starts with condensation of chromatin. Long filaments of chromatin shorten and thicken to transform into chromosomes. Centrioles diverge to cell poles and the microtubules of the division spindle appear. Nucleoli and nuclear envelope dissolve.

2. **Metaphase** (2n2chr). Chromosomes stay are lined up at the equator of the cell. This line is called metaphase plate. Microtubules of the division spindle attach to centromere regions of each chromatid of each chromosome.

3. **Anaphase** (2n1chr at each cell’s pole). Chromosomes segregate into two chromatids (now they are daughter chromosomes). Microtubule pull the chromosomes to different sides, so they move in opposite directions.

4. **Telophase** (2n1chr at each pole). Chromosomes uncondense and lose their clear outlines. Nucleoli restore and nuclear envelope appears.

The final stage of mitosis is division of the cytoplasm between daughter cells (cytokinesis). A ring of microfilaments contracts and cytoplasm is halved (fig. 25).
Meiosis is the cell reproduction that consists of two cell divisions. Unlike mitosis, meiosis produces 4 haploid cells.

Meiosis is associated with sexual reproduction of organisms. During such reproduction two haploid cells (sperm and egg cell) fuse together into a single diploid cell. Such In cells are called gametes and the 2n cell they form is zygote. The zygote then divides and develops into a new organism.

For example, human gametes are haploid and contain 23 different chromosomes. All other (somatic) cells in the human body are diploid and contain 46 chromosomes (23 pairs). When male’s and female’s gametes fuse together into a zygote, their haploid sets unite. Therefore, new organism has diploid chromosome set consisting of both mother’s and father’s chromosomes and it would have traits of both parents.

Meiosis is a type of cell division which is necessary for creation of gametes. It consists of two divisions which are called meiosis I and meiosis II. As a result of meiosis I chromosome number is halved. For this reason, the first meiotic division is called reductional. Meiosis II is called equational division. Chromosomes are separated into chromatids, like in mitosis, but haploid chromosome set is preserved.

Both divisions have four phases: prophase I, metaphase I, anaphase I, telophase I and prophase II, metaphase II, anaphase II, telophase II (fig. 26).
Meiosis I:
1. **Prophase** of meiosis I is complicated. There occur processes of synapsis and crossing over of homologous chromosomes. 

   *Synapsis* is a connection of homologous chromosomes throughout their length. *Crossing over* is exchange of the same segments of homologous chromosomes. Synapsis and crossing over result in recombination of genes in the chromosomes. The homologous chromosomes connected to each other after synapsis are called *bivalents*. The content of the genetic material is $1n_{\text{biv}}4\text{chr}$: $1n_{\text{biv}}$ — haploid set of bivalents, $4\text{chr}$ — each bivalent contains four chromatids.

2. **Metaphase** of meiosis I: bivalents are located along the equator of the cell; chromosomes are clearly seen; set of genetic material is $1n_{\text{biv}}4\text{chr}$.

3. **Anaphase** of meiosis I: bivalents separate into homologous chromosomes. Division spindle pulls chromosomes (but not their chromatids!) to cell poles. Each chromosome still contains 2 chromatids. The content of genetic material at each cell pole is $1n2\text{chr}$. During this phase the reduction (decrease) of the number of chromosomes occurs — a diploid nucleus divides into two haploid ones.

4. **Telophase** of meiosis I: cytokinesis takes place, and two haploid daughter cells with content of genetic material $1n2\text{chr}$ are formed. Uncondensation of chromosomes does not occur.

Thus, overall, the first division of meiosis provides two major mechanisms for new genetic combinations:

- recombination of parental chromosomes;
- independent assortment of maternal and paternal chromosomes.

Period between the two divisions of meiosis is **interkinesis**.

**Meiosis II is similar to mitosis:**
1. **Prophase** of meiosis II. Condensation of chromatin into chromosomes does not occur (it is already done in meiosis I). Chromosome set is $1n2\text{chr}$.

2. **Metaphase** of meiosis II. Chromosomes are on the equator of the cell. Chromosome set doesn’t change ($1n2\text{chr}$).

3. **Anaphase** of meiosis II. Chromatids diverge to cell poles. Chromosome set at each cell pole is $1n1\text{chr}$.

4. **Telophase** of meiosis II is similar to that of mitosis. Each daughter cell gets a complement of genetic information $1n1\text{chr}$.

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

**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 is multiplication of somatic cells while meiosis takes place only in gonads to form haploid cells;
- meiosis consists of two divisions;
- synapsis and crossing over occur in the prophase of meiosis I;
- in meiosis a diploid cell divides into 4 haploid cells; in mitosis a diploid cell divides into 2 diploid cells.
Section 2. GENETICS

1. GENETICS AS A SCIENCE. NUCLEIC ACIDS. SYNTHESIS OF PROTEINS

Genetics is the biological discipline studying heredity and variation. Heredity is transmission of characteristics from ancestor to descendant (from parents to children). Variation is the changes which occur in descendants. It causes species to evolve.

The characteristics inherited from parents are encoded in their DNA. This information is genetic information. More exactly, DNA carries the information about the structure of various proteins. A DNA segment carrying the instructions for creation of a protein is called gene.

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.

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 (fig. 27). Nucleotide consists of 3 parts: nitrogenous base, 5-carbon sugar (i.e. pentose) and residue of the phosphoric acid (phosphate). Five-carbon sugars are deoxyribose (in DNA) and ribose (in RNA). Nucleotides may have one of 5 nitrogenous bases: adenine (A), guanine (G), cytosine (C), thymine (T), uracil (U). They are of 2 types: purines (adenine and guanine) and pyrimidines (cytosine, thymine and uracil). Such nucleotides are connected into chains (strands).

DNA consists of two strands which are coiled into a double helix. A DNA nucleotide consists of four nitrogenous bases (adenine, guanine, cytosine or thymine, but not uracil), deoxyribose and a residue of phosphoric acid (fig. 28).

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 only with thymine (with two hydrogen bonds – A=T)
- guanine is bound only with cytosine (with 3 hydrogen bonds – G=C).

The complementarity of nitrogenous bases was understood due to works of Ervin Chargaff.
Chargaff’s rules:
1. The number of purine bases in DNA is always equal to the number of pyrimidine bases: \( A + G = C + T \);
2. The amount of adenine in DNA is equal to the amount of thymine \( (A = T) \), the amount of guanine is equal to the amount of cytosine \( (G = C) \).

Fig. 28. Models of DNA

Apart from the nucleus, DNA is present in mitochondria and plastids. DNA is capable of replication (self-doubling) and repair (restoration of the structure after impairment of the molecule). This is done by many different proteins associated with DNA.

Replication occurs in the S-phase of the cell cycle. It is the process which copies genetic information for further cell division. DNA polymerase is the enzyme that play main role in this process. The segment of DNA where replication occurs is called replication fork. Enzymes break the hydrogen bonds between the nitrogenous bases of the two strands and separate them (fig. 29). DNA polymerases assemble chains of complementary nucleotides on each strand. That is how two new DNA molecules are formed. After replication, each DNA molecule contains one maternal chain and the second newly synthesized daughter chain. This mechanism of DNA doubling is called semi-conservative synthesis.

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

RNA is a polynucleotide which is similar to DNA. Though it consists of only one strand, its nucleotides contain sugar ribose instead of deoxyribose and uracil instead of thymine. In some viruses, RNA can be double-stranded.
Cells have 3 main types of RNA. They are in the nucleus, cytoplasm, mitochondria and plastids. About 3–4% of the whole RNA is the messenger RNA (mRNA). It «records» the genetic information from DNA and transmits it into ribosomes where protein molecules are assembled. The ribosomal RNA (rRNA) composes 80–85% of the whole RNA. It is crucial functional part ribosomes and provides especial spatial relations between mRNA and rRNA. The transfer RNA (tRNA) comprises 10–20% of the whole RNA (fig. 30). Such tRNAs deliver amino acids to ribosomes.

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

The recording of genetic information as a nucleotide sequence in DNA and mRNA is genetic code. Each nucleotide triplet (3 adjacent nucleotides) codes for a definite amino acid. Such coding triplet is called a *codon*.

**Properties of the genetic code:**
- tripletness — one amino-acid is coded by three nucleotides — codon (e. g. AUG — methionine, CCG — proline);
- universality — a codon codes for the same amino acid in all species;
- no overlapping — one nucleotide cannot be read twice. I. e. it cannot be in two adjacent codons at the same time;
- degeneracy, or redundancy — some amino acids are encoded by several different codons (there are 20 amino acids, and 64 possible triplets);
- continuity — there are no disjunctive symbols between codons;
- single direction (ribosome moves in the direction from 5’ to 3’ end of mRNA);
- presence of codons-terminators (they don’t specify any amino acids, but only determine the end of protein biosynthesis).
- co-linearity — nucleotide sequence in nucleic acids corresponds to amino acid sequence in proteins.

**Protein biosynthesis** begins from making complementary RNA copy of a gene (it is called mRNA). The enzyme doing this is called RNA-polymerase, and mRNA synthesis is called *transcription*. The nucleotide sequence of such RNA (or the sequence of its codons) defines the sequence of amino acids in a protein. Then the mRNA is transported from the nucleus to the cytoplasm, where ribosomes «read» the codons and synthesize proteins.

Synthesis of protein on the mRNA matrix is called translation (fig. 31).

The start of translation is *initiation* (small subunit connects to mRNA, first tRNA with amino acid attaches to the first codon and large subunit comes). The
formation of peptide bonds between amino acids which are continuously brought to the ribosome by tRNAs is *elongation*. The end of translation when protein is assembled and ribosome dissociates is termination.

**Ribosome** has two sites (aminoacyl and peptidyl or A and P) where two mRNA codons are placed simultaneously. The transport RNA (tRNA) has a specific structure: one end of the molecule contains a nucleotide triplet which is called an anticodon. It defines the amino acid which can be carried by the tRNA. An amino acid joins the proper tRNA due to enzyme amino-acyl-tRNA-synthetase and ATP. The amino acid with its tRNA forms a complex: amino-acyl-tRNA. Recognition (recognizing of its own amino acid by tRNA) occurs in the cytoplasm.

Elongation begins after initiation. 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 the 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. When ribosome reaches them its subunits dissociate, mRNA and protein are released.

Several ribosomes may work on the same mRNA. Such complex of several ribosomes united by one mRNA, is called polysome.


Basic regularities of heredity were discovered by **Gregor Mendel** in 1865 year (fig. 32). He carried out experiment on pea plants with different traits: red or white flowers, yellow or green seeds and etc.

Traits (characteristics) that exclude each other (cannot exist together in one individual) are called alternative traits (i.e., seeds cannot have two colors at the same time). They develop under the action of different variants of the same gene. Such gene variants responsible for different alternative characteristics are called *alleles* (allelic genes).
Genes have constant location in chromosomes. Therefore, alleles are situated in the same loci of homologous chromosomes. The sum of all variants of alleles in an individual that were inherited from parents is \textit{genotype}.

Diploid organisms have two alleles of every gene because they have pairs of chromosomes. Homologous chromosomes are inherited from different parents. The organism that inherited same alleles from both parents (and has the genotype AA or aa) is \textit{homozygote}.

As soon as homozygous organisms have same alleles, all their gametes may contain only that allele. I.e. they form only one type of gametes. Consequently, all the children of homozygous parents have identical genotype.

\textbf{Heterozygous} organism has different alleles (Aa). Heterozygotes form two types of gametes. There is segregation of characteristics 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 allele pairs that are in heterozygous state. For example, a homozygote AA form only one type of gametes — A \((2^0 = 1)\); a heterozygote Aa form two types of gametes — A and a \((2^1 = 2)\).

Alleles 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 called \textit{phenotype}.

Alleles of heterozygotes (Aa) may not cause development of both their traits. Only one trait develops and suppresses the effect of the other allele. Such allele is called \textit{dominant} and denoted with capital letter \( A \). So, the trait of the dominant allele develops both in homozygous (AA) and heterozygous (Aa) organisms (for example, yellow seeds of pea).

The trait which develops only in homozygous state (aa) and is always suppressed by the dominant allele is called \textit{recessive} (green seeds).

G. Mendel crossed pea plants. The method of crossing and analysis of descendants is called hybridological method.

If the organisms are analyzed by only one pair of traits (only color of seeds), the cross is called monohybrid. G. Mendel denoted the traits of pea:

\( A \) — the allele of yellow seeds, \( a \) — the allele of green seeds, \( P \) — parents, \( G \) — gametes, \( \times \) — crossing, \( F_1 \) — filial generation 1.

G. 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.

\[
\text{P: } \quad \text{AA (yellow) } \times \text{ aa (green);} \\
\text{G: } \quad \begin{array}{c} A \\ a \end{array} \\
\text{F}_1: \quad \text{Aa — 100% yellow}
\]

The result of the first experiment is heterozygous plants with yellow seeds. According to the results of the cross, G. Mendel formulated his first law — \textbf{the Law of Hybrid Uniformity}: if homozygous individuals differing in one pair
of alternative characteristics are crossed and analyzed, their descendants are uniform (have same phenotype and genotype).

Then G. Mendel crossed those hybrids.

\[ \text{P: } (F_1) \text{ Aa (yellow)} \times \text{Aa (yellow); } \]

\[ G: \begin{array}{cc}
\text{A} & \text{a} \\
\text{A} & \text{a} \\
\end{array} \]

\[ F_2: \begin{array}{ccc}
\text{AA} , & \text{2Aa} , & \text{aa}. \\
\end{array} \]

Phenotypic segregation ratio was 3 : 1 (75 % : 25 %) (3 yellow : 1 green).
Genotypic segregation ratio was 1 : 2 : 1 (25 % AA : 50 % Aa : 25 % aa).

G. Mendel got ¾ of plants with yellow seeds and ¼ with green ones. There was homo- and heterozygotes among the plants with yellow seeds. On the ground of the experiment, G. Mendel formulated his second law — the Law of Segregation: if heterozygotes are crossed and analyzed by one pair of alternative characteristics, segregation ratio of phenotypes 3 : 1 and the ratio of genotypes 1 : 2 : 1 are observed in descendants.

3. DIHYBRID CROSS. THE LAW OF INDEPENDENT ASSORTMENT

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

G. 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

\[ \text{P. } \begin{array}{cc}
\text{AABB} & \times \text{aabb} \\
\end{array} \]

\[ G. \begin{array}{cc}
\text{AB} & \text{ab} \\
\end{array} \]

\[ F_1. \begin{array}{cc}
\text{AaBb} & 100 \% \text{ yellow smooth.} \\
\end{array} \]

Then G. Mendel crossed the hybrids:

\[ \text{P. } (F_1). \text{AaBb } \times \text{ AaBb} \]

\[ G. \begin{array}{cccc}
\text{AB} & \text{Ab} & \text{aB} & \text{ab} \\
\end{array} \]

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 G. Mendel formulated his third law — the Law of Independent Assortment: if heterozygotes are crossed and analyzed by several pairs of alternative characteristics, independent assortment of gametes and genes is observed 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 G. 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 allele of a gene passes to each gamete. Each chromosome carries its own genes to the gamete. Chromosomes are combined randomly during meiosis.

Significance of G. Mendel’s laws:
– The laws are universal. They explain mechanisms of inheritance for all diploid organisms.
– The laws are statistical: 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 situated in the same chromosome is called a linkage group.

In 1911 year Thomas Morgan (fig. 33) described the genetic linkage — joint transmission of several genes from parents to offspring. He carried experiments on fruit flies (Drosophila). They are convenient for experiments because:
– they have just a few chromosomes (8);
– they produce many descendants;

Fig. 33. Thomas Morgan
they early reach sexual maturity, so many generations can be analyzed during relatively short period of time;

– it is possible to use hybridological method (crossing).

Morgan analyzed inheritance of such traits as 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 T. Morgan crossed homzygous flies which had 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:

\[
P. \quad BBVV \times bbvv \\
G. \quad BV \quad bv \\
F_1. \quad BbVv — 100 \% \text{ grey long-winged.}
\]

That corresponded to the first Mendel’s law.

In the second experiment, Thomas Morgan crossed recessive female and diheterozygous male Drosophilae. It was reasonable to expect phenotypic segregation with the ratio 1:1:1:1, i.e. per 25 % of different phenotypes. However, he got two types of flies (50/50 %) which had parental traits. There were no individuals with new combinations of the traits:

\[
P. \quad bbvv \times BbVv \\
G. \quad bv \quad BV \quad bv \\
F_1. \quad bbvv \quad BbVv \\
50\% \quad 50\%
\]

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

During the meiosis the chromosome containing the genes \( BV \) passes to one gamete while the chromosome carrying genes \( bv \) to the other one. That explains why diheterozygous male Drosophila forms 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 same chromosome. Genetic linkage in the male Drosophila is complete and characteristics are always inherited together.

Though in one of other experiments T. Morgan crossed di-heterozygous female and recessive male Drosophilae and observed different result:

\[
P. \quad BbVv \times bbvv \\
G. \quad BV \quad bv \quad BV \quad bv \quad bv \\
F_1. \quad BbVv, \quad Bbvv, \quad bbVv, \quad bbvv \\
41.5 \% \quad 8.5 \% \quad 8.5 \% \quad 41.5 \%
\]

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

Morgan’s experiments agreed with Boveri’s and Sutton’s **Chromosome Theory of Inheritance** and completed it:

1. Genes are situated in chromosomes in a linear order in definite loci. Alleles of the same gene are in identical loci of homologous chromosomes.
2. All genes of one chromosome 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 identical segments) is possible between homologous chromosomes.
4. The frequency 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 that was named in honor of T. Morgan.

**5. Genetics of sex**

**Sex** is the complex of all morphological, physiological and other characteristics of an organism which determine its reproductive role. Reproduction is the ability of organisms to create new individuals of their kind.

**Sexual dimorphism** is the sum of all morphological, physiological, biochemical and other differences (sexual characteristics) between males and females of the same species.

**Primary sexual characteristics** are the organs taking direct part in reproduction. They develop during the embryonic development. **Secondary sexual characteristics** develop under the action of sex hormones and appear during puberty (facial hair, peculiarities of voice and constitution and etc.).

**Human karyotype** consists of 46 chromosomes (23 pairs). Most of them are *autosomes* (22 pairs), the last, 23rd pair is called *sex chromosomes*. Autosomes are the chromosomes which are same in men and women (human has 22 pairs of autosomes). They do not determine the sex of the person. Autosomal genes determine most of human characteristics (hair color, skin color, height and others).

Unlike autosomes, sex chromosomes (also known as heterochromosomes) are different in men and women. They determine the sex of the person.

The sex chromosomes of women are two homologous X-chromosomes. In a man they are non-homologous X-chromosome and Y-chromosome (fig. 34). Such sex determination is typical not for all animals. In birds,
males have same sex chromosomes (ZZ) and females have different sex chromosomes (ZW).

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

The X and Y chromosomes of human have small homologous regions containing alleles of same genes. Though these chromosomes mostly have non-homologous (or differential) regions which contain different genes. The genes situated in the differential region of sex chromosomes are called sex-linked. The genes in differential region of the X-chromosome are called X-linked (i.e. genes some alleles of which cause hemophilia and color blindness). The genes in differential region of the Y-chromosome are called Y-linked (holandric) The alleles of some holandric genes are known to cause 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.

\[
P. \text{XX} \times \text{XY}
\]

\[
\begin{array}{c|c|c}
G. & X & Y \\
\hline
F_1. & XX & XY \\
\hline
& 50 \% & 50 \% \\
\end{array}
\]

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

6. Variation

**Variation** is the property of living organisms to get new characteristics during their development. 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 characteristics 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 in and above water have different shape. Modifications are not caused by changes of genotype. Consequently, they are not inherited.
Properties of modifications:
– not inherited;
– reversible — can disappear after changes of the environmental conditions;
– massive involvement — similar modifications appear in all organisms that are exposed to the same factor (i. g. suntan);
– adaptability — modifications «adjust» the organism to some environmental conditions and commonly are useful for the organism (storage of fat tissue);
– modifications are not matter for the natural selection;
– predictable.

The range of possible changes is called 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 causing mutations are called mutagens. They are:
1. Physical — ultraviolet rays, radiation, temperature.
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 studies normal human genotype and karyotype and its changes in case of various genetic disorders, causes of the disorders, their prophylaxis and treatment. Human is complicated genetic object.

There are difficulties of studying human genetics:

– some methods are not applicable for human (i.e. hybridological method), experiments on human are not possible;
– many chromosomes (46) and genes (about 20–25 000);
– late sexual maturity, long alternation of generations (usually just a few generations are available for analysis);
– small number of children complicates statistical analysis;
– it is not possible to make same environment for all people.

Nevertheless, there are some advantages of studying human genetics:

– human is the most explored genetic object;
– international co-operation of scientists;
– great number of individuals.

Some methods of human Genetics are:
1. Genealogical analysis;
2. Karyotyping (cytogenetic method);
3. Biochemical tests.

Genealogical analysis is based on drawing up pedigrees (family tree, genealogy). It is analysis of a family with particular characteristic (e.g. genetic disorder) in order to reveal patterns of its inheritance. 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. Genotypes of family members.
4. Probability of giving birth to a sick child in a family.

The key for drawing pedigrees is shown in the fig. 35.

Autosomal dominant inheritance:

– sick children are born by only parent (or both parents are sick) sick;
– both men and women fall ill with equal probability;
– if one of the parents is dominant homozygote then the probability that the characteristic will be inherited by a child is 100 %; if both parents are heterozygous — 75 %, if one parent is heterozygous and the other is recessive homozygote — 50 %.
Autosomal recessive inheritance:
- sick children can be born by healthy parents (not always, but it is possible);
- both men and women fall ill with equal probability;
- if both parents are heterozygous then the probability that the characteristic will be inherited by a child is 25 %; if one parent is heterozygous and the other is a recessive homozygote — it is 50 %; if both parents are recessive homozygotes — 100 %.

X-linked dominant inheritance has the same signs as autosomal-dominant one. The key feature is the fact that a man having the X-linked dominant character can transmit the gene only to daughters (sons get his Y-chromosome).

X-linked recessive inheritance:
- mostly/only men fall ill;
- sick children can be born by healthy parents;
- if parents are healthy then probability giving birth to a sick child is 50 % for boys, and 0 % for girls (i.e. 25 %).

Holandric (Y-linked) inheritance:
- only men can have the character;
- such men are in all generations;
- if a father is sick then all his sons are sick and vice versa.

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

Karyotyping (cytogenetic method) is the technique allowing to see human chromosomes extracted from the cells of blood or epithelium under the microscope. This method reveals the number of chromosomes, their structure, the genetic sex of the analyzed individual. Karyotyping is used for making the diagnosis of genome and chromosome mutations.

Biochemical tests can reveal the concentration of enzymes, amino acids and various metabolic products in specimens taken from healthy and sick persons. They help to confirm the diagnoses of metabolic diseases.
More than 4000 hereditary disorders are known at the present day. Medical genetics is the discipline that deals with hereditary disorders. These disorders 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 syndrome** (47, XX, 21+; 47, XY, 21+) is trisomy of the 21st chromosome. Trisomy is a genome mutation when 3 homologous chromosomes are present 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. The life span is usually shorter than that of healthy people.

**Shereshevsky–Turner syndrome** (45, X0) is caused by the absence of the second sex chromosome (monosomy). Phenotype is female. Symptoms: low height, short neck, underdeveloped primary and secondary sexual characteristics, sterility. Intellect is not affected.

**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 sexual characteristics, usually lower intellectual abilities than healthy people.

**X-trisomy syndrome** (47, XXX) is caused by the increase of the number of X chromosomes in females (additional X-chromosome). Such women usually do not have considerable physical features. Intellect is usually not affected. Such children have higher risk of speech and language delays and the delays of motor skills.

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

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

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

**Phenylketonuria** is also caused by disturbance of amino acid exchange. The amino acid phenylalanine is not transformed into tyrosine and is transformed into phenylpyruvic acid. Sick children get increased neural irritability, muscle tone, mental retardation.

Hereditary disorders 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 counseling is a medical discipline that strive to prevent birth of children with hereditary diseases.

Aims of genetic counseling are 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 AND PHYSIOLOGY

1. THE 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 same origin, structure and functions. The human body is composed of four types of tissues epithelial, connective, muscle and nerve (fig. 36).

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 extracellular matrix or it is absent.

Types of epithelium according to the number of layers: simple (single-layer) and stratified (multilayer). According to the shape of cells in the superficial layer epithelium can be 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 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 extracellular 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 produces 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, contract slowly and present in internal organs (walls of blood vessels, alimentary tract, urinary bladder and others);
– striated muscles are multinucleate, voluntarily controlled; form skeletal muscles;
– cardiac cells are not multinucleate, but are striated.

Muscle tissue performs motor function.

4. Nervous tissue forms the brain and spinal cord, ganglions, nerves. It consists of nerve cells — neurons which have two types of cytoplasmic processes (extensions): dendrites and axons. Cells of neuroglia are in between of neurons. Neuroglia performs nutritional, supportive 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 synapse.

Functions of the nervous tissue are:
– receptor — percept stimuli;
– conductive — transmits nerve impulses.
Tissues form organs (fig. 37). The organ is a body part which has particular shape, structure, location and performs a specific function (i. e., heart, lungs, stomach).

Fig. 37. Roles of various tissues in the body

Organs have many various forms and are composed of several tissues. The stomach contains epithelial, connective, smooth muscle and even elements of nervous tissues. Bones are mostly composed of hard connective tissue though they have nerves, other types of connective tissue in their cavities, smooth muscles and epithelial cells 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 referred to as musculo-skeletal or locomotor system.
3. **Integumentary system** includes skin, hair, fat, nails and exocrine glands of the skin.

4. **Nervous system** (NS). Includes the brain, spinal cord, nerves, and ganglia- ons. The nervous system allows perceiving, comprehending, and responding to the environmental signals.

5. **Circulatory system** ([cardiovascular system, CVS]). 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.** It includes digestive glands, mouth, esophagus, stomach, intestines. The system performs mechanical and chemical processing of food.

8. **Reproductive system** includes the female (ovaries, fallopian tubes, uterus, vagina, mammary glands) and male (testes, vas deferens, seminal vesicles and prostate) sex organs 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 referred sometimes to 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. Abdominal cavity contains stomach, intestines, liver, kidneys and reproductive organs. The heart, largest vessels, lungs, trachea and esophagus are located in the thoracic cavity.

### 2. THE STRUCTURE, CONNECTION AND GROWTH OF BONES

Bones together with muscles comprise the human musculoskeletal system. **Chemical composition of bone:** 50% water, 12.5% protein 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, and hydroxyapatite including phosphate and calcium (Ca_{10}(PO_{4})_{6}(OH)_{2}). It makes bones hard and strong.

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

- osteocytes are mature bone cells which produce extracellular matrix;
– osteoblasts are bone cells that divide to form new osteocytes;
– osteoclasts are cells of the bone that break down old osteocytes.

Bones consist of 2 types of substance:
– Spongy bone (looks similar to sponge) consists of trabeculae and space between them. It is inside the bones. Such substance contains red bone marrow which creates blood cells (predominantly in flat bones).
– Compact bone is dense and homogenous. It forms wall of bones.

According to the shape, bones are:
– Long bones: thighbone, humeral bone (upper arm), phalanges and etc.
– Short bones: carpals, tarsals.
– Flat bones: bones of the skull, sternum (breastbone), scapula (shoulder blade), ribs and etc.
– Irregular bones: zygomatic bone, mandible and etc. Such bones have characteristics of all previous groups.

Long bone (fig. 38) consists of a diaphysis (body) and two epiphyses (heads).

Fig. 38. Regions and the structure of long bone
Growth of bones in length associated with body growth is provided by cartilage that between the diaphysis and epiphysis. Bone heads consist of spongy bone and contain red bone marrow which produces blood cells. The heads are covered with cartilage (hard 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.

The structural unit of long bone is osteon. Osteons look like long multilayer cylinders. They contain osteocytes which are enclosed by extracellular matrix they produce. Such matrix contains much inorganic salts and protein collagen. Periosteum contains nerves and blood vessels; it is connective tissue. Periosteum provides bone grows in thickness due to division of its cells (osteoblasts).

Most of bones are connected. **There are 3 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 (sacral vertebrae).

- **Semi movable** (amphiarthrosis) is a connection that allows slight mobility. It is the connection by cartilage (connection of the sternum to ribs, vertebrae in the spine).

- **Movable** (diarthrosis). Movable connection of bones is called synovial joint (or articulation).

Each synovial joint consists of articular surfaces of bones, joint capsule, joint cavity and synovial fluid (fig. 39). Such joint connects several bones. Surface of one bone is usually convex (ball) and that of the other one is concave (socket). Articular surfaces of bones are covered with smooth cartilage which facilitates the movement of the bones.

Synovial joint is enclosed 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. Synovial joints are between the thigh bone and shin, between the bones of the upper arm and forearm. Examples of joints: knee, hip, shoulder, elbow and others. Synovial joints are fixed with ligaments.

*Fig. 39. The anatomy of synovial joint*
### 3. The Structure of the Human Skeleton

**Skeleton** is the passive part of the locomotor system. The human skeleton consists of more than 200 bones. The bones of the skeleton are grouped in 3 regions: head skeleton (skull); axial skeleton (skeleton of the trunk); appendicular skeleton (skeleton of limbs with their girdles).

**The skeleton of the head** is skull. It has two regions: the **neurocranium** (cerebral cranium) which encloses the brain, and **viscerocranium** (facial cranium). Eight bones comprise the **neurocranium** (fig. 40):
- 2 parietal bones;
- 2 temporal bones;
- frontal bone;
- occipital bone;
- ethmoid bone;
- sphenoid bone.

Fourteen bones and the hyoid bone form the **viscerocranium** (fig. 41):
- 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 the mandible which is connected with synovial joints).

**The axial skeleton** forms the spine and thorax. The spine is composed of 33–34 vertebrae and has 5 regions (fig. 42):
- cervical region (7 vertebrae);
- thoracic region (12 vertebrae);
– lumbar region (5 vertebrae);
– sacrum (the bone composed of 5 vertebrae which are fused together);
– coccyx (the bone composed of 4–5 vertebrae which are fused together).

Each vertebra consists of 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 while walking, jumping and running and increase the volume of the chest and pelvis.

Each of twelve thoracic vertebrae has a pair of ribs, i.e. human has 12 pairs of ribs. Thoracic vertebrae, ribs and sternum form the chest (thoracic cage). There are 3 groups of ribs (fig. 43):

- True (vertebrosternal) ribs (1–7 pairs)—their anterior 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 anterior 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 consists of two scapulae and two clavicles.
The 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. The 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 grown to the sacrum.
The lower extremity consists of the upper leg, lower leg and foot. The bone of the upper leg is femur; those of the lower leg are tibia and fibula. The groups of bones in the foot are tarsals (compose tarsus), metatarsals (compose metatarsus), and phalanges.

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

4. MUSCULAR SYSTEM

The other part of musculoskeletal system is muscles. Muscles are the 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>Characteristics of the muscle tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth muscle tissue</td>
</tr>
<tr>
<td>Work involuntarily</td>
</tr>
</tbody>
</table>
### Tissues of the internal organs

<table>
<thead>
<tr>
<th>Located in the internal organs, such as walls of the stomach, esophagus, urinary bladder, intestines, bronchioles, bile ducts, uterus, blood vessels</th>
<th>The tissues of skeletal muscles, muscles of oral cavity, tongue, pharynx, upper esophagus, larynx, facial muscles, diaphragm</th>
<th>The only organ made of this tissue is the heart</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consists of separate cells. The length of such cell is on average 0.1 millimeter. Cells contain have myofibrils (contractile fibers) and a single nucleus</td>
<td>Consists of long muscle fibers (the length reaches 10–12 cm, thickness – 50–100); each fiber contains cytoplasm, numerous nuclei and myofibrils — special organelles with light and dark areas (disks)</td>
<td>Branching chains of cells which have one nucleus. 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 contain blood vessels, nerves and nervous terminations (receptors).

Fibers of striated muscles form fascicles. Group of fascicles is covered with a capsule of connective tissue and forms a skeletal muscle. Each muscle has belly and tendons (fig. 44). These tendons are attached to bones. One end of mimic muscles 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 or masseter, mimic);
- muscles of the neck;
- muscles of the chest;
- abdominal muscles;
- muscles of the back (or dorsal muscles);
- muscles of the limbs and girdles.

The work of muscles is their **contraction**. It requires energy (ATP). Muscle work has a reflex character. **Reflex** is an automatic response of the body to a stimulus with participation of the nervous system. The environmental stimulus causes excitation of receptors. This excitation (impulse) is transmitted through the senso-

![Fig. 44. Skeletal muscle](image-url)
Skeletary neurons to intercalary neurons of the spinal cord and then through the motor neurons to the muscle (fig. 45). This causes contraction of the muscle.

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

*Skeletal muscles are innervated by the somatic nervous system.* It provides voluntary control of muscles. In addition, the muscles are innervated by the autonomic nervous system that regulates their metabolism and contractility.

The central nervous system (CNS) has 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 $O_2$ 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 transparent liquid in lymphatic vessels. Its chemical composition is similar to blood plasma, but it contains less proteins. It does not contain cells except lymphocytes. Lymph originates from interstitial fluid and moves through the lymphatic vessels (fig. 46). Numerous lymph nodes are located along lymphatic vessels. Lymphocytes are arrived into the lymph from the lymphatic nodes. The largest lymph vessels fuse into the thoracic and right lymphatic ducts that empty into vessels joining the superior vena cava. About 1–3 liters of lymph return 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 of an adult is approximately 5–6 liters so it constitutes 7–8 % of body weight.

Blood consists of the liquid intercellular substance (blood plasma) (fig. 47) and formed elements (blood cells) (fig. 48).

Fig. 46. Lymphatic system and the organs of the immune system

Fig. 47. The composition of blood
Plasma is 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 have a shape of biconcave disc 7–8 µm in diameter (fig. 49). They have no nucleus — it is extruded from the cells as they mature. All the erythrocyte is filled with hemoglobin — the protein which is able to hold oxygen and carry it to cells. Due to hemoglobin, blood is red. Erythrocytes have high plasticity allowing them to squeeze through the capillaries without breaking.

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 liter of blood contains 4–5 × 10¹² erythrocytes.

The function of red blood cells is transport: they bring O₂ from lungs to tissues and organs and take CO₂ from tissues and organs to the lungs.

In the arterial blood, hemoglobin binds with O₂ to form oxyhemoglobin. In venous blood, hemoglobin binds to CO₂ and forms carbhemoglobin. 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. There are several types of leukocytes: basophils, eosinophils, neutrophils (they are granulocytes), monocytes, lymphocytes (they are agranulocytes). Sizes of different leukocytes vary from 6 to 25 micrometers. Unlike erythrocytes, they have nucleus. Leukocytes can move due to pseudopodia they form. There are approximately 4.5–9 × 10⁹ of white blood cells in one liter of blood of a healthy adult man (most of them are neutrophils). Leukocytes are produced in the red bone marrow and mature in spleen, lymph nodes. Granulocytes live 2–4 days, agranulocytes can live much longer. These cells are destroyed in the spleen and lymph nodes.

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 of phagocytosis. In addition, some lymphocytes form protective proteins — antibodies.
Thrombocytes (platelets). One liter of blood contains 150–450 × 10^9 platelets. Like erythrocytes, they do not have nucleus. Their shape is irregular; sizes are of 2–5 micrometers (fig. 50). 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 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. THE 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 which is called 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 is 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. 51). 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’s another name is mitral valve. Between the right atrium and right ventricle is the tricuspid valve (has three cusps).

![Diagram of the heart](image)

**Fig. 51. The anatomy of the heart**

Blood is always pumped from atria to the ventricles and tendon threads that keep the valves prevent reverse movement of blood from ventricles to the atria. Due to these tendons the valves can open only to the ventricles.

Each chamber is connected with large blood vessels:
- *superior and inferior vena cava* join the right atrium;
- *4 pulmonary veins* deliver blood to the left atrium;
- *pulmonary trunk* begins from the right ventricle and then divide into 2 *pulmonary arteries*;
- *aorta* carries blood from the left ventricle.

The heart muscle is fed with blood due to 2 coronary arteries which branch from the aorta.

*There are semilunar valves* between the pulmonary trunk (*pulmonary valve*) and right ventricle and between left ventricle and aorta (*aortic valve*). Semilunar valves do not allow blood return from these vessels back to the ventricles.

The work of the heart is its contraction. It works rhythmically and does 70–75 beats per minute (at rest). Consequently, one cardiac cycle lasts approximately \( \frac{60}{75} = 0.8 \) seconds. **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 and blood from atria fills the ventricles (fig. 52).
Fig. 52. The stages of the cardiac cycle

Period including systole of the atria and ventricles plus the overall pause is cardiac cycle. 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 functioning. Acetylcholine and potassium ions depress the heart activity.

7. THE STRUCTURE OF BLOOD VESSELS. BLOOD CIRCULATIONS

Heart contracts to pump the blood to the blood vessels. There are three types of blood vessels (fig. 53) in the circulatory system: arteries, capillaries and veins.

Fig. 53. Blood vessels

Arteries are the vessels that carry blood from the heart to organs and tissues. The largest artery in the human body is the aorta (2.5 cm diameter). In arteries,
blood moves under high 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 branch out into smaller arteries; they branch out into arterioles and the arterioles 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-section area of all capillaries of the body is 6300 m².

Exchange of substances and gases occurs through the capillary walls:
- O₂ and nutrients diffuse from blood to tissues;
- various metabolites (including metabolic wastes) and CO₂ from tissues enter 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 lower 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. All the vessels in the human body belong to systemic (greater) and pulmonary (lesser) circulations.

**The systemic circulation** (fig. 54) begins in the left ventricle and ends in the right atrium. The left side of the heart contains arterial (oxygenated) blood.

![Fig. 54. Pulmonary and systemic circulations](image)

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

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 CO₂. 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 branch 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. THE 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 provides 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, pharynx, larynx, trachea, bronchi and 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 opens to 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. The nasal cavity contains olfactory receptors perceiving various odors.

Air passes from the nasal cavity into the pharynx (nasopharynx, oropharynx, laryngopharynx) and other parts of the pharynx, then into the larynx. Openings between the nasal cavity and the nasopharynx are called choanae.

The larynx consists of cartilage and muscles (fig. 55) and its cavity is covered by mucous membrane (mucosa).
The epiglottic cartilage (epiglottis) closes the entrance to the larynx during swallowing. There are 9 cartilages in the larynx:
- thyroid cartilage, cricoid cartilage and epiglottis (single cartilages);
- 2 arytenoid, 2 corniculate and 2 cuneiform cartilages (paired cartilages).

There is a vocal apparatus in the larynx. It consists of vocal cords and glottis. The vocal cords are stretched from the arytenoid cartilages to the thyroid cartilage. Hole between the vocal cords is the glottis. Voice occurs 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 enter the right and left lungs. In the lungs, the bronchi branch out to form the bronchial tree. These smallest bronchi branch into bronchioles. The walls of the bronchioles have muscle fibers. At the ends of the bronchioles are the alveoli. Alveolar diameter is 0.2–0.3 mm. Their walls consist of a single layer of epithelial cells. Lungs contain 300–400 million alveoli. In the alveoli gas exchange occurs — they are surrounded by blood capillaries.

Lungs (fig. 56) are in the thoracic cavity. Each lung has an apex and the base. Bronchi, blood vessels and nerves enter the lungs through the roots of lungs on the medial surface. Lungs consist of lobes: the right lung has three lobes, the left one — 2 lobes.
A serous membrane pleura covers lungs. The pleura consists of two layers: the external (parietal), which lines the chest, and internal (visceral) covering the lungs. Between the layers 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, pharynx and nasal cavity. 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 internal 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 carbamino-hemoglobin. 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 increases 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. THE 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 (fig. 57).

Fig. 57. The anatomy of the digestive system

The digestive system processes food mechanically and chemically. Chemical processing occurs under the action of enzymes made by digestive glands. Mechanical processing is performed by teeth and muscles of the digestive tract.

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

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. 58). A tooth consists of a crown, neck and root. Teeth are laid down 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.

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 teeth of different types corresponds to their role in food mastication.
In the oral cavity is tongue — a muscular organ covered with a mucous membrane. The tongue consists of a root, body and apex. In the mucosa are taste buds. The apex of the tongue has the receptors that perceive sweet, the sides of the tongue perceive sour and salty, the root of the tongue — bitter. Though newer information suggests that all types of receptors are present on all the surface of the tongue.

The tongue manipulates food in the mouth, determines the taste and the food temperature, participates in the swallowing and formation of speech.

There are three pairs of salivary glands: parotid, submandibular and sublingual. Their ducts 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 bolus 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 regions of the stomach are fundus, cardia, body, and pylorus.
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 glands producing *gastric juice* in the gastric mucosa:
- chief cells secrete enzymes pepsin and chymosin;
- parietal cells secrete hydrochloric acid;
- the cells of the mucous neck secrete mucus.

**The small intestine** (fig. 59) 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 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.

Each villus contains blood and lymph vessels and is covered with a simple epithelium. Its function is absorption of nutrients.

The mucosa contains glands that secrete *intestinal juice*. Smooth muscles of the intestinal wall have two layers: the inner (circular) and external (longitudinal). Their contraction propels food through the intestine.

**Liver** (fig. 60) 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 hepatis (Latin «liver gate») is located on the bottom of the liver in the center. Vessels, nerves and bile ducts enter the liver here.

**Gallbladder** (biliary vesicle, cholecyst) is a pear-shaped sac attached to the bottom surface of the liver which is a storage reservoir for bile. It 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. Its length is 12–15 cm (fig. 61).

![Fig. 61. The anatomy of pancreas](image)

The pancreas consists of a head, body, and tail. Pancreatic juice produced by pancreatic cells contains digestive enzymes. It is 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. 62). Muscular layer of the colon is larger than that of the small intestine. There cecum has a small outgrowth which is called **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.

![Fig. 62. Regions of the large intestine](image)
10. Enzymes. Digestion 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 lipids (fats).
   - Glycosidases such as amylase, 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.

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 simpler peptides;
- chymosin that curdles 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 regulating digestion is situated in the medulla oblongata.
Substances that are absorbed in the stomach are glucose, water, dissolved salts, and some medicine. 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 down proteins into smaller peptides;
- lipase that breaks down fats into glycerol and fatty acids;
- amylase and maltase that break starch;
- nucleases break down nucleic acid into nucleotides.

**Bile** does not contain enzymes. **Functions of bile:**
- emulsifies fats — breaks them up into small drops;
- activates intestinal enzymes;
- facilitates the absorption of fats and fat-soluble vitamins;
- stimulates 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 about 2 liters.

Intestinal juice contains 22 enzymes:
- proteases such as aminopeptidase, carboxypeptidase break down proteins into amino acids; enterokinase activates trypsin;
- glycosidases such as amylase, maltase, lactase break down carbohydrates;
- lipases break down fats;
- nucleases digest 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 and then enter the lymphatic vessels.

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

There are numerous bacteria in the large intestine. They break down some compounds and synthesize vitamins (such as B1, B9, B12, K). The large intestine forms stool that is excreted through the anus.

11. **Excretory system. The structure and functions of kidneys.**

**The 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, urinary bladder and urethra (fig. 63).
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 kidney of an adult has length about 10 cm and weight of 150 grams. It is roughly bean-shaped with an indentation called hilum on the medial side. A ureter, renal arteries and veins, nerves, lymphatic vessels enter the kidney in this region. Each kidney is covered with 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. 64).

Fig. 64. The anatomy of 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. 65).

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 a renal pelvis.

Urine containing metabolites is produced by the kidneys. Its formation occurs at 2 stages and is based on 3 processes:

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 many substances essential for the body (glucose, amino acids, and mineral salts).

2. **Reabsorption** (formation of secondary urine) occurs in the tubules of the nephron. 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. Secondary urine contains water, urea (main nitrogen-containing product of urine), ammonia, uric acid, ions of sodium, potassium, calcium, magnesium.

3. **Tubular secretion** is the transport of substances from peritubular capillaries to the renal tubules. The direction of this transport is opposite to reabsorption.

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

**Ureters** are small tubes that carry urine from the renal pelvises to the urinary bladder. Their length is about 25 cm.

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

**Urethra** is a thin-walled tube through which urine is excreted from the urinary bladder to the outside.

**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. 66):

1. **Epidermis** is the outermost layer of the skin composed of squamous cells. This layer can be of two distinct types: thick skin (palms, feet) and thin skin (most of the body).
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.

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

**Fig. 66.** The structure of the skin

**Epidermis** is epithelial tissue. Its thickness is 0.07–2.5 mm. There are 5 layers in the epidermis. The outer layer is **stratum corneum** (consists of keratinocytes), the lowermost one is the **stratum basale** (consists of basal cells and melanocytes). The stratum corneum consists of dead cells. Basal layer consists of living cells. These cells constantly divide to produce new cells that are pushed upward to form the layers above. Basal cells ultimately transform into new keratinocytes, which replace the older ones that die and are shed off. 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.

**Dermis** is the thickest layer of skin (0.5 to 5 mm). It consists of papillary and reticular layers. The papillary layer is of loose fibrous connective tissue and forms
protrusions into the epidermis. It contains blood and lymph vessels, receptors, fibers providing strength and elasticity to the skin. Under the papillary layer is the reticular layer. It contains sebaceous and sweat glands, hair follicles.

*Sweat glands* regulate body temperature by transporting water to the surface of skin where it evaporates to cool down the skin. Such gland consists of a body and excretory duct. The human organism has 2–3 million sweat glands. A lot of them are on the face and hands. Sweat glands secrete sweat. Sweat contains H₂O, ammonia, urea, mineral salts.

*Sebaceous (oil) glands* secrete oil (sebum) that helps to waterproof the skin and protects 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 enter the hair follicle. Muscles attached to the hair follicle raise 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 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. THE STRUCTURE AND FUNCTIONS 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;
- it 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. 67) 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 areafferent 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 the brain and spinal cord (fig. 68). 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, and organs of sense.

**Spinal cord** is situated in the 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 anterior and posterior 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. 69).

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**Fig. 68.** The anatomy of the spinal cord

**Fig. 69.** Transverse section of the thoracic region of the spinal cord
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.

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 horns.

Axons of sensory neurons (the visible fibers they form are posterior roots) enter posterior horns and transmit excitation into the spinal cord. The bodies of sensory neurons are in the spinal ganglia (fig. 70).

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 anterior (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.

Fig. 70. Reflex arc

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, micturition, elimination of feces from the intestine and sexual function.

The spinal cord is controlled by the brain.

13. THE STRUCTURE AND FUNCTION OF THE BRAIN

The brain is situated in neurocranium of the skull. The average volume of the brain is 1350 cubic centimeters. 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 (midbrain), metencephalon and medulla oblongata (together they are hindbrain) (fig. 71). 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.

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 (cavity with cerebrospinal fluid) is situated there.

Functions of the medulla oblongata are:
– Conductive. Conduction of impulses from the spinal cord into the overlying 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.).

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 are covered with cortex (consists of gray matter) which has sulci. 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;

Midbrain (mesencephalon) is between the diencephalon and the cerebellum. It consists of quadrigemina (Latin for four-hills) and cerebral peduncles (Latin for «legs of the brain»). In its center a narrow canal which 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 colliculi) and hearing (lower colliculi).

The diencephalon (interbrain) is situated above the midbrain below the cerebral hemispheres. 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 work of 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 except smell (sight, hearing, touch, taste). There are centers participating in regulation of emotions and mental activity. The hypothalamus contains the centers which regulate metabolism, homeostasis, and activity of cardiovascular system, centers of digestion, thirst, hunger, body temperature, sleep and wakefulness.

Cerebrum (telencephalon) includes the cerebral hemispheres (about 80% of the mass of the brain) connected with corpus callosum. Two cerebral ventricles are situated there on the left and right sides (lateral ventricles).

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 (basal ganglia) are situated. The cortex has sulci (fissures) and gyri (curves). 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. 72). 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. 72. Lobes and the structure 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. THE 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.

Any analyzer consists of 3 parts:
1. The peripheral part is receptors of sense organ;
2. The conducting part is the nerves which transmit excitation (impulse) 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, lacrimal 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:
– outer — fibrous tunic (sclera, cornea);
– medial — vascular tunic (choroid, ciliary body, iris);
– inner — internal tunic (retina).

The front transparent part of the fibrous tunica is the cornea; the rest of the tunica forms the dense part called 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. 73). 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. 74).

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 conducts the impulse from receptors into visual area of the cortex (the occipital lobe) which analyzes visual stimuli.
4. A person can see things around.

Fig. 73. The structure of retina

Fig. 74. The anatomy of eye
If the light rays cannot be focused on the surface of the retina, vision impairments occur:

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

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

15. **THE 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. 75). Receptors of hearing organ are the peripheral part of the auditory analyzer.

![Fig. 75. The anatomy of human ear](image)

**Outer ear** includes the auricle, external auditory canal, tympanic membrane (or eardrum). The auricle consists of cartilage covered with skin. It collects sound. The external auditory canal is a tube approximately 30 millimeters in length.

There are glands that secrete earwax which retains dust and bacteria. The eardrum is a thin membrane that perceives sound waves. It is the border between the outer ear and the middle one.

**Middle ear** consists a cavity of volume about 1 cm³ (tympanic cavity). Tympanic cavity is connected with the nasopharynx by the Eustachian (acoustic) tube. The acoustic tube equalizes pressure on both sides of the eardrum.

There are 3 auditory ossicles (bones) in the tympanic cavity. These ossicles are called malleus, incus and stapes (Latin «hammer», «anvil», «stirrup»). They are connected to each other and conduct the vibrations from the eardrum to the inner ear. The malleus is connected with the eardrum and the stapes is connected to the membrane of the inner ear which is called the oval window.

**The inner ear** is located inside of the temporal bone of the skull. It contains the organ of hearing (cochlea) and the organ of equilibrium (semicircular canals). Cochlea is situated in spirally twisted bony canal (fig. 76). Two membranes (vestibular and basilar) divide this canal is into 3 scalae (ducts):

1. The cochlear duct is in the middle between the vestibular and basilar membranes. It is filled with endolymph and contains the organ of Corti which perceives sound and transforms it into nerve impulse.
2. The vestibular duct is separated from the cochlear duct with the vestibular membrane. It is filled with perilymph.

3. The tympanic duct is separated from the cochlear duct with the basilar membrane. It is filled with perilymph.

Fig. 76. The anatomy of cochlea:

a — cross-section of cochlea, b — ducts of the inner ear, c — organ of Corti, d — the pathway of sound waves
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. The sensory cells in the auditory epithelium of the organ of Corti are called hair cells. One of their ends is fixed to the membrane and the other ends with hairs. Ends of the auditory nerve begin in the fixed ends of the receptors. The surface of the organ of Corti is covered with tectorial 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 the ossicles: malleus → incus → stapes. The ossicles increase the intensity of sound up to 20 times;
3. Vibrations of stapes are transmitted to the oval window;
4. Vibrations of the oval window cause vibrations in the perilymph and endolymph;
5. The vibrations in the perilymph and endolymph cause traveling waves along the basilar membrane;
6. The motions of the basilar membrane bend and stimulate the hair cells of the organ of Corti. I.e. nerve impulse appears in the receptors;
7. The nerve conducts the impulse from the cochlea to the temporal lobe of the cerebral cortex where center of the hearing is situated;
8. The temporal lobe of the cerebral cortex analyzes the acoustic signal.
Hearing organ allows orientation in the environment and communication with other people, hearing music, speech and etc.

16. **Reproductive system. The structure and production of gametes**

**Reproduction** is the property of organisms to create new individuals of the same species. Due to reproduction new generations can replace old ones. Thus reproduction provides the continuity of life and is the basis for existence of the species.

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

The reproductive system consists of internal and external genital organs.

**Male internal genital organs** (fig. 77) are 2 testes and their epididymides (singular — epididymis), vasa deferentia (singular — vas deferens) with seminal vesicles and prostate.

**Male external genitalia** are penis and scrotum.

**Testes** are male sex glands. They are located in the scrotum. Testes produce sperms and male sex hormones (such as testosterone). Their size is about 3–5 cm, weight is 15–30 g.
Female internal genital organs (fig. 78) are 2 ovaries, fallopian tubes, uterus and vagina.

Female external genitalia are labia majora, labia minora, clitoris.

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; the 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.

The process of formation of gametes is called gametogenesis (table 3). The gametogenesis of female gametes is called ovogenesis.
Formation of ovocyte takes place once a month from puberty (12–13 years) and up to 45–50 years old. **Ovogenesis consists of periods:**

1. During the period of proliferation diploid ovogonia (set of chromosomes is 2n2chr) divide by mitosis to multiply.
2. During the period of growth, ovogonia accumulates nutrients, grow and transform into primary ovocytes (set of chromosomes is 2n2chr).
3. During the period of maturation primary ovocytes begin meiosis. After first meiotic division the primary ovocyte divides into two haploid cells (set of chromosomes is 1n2chr) a large secondary ovocyte and a small polar body. During the second meiotic division, the secondary ovocyte 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. 79). 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 divides into 2 spermatids (1n1chr). Consequently, each primary spermatocyte form four spermatids;

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

Spermatozoa consist of a head, midpiece and tail (fig. 80). The head contains the haploid nucleus and an acrosome (modified Golgi apparatus). The midpiece contains cell center and the mitochondria. Sperms are much smaller than egg cells, their length are 55 micrometers (head is about 5 micrometers).

![Fig. 80. Spermatozoon](image)

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. MIROBIOLOGY AND ZOOLOGY**

**THE CONCEPT OF PROKARYOTES AND EUKARYOTES. BACTERIA**

There are two huge groups of living organisms: prokaryotes and eukaryotes. Bacteria (singular — bacterium) refer to the first group. Their cells do not have nuclei and membrane-enclosed organelles; division by mitosis or meiosis is not possible for them. The second group is eukaryotes (plants, animals, fungi, protists). Such cells have nucleus and membrane-enclosed organelles; they are able to divide by mitosis and meiosis.

Bacteria are tiny unicellular (i.e. consisting of one cell) organisms. Their sizes are from 0.2 to 13 micrometers. Bacteria are seen only under a microscope.

*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* (fig. 81). Shapes of bacteria may vary. Sphere-like bacterium is called *coccus* (plural — cocci), rod-like bacterium is *bacillus* (plural — bacilli), comma-shaped one — vibrio, spiral-like one — *spirillum* (plural — spirilla).
There are motile and non-motile 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 (fig. 82), cell wall and plasma membrane cover the cell of a bacterium. The capsule is a protective covering.

The genetic material of bacteria is a circular DNA that is called nucleoid. It is attached to the plasma membrane. Apart from the nucleoid, bacteria may have a number of small circular DNA — plasmids. Bacteria have ribosomes which make proteins.

None of bacteria has membrane-enclosed organelles. It was found that bacteria have mesosomes which are invaginations of the plasma membrane. Though modern techniques suggested that mesosomes are artifacts formed due to damage of membranes after chemical fixation (it is necessary for microscopy) and they do not exist in living bacterial cells.

According to feeding type (assimilation), bacteria are autotrophic and heterotrophic. The autotrophic ones synthesize organic compounds from inorganic substances for themselves (use inorganic substances as a source of carbon). 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 (use other organic substances as a source of carbon). For instance, lactic-acid bacteria transform sugars into the lactic acid. Another example of heterotrophs are bacteria-parasites. They feed on organic compounds of living organisms.

According to dissimilation type, 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 by binary fission (a cell simply divides into two). In favorable environmental conditions, bacteria can divide every 20–30 minutes and produce more than 600 million new bacteria from one cell in one day. There is a sexual process called conjugation in some bacteria. During this process, two bacteria form a cytoplasmic «bridge» (pilus). Through pilus, the donor cell shares particular DNA with the recipient cell. Such gene transfer helps to spread some genes in bacterial population.

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 help to recycle carbon, nitrogen and other elements of organic substances. Human found the way to use bacteria for making food: sour crème, cheese, 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 some antibiotics, vitamins, enzymes, hormones.

Many bacteria are even harmful for human. They spoil food, 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.

Many methods of controlling the diseases elaborated such as illuminating the hospital wards with ultraviolet rays. Surgical tools 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. 83). For example, Homo sapi-
ens — wise man. The largest taxonomy unit is kingdom, the next lesser taxon is phylum.

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

This kingdom includes the following phyla:
1. Sarcomastigophora (examples – Amoeba, Euglena, Giardia);
2. Ciliata (example – Paramecium caudatum);
3. Apicomplexa (example – Plasmodium (malaria parasite)).

Many protists such as amoeba (fig. 84), euglena (fig. 85), ciliates are free-living. They live in the soil and water. Their «body» is just one cell performing the functions of the whole organism. The shape of amoeba is changeable; that of euglena and ciliates is constant.

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.

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.

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.

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 which regulates cell metabolism. The micronucleus is the generative nucleus involved in the sexual process.
According to the feeding type, protists are autotrophs and heterotrophs. Amoebae and ciliates are heterotrophs. The euglena is both autotrophic and heterotrophic (has green pigment chlorophyll). Amoeba feeds by phagocytosis. It surrounds food particles with pseudopodia, then they merge and form food 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 through the oral groove and «mouth» (cytostome). Remains of food are excreted through the anal pore.

Some protists (fig. 86) have organelles that help them to excrete water and liquid metabolic products — contractile vacuoles. Breathing of protists occurs by diffusion through their surface.

Reproduction of protists is asexual. It occurs by mitosis or amitosis. Ciliates have sexual process (but not reproduction!) — conjugation. During the conjugation two ciliates connect, their macronuclei disappear, the micronuclei divide by meiosis. Each ciliate gains own and foreign haploid micronucleus, they merge and form new micro- and macronuclei. This increases genetic diversity of the population.

If the environmental conditions become unfavorable, protists form cysts: the cell shrinks, drops or draws-in their locomotion organelles, stops feeding and forms protective covering. The covering protects the cell from drying out, low temperature, toxic substances. Cysts also help protists to spread on.

The capability of protists to response to 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 at the expense of other organisms, receive food from them and harm them 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 causes is called *giardiasis*.

*Entamoeba histolytica* also belongs to the phylum *Sarcomastigophora* and causes *amoebiasis* in human. Cysts of amoebae are transmitted through contaminated food and water. This is the way the amoeba enters 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 Anopheline mosquito. Parasites from the mosquito's saliva pass into the blood of human. Then parasite travels to the liver where it multiplies. Such asexual reproduction of plasmodia is called *schizogony* – one cell divides into many daughter cells. Then such reproduction repeats red blood cells many times.

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

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. *Eddy worms* (*Turbellaria*). For example, planaria. They are free-living.
2. *Flukes* (*Trematoda*). Examples are liver fluke (lat. *Fasciola hepatica*) and cat liver fluke (lat. *Opisthorchis felineus*). All flukes 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 from 3 germ layers — ectoderm, endoderm and mesoderm.
The body of flatworms is covered with the dermo-muscular wall. Its 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 eddy worms, 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. 87). The space between organs is filled with connective tissue which develops from the third gerninal layer (mesoderm). It performs structural function, participates in metabolism and regeneration.

![Fig. 87. The cross-section of flatworm](image)

Flatworms have digestive, excretory, reproductive and nervous systems (fig. 88).

![Fig. 88. The anatomy and excretory system of planaria](image)
Tapeworms are the parasites which have no digestive system. The digestive system of eddy worms and flukes consists of *foregut* and *midgut*. The foregut includes mouth and pharynx. Digestion and absorption occur in the midgut. Flatworms have no hindgut with anal opening and remove the undigested material through the mouth. Planarian 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.

*The excretory organs are protonephridia.* They begin in the connective tissue 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 connective tissue.

*The nervous system* of flatworms consists of two 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*. This means that they have male and female sex organs (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.

Eddy worms multiply sexually (but also can multiply asexually by *fragmentation* when cut). Sexual reproduction is more common than asexual because it increases the genetic diversity of population. This is necessary for survivability of 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.

4. **Characteristics of the class **Trematoda** (Flukes)**

Parasitic worms of any phylum and class which cause diseases are called helminthes. The diseases caused by helminths are helminthias (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*).

*Fasciola hepatica* (fig. 89) has leaf-shaped body which can reach 3–5 cm in length. There are oral and ventral suckers on the abdominal surface.

![Fig. 89. Fasciola hepatica](image)
*Fasciola hepatica* lives in the liver ducts of many mammals, especially ruminants and humans. It attaches to the wall of the bile duct by suckers.

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

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

*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.

*Excretory organs* are protonephridia. *Circulatory and respiratory systems are absent.*

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

*Reproductive system.* Flukes are hermaphrodites. They have complex life cycles. The life cycle (fig. 90) of a liver fluke includes two hosts and several stages of larvae. The organism where sexual reproduction of mature fluke occurs is called the definitive host. The *definitive hosts* of the liver fluke are cattle or human.

*Fig. 90. The life cycle of Fasciola hepatica*
The definitive 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* — freshwater snail. In the intermediate host the parasite reproduces 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 *adolescencia*. The adolescaria are swallowed by the cattle or sometimes humans during drinking non-boiled water from reservoir, and also eating the vegetables and fruit which are washed up with this water. In the duodenum, the adolescaria 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.

The disease caused by the liver fluke is called *fascioliasis*. It refers to helminthiases. 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. Tapeworms live in the digestive system.

**External anatomy.** As is seen from the name of the class, tapeworms have tape-like body shape. Its length is from 1 mm to 10–18 m. The body consists of *scolex* (head), *neck*, and *strobila* (segmental body). Commonly 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 and no 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*. Microvilli are outgrowths of the tegument which increase the body surface for better absorption of nutrition.

*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 (definitive and intermediate).

A representative of tapeworms is 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 but no hooks* (fig. 91). The neck is the tapeworm’s growth zone which forms new (immature) 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 mature (or hermaphroditic). Segments in the rear end of the body are gravid. Such segment contains uterus with large amount of eggs.

The **life cycle** is complex (fig. 92).

![Fig. 91. *Taeniarhynchus saginatus*](image1)

![Fig. 92. The life cycle of tapeworms](image2)

The **definitive 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 *measle* (*cysticercus*).

Cysticercus looks like a little bubble containing the head of a young beef tapeworm. Humans can become infected by eating raw or undercooked meat with measles. In the human intestine adult worm of beef tapeworm is develops from cysticerci.

*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. Pork tapeworm (*Taenia solium*), broad tapeworm (*Diphyllobothrium latum*), dwarf tapeworm (*Hymenolepis nana*) can parasite in the small intestine of human.

**6. CHARACTERISTICS OF THE PHYLUM **NEMATHELMINTHES** (ROUNDWORMS)

*Phylum Roundworms* has five classes. The number of species is about 15,500. The most considerable class is the class *Nematoda*.

There are free-living and parasitic nematodes. Habitats are water, soil, the human body, animals and plants.

**External anatomy** (fig. 93). Bodies of roundworms are not segmented. They have round body shape in cross section. This gave the name to the class. The body length of nematodes varies 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*. Its external layer is cuticle. The cuticle 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*). This is the body cavity developing from the primary cavity in embryo. It does not have lining. 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. 94) of nematodes consists of three regions: 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.

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 ganglions, 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.

Ascaris lumbricoides is a parasitic nematode which affects human. The length of a female is 15–40 centimeters; that of a male is about 15–25. The 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 240,000 eggs per day. They are passed to the environment with feces. In 2–3 weeks, larva develops in the egg in if conditions are favorable (temperature is 20–25 °C, humidity, presence of oxygen). Such eggs may be ingested by a host organism with unwashed vegetables, fruit and water. Larvae hatch from the eggs in the small intestine, perforate its wall and migrate through the blood vessels. They migrate through the liver, right atrium and right ventricle and reach lungs. From alveoli, larvae ascend into bronchioles, bronchi, trachea and get into the pharynx where they are swallowed. In 3 months,
they transform into sexually mature forms in the small intestine. Larvae migration lasts about 2 weeks. Life span of the mature *A. lumbricoides* is about 1 year.

*Ascaris* causes the disease *ascariasis*. 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 feces;
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 million 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. 95) 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 such chitinous exoskeleton.

As the chitin limits the growth of arthropods, they periodically undergo molting when they leave their chitin and replace it with a new one.

*Organs of locomotion*. All arthropods have jointed appendages (consist of segments). They can be modified to perform various functions: walking, feeding, protection from enemies and etc. Arthropods of different classes have different number of walking legs: crustaceans have 5 pairs, arachnids have 4 and insects — 3.

*Internal anatomy*. The body cavity is formed by confluence of the primary and secondary body cavities. Such cavity is called *mixocoel*. It is filled with fluid called hemolymph. It is colorless liquid functions of which are similar to both those of blood and interstitial fluid.
Digestive tract consists of 3 regions (foregut, midgut, hindgut). They are differentiated into regions (esophagus, stomach and etc.) There is a complex apparatus of appendages near the mouth. They are specialized for different types of feeding.

Excretory organs are green and coxal glands (in crustaceans and arachnids respectively) or Malpighian tubules (in insects and arachnids). Malpighian tubules are outgrowths of the gut between the midgut and hindgut.

Insects have fat body — the organ which performs many metabolic functions such as storage of glycogen and lipids, and, in addition, accumulates some metabolic wastes.

Circulatory system of arthropods consists of a heart and, in spiders, a number of vessels. The heart is located at the dorsal side of the abdomen (fig. 96). 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. 96. The anatomy of spider

Respiratory organs of arthropods are various: aquatic ones breathe with gills while the terrestrial ones use book lungs or trachea.

Nervous system includes a cerebral ganglion («the brain»), circumpharyngeal nerve ring and ventral nerve cord. All sense organs are developed in arthropods: sight, smell, touch, 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. Such development is characteristic of bugs and lice.

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 abdomen. The cephalothorax carries 6 pairs of appendages, two of them are near the mouth. The first pair is two chelicerae and the second pair is two
pedipalps (tentaculites). Spiders paralyze their prey with venom. The ducts of venomous glands open at the tips of chelicerae. 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, genital 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. 97). Digestive system includes foregut, midgut, hindgut. Predatory arachnids eat other organisms, parasites may feed on host’s blood or plant juices. Digestion starts outside the digestive system: enzymes of salivary glands are injected into the prey. Muscular pharynx and pumping stomach help the spider to suck in liquid food. Ducts of the liver open into the midgut. Branches of the midgut also extend into the abdomen and surround other bodily structures. This large and extended digestive tract allows spiders to survive for many days without feeding. The process of digestion completes there. Undigested remains of food are passed through the hindgut and eliminated through the anal opening.

![Fig. 97. The internal anatomy of spider](image)

**Excretory organs** of arachnids are coxal glands and Malpighian tubules. Coxal glands open on the body surface near the walking legs while the Malpighian tubules join into the digestive tract between the midgut and hindgut.

**The circulatory system** of arachnids is open. The tubule-shaped heart is situated at the dorsal side of the abdomen. Hemolymph is pumped from the heart to the body cavity where it bathes the respiratory organs.

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

**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 paired, 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 form capitulum which serves as 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.

**Itch mites** live in the human skin. Their sizes are about 0.3 mm. Females gnaw through the skin forming tunnels 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 lower regions of the abdomen and 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.

### 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 cuticle consisting of 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 segmented appendages at the ventral side of the thorax and one or two pairs of wings at its dorsal side. Some parasitic insects such as lice and fleas do not have wings.
Internal anatomy (fig. 98). Digestive system includes foregut, midgut and hindgut. Foregut begins with mouth. There is a complex apparatus of appendages near the mouth – mouthparts. They are specialized for different types of feeding. The appendages of the mouthparts are upper and lower labia (lips), a pair of maxillae (lower jaw) and a pair of mandibles (upper jaw). The structure of mouthparts depends 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).

The foregut includes the mouth, pharynx, esophagus, crop, proventriculus. Ducts of salivary glands are open into the oral cavity. The midgut includes the ventriculus (stomach) with gastric ceca. The posterior region of the digestive tract is hindgut. Insects have no liver. Digestive enzymes are released by the wall of the midgut. Digestion and absorption of nutrition also occur in the midgut.

Excretory organs are Malpighian tubules. The Malpighian tubules are open into the digestive canal between the midgut and hindgut. Insects have fat body which is the organ performing many metabolic functions such as storage of glycogen and lipids, and, in addition, accumulating some metabolic wastes.

Circulatory system is open. The heart having the shape of a tubule lies 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.

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.

Nervous system of insects is complex. It composed of suprapharyngeal ganglion, ventral nerve cord and nerves. The suprapharyngeal ganglion is highly developed (brain) and is responsible for complex behavior of insects. It consists 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 PHYLUM 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: endoderm, mesoderm and ectoderm. Body cavity is secondary; it is also known as coelom.

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

Embryos of all chordates have axial supporting organ notochord. In most of adult chordates, it is replaced with a spine.

Above the notochord is nerve tube. 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 is the alimentary tube. It consists of anterior, middle and posterior regions. The anterior region of the tube has pharyngeal slits (gill slits) In aquatic animals they give rise to breathing organs – gills. Terrestrial chordates breathe with lungs. Their gill slits develop into other organs.
Circulatory system is closed and composed of one or two circulations (fig. 99). The heart is situated at the ventral side below the alimentary tube.

Excretory organs are nephridia or kidneys. There are two types of kidneys: mesonephric (primordial) kidneys and metanephric (pelvic) ones.

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

Taxonomy 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. Lancelets are one of the simplest chordates, though they have all typical anatomical peculiarities of chordates.

Lancelets inhabit the sand of a reservoir’s bottom.

External anatomy. Lancelet has streamline body shape, its length is approximately 4–8 cm. The body regions are head, trunk and tail. Body covering is skin consisting of simple (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: oral cirri surrounding the mouth propel water with food particles to the mouth. Water is removed through gill slits. 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 time as feeding. Gas exchange occurs in the vessels of gill slits.

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

Circulatory system is closed; pulsing abdominal 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 the pharynx. Fertilization is external, development occur in the water. Development is indirect.

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. Body of fishes consists of 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 fins are single. They provide body stability and locomotion (fig. 100).

![Fig. 100. The external anatomy of fish](image)

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. The skeleton of fish is made of bone and cartilaginous tissues. It supports the body and organs. Two massive tapes of fish muscles are 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 forms immobile static connection. The skull consists of a neurocranium and visceral cranium. The neurocrani-
um 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 truncal and caudal regions. Truncal vertebrae have ribs.

**Digestive system** includes mouth, pharynx, esophagus, stomach, intestine (small and large) and anus (fig. 101). There are jaws equipped with teeth in the oral cavity. The wall of the pharynx has gill slits. Fishes have digestive glands such as a liver with a gallbladder and pancreas.

![Generalized fish anatomy](image)

**Fig. 101.** The external anatomy of fish

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 ascend and decrease it to descend 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 (unoxynogenated) blood.

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

**Central nervous system** (CNS) consists of the brain and the spinal cord. The brain consists of 5 regions: metencephalon, diencephalon, mesencephalon, metencephalon 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.

12. Characteristics of the class Amphibia

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

There are 3 orders of the class amphibia:
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 the bones of upper arm, bones of forearm and bones of the palm.

Bones of the pectoral girdle are sternum (breastbone), coracoids, clavicle (collar bone) and scapulae (shoulder blade).

The skeleton of the hind limb includes femur (hip), tibia with fibula (shin) and foot.

The pelvic girdle is made of pelvic bones.

The most developed of muscles in amphibians are those of hind limbs, head, abdomen and oral cavity.

Digestive system (fig. 102) 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 cloaca through which undigested remains of food are eliminated. 

*Excretory organs* are mesonephric kidneys. Kidneys and the urinary bladder open into cloaca.

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

*Circulatory system.* 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 except the brain receive mixed blood, the brain receives arterial blood.

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

*Nervous system.* The brain consists of 5 regions: metencephalon, diencephalon, mesencephalon, metencephalon and medulla oblongata. The endbrain of amphibians is developed better than that of fishes and includes two hemispheres. Cerebellum is developed less than that of fishes. It is associated with simplicity of their movements 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 with upper and lower lids and nictitating membrane. Lids prevent drying out of the eyes. The hearing organ is composed of inner and middle ears. The middle ear is separated from the environment by an eardrum. There is an ossicle — stapes. Olfactory function is performed by nostrils. Taste organ is tongue. Touch organ is skin. All larvae and aquatic adult amphibians have lateral line.

*Reproductive system.* Reproduction is sexual, sexes are separate. Fertilization is external and occurs in water. Development is indirect.

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 fishes are ancestors of amphibians (fig. 103).
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Fig. 103. The life cycle of frog

13. Characteristic of the class Reptilia

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

Orders of the class Reptilia:
– The order Squamata (lizards and snakes);
– The order Crocodilia (alligators and crocodiles);
– The order Chelonia (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 drop their tail in case of danger and grow it again later. Such phenomenon when organism 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 movable neck.

Body covering is skin which includes epidermis and dermis. It is covered with corneous scales and has no glands. Such body covering prevents water loss and protects the animal. Since the scales hold down body growth, reptiles have to shed their skin periodically. This phenomenon is called moulting.

The skeleton of reptiles is composed of the skull, the axial skeleton and the skeleton of limbs with girdles. The skull has oblong shape and consists of neurocranium and visceral cranium. It is connected with the spine movably. Reptiles are first who evolved hard bony palate which separated nasal and oral cavities. The spine which is a trunk skeleton consists of 5 regions: cervical, thoracic, lumbar, sacral and caudal. There is a chest which is made of thoracic vertebrae, ribs and breastbone.

Muscles of reptiles are more developed than those of amphibians. There are new groups of muscles: those of neck, fingers, intercostal, subcutaneous.
The spine of snakes has only truncal and caudal regions, skeleton of limbs and girdles is absent. They also have no sternum and thus chest.

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 with fibula (shin) and foot. There are claws on the fingers.

**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 cloaca through which undigested food remains are eliminated. There are liver and pancreas (fig. 104).

![Fig. 104. The internal anatomy of crocodile](image)

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 than those of amphibians. Air passes there through respiratory tract: 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 septum in the ventricle. Crocodiles have four-chamber heart due to the complete septum. Systemic 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 (ex-
cept the brain and forelimbs) are fed with mixed blood. The brain is supplied with arterial blood.

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

Nervous system. The brain consists of 5 regions: metencephalon, diencephalon, mesencephalon, metencephalon 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. Hearing organ consists of inner and middle ears, the middle one is separated from the environment by an eardrum. There is one os- sicle (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. It provides protection from injures and drying-out.

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. The subclass Prototheria (Yinotheria):
   – echidna, long-beaked echidna, platypus. They are the most primitive mammals (have cloaca, lay eggs).

2. The subclass Theria includes 2 infraclasses.
   The infraclass Marsupials (newborns are poorly developed and are carried in a pouch): kangaroos, koalas, possums, marsupial wolves.

The infraclass Placentals (intrauterine development):
   – The order Insectivores: moles, hedgehogs, muskrats;
   – The order Chiropterans: vampires, bats, fruit bats;
   – The order Rodents: mice, rats, gophers, beavers, squirrels;
   – The order Lagomorphs: hares, rabbits;
   – The order Carnivores: bears, cats, dogs, wolves;
   – The order Pinnipeds: seals, walruses;
   – The order Cetaceans: blue whales, dolphins;
   – The order Even-toed ungulate: deer, roe deer, cows, pigs;
   – The order Odd-toed ungulate: rhinos, zebras, horses;
   – The order Proboscideans: african and indian elephants;
   – The order Primates: gorillas, chimpanzees, lemurs.

Peculiarities of mammals: hair covering, viviparity, breast-feeding, developed nervous system, complex behavior, diaphragm.

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**External anatomy.** Bodies consist 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).

The skeleton consists of 3 parts: the skull, axial skeleton and the skeleton of limbs with girdles. The 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.

The pectoral girdle consists clavicles and scapulae (shoulder blade).
The 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.
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. 105). 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).

![Fig. 105. The internal anatomy of dolphin](image)

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 (unoxgenated) 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 (homeothermal) animals.* Their body temperature is constant and does not depend 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 ossicles 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 intra-uterine development. Young animals are fed with mother’s milk (breastfeeding). Most of mammals are placental. They develop in the uterus. Nutrition and gas exchange are provided by the placenta which is an organ connecting organisms of fetus and mother. Parental care is observed in all mammals.

**LITERATURE**


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