MASARYK UNIVERSITY
Faculty of Medicine

OVERVIEW OF GENERAL BIOLOGY

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Guide to the Required Knowledge of Biology, with Basic English Terminology, for Pre-Medical Course Students
(Not to be used as a standard textbook)

This textbook has not been subjected to language revision.

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PREFACE

Biology is a basic natural science subject and its good knowledge is a prerequisite for success in the study of medicine. General biology includes a great variety of fields, amongst them also medicine, which base their study and development on those topics and concepts of biology which are relevant to their specific needs. Therefore, it is advisable for students in medical courses to have good foundations of molecular and cell biology, genetics and human somatology, to be able relate the human organism to the hierarchy of living systems and to know the basic information on evolutionary and environmental issues. The texts on biology presented here cover all the mentioned areas in relation to the extent required.

The applicants for medical courses finish their secondary education in various types of schools which differ greatly in the standard of knowledge. For some students, these biology texts will provide a pleasant guide to the revision of study materials for the entrance tests, for others, they will be an unpleasant surprise when they reveal how many more facts will have to be learned.

This publication is not a textbook but a review of basic facts in general biology which are required for the entrance examinations at the Medical Faculty in Brno and at some other medical faculties in CR. However, it cannot replace the course in biology taught in grammar schools for three or even four years. Any student who will find any of the topics less familiar or even unknown should complete the knowledge by studying from a good biology textbook.

This review of basic biology in English can also assist foreign students in their basic science courses or help Czech students who, in the framework of their medical course, need to communicate in English in the field of biology.

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Roman Janisch

1 GENERAL CHARACTERISTICS OF LIVING SYSTEMS

Classification of Biological Sciences

General biology is the "science of living things" studying morphology, function and all processes in living systems. There are many branches of biological sciences:

anatomy – the study of morphology and gross structures, especially by dissection,
biochemistry – the chemistry of substances constituting living systems,
botany – the science dealing with the biology of plants,
chemistry – the science of substances in general,
cytology – the study of cell structure and function,
ecology – the study of the interactions of living organisms with their living and non-living environments,
embryology – the study of the formation and development of embryos,
genetics – the study of the inheritance or transmission of traits from one generation to another,
histology – the study of tissues by microscopy,
microbiology – the study of microorganisms,
molecular biology – the study cellular function in molecular level,
palaeontology – the study of the distribution of organisms in time as revealed by their fossil records in the strata of the earth's surface,
pathology – the study of diseases and abnormal structures or functions, including causes, symptoms and effects,
physiology – the study of the functioning of an organism or its parts,
taxonomy – the systematic classification of organisms,
zoology – the science dealing with the biology of animals.

Methodology of Scientific Work in Biology

The basic steps in scientific method are:

1. Recognition of the problem
2. Accurate preliminary observation
3. Formulation of a hypothesis
4. Testing the hypothesis
5. Evaluation of the collected data
6. Drawing logical conclusions
7. Repeatability and reporting the results

The basic method of testing a hypothesis is by the use of a **controlled experiment.** The experimental population is randomly allocated to either **treated** or **control** groups. These groups are maintained **under identical conditions** apart from application of the treatment to be assessed. Assessment of the effects, as compared with the control group, is based on specific characteristics – the **variables.**

History of Biology

The first scientific and systematic work was developed in **Greece**. The early **Romans** seemed to be interested more in the practical or applied side of science, whether in agriculture, engineering, transport, etc. After the Greek and Roman periods there was **a decline in European science during the Middle Ages** between the 3rd and 12th century A.D. During this time science was opposed by public opinion and authority and, in this unproductive period, the emphasis was placed on the "opinions" or "judgements" of a few so-called authorities. There was considerable biological scientific activity in Arabia, centred around medicinal plants.

A **revival of the scientific studies** of plants and animals occurred between the 13th and 16th century in the period described as the **Renaissance**. **Scientific societies** were established and publication of **scientific journals** began. Rapid scientific progress came in the 17th century with the advent of the **microscope** which uncovered a new world of microorganisms. The 20th century has seen many improvements of microscopy including ultramicroscopes, ultraviolet, dark-field, bright-field and phase-contrast microscopes, and **transmission and scanning electron microscopy.**

Today the study of structure and function of living systems is carried out at the **molecular level**. The structure-function concept is crucial for the understanding of the relationship between chemistry and biology. Biological functions depend on chemical structure. An understanding of biology at the cellular and molecular levels is essential in order to interpret wider biological issues in the present-day circumstances.

Prominent Personalities in Biology

Aristotle (384-347 B.C.), a Greek philosopher who stressed the importance of **accurate and direct observation** and initiated the basis for a **scientific method** of solving problems.

A. Vesalius (1514-64), a Belgian anatomist who stressed the importance of direct observation and published a large treatise on **human anatomy** based on **dissections.**

V. Harvey (1578-1657), an English physician who proved that **blood circulates** in arteries and veins and that the **heart is a muscular pump.**

M. Malpighi (1628-94), an Italian scientist and physician who studied the **structure of plants and animals**. He is considered the **"Father of Microscopic Anatomy"** and discovered existence of blood capillaries.

A. van Leeuwenhoek (1632-1723), a Dutch **microscopist** who developed a simple microscope (about 1673) and was the first to study bacteria, moulds, protozoans, red blood cells, etc.

R. Hooke (1635-1703), an English **microscopist** who constructed a microscope in 1665 and described many types of natural objects. In cork tissue, he observed minute, box-like structures that he called **"cells"**.

C. Linneaus (1707-78), a Swedish biologist who is considered the **"Father of Classification and Taxonomy"**. He revised and reorganized the **biological nomenclature** and established the **binary system of description.**

J. B. Lamarck (1744-1829), a French biologist who was a student of organic evolution. He believed that environmental influences, and the effects of use and disuse of body parts, were causes of evolutionary changes – a theory that laid the foundation for the **"Theory of the Inheritance of Acquired Traits"**.

J. E. Purkinje (1787-1869), a Bohemian physiologist who introduced the term **"protoplasm"**. He belongs to the "three fathers" of the **"Cell Principle"**.

M. Schleiden (1804-81), a German botanist who participated in the promulgation of the **"Cell Principle" (1839).**

T. Schwann (1810-82), a German zoologist who also participated in the promulgation of the **"Cell Theory"**.

Ch. Darwin (1809-82), an English naturalist who proposed the evolution of species by the development of varieties from common stocks. This process entailed a "struggle for existence", which resulted in a "natural selection of species" and a "survival of the fittest". **(The Origin of Species by Means of Natural Selection, 1859).**

J. G. Mendel (1822-84), a Bohemian scientist and monk who gave the first **scientific interpretation of the heredity mechanism** after 8 years of experimental work with garden peas. This interpretation led to the formulation of his famous laws and laid the foundation for future studies in **genetics**.

L. Pasteur (1822-95), a French bacteriologist and chemist who proved that fermentation and decomposition of substances resulted from the activities of microbes. He proved that certain diseases were caused by bacteria and he is often called the **"Father of Bacteriology"**.

R. Koch (1843-1910), a German **bacteriologist** and **physician** who devised a plate method for growing bacteria on solid media and proved that specific **bacteria caused the diseases** of anthrax (1877) and tuberculosis (1882).
I. P. Pavlov (1849-1936), a Russian physiologist who proposed the concept that **acquired reflexes** play a role in the nervous reaction pattern in animals.
T. H. Morgan (1866-1945), an American biologist and Nobel Prize winner (1946) who contributed to the knowledge of the **mechanism of heredity**. He reported the first gene mutation in the fruit fly (*Drosophila*).
A. Carrel (1873-1944), a French surgeon and biologist who introduced the **method of tissue** and **cell cultures** – cultivation of tissues outside the body (in vitro).
A. Fleming (1881-1955), an English bacteriologist who discovered the first **antibiotic - penicillin,** (1929).
J. D. Watson (1928) and **F. H. Crick (1916-2004)** of Harvard University, USA, and Cambridge, England, respectively, found (1953) that molecules which control heredity in the organism are made of DNA and they described the **molecular structure of DNA.**
H. G. Khorana (1922) and M. W. Nirenberg (1927-2010) received the Nobel Prize in 1968 for their part in cracking the genetic code.
L. C. Pauling (1901-1994) discovered several of the basic structural features of protein molecules.
B. McClintock (1902-1992) one of the world's most distinguished cytogeneticists; he was awarded the Nobel Prize in 1983 for the discovery of genetic transposition.

Biological Species

Diversity is a characteristic of life. There are more than **3 million named types of organisms.** The grouping used in most **biological classification** is the species.
A **biological species** is a population or group of populations whose members can interbreed in nature and produce fertile offspring but cannot successfully interbreed with members of other populations. Two or more species having some characteristics in common form a **genus**. Similarly, two or more genera with common characteristics form a **family**. Families are grouped into **orders**, orders into **classes** and classes into **phyla**. All of the phyla constitute a **kingdom**.

Systematics and Taxonomy

Taxonomy groups organisms in ways that reflect relationships and help distinguish one organism from another. **The binomial nomenclature** is a **two-word naming system** for each species. This system was first devised by **Carolus Linneaus** (*Systema Naturae, 1758*).
The first word is the **genus name,** the second word is the **specific name**. Together these two words are called the **species name. Latin names** are used in binomial classification in scientific communication.

Examples of Classification Hierarchies

	human	white oak	bread mould	amoeba	cyanobacteria
species	*H. sapiens*	*Q. alba*	*R. stolonifer*	*A. proteus*	*A. circinalis*
genus	*Homo*	*Quercus*	*Rhizopus*	*Amoeba*	*Anabaena*
family	*Hominidae*	*Fagaceae*	*Mucoraceacae*	*Amoebidae*	*Nostocaceae*
order	*Primates*	*Fagales*	*Mucorales*	*Amoebina*	*Oscillatoriales*
class	*Mammalia*	*Dicotyledoneae*	*Phycomycetes*	*Lobosa*	*Eubacteria*
phylum	*Chordata*	*Anthophyta*	*Zygomycota*	*Sarcodina*	*Cyanobacteria*
kingdom	*Animalia*	*Plants*	*Fungi*	*Protista*	*Monera*

Hierarchical Structure of Living Systems

1. **Subcellular organisms (acellular)** – viruses, phages.
2. **Unicellular organisms** – bacteria, cyanobacteria, protozoa (*Paramecium*, *Amoeba*), algae (*Chlamydomonas*), fungi (yeast cells).
3. **Cell colonies** – algae (*Volvox*), slime mould (*Physarum*).
4. **Multicellular organisms** – animals, plants, fungi.
5. **Animal societies** – social insects (honeybee society, termites, etc.).

Building Hierarchy in Multicellular Organisms (with examples):

1. **Atoms** (carbon, oxygen, hydrogen, nitrogen)
2. **Molecules** (actin, tubulin, globulins, DNA, RNA)
3. **Supramolecular complexes** (microtubules, membranes)
4. **Organelles** (mitochondria, chloroplasts, lysosomes)
5. **Cells** (neurons, muscle cells, leucocytes)
6. **Tissues** (connective, epithelial, muscle, nervous tissues)
7. **Organs** (stomach, salivary gland, brain, eye, heart)
8. **Systems of organs** (digestive, respiratory, excretory)
9. **Organisms** (human)

General Properties of Organisms and Differences Between Living and Inanimate Nature

Characteristics of Life:

1. **Chemical construction** – organic biopolymers
2. **Cellular nature** – cells are the basic units of all living systems
3. **Metabolism** – chemical and energy changes leading to a decrease in entropy
4. **Growth** – increase in volume
5. **Reproduction** – continuity of life through generations
6. **Heredity** – phenomenon wherein the traits are transmitted from one generation to another
7. **Variation** – divergence amongst individuals of a species
8. **Movement** – locomotion and intracellular movement
9. **Evolution** – production of new adaptive forms
10. **Irritability** – ability to react to various stimuli
11. **Differentiation** – complex of changes involved in the progressive diversification of structure and function
12. **Regeneration** – ability to replace certain parts that have been lost
13. **Adaptation** – any changes and characteristics of the living system that improve its chances for survival in a changing environment.

The complex of all these characteristics is typical of living systems.

Dependence of Organisms on the Environment

Living organisms are independent entities distinctly separated from their environments, on which, however, they are dependent. Organisms have adapted to abiotic factors that shape their environment. Environmental factors can be abiotic or biotic.

Abiotic Environmental Factors

Abiotic environmental factors are **physical** or **chemical** in nature:
- **Environmental temperature.** Life events of the living organisms occur within certain temperature limits, i.e., 0 to 50°C. The lower limit is defined by a change of water into ice, the upper limit is defined by irreversible changes in protein molecules.
- **Atmospheric pressure.** In the above temperature range, water molecules remain in the liquid state only within certain levels of atmospheric pressure.
- **Light energy.** Only autotrophic organisms are directly dependent on light energy. They transform this into chemical energy. Heterotrophic organisms depend on light only indirectly: they use energy from substrates produced by autotrophic organisms.
- **Chemical composition of the environment.** To sustain life, the environment must provide all necessary elements in appropriate compounds. At the same time, it must not contain components which are harmful to living organisms.

The origin of life and its further development was made possible by the existence of favourable abiotic conditions. During this development, however, the conditions were changing and organisms were gradually adapting to them. The ability of an organism to adapt to changing conditions is the basic principle of evolution. Species with low adaptability died out.

Biotic Factors

The relationships of an organism with other living organisms in the environment are essential for maintaining the life of species and genera. All these interrelationships together are termed "biotic conditions of life".
All environmental factors will be discussed in more detail in the chapter on ecology (see p. 75).

General Principles of Reproduction in Living Systems

Organisms reproduce by **asexual** or **sexual** means. Asexual reproduction (vegetative) requires only one parent and the offspring is a duplicate of the parent.
Ways of vegetative reproduction are budding, fragmentation and cell division (in unicellular organisms)
Asexually reproduced organisms (with examples) **are:**
- unicellular organisms (bacteria, protozoa, diatoms)
- plants (grasses, strawberries, potatoes, onion)
- phylogenetically lower animals (sponges, coelenterates, helminths)

The offspring are genetically identical to their parent and are known as **clones**.

Sexual reproduction in higher animals and some plants:
- requires two parents,
- a new organism develops from a fertilized egg,

- includes two processes:
- gametogenesis (production of reproductive cells – gametes),
- genetic recombination (sexual process or fertilization),
- in gametes, a haploid number of chromosomes is achieved by means of a special kind of cell division known as meiosis,
- meiosis and fertilization are complementary processes in sexual reproduction,
- is a source of genetic variation and raw material of evolution.

In the life cycle of animals, meiotic cell division usually occurs only when gametes are produced. In some plants, however, meiosis produces cells that grow into new, multicellular haploid plants. These, after maturation, produce female and male gametes by mitosis. Fusion of these gametes produces a diploid plant. Thus, in their life cycle, **a haploid stage alternates with a diploid stage.**

Individual Development of Multicellular Organisms

Development of a new organism begins with **fertilization**, the union of egg and sperm nuclei. Fertilization initiates a series of events that converts a single cell, **zygote,** into a complex organism of billions of cells with different structures and functions.
A zygote undergoes multiple rounds of mitosis by the process of **cleavage,** first forming a cluster of cells, **morula**, then a hollow ball of several hundred cells, **blastula,** and, finally, a sphere with three distinct cell layers, **gastrula**.
An increase in the number of cells and their differentiation are essential components of development in multicellular organisms.

Gastrulation produces three layers:
- **ectoderm** gives rise to epidermis of skin, epithelial lining of mouth and rectum, sense receptors in epidermis, nervous system and adrenal medulla,
- **endoderm** gives rise to epithelial lining of digestive tract, epithelial lining of respiratory system, liver, pancreas, thyroid, lining of urinary bladder,
- **mesoderm** gives rise to skeletal, muscular, circulatory, excretory and reproductive systems, dermis of skin, lining of body cavities and adrenal cortex.

Following the gastrula stage, many animals develop directly into adults but others develop first into one or more larval stages which then undergo a complete change of body form called **metamorphosis**.

There are three kinds of metamorphosis:
- **ametamorphosis**, the egg develops into a young form that resembles the adult in all respects except size,
- **incomplete metamorphosis,** the egg develops into a larva that may display some resemblances to the adult and gradually transforms into an adult (in insects such larval forms are usually called **nymphs**),
- **complete metamorphosis,** in some insects the egg develops into a segmented larval stage, to be followed by a quiescent pupal stage, which in turn develops into an adult – **imago.**

2 SURVEY OF THE SYSTEMS OF LIVING ORGANISMS

Classification System of Living Organisms

The classification system provides an organized approach to the study of the great diversity of organisms in the biosphere. It is based on the most important structural, biochemical and evolutionary homologues.

A Brief Survey of the Classification System (with examples)

1. Kingdom – **MONERA** (prokaryotes)
   1. **Subcellulates** (viruses)
   2. **Protocellulates**
      1. **Bacteria** (*Escherichia coli, Staphyloccocus aureus, Mycobacterium tuberculosis*)
      2. **Cyanobacteria** (*Oscillatoria, Anabaena*)

2. Kingdom – **FUNGI**
   1. **Slime molds** (*Physarum, Badhamia, Arcyria*)
   2. **Chytridiomycetes** (*Phytophtora infestans, Plasmopara viticola*)
   3. **Zygomycetes** (*Mucor mucedo, Rhizopus nigricans*)
   4. **Endomycetes** (*Sacchacomyces cerevisiae*)
   5. **Ascomycetes** (*Claviceps purpurea, Penicillium*)
   6. **Basidiomycetes** (mushrooms)

3. Kingdom – **PLANTAE**
   1. **Lower plants** – algae (brown – diatoms; red – *Chondrus, Agarum*; green – *Pandorina*,)
   2. **Higher plants** (mosses, club mosses, horsetails, ferns, cykads, gingoes, conifers, monocots, dicots)

4. Kingdom – **ANIMALIA**
   1. **Protozoa**
      1. **Flagellates** (*Euglena viridis, Trypanosoma gambiense, Trichomonas vaginalis*)
      2. **Sarcodines** (*Amoeba proteus, Entamoeba histolytica*)
      3. **Sporozoans** (*Plasmodium malariae, Nosema apis, Toxoplasma gondii*)
      4. **Ciliates** (*Paramecium caudatum, Stylonychia mytilus, Stentor coeruleus*)
   2. **Metazoa**
      1. **Sponges** (bath sponge)
      2. **Stinging tentacled animals** (*Cnidaria* – coral, jellyfish, sea anemones)
      3. **Flatworms** (*Platyhelminthes* – tapeworm, planarian)
      4. **Roundworms** (*Nematoda* – *Ascaris*, hookworm, rootworm)
      5. **Molluscs** (*Mollusca* – snail, clam, octopus)
      6. **Segmented worms** (*Annelida* – earthworm, leech)
      7. **Arthropods** (*Arthropoda* – crustaceans, insects, arachnids, millipedes, centipedes)
      8. **Echinoderms** (*Echinodermata* – sea urchin, starfish, sea cucumber)
      9. **Chordates** (*Chordata* – tunicates, lancelates, acorn worms, vertebrates)

Vertebrates:
1. **Jawless fish** (sea lamprey, Atlantic hagfish)
2. **Cartlaginous fish** (shark, stingray)
3. **Bony fish** (toadfish, tuna, American eel, rainbow trout)
4. **Amphibians** (tiger salamander, green toad)
5. **Reptiles** (rattlesnake, corn snake, box turtle, chameleon)
6. **Birds** (ostrich, parrot, pheasant, owl, sparrow, king penguin)
7. **Mammals** (monotremes – duckbilled platypus; marsupials – kangaroo, opossum; placentals – seal, horse, rabbit, bat, manatee, gorilla, human)

In the other types of classification, unicellular eukaryotes are grouped in another kingdom – **Protista** which includes slime molds (fungus like protists), algae (plant like protists), and protozoa (animal like protists), all mentioned above.

Acellular Organisms

Acellular organisms are **viruses.**
Characteristics of viruses:
- particles of submicroscopic size (20–250 nm) called virions,
- spherical or rod-like shape with a central core,
- chemical composition:
  - nucleic acid (DNA or RNA) in the centre,
  - proteins, lipids and polysaccharides as the capsid on the periphery,
- intracellular parasites (reproduction only in a living cell),
- specifity to a certain cell type:
  - animal viruses,
  - plant viruses,
  - bacterial viruses or phages (bacteriophages), their usually spherical particle (head) furnished with an extended tail comes into contact with the surface of a bacterial cell,
- causes of human diseases: AIDS, herpes, influenza, measles, mumps, smallpox, chickenpox, poliomyelitis, infectious hepatitis, infectious mononucleosis, virus pneumonia.

When the virion comes into contact with the appropriate host, it becomes active and is then referred to as a virus. If any virus is to replicate, it must infect a suitable host cell and take over the host cell's synthetic machinery.

Unicellular Organisms

The whole body of a unicellular organism consists of a **single prokaryotic or eukaryotic cell.** In this category there are bacteria, blue-green algae (prokaryotic cells), fungi (yeasts), algae and protozoa. A single cell of such an organism is an **entity capable of independent life** – it can feed itself, produce all necessary substances and reproduce itself. In comparison with component cells of a tissue, unicellular organisms show striking diversity in size and inner structure. The structural principle of the cell, however, remains the same. In some unicellular organisms, the cells contain specialised, highly differentiated structures not found in other cell types. This can be observed, for instance, in infusoria with their contractile and digestive vacuoles, nuclear dimorphism, oral apparatus or the system of locomotor organelles. The nutrition of unicellular organisms can be either auxotrophic (blue-green algae, algae) or heterotrophic (bacteria, yeasts, protozoa).

Reproduction in unicellular organisms is maintained by cell division. The **high reproduction rate**, typical of unicellular organisms, is very important for sustaining the life of the species. Independently of this reproduction, a **sexual process – conjugation** – can also take place. This is known in all species of unicellular organisms.
Some unicellular organisms, such as bacteria, can produce very resistant spores or cysts, such as found in protozoa. These dormant forms serve to survive unfavourable physical conditions (high temperature, radiation, dryness) and thus maintain the life of the species.
In evolutionary terms, unicelullar organisms are primitive forms of life which either maintained their simple cellular organisation (bacteria) or developed complex cellular structures (infusoria).
In the reproduction of some unicellular organisms, such as yeasts, bacteria or blue-green algae, the divided cells remain close together and produce aggregates of a large number of cells which are called **colonies**. One colony can consist of tens of millions of cells and can be seen by the naked eye. In blue-green algae and algae, cells produced by division remain joined into long chains. Within a colony, some cells can undergo distinct structural and functional differentiation – surface cells develop flagella to assist movement, some cells ensure food intake, other cells specialise to carry out a reproductive function. This type of colony is designated **"cellular colony"** and is a step in the development towards multicellular organisms.

Bacteria

Bacteria are grouped among prokaryotic cells.

Charateristics of bacteria:

- **microscopic size** (1–10 μm),
  - spherical (coccus), rod-shaped or cylindrical (bacillus), spiral or helical (spirillum) shape,
  - the cell is surrounded by a wall composed of mucopeptides and peptidoglycans,
  - some bacteria are surrounded by a **gelatinous capsule** around the cell wall; they are more virulent,
  - some bacteria can transform into highly resistant **spores**,
  - some bacteria can move by **flagella**, made of the protein flagelin, which are quite different from eukaryotic flagella,
  - they can be classified as aerobes or anaerobes, autotrophs, heterotrophs or chemoheterotrophs, parasites or saprophyts,
- **parasitic bacteria** are the causes of many human, animal and plant diseases :
  - human diseases: tuberculosis, anthrax, whooping cough (pertusis), diphteria, tetanus, botulismus, typhoid fever, cholera, gonorrhea, meningitis, syphilis, leprosy, tonsillitis, puerperal sepsis,
  - animal diseases: tuberculosis of cattle and pigs, anthrax of sheep, tularaemia,
  - plant diseases: soft rot of carrots, cabbage and cucumbers; potato canker, fire blight,
- **saprophytic bacteria** decompose organic wastes and dead organisms and, in the process, return elements to the environment in inorganic forms which are available for use by other organisms,
- **nitrogen-fixing bacteria** convert atmospheric N_2 into ammonia and, together with ammonifying bacteria, enrich the soil with nitrogen,
- **nitrifying bacteria** convert soil ammonia to nitrate.

Some bacteria have beneficial activities. They are involved in the production of sauerkraut, pickles and vinegar, butter, yoghurt and cheese, and in the curing of coffee, cocoa beans and black tea.. Bacteria are used in many industrial and agricultural processes and some species play a role in the physiology of digestion.

Cyanobacteria

Cyanobacteria or **blue-green** algae are photosynthetic prokaryotic cells commonly found in lakes, ponds, tropical oceans and on wet rocks or in other moist places. They are simple, unicellular forms, often producing a filament or a colony. The thick-walled cells are often surrounded by a slimy, gelatinous sheath. In the system of membrane lamellae called thylakoids, the **photosynthetic pigments** chlorophyll a, β-carotene, phycocyanins and phycoerythrins are present.
Several species of blue-green algae are able to fix atmospheric N_2 and play a role in maintaining the fertility of certain soils. Species growing in hot springs (over 80°C) precipitate calcium and magnesium salts to produce travertine with brilliant colours. Cyanobacteria belong to the **oldest organisms** that dominated Earth some 3 billion years ago.

The eukaryotic unicellular organisms – **algae see** p. 13, fungi see p. 14, and protists see p. 15.

Multicellular Organisms

A multicellular organism is a complex, **hierarchically organised system**. The basic building unit is the cell. Large numbers of cells, similar in structure and function, associate to form higher units called tissues. Cells of a tissue are attached or connected to each other. Amongst the cells there are narrow or wide intercellular spaces.
In **plant tissues**, cell walls are perforated with minute apertures which allow for contact between plasma membranes and exchange of substances between neighbouring cells. These connections are called plasmodesmata. Plant tissues are classified, by function, as **meristematic, epidermal, ground,** and **conducting**. Several tissues may combine in a single structure (for example, a plant leaf is made up of epidermal, ground and conducting tissues).
In **animals,** tissues are categorised according to highly specialised functions, into **epithelia, connective, nerve**, and **muscle tissues** and **body fluids**. Several differentiated tissues make up **organs**, each of which performs a specific task (for example, an animal muscle is composed of muscle, connective and nerve tissues). Several organs together constitute **systems** responsible for specific essential functions in the organism (digestion, respiration, excretion, regulation, reproduction).

Plants

Plants have **cellulose-containing cell walls**. Nutrient reserves are stored as **starch**. The cells contain **chloroplasts with chlorophyll** and, by the process of **photosynthesis**, combine carbon dioxide and water in the presence of energy-supplying light. There are two subkingdoms: **simple plants** (*Thallophyta*) and **higher plants** (*Embryophyta*).

Simple Plants

Simple plants are **algae**, without true leaves, stems or roots; they do not form multicellular embryos and have no true vascular (conducting) tissues. Some species are unicellular but the majority of them are multicellular. These consist either of a linear series of cells or are composed of sheet-like masses of cells. Algae usually live in water or moist places, they supply food for fresh water and marine animals and some may form the lime salts which contribute to the formation of reefs in the ocean.

Higher Plants

Higher plants produce a multicellular embryo. They are **mainly terrestrial** (land plants) and are classified into four groups:

- liverworts and true mosses
- club "mosses", horsetails and ferns
- conifers and allies
- flowering plants

Mosses may prevent soil erosion because of their abundant growth. Also, their natural water-absorbing qualities enable them to assist in flood control by preventing rapid runoff of water.
Club "mosses", horsetails and ferns were involved in the formation of coal.
Conifers produce much valuable timber and large quantities of resins, oils and amber products.
Flowering plants (angiosperms) possess true leaves, stems and roots. Stems may be herbaceous or woody. They are primarily terrestrial and widely distributed and they constitute the dominant and, economically, the most important class in the plant kingdom. They are divided into **dicotyledonous** and **monocotyledonous.**

Fungi

Fungi are unicellular or multicellular and form filaments called **hyphae**. They are heterotrophic **saprophytes** or **parasites** without true leaves, stems, roots or vascular tissues. Some species destroy foods and other organic material such as paper, leather and timber; other species may cause skin infections in animals including man. Fungal **cell walls contain chitin** and the cytoplasm of some species contains coloured pigment grains. Fungi reproduce by means of microscopic **spores** which are dispersed by air, water or animals.

Characteristic representatives of fungi:
Black bread mould (*Rhizopus nigricans*) is a common saprophytic mould living on moist organic materials such as bread, fruit and animal dung.
Blue-green moulds (*Penicillium*) are used in the manufacture of the antibiotic penicillin, while other species are involved in cheese production.
Yeasts are unicellular fungi. Certain species produce an enzyme, zymase, which ferments sugars to form ethyl alcohol. In bread-making, released bubbles of carbon dioxide cause the bread to "rise". Some yeasts produce vitamins, while others synthesize protein from molasses and ammonia. Pathogenic yeasts produce a variety of diseases in plants (peach leaf curl, apple scab, powdery mildews, etc.) or in man and animals (moniliasis, sporotrichosis, dermatomycosis, actinomycosis, etc.).
Mushrooms are saprophytic fungi with vegetative bodies composed of masses of hyphae, some of which penetrate the substratum. In addition to a large number of edible mushrooms, there are a few poisonous species, especially those belonging to the genus *Amanita*.
Bracket (shelf) fungi secrete enzymes that digest wood and bark causing decomposition. Parasitic species attack living trees.
Smuts are parasites of flowering plants. They produce heavy-walled, dark-coloured, ill-smelling smut spores. Corn smut causes great losses in crops.
Ergots infect grains of rye, wheat and oats. Poisons from ergots can cause gangrene, nervous spasms, hallucinations and death. Some medical preparations which are useful in treating high blood pressure are manufactured from these substances.

Animals

Animals are divided into *Protozoa*, unicellular organisms composed of a single cell or associations of cells forming a colony, and *Metazoa* which are composed of many cells which form tissues and organs.
The **protozoan cell** is either without external cover or with a non-rigid cuticle or a shell of inorganic materials. Most of the adult protozoans are motile. Their cell is often very complicated and equipped with many special organelles.
Metazoan animals have bodies composed of distinct tissues and organs, often with several organ systems. Metazoan cells have no cell walls. They possess multicellular reproductive organs and their development passes throught distinct embryonic stages. Animal bodies possess a structural architecture that reflects a way of life based on alimentation and locomotion. The lower metazoans are **diploblastic**, i.e., they have two cellular levels – **ectoderm** and **endoderm**. More complicated **triploblastic** animals have, in addition, a middle embryonic cellular layer – **mesoderm**.

Protozoa

Protozoa are single-celled animals. They may be **free-living** or may exist as partners in every type of **symbiotic** or **parasitic** relationship. Protozoa thrive in all types of aquatic environments including water droplets in wet moss and soil or the watery environment inside animals. The cells function by means of many kinds of special organelles. Most protozoans contain only one nucleus but some types are multinucleated.
Parasitic protozoa cause some of the world's most harmful **human diseases**.

Classification of Protozoa

Sarcodines (Amoebas)
- great flexibility of the cell
- movement by means of pseudopodia
- some kinds are intestinal parasites in man (*Entamoeba histolytica* – amoebic dysentery; *Naegleria* – amoebic meningoencephalitis).

Flagellates
- movement by means of one or more flagella
- most species are free-living
- some kinds are parasitic and cause important human diseases (*Trypanosoma* – sleeping sickness common in some parts of Africa; *Trichomonas* – vaginitis; *Giardia* – diarrhea; *Leishmania* – leishmaniasis, etc.).

Ciliates
- movement by cilia
- nuclear dimorphisms (vegetative macronucleus and generative micronucleus)
- most species are free-living (*Paramecium*)
- some kinds are parasitic (*Balanditium* – intestinal diarrhea).

Sporozoans
- large group of parasitic protozoans (*Plasmodium* – malaria; *Coccidia* – coccidiosis of poultry and rabbits; *Toxoplasma* – toxoplasmosis).

Flatworms (Platyhelminthes) and Roundworms (Nemathelminthes or Nematodes)

Flatworms have a distinct middle germ layer, called mesoderm, giving rise to muscle layers which permit flexible movement. Because they have a compact mesoderm instead of an open body cavity, they are often called **acoelomates.**

The **free-living** species occurring in freshwater ponds and streams are commonly called **planarians**. They avoid light and sometimes hundreds of them can be found on the underside of a submerged leaf or rock.

All other flatworms are **parasitic** – **flukes** and **tapeworms.**

Flukes are the flatworm **parasites of vertebrates.** Since some stages of their cycle occur in man they are of great medical importance. For instance, the sheep liver fluke (*Fasciola hepatica*) is parasitic in the liver of sheep, cows, and pigs, where it may cause great damage, but few cases of human liver infections are known. On the other hand, blood flukes are the cause of very serious diseases in many parts of Africa and Asia where, in some areas, up to 90% of the population may suffer from their effects.

The **pork tapeworm** (*Taenia solium*) lives in the human alimentary canal, where it may grow up to 3 meters in length. Larval stages are found in the muscles of pigs. The worm is composed of a linear series (up to a 1000) of segments called proglottids. As the posterior, mature proglottids break off, they pass out with the faeces and disintegrate, thus depositing eggs and embryos on grass and soil where they may be ingested by pigs.

Roundworms, in contrast to flatworms, have a **pseudoceol**, which is a body cavity not lined by a special layer of epithelial cells. There are free-living, **predatory** and **parasitic** species. The latter are of interest because they cause damage to crops and diseases in man and other animals. Examples of nematodes are: **human roundworm** (*Ascaris lumbricoides*) which causes ascaridiosis; **pork roundworm** (*Trichinella spiralis*) which causes trichinosis; **filiar worms** (*Wuchereria bancrofti*) living in the lymphatic system of man where, due to obstruction of the flow of lymph, cause elephantiasis – enormous swelling and growth of connective tissue in the limbs.

Arthropoda

Arthropoda constitute the **largest phylum** in the animal kingdom. They occupy every type of habitat, consume every type of food, exhibit every type of relationship, and show every type of motility. They are bilaterally symetrical with a **segmented body** fused into two or three parts and equipped with jointed appendages adapted for walking, swimming, feeding, sensory reception and defense. The body, including the appendages, is covered by a **chitin exoskeleton** composed of a polysaccharide and proteins. In order to grow, an arthropod must periodically shed its old exoskeleton and secret a new, larger one by a process called moulting.

Five classes are included in the phylum Arthropoda:

- **Crustaceans** have bodies consisting of two parts – **cephalothorax** and **abdomen**. They are mostly aquatic, exchanging gasses through gills (lobster, horseshoe crab, etc.).
- **Arachnids** have two body parts, no wings, no antennae, four pairs of legs and gas exchange through trachea, lungs or gill books (scorpions, spiders, ticks and mites).
- **Milipedes** are wormlike land-animals with a multi-segmented, cylindrical body, with two pairs of legs per segment. They feed on decaying plant matter and are important forest scavangers.
- **Centipedes** are terrestrial carnivores with a pair of poison claws. Their body is multi-segmented with one pair of legs per segment.
- **Insects,** generally, have a three-part body consisting of a **head**, a **thorax** and an **abdomen**, one pair of antennae, three pairs of legs and, commonly, one or two pairs of wings. Gas exchange occurs through trachea. About a million insect species are known today and it is estimated that at least twice this number exist

(mostly in tropical forests) but have not yet been discovered. Systematics classify insects into about 26 orders, including orthopterans, dragonflies, true bugs, beetles, butterflies, flies, hymenopterans, etc. During development, insects undergo changes called **incomplete** or **complete metamorphosis**. The former has stages of **egg**, **larva** and **imago** (adult), whereas the latter has four stages with a pupal stage between larva and imago. There are many types of insects **harmful** to plants, fruit trees and their products, vegetables, domestic animals, and also to building structures. Insect transmitted diseases include: malaria and yellow fever by mosquitoes; typhoid and dysentery by flies; sleeping sickness by tsetse flies; bubonic plague by fleas. On the other hand, some species of insects are **beneficial**, making products of importance to man, such as honey, beeswax, and silk. Other types are necessary for cross-fertilization of flowers. Predatious insects destroy great numbers of other injurious insects. Insects also supply foods for animals, such as birds and fish.

Chordata

Chordata are characterised by:
- a semi-rigid skeletal axis (the dorsal notochord), which is present at some time during the life cycle,
- a tubal nervous system dorsal to the digestive system,
- paired pharyngeal clefts (gill slits) which connect the pharynx with the external environment at some stages in the life cycle,
- a post-anal tail

Lower chordates (up to and including fish) are marine animals which respire by means of gills. In higher chordates gills are present only in the larval or embryonic stages. In mammals, the gill slits never open but are modified for other purposes. Most chordates have a segmented spinal column.
Chordates include:
- **tunicates**, stationary marine animals adhering to rocks, boats and coral reefs,
- **lancelets**, marine, sand-dwelling animals with transparent and fishlike bodies pointed at both ends,
- **vertebrata**, comprising most of the chordates.

Vertebrata

All vertebrates have an **axial, dorsal skeletal rod** (notochord) present through life in some of the lower vertebrates but disappearing before adulthood in others. In higher vertebrates, the notochord becomes modified into a **segmented vertebral column**. A dorsal nerve tube is connected anteriorly with the brain. Gill slits (pharyngeal clefts) are present during some stages of the life cycle. The vertebrate skeleton, an endoskeleton, is made of either flexible cartilage or a combination of hard bone and cartilage. The heart is situated ventrally and has either two or four chambers. The vertebrates are either cold- or warm-blooded.
Vertebrates include **cyclostomes** (jawless fishes), **sharks** (cartilaginous fish), **bony fishes, amphibians, reptiles, birds** and **mammals**.

Mammalia

There are three major groups of mammals:
- **montremes**, egg-laying mammals (e.g., duck-billed platypus) living along rivers in eastern Australia,
- **marsupials**, so-called pouched mammals, whose tiny offspring usually complete development in a pouch, attached to their mother's nipples. Most of these species live in Australia,

- **placentals,** mammals whose embryos are nurtured inside the mother by an organ called the placenta. They make up almost 95% of all mammalian species.

Mammals are **endothermic** animals with hair which protects their bodies against extreme temperatures. The young are nourished by milk produced in the mammary glands. Mammals have bony skeletons, four-chambered hearts and they exchange gas through lungs. They possess two pairs of appendages, although these are reduced in some species. The appendages are adapted for walking, digging, climbing, swimming or flying. The excretory system consists of a pair of kidneys, a pair of ureters, the urinary bladder and the urethra.

3 BIOLOGY OF THE CELL

Cell Theory

This theory was developed in the **mid-19th century** by three scientists: the German botanist ***Schleiden***, the German zoologist ***Schwann*** and the Czech physiologist ***Purkinje***. It is based on the presumption that the cell is the basic structural and functional unit of all organisms and that all forms of life are associated with cells. All cells have a uniform principle of structure. New cells arise by division of parental cells. In unicellular organisms, the cell is the body, whereas in multicellular organisms, the body is built from many differentiated cells which differ in morphology according to their different functions. The recent achievements of molecular biology contributed to the cell theory by the discovery of the universality of the genetic code existing in nature. All cells possess the same kind of record of their inherent genetic memory.

From the point of view of evolution, we can distinguish older, simple, **prokaryotic cells** from younger and more complex **eukaryotic cells** which are the basis of all multiple cell organisms. From the structural point of view, there are differences between animal, plant and fungal cells. More details see pp. 22-23.

The size range of cells is **from 0.3 μm to 3 mm.**

The smallest cells are prokaryotic cells (0,3–10 μm). Most eukaryotic cells lie in the range of 20-100 μm. The largest cells are animal eggs, nerve and muscle cells and some protozoa. Shape and function of cells are related (muscle cells are elongated, aster-like nerve cells have long protrusions, eggs are bulky and leucocytes are amoeba-like).

Chemical Composition of the Cell

About 25 of the 92 natural elements are essential to life.

Main elements present in living organisms (% by weight)

Oxygen (O)	76.0	Iron (Fe)	0.01
Carbon (C)	10.0	Sulphur (S)	0.2
Hydrogen (H)	10.0	Chlorine (Cl)	0.1
Nitrogen (N)	2.5	Sodium (Na)	0.04
Phosphorus (P)	0.3	Calcium (Ca)	0.02
Potassium (K)	0.3	Magnesium (Mg)	0.02

Trace elements are also essential but are required only in minute quantities, **less than 0.01%,** and to a differing extent in different organisms. They are: boron, chromium, cobalt, copper, fluorine, iodine, manganese, molybdenum, selenium, silicon, tin, vanadium and zinc.
Elements combine to form inorganic salts, water and organic compounds.
Water is the versatile solvent in living systems and constitutes about 80% of the average cell content. Water is the medium for all life processes and also has the capacity to absorb and conduct heat.
Most **inorganic constituents** of cells are present in the form of ions. While the majority of inorganic compounds occur in the form of electrolytes, many of the **organic compounds** occur in the form of non-electrolytes.
Compounds containing **carbon**, on which life's diversity is based, are known as **organic compounds** whose basic units are molecules. Large molecules (macromolecules) are constructed by the joining together of smaller molecules (monomers) into chains called polymers.
Organic compounds in living systems are **proteins, carbohydrates, nucleic acids** and **lipids.**

Organic Cell Compounds

Proteins

Proteins are biopolymers consisting of amino acids – building blocks. There are 20 different amino acids occurring in proteins. They are linked together by **peptide bonds** into a **polypeptide chain** which may contain between 50 and 3000 amino acid molecules.
A protein molecule is based on 4 types of structures. The **primary structure** is a sequence of amino acids, the **secondary structure** is the formation of a α-helix or a β-folded sheet, the **tertiary structure** has a complicated, three-dimensional shape or architecture, and in the **quartiary structure,** two or more tertiary forms can combine to form the complex macromolecule of a protein.

Protein functions are:
- **structural**, building material of cell structures,
- **metabolic**, enzymes, source of energy,
- **regulatory**, signals, receptors, inhibitors, repressors, inductors, stimulators, hormones,
- **defensive**, antigens, antibodies.

New proteins are synthesised on ribosomes alongside a chain of messenger RNA.

Nucleic Acids

Nucleic acids are biomacromolecules made of relatively simple monomeric units – **nucleotides.** Each **nucleotide** consists of three parts:
- **sugar pentose**, which can be **ribose** or **deoxyribose,**
- **nitrogen** base, which can be **adenine, guanine, cytosine, thymine** or **uracil,**
- **phosphoric acid group**.

There are two types of nucleic acids: deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).

Structure of the DNA molecule
It occurs as a **double strand** of two helically twisted polynucleotide chains in which nucleotides are held together between their deoxyriboses by phosphate groups. The nitrogen base in the DNA nucleotides can be adenine, guanine, cytosine, and thymine. The nucleotide sequence of the strands are parallel in reverse order. Between

strands, the nucleotides are connected by **complementary base pairing** (adenine with thymine, cytosine with guanine).

DNA function

DNA forms **genes**, units of genetic information, that pass from parents to offspring.
Genetic information is encoded in the sequence of nucleotides (primary structure) of polynucleotide strands.

DNA in the cell is located in:

nuclear chromosome, mitochondrial chromosome, plastid chromosome, plasmids in the cytoplasm. DNA is replicated during the S phase of the cell cycle.

Structure of the RNA molecule

RNA contains the sugar **ribose** instead of deoxyribose and the base **uracil** instead of thymine. Nucleotides are arranged in a long chain which usually occurs as a **single strand.**

Function of RNA

There are three classes of RNA involved in the **expression of genetic information** (translation):
- **Messenger RNA (mRNA)** is a large RNA molecule which functions during the formation of a protein to specify the sequence of amino acids in the nascent polypeptide.
- **Transfer RNA (tRNA)** is a small RNA molecule that transfers an amino acid to a growing polypeptide chain during translation.
- **Ribosomal RNA (rRNA)** is a large molecule that forms part of ribosomes that are the sites of translation.

RNA occurs in the cell in cytoplasm, nucleolus, nucleus, mitochondria, and plastids. New molecules of RNA are synthesised in the nucleus directly alongside **segments of the DNA** strand to be copied.

Saccharides

Saccharides contain only three elements – carbon, hydrogen, and oxygen. Saccharides differ only in number and arrangement of the three kinds of atoms. They supply energy for cell activities by being oxidized, e.g., their atoms either are combined with oxygen or hydrogen is taken away from them. Glucose molecules are the **main fuel for cellular work** and energy liberated by oxidizing glucose is used for vital activities.
Polysaccharides are usually stored as **glycogen** in animals and as **starch** in plants. Many polysaccharides serve as building material for structures that protect cells and support whole organisms. **Cellulose** forms cable-like fibrils in walls that enclose plant cells and is a major component of wood. The main component of fungal cell walls is **chitin.**

Lipids

Lipids are diverse compounds consisting mainly of carbon and hydrogen atoms linked by non-polar covalent bonds. Being mostly non-polar, lipid molecules are not attracted to water molecules which are polar. Lipids do not mix with water, they are **hydrophobic**.
Fats (large lipid molecules) are composed of two kinds of smaller molecules: glycerol and fatty acid. Fats are energy sources which play an important role in membrane formation.
Phospholipids, important biological molecules, are major components of cell membranes.
Waxes are more hydrophobic than fats and provide effective natural coatings for fruits. Some insects may have waxy coats to help prevent them from drying.

Steroids are lipids with a ring molecular pattern. **Cholesterol** is a common substance in animal cell membranes and is also used as a base material for making other steroids, including female and male **sex** hormones. Too much cholesterol in the blood may contribute to atherosclerosis.

Prokaryotic and Eukaryotic Cells

Prokaryotic cells are small and structurally simple, they lack an organized nucleus since they have neither a nuclear membrane nor a complex chromosome. There is only one chromosome comprising a continuous, usually circular molecule of double-stranded DNA; genes are not present in pairs. The chromosome is attached to the plasma membrane and is located in an area of the cell known as the nucleoid. Ribosomes are smaller than in eukaryotic cells.

Prokaryotic cells also lack other membrane-bounded structures, such as mitochondria, lysosomes, plastids, Golgi apparatus, endoplasmic reticulum or vacuoles. Some enzymatic functions, which these structures perform in eukaryotic cells, may take place along the indentations of the plasma membrane.

Prokaryotic cells do not contain any cytoskeleton. If flagella are present, as in some bacteria, they are simple protein structures lacking in microtubules.

Most prokaryotic cells range in size from 2 to 10 μm. Their rigid cell wall is made of lipids, saccharides and proteins but there is no cellulose.

Species based on prokaryotic cells are *Archea*, *Eubacteria* and *Cyanobacteria*.

Eukaryotic cells are partitioned into smaller **functional compartments** or **cell structures**. Some of these are called **organelles**. Components of a eukaryotic cell are: plasma membrane, cell wall, cytoplasm, nucleus with nuclear envelope, nucleolus, linear chromosomes, endoplasmic reticulum, ribosomes, Golgi apparatus, mitochondria, plastids, lysosomes, vacuoles and cytoskeleton (the latter is constituted from microtubules and their complexes – centrioles, basal bodies and axonema of cilia and flagella, microfilaments and intermediate filaments).

Eukaryotic cells are found in both plants and animals.

There are two types of cells – **animal** and **plant cells**. Three cell structures are typical for plant cells -**cell wall, plastids,** and **vacuole** and are not present in animal cells.

A Survey of Differences between Prokaryotic and Eukaryotic Cells.

Prokaryotic cells have	Eukaryotic cells have
no nucleus	a nucleus
no membrane-enclosed organelles	membrane-enclosed organelles
usually single circular chromosome	linear chromosomes in pairs
no cytoskeleton	a complex cytoskeleton
no streaming in the cytoplasm	streaming in the cytoplasm
cell division without mitosis	cell division by mitosis
simple flagella	complex flagella with microtubules
smaller ribosomes	larger ribosomes
no cellulose in cell walls	cellulose in cell walls
no histone proteins in the chromosome	DNA bound to histones

Biomembranes and Membrane Organelles

Biomembranes are thin molecular layers of **lipids** and **proteins** responsible for many functions essential to life. Lipids and proteins are fluid and float around each other – the **fluid-mosaic model** of biomembranes. Biomembranes are about **7.5 nm in thickness**.
Membranes form and organise many **organelles**: plasma membrane, nuclear envelope, endoplasmic reticulum, Golgi apparatus, mitochondria, plastids, vacuoles and lysosomes.

Function of biomembranes:
- compartmentalization of a eukaryotic cell,
- interface between the cell and environment or intracellular compartments,
- barrier to water-soluble molecules,
- regulation of the flow of molecules, energy and information,
- carrier for biologically active molecules allowing higher efficiency of biochemical reactions.

Plasma membrane
The plasma membrane is a living, ultra-thin, elastic, porous and semipermeable covering present in all kinds of cells. Externally, in animal cells, it has a layer of glycoproteins called **glycocalyx** whereas in plant and fungi cells there is a thick and rigid, permeable cell wall.
The plasma membrane grows as the cell enlarges and has a limited ability to repair itself. Its selective permeability is not constant but is subject to constant, rapid changes.
Endoplasmic reticulum, Golgi system and lysosomes
The endomembrane system of a cell is formed by a cytoplasmic membrane network of endoplasmic reticulum, Golgi system and lysosomes. Organelles of this system work together in the synthesis, storage and export of important molecules.
The **endoplasmic reticulum** (ER) is a system of membranes forming tubes and channels, sometimes connected with the nuclear envelope and plasma membrane. There are two kinds of ER: **rough** with many ribosomes on the outer surface and **smooth** without ribosomes. The ribosomes on the surface of rough ER produce proteins that are then secreted from the cell. The smooth ER synthesises lipids.
The **Golgi apparatus** is a complex of flattened sacs formed by membranes. It receives, modifies, sorts, and packages ER products in vesicles for secretion or for delivery to other organelles. The ER and Golgi system in gland cells participate in **the secretory pathway** (endoplasmic reticulum → Golgi apparatus → plasma membrane) by which enzymes and other proteins are released from the cell.
Lysosomes are vesicles of digestive enzymes budded off the Golgi apparatus. Lysosomal enzymes digest food, destroy bacteria and recycle damaged organelles. Plant cells contain a large central vacuole with both lysosomal and storage functions.
Mitochondria and chloroplasts
Two membranous cell organelles are involved in energy conversion – mitochondria and chloroplasts. They contain a single circular DNA molecule.
Mitochondria are rounded or rod-like double-membrane organelles; their size may vary from 1 to 10 μm. The inner membrane is folded into many cristae extending inwards and bearing enzyme molecules that make **ATP**. Mitochondria can be called the powerhouses of the cell.
Chloroplasts are spherical bodies enclosed by double membranes. Inside there is a structure called the **granum**, which is a plate-like lamella resembling a stack of coins. In chloroplast membranes, molecules of the light-absorbing pigment, **chlorophyll**, are embedded. All **photosynthetic reactions** occur in chloroplasts.

Cytoskeletal System

The **cytoskeleton** is a complex matrix of protein filaments with three major components: **microtubules, microfilaments** and **intermediate filaments.**

Microtubules
are hollow tubes about **23 nm in diameter** made of the protein **tubulin.** They are present in the **cytoplasm** (microtubular network), in **cilia** and **flagella,** in **centrioles** and **basal bodies (kinetosomes)** and in **mitotic spindles.**
Microtubular functions:
- motile activities (movement of chromosomes, beating of cilia, axon transport, etc.),
- determination of cell architecture (cell polarity and shape),
- determination of migration of cell organelles within the cell.

Microfilaments
are about **7 nm thick** filaments built of the protein **actin.** They form a dynamic cytoplasmic network.
Microfilament functions:
- determination of cell surface morphology,
- determination of cell polarity,
- generation of contractile force in the cytoplasm (interaction of actin and myosin – streaming of cytoplasm, phagocytosis, cytodieresis).

Intermediate filaments
are fibrils, 7 to 10 nm in diameter, which give the cell mechanical strength. They are typical for animal cells.

Transport into and out of the Cell

The **plasma membrane** is the **boundary** between the living cell and its surroundings, controlling the **transport of molecules** into and out of the cell.
Membranes regulate this movement of material in several ways:
- **diffusion** and **osmosis,**
- **selective permeability** (by transport proteins),
  - **passive transport,**
  - **facilitated diffusion,**
- **active transport** (needs energy, usually as ATP),
- **endocytosis** and **exocytosis,**
- **phagocytosis.**

Diffusion and Osmosis

Diffusion is the movement of molecules from an area of greater concentration into an area of lesser concentration until the concentration is uniform. It is a spontaneous **process, increasing the entropy** of a system. Diffusion is responsible for moving large volumes of substances, such as **gasses** and some **cellular wastes,** into and out of the cell.
Osmosis is the passive transport of water molecules across a selectively permeable membrane. A **hypertonic** solution has a higher concentration of solutes than the surrounding medium. A **hypotonic** solution has a lower concentration. **Isotonic solutions** have equal solute concentrations.

Water balance between cells and their surroundings is crucial to living systems. The control of water balance is called **osmoregulation**.
Plasmolysis – changes in plant cells in a hypertonic environment.
Plasmoptysis – swelling of a cell in a hypotonic environment.
Plasmorhisis – shrinkage of animal cells due to hypertonicity. An isotonic solution of 0.9 % NaCl, called **physiological saline,** keeps well the rounded form of red blood cells which are in the hypertonic solution shrinked into so called echinocytes.

Carrier-mediated Transport

Many molecules move across a membrane with the help of **transport proteins** in the membrane. When one of these proteins makes it possible for a substance to move down its concentration gradient, the process is called **facilitated diffusion**. Without the protein, the substance does not cross the membrane or it diffuses across it slowly, described as **passive carrier-mediated transport.**
Other necessary molecules cannot enter or leave cells without **active transport.** Transport proteins assist the process against the concentration gradient. For this active carrier-mediated transport, membrane proteins need energy, usually in the form of ATP.

Endocytosis and Exocytosis

Transport of large molecules or particles must be assisted by **vesicles** derived from membranes. A membrane-bound vesicle may either fuse with the membrane and expel its contents (exocytosis) or the membrane may fold inwards, trapping material from the outside (endocytosis).
In the first step of **exocytosis,** a membrane-bound vesicle filled with macromolecules moves to the plasma membrane. The vesicle membrane then fuses with the plasma membrane and the vesicle contents spill out of the cell.
Depending on the incorporated material, there are three kinds of **endocytosis: phagocytosis, pinocytosis** and **receptor-mediated endocytosis.**
In **phagocytosis,** the cell engulfs a relatively large food particle, e.g. bacteria, by wrapping extensions (pseudopodia) around it and packing it within a vacuole. The vacuole then fuses with a lysosome whose hydrolytic enzymes digest the contents.
Pinocytosis or "cellular drinking" is the process of taking droplets of fluid from the suroundings into tiny vesicles. Pinocytosis is not specific; it can take in any kinds of solutes dissolved in the droplets.
Receptor-mediated endocytosis is highly specific. The plasma membrane is indented to form a pit, lined with receptor proteins which can pick up specific molecules from the surroundings. The pit then closes to form a vesicle that carries the molecules into the cytoplasm.

Energy Transformation

Metabolism involves all the chemical activities of the cell. There are two kinds of metabolism:
- anabolism ("building-up" reactions)
- catabolism ("breaking-down" reactions)

Catabolism releases free energy. Cells use free energy in catabolism to drive the reactions of anabolism. This process is possible by the **energy carrier ATP,** adenosine triphosphate.

Cells need energy to: fuel biosynthesis, grow, remove wastes and take up nutrients, move, reproduce, maintain internal order, do mechanical work, respond to changes in the environment, etc..

Autotrophy and Heterotrophy

Organisms can obtain energy and nutrients in two different ways, autotrophy and heterotrophy.
Autotrophs obtain energy and nutrients from non-living sources such as sun, soil, and air. Green plants and some bacteria absorb energy from sun and use it to synthesize organic compounds from inorganic materials taken in from their surroundings. The system of chemical reactions through which autotrophs absorb sunlight energy and use it to synthesize glucose from carbon dioxide and water is called **photosynthesis.** Organic compounds made during photosynthesis are used as building blocks for maintenance, growth and reproduction.
Heterotrophs obtain energy and nutrients from other organisms, either living or dead. They consume autotrophs and other heterotrophs as food that supplies the energy and organic nutrients needed for their lives. Animals, fungi and most bacteria are heterotrophs.
Mixotrophs obtain energy and nutrients from both the non-living sources and other organisms, either living, or dead. Carnivorous plants, such as sundew and Venus flytrap thrive by obtaining their nutrients from insects are examples of mixothrophs. Also, the hemiparasite mistletoe growing on deciduous trees belongs to this category. This plant is photosynthetic, but it supplements its diet by using its roots to siphon sap from the vascular tissue of the host tree.

Liberation of Energy

Cellular respiration is the process by which cells obtain free energy stored in nutrients. It is a stepwise series of catabolic reactions which **break down complex molecules (mainly glucose) to carbon dioxide and water, and release energy**. Raw materials for cellular respiration are saccharides, fat and proteins, but the primary food molecule is the monosaccharide glucose.
There are three main stages in the respiration of glucose: **glycolysis** (anaerobic), the **Krebs cycle** and the **electron transport system** (aerobic respiration or oxidative phosphorylation). Glycolysis occurs in the cytosol; the Krebs cycle and electron transport system take place in mitochondria.
In **glycolysis**, ATP energy is used to split a glucose molecule into two parts. This releases some of the cellular energy, yielding **2 ATP molecules** and providing electrons and H^+ to the coenzyme NAD^+ (nicotinamide adenine nucleotid). Glycolysis converts each original glucose molecule into two molecules of pyruvic acid. Each pyruvic acid molecule then breaks down to form CO_2 and a two-carbon acetyl group which can then enter the Krebs cycle. Many organisms, such as yeasts and bacteria, use glycolysis alone to produce small amounts of ATP from each glucose molecule. The pyruvic acid may be converted into other substances, such as alcohol and CO_2 (alcoholic fermentation) or lactic acid (lactic acid fermentation). Human muscle cells can use lactic acid fermentation to make ATP for short periods when oxygen is in short supply.
The **Krebs cycle** is a series of reactions in which carbon is completely oxidized and released as CO_2. Two ATP molecules are produced directly but most of the glucose energy is stored in the reduced coenzyme NADH. The electrons from NAHD travel down the **electron transport system** and combine with oxygen and H^+ to form water. Energy released by the passage of electrons is used to pump H^+ into the space between the membranes of mitochondria. In the process called chemiosmosis, the H^+ ions diffuse back across the inner membrane producing as many as 36 ATP molecules. The total energy yield of **aerobic respiration is 38 ATP molecules.**

ATP in the cell

ATP (adenosine triphosphate) has three parts:

- adenine, a nitrogenous base,
- ribose, a five-carbon sugar,
- a chain of three phosphate groups.

ATP energises nearly all forms of cellular work because it both releases and stores all the usable energy (exergonic and endergonic reactions).

The covalent bonds connecting the second and third phosphate groups are unstable and can readily be broken down by hydrolysis, **ATP is converted into ADP and energy** (about 30 kJ) **is released**. Transfer of a phosphate group to any molecule is called **phosphorylation** and most cellular work depends on ATP energising other molecules by phosphorylation. In the cell, this occurs during biosynthesis (ribosomes), active transmembrane transport, cytoplasmic streaming or cytodieresis (actin and myosin), ciliary and flagellar movement (dynein and microtubules) or axon transport (kinesin and microtubules). ATP is a renewable resource that the cell can regenerate in mitochondria.

DNA Replication, DNA and Protein Synthesis.

DNA replication

The DNA double helix is uncoiled and flattened and the two strands are separated. New, complementary nucleotides begin to pair with those of the original strands. These new nucleotides are bound by means of **DNA polymerase**. This is known as **semiconservative replication**, i.e., the new molecule conserves one strand of old DNA while adding one strand of new DNA. Replicated molecules are identical, in their primary structure, to the parental double helix due to the complementarity of bases.

RNA synthesis

New molecules of RNA are synthesised on a **DNA template**. The DNA double helix uncoils and the strands separate. RNA nucleotides line up along one coding strand of the DNA and are linked by hydrogen bonds following the base-pairing rules. In this way, a noncoding strand of DNA is transcribed by **RNA polymerases** into a primary RNA transcript which may be processed to tRNA, rRNA or mRNA in the nucleus (see also p. 43).

Protein synthesis

The sites for protein synthesis are the **ribosomes**. These are particles, about 30 nm in **size**, consisting of **two subunits**, one large and one small, both made up of **proteins** and **rRNA**. Ribosomes are found either free in the cytoplasm or attached to the membranes of endoplasmic reticulum where they coordinate functioning of mRNA and tRNA and the production of polypeptides.

A ribosome attaches to the mRNA and assembles a specific polypeptide, aided by **tRNAs** which act as interpreters. Each tRNA is a folded molecule bearing a base **triplet**, called an **anticodon**, on one end while a specific amino acid is added to the other end. The mRNA moves relative to the ribosome a codon at time, adding its amino acid to the peptide chain. Thus the sequence of codons in DNA, via the sequence of codons in mRNA, spells out the structure of polypeptide (see also p. 43-44). This process requires energy supplied by ATP and GTP.

Nucleus

The nucleus contains **chromosomes** carrying genes that transmit hereditary traits from one generation to another. The nucleus is surrounded by a thin, double-membrane **nuclear envelope** supplied with minute, pore-like perforations, **nuclear pores.** In the interphase nucleus, chromosomes form a diffuse mass of very long, very thin fibres of **chromatin**, which is a **complex of DNA and proteins**, and a conspicuous **nucleolus** is present. This is composed of RNA and has a high concentration of proteins. As the cell prepares to divide, its chromatin coils up, forming compact and distinct chromosomes. Chromosomes are clearly visible only when a cell is in the process of dividing.

Chromosome number

Each species has a characteristic number of chromosomes. In eukaryotes, the chromosomes occur in pairs. In each pair, one chromosome comes from the male and the other from the female parent.. The two chromosomes in the pair are homologous.

Chromosome sets can be:

- **diploid,** with both sets of chromosomes (somatic cells),
- **haploid,** only one set of chromosomes (in gametes),
- **polyploid,** the number of chromosome sets is greater than two (triploid, tetraploid, hexaploid),
- **aneuploid,** the chromosome number is not an exact multiple of a typical haploid set (monosomy, trisomy).

Diploid number of chromosomes in various organisms

Green alga (*Spirogyra*)	24	Snail (*Helix*)	48
Pear moss (*Sphagnum*)	40	Crayfish (*Cambarus virulus*)	200
Fern (*Dryopteris cristata*)	328	Fruit fly (*Drosophila melanogaster*)	8
Pine tree (*Pinus*)	24	Frog (*Rana*)	26
Pea (*Pisum*)	14	Pigeon (*Columba*)	16
Wheat (*Triticum vulgare*)	42	Rhesus monkey (*Macaca mulatto*)	42
Horse roundworm (*Ascaris*)	2	Man (*Homo sapiens*)	46

Cell Cycle and Its Phases

The cell cycle extends from the time a new cell is formed until the next division producing more cells is completed. It comprises a **continuous sequence of events in the life of a cell.**

A cell cycle consists of **four main phases:**

- **G_1 (growth$_1$)**, new offspring cells are metabolically active especially in the synthesis of RNA and proteins; some non-dividing cells may remain in an extended G_1 phase (G_0)
- **S (DNA synthesis)**, the DNA content of the nucleus is doubled
- **G_2 (growth$_2$)**, proteins, RNA and other macromolecules are newly synthesized.
- **M (mitosis)**, visible chromosomes are replicated and two cell nuclei are formed from one.

Regulation of the Cell Cycle

Cells from different organisms or cells within a multicellular organism **divide at different rates.** Nerve, muscle and red blood cells do not divide but remain in phase G_0. Other animal cells, such those of skin, bone marrow and the lining of the intestine, divide rapidly.

The rate of cell division is under **genetic control**. In the case of **cancer**, genetic **control over cell division is altered** and the position of cells in a specific tissue is permanently changed. **Altered regulatory genes** which have the potential to induce cancerous transformation are called **oncogenes**. More than 30 viral oncogenes have now been isolated.

Mitosis

Division of eukaryotic cells is accomplished through a process called mitosis. It is a continuous event which usually involves intervals called **prophase, metaphase, anaphase** and **telophase**.

Prophase

The **centrioles** move away from each other towards opposite sides of the cell. Ray-like fibres, called **asters**, are formed around the centrioles. The nuclear membrane begins to disappear and the nucleoli are no longer visible. **Microtubules** connecting two migrating asters develop to form the **mitotic spindle**. The nuclear material condenses into a coiled network of chromatin threads, called **chromonemata**. The chromosomes become visible, each with a clear area called the **centromere** or **kinetochore**, which is later involved in the orientation and division of chromosomes.

Metaphase

The chromosomes move to the equator of the mitotic spindle, each divided length-wise into two chromatids, and are attached to spindle microtubules by means of the centromeres. When these divide, the **separation of chromosome chromatids** begins.

Anaphase

During anaphase, the chromatids are completely separated and the newly formed **daughter chromosomes move to opposite poles** of the spindle. At this time, the **spindle elongates** and the cell itself may become longer so that groups of daughter chromosomes eventually lie far apart at opposite ends of the cell.

Telophase

In telophase, the chromosomes elongate and the coils of chromonemata loosen and gradually assume a thread-like nature. The **spindle and aster disappear** but the centrosomes persist, one with each daughter nucleus. A nuclear membrane reforms around the nucleus; nucleoli reappear and the daughter nucleus is again in the interphase period. Subsequently, the daughter cells are separated by the process of **cytokinesis.**

Cytokinesis

Cytokinesis or cell division typically occurs in telophase, although it may actually begin in late anaphase. In animal cells, cytokinesis occurs by a process known as **cleavage**. The first sign of cleavage is the appearance of a **cleavage furrow**. At the site of the furrow, the cytoplasm has a **ring of actin microfilaments** which facilitates contraction.

Cytokinesis in plant cells is different. Membrane bounded-vesicles, containing cell wall material, collect at the midline of the parent cell. The vesicles then fuse, forming a membrane-bounded disc, called the cell plate, which grows outward and accumulates more cell wall material as more vesicles fuse with it. Eventually, the cell plate membrane fuses with the plasma membrane. The result is two daughter cells, each bounded by its own continuous plasma membrane and cell wall.

Cell Differentiation

As the zygote of a multicellular organism develops, cells become specialised or differentiated. The phenomenon of differentiation marks each living cell with the uniqueness of structure and function. Differentiation also occurs in an adult whenever new cells replace old or damaged ones. Most differentiated cells retain a complete set of genes. In general, the somatic cells of a multicellular organism all have the same genes but they are only differentiated because different genes are expressed.

Gene expression is effected and regulated by **DNA packing** in chromosome and by means of **post-transcription modifications**. There are also so-called homeotic genes containing nucleotide segments called **homeoboxes**. Their proteins activate or repress batteries of genes, shaping development in major ways.
Conrol mechanisms normally regulate the growth and division of differentiated cells, but sometimes cells escape these restraints and multiply into masses called tumours.

4 LIFE FUNCTIONS OF HIGHER PLANTS AND ANIMALS

Plants and Water

Many substances necessary for various activities of plants must be absorbed through their roots, particularly through **root hairs**. The absorption of water and solutes involves several complex phenomena, including **imbibition, diffusion** and **osmosis.**
Imbibition is the process by which solid particles, chiefly colloidal, absorb liquids and increase in volume. In plants, these particles are cellulose, cytoplasmic proteins and pectin. **Diffusion** is the passage of molecules and ions from a region of high concentration to a region of low concentration. **Osmosis** is the diffusion of water through a differentially permeable membrane from a region of high water concentration to a region of low water concentration. **Ion exchange** occurs between soil particles and adhering root hairs without entering into solution in the soil.
Water is important to plants because:
- colloidal constituents of the cytoplasm are dispersed in water,
- water and carbon dioxide are used to manufacture food by photosynthesis,
- solids are usually dissolved in water before they can enter or leave a cell or be moved from one part of a plant to another,
- it provides internal pressure to maintain form and give support to the plant,
- it is the primary medium in which most of the chemical reactions of living cytoplasm occur.

Most of the force that moves water and solutes upwards in the **xylem** comes from **transpiration**, the evaporation of water from leaves. **Cohesion** causes water molecules to stick together, relaying the pull of transpiration along a string of water molecules all the way down to the roots. **Phloem** transports food molecules derived from photosynthesis by a **pressure-flow mechanism.**
Although most water passes from plants as a vapour, it may leave in liquid form by the process of **guttation**, in which the drops of water are confined to the margins and tips of the leaves.

Nutrition

Most plants are **autotrophs**, their ability to create food depends on nutrients they obtain from the environment. **Macro-nutrients**, such as carbon, oxygen, hydrogen, nitrogen, and phosphorus are required in large amounts, mostly to build organic molecules. **Micro-nutrients**, including iron, copper and zinc, act mainly as co-factors of enzymes. Stunting, wilting, and colour changes indicate nutrient deficiencies.
Soil characteristics determine whether a plant will be able to obtain the nutrients it needs to grow. Fertile soil contains a mixture of small rock and clay particles which hold water and ions. **Humus**, decaying organic material, consists of nutrients, air spaces and water. It supports the growth of organisms which enhance soil fertility.

Water conservation, irrigation, erosion control and prudent use of herbicides and fertilizers are aspects of good soil management. Organic farming protects the environment, and organically grown foods have become increasingly popular.

Photosynthesis

Photosynthesis is the system of chemical reactions through which autotrophs absorb energy from sunlight and use it to synthesise organic compounds from carbon dioxide and water.

Three major events occur in photosynthesis:
- absorption of light energy (chlorophyll)
- conversion of light energy into chemical energy (light reactions)
- storage of chemical energy in sugars (Calvine cycle).

The chemical equation for photosynthesis is:

$$6\,CO_2 + 6\,H_2O + \text{light energy (2760 kJ)} \rightarrow C_6H_{12}O_6 + 6\,O_2$$

Light reactions take place in the **thylakoid of a chloroplast** where **chlorophyll** absorbs light energy, water molecules are split into hydrogen and oxygen, and oxygen is released to the atmosphere. Light energy is stored as chemical energy.
The **Calvine cycle** occurs in the stroma of chloroplasts and this is where carbon fixation takes place and sugar is manufactured. Many plants make more sugar than they need, the excess is stored in roots, tubers and fruits, and is a major food source for animals.
Photosynthesis produces billions of tons of organic matter each year, including our food, and sustains almost all life on the planet.

Respiration

Respiration is a chemical reaction through which the common sugar, **glucose, is oxidised** into simpler substances with the **release of energy**, as summarised by the following equation:

$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O + \text{Energy (2760 kJ)}$$

From the standpoint of energy loss or gain, the reaction in the process of **respiration is the opposite to that of photosynthesis**. The energy liberated in respiration is used in part to form heat and in part for such plant functions as cytoplasmic flow, movement of cell parts, assimilation processes, synthesis of fat and protein from sugar, accumulation of solutes from soil and synthesis of pigments, vitamins, enzymes, oils, resins, organic acids and tannins.
During the day, photosynthesis usually proceeds at a rate several times that of respiration so that foods and energy are stored. At night, only respiration occurs so the plant uses food and oxygen and liberates carbon dioxide.
Under certain conditions, respiration may occur in the absence of free oxygen – **anaerobic respiration**. This does not release much energy (about 70 kJ) and does not form the usual end products of carbon dioxide and water but produces a number of different compounds, including alcohol, carbon dioxide and organic acids.

Reproduction

Multicellular organisms which reproduce sexually go through a cycle, such as **egg**, **embryo**, **adult** and next generation egg. In **sexually-reproducing plants**, this cycle is complicated by having two aspects of the adult-to-egg stage: gamete-producing **gametophyte** and spore-producing **sporophyte generations**.

Many plants reproduce by specialized **sex cells**, called **gametes**. The fusion of a pair of gametes is called **fertilization**, and the result is a **zygote**. In many plants, minute specialized cells, called **spores**, are produced for reproduction by **sporogenesis**.

There are two phases in the life cycle of most plants which result in the **alternation of generations**. The gametophyte generation bears male and female sex organs and produces gametes which fuse to produce a fertilised egg. The fertilized egg then develops into the sporophyte generation which produces spores. Each of these spores eventually develops into a new gametophyte.

In seed-producing **angiosperms** (flowering plants), two kinds of spores are produced in the flower: **microspores** (pollen grains) and **megaspores** which are retained within the spore case and germinate into female gametophytes. The whole structure is known as an **ovule** (immature seed). Microspores (pollen grains) are liberated into the air and, when carried to a different ovule, they fertilise the **egg** to form an **embryo**. **Meiosis** (see p. 46) precedes the formation of microspores (pollen grains) and megaspores (embryo sacs).

A **zygote** (fertilised egg) divides repeatedly by mitosis to form groups of cells which eventually differentiate to produce various tissues and organs.

Many plants are also able to **reproduce asexually**, by means of bulbs, sprouts or runners. Propagating plants from cuttings or cloning plants from bits of tissue exploits **vegetative reproduction**, which can increase agricultural productivity but can also reduce genetic diversity.

Movements

Active movements of plants are based on unequal growth rates in different parts of a plant organ or on turgor movements caused by a change in water pressure (turgor pressure) of certain tissues of an organ.

Growth movements include:
- **nutations**, nodding movements of the growing apices of certain organs,
- **twining movements**, discernible, spiral movements of the growing apex,
- **nastic movements** of flattened organs such as petals, leaves and bud scales, in which one surface grows faster than the other, thereby resulting in the closing or opening of an organ,
- **tropisms**, rather slow bending movements of cylindrical organs, such as stems, leaf petioles, flower stalks and roots, occurring in response to external stimuli (phototropism, chemotropism, hydrotropism, thigmotropism or geotropism).

Turgor movements are:
- **contact movements** induced by contact and pressure stimuli, such as displayed by leaves and flowers when trapping an insect,
- **rapid movements** displayed by reactions of the leaves of some sensitive plants (e.g., Mimosa) initiated by stimuli, such as contact and temperature changes,
- so-called **sleep movements** induced in many plant leaves because of changes in light intensity (**nyctitropism** – horizontal position in bright light and vertical position in diminished light).

5 LIFE FUNCTIONS IN HIGHER ANIMALS

Homeostasis

Animals survive **fluctuations in the external environment** by means of homeostatic ("steady-state") control mechanisms which tolerate only a narrow range in the fluid environment of their cells. There are five main elements of homeostasis: balance of acidity (pH), thermoregulation, osmoregulation, excretion and chemical regulation.

The **pH balance** is maintained by **buffers** – substances which resist pH change by accepting H^+ ions when these are in excess and donating H^+ when they are depleted. In the human body, haemoglobin acts as a buffer by picking up most of the H^+ ions, thus preventing them from acidifying the blood. The CO_2 molecules built into bicarbonate ions in the blood are also an important part of the **blood-buffering system.**

Thermoregulation is the maintenance of body temperature within a tolerable range. It depends on the production, gain or loss of heat. Depending on the main source of body heat, animals are either **ectotherm** (cold-blooded) which obtain heat by absorption from their surroundings, or **endotherm** (warm-blooded) which derive most of their body heat from their own metabolism.

Osmoregulation is the control of gain and loss of water and dissolved solutes. The metabolic reactions on which life depends require a precise balance of water and dissolved solutes. Aquatic animals living in the sea are called **osmoconformers** – they have body fluids with a solute concentration equal to that of seawater. Freshwater and land animals are called **osmoregulators** – their body fluid concentration differs from that of the environment and must be controlled.

Excretion is the disposal of metabolic wastes. Metabolism produces a number of **toxic by-products**, particularly nitrogenous wastes resulting from the breakdown of proteins and nucleic acids. The excretory system plays a key role in homeostasis.

Chemical regulation is based on many types of chemical signals which regulate various body activities. There are two types of this regulation: **endocrine glands** produce **hormones** and **neurosecretory cells** secrete **neurotransmitters.** This system cooperates with the nervous system in regulating all body activities.

Most of the known control mechanisms of homeostasis are based on **negative feedback.** Control systems sense changes and trigger responses which counteract further changes in the same direction. Feedback mechanisms keep fluctuations in internal conditions within the narrow range compatible with life.

Body Temperature

Animals, both **ectoderms** and **endosperms**, regulate **heat gain and loss by conduction, convection radiation** or **evaporation**. Fur and feathers help the body retain heat. Blood flow to the skin also affects heat loss. In a counter-current heat exchanger, blood from the core of the body warms cooler blood returning from the skin or limbs, thereby conserving body heat. Behaviour also affects thermoregulation. Animals may bask in the sun, seek shade, bathe, burrow, huddle or migrate. Torpor, which includes hibernation in cold weather and aestivation in warm weather, is a state of reduced activity that saves energy.

In endoderm animals, the body's major thermostat is the **hypothalamus** located in the brain.

Respiratory Systems

Energy metabolism of animals **requires oxygen** and **generates** waste – the gas **carbon dioxide**. Thus cells must dispose of CO_2 as well as obtain O_2.

Gas exchange involves three phases:
- breathing
- transport of respiratory gasses
- gas exchange in body tissues.

Organs for **gas exchange** have evolved differently in various organisms; higher animals have a very specialized **respiratory system**.

There are differences in gas exchange systems:
- **diffusion** through the cell or body surface found in unicellular organisms and small multicellular animals (protozoa, sponges, coelenterates and planarians),
- **gills** are networks of capillaries extended into the surrounding water found in larger and more complex aquatic animals (aquatic worms, crustaceans, molluscs and fish),
- **tracheae** are systems of small, branched air ducts carrying oxygen though the body found in insects,
- **lungs** are internal sacs equipped with extensively branched inner surfaces of tiny alveoli, lined with moist epithelium found in the majority of terrestrial vertebrates. Breathing supplies the lungs with O_2-enriched air and expels CO_2-enriched air.

Cardiovascular Systems

Most animals have a circulatory system which **transports oxygen and nutrients** to cells, removes carbon dioxide and other **wastes** and regulates the make-up of the interstitial fluid in which the cells live.
Three types of internal transport systems have evolved in animals:
- **gastrovascular cavity**, in hydras and jellyfish, functions in both digestion and internal transport,
- **open circulatory system**, in many invertebrates (spiders, crayfish, grasshoppers, etc.), is based on blood being pumped through open-ended vessels and flowing out among the cells,
- **closed circulatory system** found in vertebrates is called cardiovascular because it consists of a heart and a network of tube-like vessels.

In the cardiovascular system, there are three kinds of vessels:
- **arteries**, carry blood away from the heart to organs,
- **veins**, return blood to the heart,
- **capillaries**, microscopic vessels, convey blood between arteries and veins and allow for the diffusion of substances between blood and tissue cells.

The walls of capillaries are very thin, formed only of a single layer of epithelial cells. The walls of arteries and veins are thicker and reinforced by two other layers – the middle one of smooth muscle and the outer one of connective tissue. The walls of arteries are thicker because of higher blood pressure. Veins have valves preventing the backward flow of blood.

Three types of pumping system have evolved in vertebrates. Fish have a **two-chambered heart** with one **atrium** and one **ventricle**. Amphibians and reptiles have **three-chambered hearts** with only one ventricle. Birds, mammals and crocodiles have **four-chambered hearts** and two separate systems for gas exchange and circulation.

Body Fluids

Body fluids are **lymph** and **blood** which are solutes of proteins and some inorganic compounds containing special cells. In animals with the open circulatory system, there are no special cells carrying an oxygen-transporting pigment in the blood. **Red blood cells with pigment specialized for oxygen transport** are found, first, in segmented worms and then in vertebrates.

Different kinds of pigments capable of combining with oxygen are found throughout the animal kingdom:
- **haemoerythrin**, coloured red with iron, contained in erythrocytes of segmented worms,
- **chlorocruorin**, coloured green with iron, dissolved in plasma of some segmented worms,
- **haemocyanin**, coloured blue with copper, dissolved in plasma of molluscs,
- **haemoglobin**, coloured red with iron, dissolved in plasma of some segmented worms and molluscs, and in erythrocytes of vertebrates.

Once bound to one of these pigments, oxygen is transported to tissue cells. Haemoglobin has the highest ability to carry oxygen.
Body fluids also contain cells which have **defence functions** – white blood cells or **leucocytes**. In higher animals, these are differentiated into several types. Leucocytes have the ability of **phagocytosis** and can engulf bacteria and viruses. In mammals, a special type of white blood cells, lymphocytes, secretes special globulins called **antibodies** and is responsible for **humoral immunity.**
The **lymph** in higher animals with the closed circulatory system is similar to interstitial fluid but contains less oxygen and fewer nutrients. It has two main functions: to return tissue fluid to the circulatory system and to fight infection.

Nutrition and Digestion

Animals need nutrients from food to build their body structures and to provide **energy for living** activities. Some animals are **herbivores**, some are **carnivores** and some are **omnivores.** Food is ingested, digested and absorbed; the undigested wastes being eliminated.
Protozoans digest food particles in **food vacuoles**. Most other animals have a specialized **digestive tract**. In hydrozoans, this is a **gastrovascular cavity**, a sac with a single opening. In higher animals, the digestive tract is an **alimentary canal** running from mouth to anus, divided into specialised regions which process food sequentionally.
Food, ingested through the **mouth** and **oral cavity**, passes into the **pharynx** or **throat** and then into the **oesophagus**. Depending on the species, the oesophagus may channel food to a **crop, gizzard** or **stomach.** Some animal species have all three of these organs. In the crop, food is softened and stored temporarily; gizzards and stomachs have muscular walls and actively churn and grind the food.
Chemical digestion and nutrient absorption occur mainly in the **intestine**. The undigested wastes are expelled through the opening called **anus.** The region of the alimentary canal varies according to the type of food that is processed there.

Excretory System

Metabolism produces **toxic by-products**, of which the most difficult is the **nitrogen-containing** waste from proteins and nucleic acids.

The major types of **nitrogenous waste products** are:
- ammonia (NH_3), very toxic to body tissues,
- urea, much less toxic,
- uric acid, non-toxic because it is almost insoluble.

Types of excretion systems are as follows:
- **contractile vacuoles,** in unicellular organisms (*Paramecium*),
- **diffusion through the body surface** into the surrounding water, in small, soft-bodied invertebrates (hydra, sponges),
- **flame cells,** in more complex freshwater animals (planarians),
- **Malpighian tubules** which empty into the digestive tract, in land-dwelling insects,
- **nephrons** are excretory tubules assembled into compact organs in vertebrates (the **kidneys**).

Structure of the nephron:
- glomerulus enveloped by Bowman's capsule,
- tubule consisting of three sections,
- proximal tubule,
- loop of Henle with capillary network,
- distal tubule.

Nephrons have four functions: filtration, reabsorbtion, secretion and excretion.

Nervous Systems

The nervous system enables an animal to respond quickly and precisly to environmental changes. The functional units of the nervous system are neurons. A **neuron** has a large cell body from which two types of fibres are extended. One type has numerous, highly branched **dendrites** conveying signals to the cell body, the other, **axon** or **neurite,** is a single fibre conducting signals away from the cell. Axons are enclosed by an insulating material called the **myelin sheath.** Three kinds of neurons correspond to the main functions of the nervous system. **Sensory neurons** conduct signals from receptors to the central part of the system, **interneurons** integrate this information and transmit it to **motor neurons** which, in turn, conduct signals to muscles or glands which make the effective responses.

With few exceptions, nervous systems have two divisions: **central nervous system** (brain and spinal cord in vertebrates) and **peripheral nervous system** (mostly nerves).

A wide variety of nervous systems have evolved in the animal kingdom:
- **Nerve ladder,** with two indicators of bilateral symmetry (cephalisation and centralisation in flat worms). **Cephalisation** indicates the concentration of the nervous system at the head end. **Centralisation** indicates the presence of a central nervous system, distinct from a peripheral one, which is represented by two parallel nerve cords joined by many cross connectives.
- **Nerve cord,** a nervous system with greater cephalisation and centralisation, where one or more nerve cords are more distinctly set off from peripheral nerves. In insects, the central nervous system has a **brain** composed of several **fused ganglia** and a ventral nerve cord with ganglia in each body segment.
- **Spinal cord,** a tubular nervous system, highly centralised and cephalised, found in vertebrates. The central nervous system consists of a prominent brain, enclosed in the skull, and a spinal cord which lies inside a bony vertebral column or spine. The brain and the spinal cord both contain hollow regions. Fluid-filled spaces in the brain, called ventricles, are continuous with the central canal of the spinal cord. The central nervous system consists of **white matter** (myelinated axons and dendrites) and **grey matter** (mainly nerve cell bodies).

Sensory Functions

Sensory organs contain specialized receptor cells which detect stimuli. **Sensory receptors** inform the animal about conditions both inside and outside its body. Receptors convert stimuli into electrical energy (sensory transduction).

Sensory receptors are: **electromagnetic receptors** which respond to electricity, magnetism and light; **mechanoreceptors** responding to mechanical energy; **chemoreceptors** responding to chemical stimuli; **thermoreceptors** which detect heat and cold; **pain receptors** which respond to physical tissue damage.

The most common types of electromagnetic receptors are **photoreceptors**, which sense light. In flatworms, **simple eye cups** register the intensity and direction of light. The **compound eyes** of insects produce a mosaic image. Some invertebrates and vertebrates have **single-lens eyes** working on a principle similar to that of a camera.

Mechanoreceptors are the most diverse of sensory cells. Different types are stimulated by various forms of mechanical energy, such as **touch** and **pressure**, **stretching** of muscles, **motion** and **sound**. All these forces produce their effects by bending or stretching the plasma membrane of a receptor cell or by bending special hairs projecting from the surface of receptor cells.

Thermoreceptors in the skin or deep in the body detect either **heat** or **cold**.

Chemoreceptors include sensory cells attuned to **gaseous chemicals** or odours, sensory cells on taste buds of the tongue and internal sensors in arteries which can detect changes in the amount of CO_2 in blood.

Pain receptors are bare ends of nerve fibres. Pain is important because it often indicates danger and usually makes an animal withdraw to safety. Pain can also make humans aware of injury or disease.

Hormonal Regulation

Animals rely on many kinds of chemical signals to regulate their body activities. **Endocrine glands** secrete **hormones**, chemical signals which are carried in the blood and which cause specific changes in target cells.

Steroid hormones, which are lipids, enter target cells, bind to receptor proteins, interact with DNA and trigger protein synthesis. **Non-steroid hormones**, which are amines, peptides or proteins, attach to receptor proteins on the target cell membranes. This triggers the formation of a **second messenger**, such as cAMP (cyclic adenosine monophosphate), which causes changes inside the target cell.

The **vertebrate endocrine system** consists of several glands which secrete more than 50 hormones. Some glands are specialised for hormone secretion only. The sex glands and adrenal cortex secrete steroids; all other glands produce only non-steroid hormones. Some hormones are very specific, while others have a wider range of targets and effects.

Locomotion

Movement is one of the most distinctive features of animals. An animal must either move through its environment or make the environment move to it.

Single-cell animals move either by amoeboid movement or by means of cilia or flagella. In **amoeboid movement**, a cell moves by extending and retracting portions of itself. The temporary projections are called **pseudopods**. Cytoplasmic **actin** and **myosin** drive this type of movement which is characteristic of amoebas and other protozoa (it also occurs in some cells in multicellular animals, such as leucocytes).

Ciliary or **flagellar movement** occurs in some protozoa, sperm cells or cells lining the air passages in the lungs.

The **molecular motors** for this type of movement are **dynein** molecules located between ciliary or flagellar **microtubules.**
Multicellular animals have a locomotive system based on contractile **muscles** working against a firm **skeleton.** The skeleton functions, apart from locomotion, in support, movement and protection of internal organs. There are three main types of skeletons: hydrostatic skeleton, exoskeleton, and endoskeleton.
Hydrostatic skeletons are found in the lower animals, such as Hydrozoa and worms. They consist of fluid held in closed compartments.
Exoskeletons are found in a variety of aquatic and terrestrial animals, such as arthropods and molluscs. In arthropods, the exoskeleton consists of **chitin**; shells of molluscs are made of **minerals** and calcium carbonate.
Endoskeletons consist of hard supporting structures situated amongst the soft tissues of the animal. Sponges are reinforced by hard spicules of **calcium salts** or **silica.** Sea stars and other echinoderms have endoskeletons of hard plates beneath their skin. Vertebrates have endoskeletons consisting of cartilage or a combination of **cartilage** and **bone.**
Bones act as levers which produce movement in response to muscle contractions. The **motor system in muscles** is based on an interaction of **actin** and **myosin** with **ATP** providing energy.

Sexual Reproduction

Sexual reproduction is the most common method of reproduction amongst animals.
It is the creation of offspring by fusion of two haploid sex cells, **gametes,** to form a diploid **zygote**. The gametes are **sperm** (male) and **ovum** or **egg** (female). Fusion of a sperm with an egg is called **fertilisation.**
Sexually reproducing animals have special organs for production of the male and female gametes – **testes** produce sperm and **ovaries** produce ova.
Hermaphroditism, both eggs and sperm are produced by the same animal.
Sexual dimorphisms, morphological diversity between males and females.
External fertilisation occurs in aquatic invertebrates, amphibians and the majority of fish.
Internal fertilisation occurs in nearly all terrestrial animals. The sperm are deposited into the female reproductive tract. Internal fertilisation requires **copulation** or sexual intercourse.
The process which follows the fertilisation of an egg (**ontogenic development**) requires complex **reproductive systems.**
Primary sex characteristics are differences in morphology of sex organs.
Secondary sex characteristics are differences in the appearance of males and females within the same species, with the exception of morphological differences of specific sex organs.

Ontogenic Development

The development of a new organism begins with **fertilisation**, the union of egg and sperm nuclei, followed by the formation of a **zygote**. This undergoes multiple rounds of mitosis (**cleavage**) to form, firstly, a cluster of cells, the **morula**, then a hollow ball of several hundred cells, the **blastula,** and, finally, a sphere with three distinct cell layers, the **gastrula**.
A gastrula consists of:

- **ectoderm** (outermost layer) giving rise to the skin and nervous system,
- **endoderm** (innermost layer) developing into the lining of the digestive system and other inner organs (e.g., pancreas, liver),
- **mesoderm** (middle layer) forming the bones, kidneys, circulatory system and connective tissue.

An increase in the number of cells and their differentiation are the critical components in the development of a multicellular organism.
Following the gastrula stage, many animals develop directly into **adults** but others develop into one or more **larval stages** which then undergo a complete change of body form called **metamorphosis.**

6 GENETICS

Heredity and Variability

Genetics is the study of inheritance or transmission of traits from one generation to another. **Heredity**, in both sexual and asexual reproducing species, is the ability of one generation of organisms to pass genetic information (genes) to the next and succeeding generations. **Genes** interact with each other and with their environment to produce distinctive characteristics or phenotypes. Offspring therefore tend to resemble their parents or other close relatives. Most genes have a number of alternative forms, **alleles,** which can occupy the same **locus** of a chromosome. The resultant **genetic variation** provides the basis for evolution by natural selection. Genetic links between generations can extend back throughout the history of a species and provide for the future continuity of that species.
Most of genetic variation is a result of **recombination** of parental genes during **meiosis** and **fertilisation. Mutations** are a further source of genetic variation. Genetic variation amongst individuals of a group (species) refers to differences amongst individuals of that species which cannot be ascribed to age, sex, and stage in the life cycle or environmental factors.
The science of genetics deals with both the heredity and the genetic variation.

Character and Phenotype

A **character** or **trait** is any detectable phenotypic property of an organism. The **phenotype** is a complex of traits in an organism produced by the genotype in conjunction with the environment. Traits which occur in an "either/or" form are described as **qualitative traits**, e.g., in plants, height (tall or short), colour of pods (green or yellow) or shape of peas (smooth or wrinkled); in humans, the ABO blood system. These traits are also called **monogenic characters** because they are each determined by a single gene.
Some traits are controlled by more than one gene, **polygenic** or **multifactorial characters,** and show continuous distribution in a population. In humans, these are, for instance, height, weight, intelligence, hair colour or skin colour. These traits are called **quantitative** and their system of heredity is called polygenic or multifactorial inheritance.
A single gene may affect many phenotypic characteristics; the impact of it on more then one trait is called **pleiotropy**.
Traits may be categorised as **morphological** (skin or eye colour), **physiological** (voice production, muscle power, etc.), **biochemical** (production of enzymes) or **psychological** (mental abilities, etc.).
From the medical point of view, traits may be divided into **standard** or normal (skin or eye colour, weight, height, etc.) and **pathological** which affect the biological quality of their carriers (sickle cell anaemia, haemophilia, cleft palate, etc.).

Gene and Genotype

Function of nucleic acids in heredity

DNA is the ultimate molecule of life. It is the polymer of which **prokaryotic and eukaryotic genes** are composed and it is a basis of inherited material of almost all living things, with the exception of those viruses in which this function is taken over by RNA.

The three classes of **RNA** (messenger, transfer and ribosomal) have essential roles in the **expression of genetic information.**

Genetic information and genetic code

Genetic information is contained in the **genes,** sequences of nucleotides of a DNA molecule, which code for specific functional products, such as transfer RNA, enzymes, structural proteins, or pigments. Genes contain instructions which control the development and function of all organisms and transmit them to each new generation.

The flow of genetic information from gene to protein is based on a **triplet code.** The "words" of the DNA "language" are **triplets of bases** called **codons.** The codons in a gene specify the amino acid sequence of a polypeptide. There are only four different kinds of nucleotides in DNA and RNA. When the four bases are taken in triplets, there are 64 (that is, 4^3) possible arrangements, more than enough to specify 20 amino acids. Some amino acids are specified by more than one codon. The code is read from a fixed starting point, in one direction, in groups of three consecutive nucleotides. One codon (AUG) has a dual function, it codes for the amino acid methionine and also can provide a signal for the start of a polypeptide chain. Three other codons are stop codons that instruct the ribosomes to end the polypeptide. The genetic code is universal; it is used by most organisms in the same way.

Genotype is the genetic constitution of an organism which includes all its genes. The phenotypic expression of a given genotype varies when measured under different environmental conditions.

Gene and its Expression

Expression of genetic information includes two processes: **transcription** (RNA synthesis) and **translation** (protein synthesis).

Transcription

The first step in the expression of a particular gene is the synthesis of RNA on the DNA template (see also p28). RNA synthesis is known as transcription because the genetic information in DNA is transcribed into the genetic code of RNA. Only one strand of DNA is the coding strand.

The **three stages** of transcription are:

- **initiation,** RNA polymerase attaches to DNA at the promoter region,
- **elongation,** RNA is synthesized from the template of the noncoding strand of DNA,
- **termination,** RNA polymerase reaches the end of the gene (coding region).

System of the genetic code

	U		C		A		G		
U	UUU	Phenyl	UCU	Serine	UAU	Tyrosine	UGU	Cysteine	U
	UUC	alanine	UCC		UAC		UGC		C
	UUG	Leucine	UCA		UAA	Stop	UGA	Stop	A
	UUA		UCG		UAG		UGG	Tryptophan	G
C	CUU	Leucine	CCU	Proline	CAU	Histidine	CGU	Arginine	U
	CUC		CCC		CAC		CGC		C
	CUA		CCA		CAA	Glutamine	CGA		A
	CUG		CCG		CAG		CGG		G
A	AUU	Isoleucine	ACU	Threonine	AAU	Asparagine	AGU	Serine	U
	AUC		ACC		AAC		AGC		C
	AUA		ACA		AAA	Lysine	AGA	Arginine	A
	AUG	Methionine	ACG		AAG		AGG		G
G	GUU	Valine	GCU	Alanine	GAU	Aspartic	GGU	Glycine	U
	GUC		GCC		GAC	acid	GGC		C
	GUA		GCA		GAA	Glutamic	GGA		A
	GUG		GCG		GAG		GGG		G

Translation
Protein synthesis is called translation because the **codon sequence in mRNA is translated into the amino acid sequence** of a protein (see also III.9, p.26).
The machinery required for translation includes the following: messenger RNA, transfer RNA, ribosomes, enzymes and a number of protein "factors" and a source of chemical energy (ATP).
Translation includes **tRNA charging** (binding of amino acid and ATP), **communication of mRNA with ribosomes**, then the **initiation**, **elongation** and **termination** of the polypeptide chain.

Prokaryotic and Eukaryotic Chromosomes and Plasmids

Prokaryotic chromosomes
In prokaryotic cells, most genes are carried on a **circular (rarely linear) DNA molecule** which, together with associated proteins, constitutes a single prokaryotic chromosome. The prokaryotic chromosome is much less complicated than that of eukaryotes. It is attached to a special region of the plasma membrane and is replicated before cell division. There are **no histones** connected with prokaryotic DNA. The same type of chromosome occurs in **mitochondria** and in the **chloroplasts** of eukaryotic cells.

Plasmids
Small, **circular DNA molecules** (sometimes also linear) in the cytoplasm of prokaryotic cells and in some lower eukaryotes (yeast cells) are called plasmids. They can be separated from the prokaryotic chromosome and are able to replicate themselves within the cell, independent of replication of the chromosome.
Some plasmids, called "**R plasmids**", carry particular genes for resistance to antibiotics. They can pose serious problems for human medicine. The **"F plasmids"** called fertility (F) factor which carries genes for bacterial conjugation. The **"Ti plasmids"** induce development of tumours in plants infected by a bacterium containing these plasmids.
Plasmids are used in genetic engineering as **vectors for transfer of genes** and their cloning.

Eukaryotic chromosomes

Each chromosome consists of a **single DNA molecule**, containing up to 10^8 base pairs, which wraps around **histones** to form a **nucleosome**, the basic packing unit of the chromosome. This level of DNA packing is followed by supercoiling, looping and folding.

Genes on chromosomes

All genes located on the same chromosome are **linked,** that is, they are inherited together. **Genetic maps** show the sequence of genes on chromosomes.

Chromosome numbers

In eukaryotes, chromosomes occur in pairs and each species contains an even number – **two sets**. The two chromosomes of a pair, **autosomes,** are described as **homologous** and are found in both males and females. Many human normal and pathological traits have the autosomal basis of heredity. Human disorders, such as albinism, galactosaemia, phenylketonuria, sickle-cell anaemia, are autosomal recessive. Dominant autosomal disorders are achondroplasia, Huntington's disease or hypercholesterolemia.

Chromosome determination of sex

One pair of chromosomes, the **sex chromosomes** or **gonosomes**, determine **a** person's **sex. Human females** have a pair of sex chromosomes, **X chromosomes, human males** have one **X** and one **Y chromosome.** These differ in size and shape, and most of the genes carried on the X chromosome do not have counterparts on the Y chromosome. Traits with genes on gonosomes (sex-linked) display gonosomal heredity. **Sex-linked genes** carried on the Y chromosome affect traits which appear only in men and are passed from father to son. Most known sex-linked genes are on the X chromosome.
Some serious human disorders are associated with sex-linked genes (red-green colour blindness, haemophilia or Duchenne muscular dystrophy).

Karyotype

This comprises the number, size and morphology of the chromosome set of a cell, individual or species. An **idiogram** is a diagrammatic representation of the karyotype of an organism.

Extranuclear Inheritance in Eukaryotic Cells

Extranuclear (cytoplasmic inheritance, non-Mendelian heredity) involves replication and transmission of **extrachromosomal genetic** information found in organelles, such as **mitochondria** and **chloroplasts,** or in intracellular parasites, such as **viruses.**
Mitochondria and chloroplasts have their own DNA. Unlike nuclear DNA, this does not come from both parents. Male gametes do not contain chloroplasts and mitochondria whereas the ovum contains both and these are replicated in the fertilised egg. Hence, all mitochondria and chloroplasts are derived from the female organism, and hence it is called **maternal inheritance**.
Certain human diseases characterized by structurally and functionally abnormal mitochondria are inherited in the maternal fashion. Research on human mitochondrial DNA contributes to the understanding of the evolutionary history of the human species.

Meiosis

All sexual life cycles involve an **alternation of diploid and haploid stages.** The haploid stage prevents the doubling of chromosome number in each succeeding generation.
Meiosis is a special kind of cell division during gametogenesis by which the **haploid number is achieved.** In sexual reproduction, meiosis and fertilisation are complementary processes. The meiotic process involves two consecutive divisions (**meiosis I** and **II**) preceded by only a single duplication of the chromosomes. The result is the haploid state of gametes.
Prophase I is the most complex phase of meiosis including **synapsis** of homologous chromosomes with the possibility of **crossing over** (recombination of genetic information).
Metaphase I involves the **independent segregation** of maternal and paternal chromosomes.
No chromosome duplication occurs between telophase I and meiosis II.
Male animals usually produce **four** equal-sized **sperms** from each original cell.
Females produce only **one ovum** and **two polar bodies.**
Genetic consequences of meiosis:
- reduction in chromosome number,
- recombination of genetic information by crossing over,
- recombination of genetic information during segregation of chromosomes.

Segregation and Recombination of Chromosomes in Diploid Organisms

Breeding and Hybridisation

Breeding is controlled propagation in plants and animals. **True-breeding** occurs in a close community (e.g., breed) leading to a group of genetically similar individuals. **Inbreeding** is an extension of this, involving mating between close relatives. **Self-fertilisation** in plants, when pollen grains released from the stamens land on the egg-containing carpel of the same flower, can produce identical offspring over generations.
Hybridisation involves **cross-fertilisation** or **cross-breeding** between different genetic populations. The offspring of such hybridization are described as hybrids and, in genetic terminology, **hybrid** is synonymous with **heterozygote.**
Parental organisms are called the **P generation** (parental), their hybrid offspring are the **F_1 generation** (filial), the next generation is F_2, etc.
A breeding experiment which follows the inheritance of a single trait is called a **monohybrid cross.** When parental varieties differ in two traits, the mating is a **dihybrid cross** and, when there is a higher unknown number of different traits, the mating is a **polyhybrid cross.** In a dihybrid cross, each pair of alleles on different chromosomes segregate and are inherited independently, **independent assortment.**
Genes located on the same chromosome are linked, inherited together and, during segregation, are not recombined – **gene linkage.** Linked alleles can only be separated by **crossing-over** in order to produce gametes with **recombinant chromosomes.**
In genetic research, reciprocal and test crosses are used. **Reciprocal crosses** involve A-female x B-male and A-male x B-female, where the individuals symbolized by A and B differ in genotype or phenotype or both. These crosses are employed to detect sex linkage, maternal inheritance or cytoplasmic inheritance. The **test cross** is a mating between an individual of unknown genotype, which shows the dominant phenotype, with a test individual known to carry only the recessive alleles (recessive homozygote).

Mendel's Laws

In the 1860s, ***Gregor Mendel***, an Augustinian monk, discovered the **fundamental principles of genetics** by breeding garden peas in an abbey in Brno, now in the Czech Republic. He argued that parents pass **discrete heritable factors** (now known as genes) to their offspring and that these retain their individuality over generations. Seven characteristics of garden peas were studied by him: flower colour and location, seed colour and shape, pod colour and shape, and stem length.

In a paper published in 1866, he developed his hypotheses, summarised as the four Mendel's laws:

1. Law of unit character

Genes occur in pairs and control the inheritance of traits as a unit.

2. Law of dominance

One gene of a pair may mask or inhibit the expression of the opposite member of that pair. The one that expresses itself is called the **dominant** gene and the other the **recessive** gene.

3. Law of segregation

The genes that make up a pair are segregated from each other when gametes are formed. Only one of each pair goes into a single sex cell.

4. Law of independent assortment

The genes representing two or more contrasting pairs of traits are distributed independently of one another at the time of gamete formation. (It was subsequently found that this is true only in the case of genes located on different chromosomes.)

Mendel appreciated the **statistical nature of inheritance. Genetic ratios are estimates of probability**, not estimates of absolute numbers. Mendel's principles can be applied to predict inheritance patterns for many human traits that involve simple dominance and recessiveness.

Heritable and Non-heritable Variability

Most traits are **multifactorial.** Their expressions are controlled by several genes and are influenced considerably by the environment. The degree to which a trait is genetically determined is called **heritability**. It is expressed as the ratio of the total genetic variance to the phenotypic variance (V_G/V_P). However, it is difficult to distinguish between genetic and environmental effects.

A monohybrid cross demonstrating Mendel's principle of segregation

P generation (true-breeding parents)	Purple flower	x	White flower
genotype	**PP**		**pp**
gametes	All **P**		All **p**
F_1 generation		All purple flowers	
genotype	**Pp**	x	**Pp**
gametes	1/2 **P**, 1/2 **p**		1/2 **P**, 1/2 **p**
		fertilisation	
F_2 generation			
genotype		**PP Pp Pp pp** 1 : 2 : 1	
phenotype		purple : white 3 : 1	

P – dominant allele for purple colour

p – recessive allele for white colour

PP – dominant homozygote with purple flowers

Pp – heterozygote with purple flowers

pp – recessive homozygote with white flowers

Mutations

Changes in genetic information – **mutations** may occur at three levels:
- gene or point mutations,
- chromosomal mutations,
- genomic mutations.

Point mutations involve a single pair of DNA and arise when a mis-pairing occurs during replication. They can be divided into two general categories: base substitution and base insertion or deletion. A **base substitution** is the replacement of one nucleotide with another. Depending on how a base substitution is translated, it can result in no change, an insignificant change or a significant change in the protein. Point mutations occur rarely - about one per million gametes for any given gene. Although most mutations are harmful and produce ineffective or inactive proteins, they are still an essential source of new alleles. Mutations involving the **insertion** or **deletion** of one or more nucleotides in a gene often have disastrous effects. Added or subtracted nucleotides may alter the reading frame (triplet grouping) of the genetic message. These mutations are called **frame-shift mutations**.

Chromosomal mutations are large-scale alterations including changes in the chromosome structure, as follows:
- **deletion**, a broken section of a chromosome is lost,
- **inversion**, a part of a chromosome can be re-attached in a reversed order,
- **duplication**, a broken fragment of a chromosome is attached to a homologous chromosome in which genes contained in the fragment already exist,
- **translocation**, broken pieces of chromosomes exchange positions on different chromosomes.

Genomic mutations are caused by changes in chromosome number, classified as:
- **aneuploidy**, a condition in which the chromosome number of an individual is not an exact multiple of the haploid set typical of the species. This may involve **polysomy** (reduplication of some but not all of the chromosomes of a set beyond the normal diploid number, such as **trisomy** of X chromosome); **hyposomy**, a lower number of chromosomes of a set; **nulosomy**, lacking both members of a pair of chromosomes
- **polyploidy**, the number of chromosome sets is greater than two (**triploidy**, **tetraploidy** or **hexaploidy**).

Many chromosomal alterations cause severe developmental problems. The majority of human miscarriages are due to abnormalities in chromosome structure or number. Chromosomal abnormalities also appear to be involved in most human cancers. Specific translocations, deletions or trisomies are consistently associated with specific types of tumours.
Mutations contained within the chromosome of a gamete, i.e. **gametic mutations**, pass to the next generation and can be a source of genetic variation. Mutations occurring in somatic cells, i.e. **somatic mutations**, are not passed to the next generation but may initiate cancer in the individual carrier.
Mutations resulting from errors during DNA replication or recombination are called **spontaneous mutations**, as are other mutations of unknown causes. When the source of mutation is a known agent, it is an **induced mutation**.
The creation of mutations, **mutagenesis**, can occur in response to various **physical and chemical** agents, **mutagens**. The most common physical mutagen in nature is **high-energy radiation** (X-rays, ultraviolet light, etc.). Some chemical mutagens are similar to the normal DNA bases but pair incorrectly. Mutations induced by both physical and chemical agents may lead to cancer.
Although mutations are often harmful, they are also extremely useful, both in nature and in the laboratory. Mutations are the source of a rich diversity of genes in the living world, a diversity that makes evolution by natural selection possible. In addition, mutations are essential tools for geneticists.

Genetics of Populations

Population genetics studies the **genetic composition of populations**, tries to estimate gene frequencies and detect the selective influences that determine them in natural populations. It is an important part of human genetics used in **genetic counselling**.
According to the method of reproduction, populations are: autogamic and panmictic. In an **autogamic population**, reproduction occurs by in-breeding from homozygous individuals. A **panmictic population** is large, reproducing within the population by random mating.
A **gene pool** comprises all the genes in a population of sexually reproducing organisms. The gene pool of an idealised panmictic, non-evolving population remains constant over the generations. The **Hardy-Weinberg law**, which explains why both gene and phenotype frequencies tend to remain constant from generation to generation in panmictic populations, is a most important concept in population genetics. It was formulated by the English mathematician G. H. Hardy and the German physician W. Weinberg in 1908. When, in a panmictic

population, there is a single autosomal locus with two alleles, dominant **A** and recessive **a**, their frequencies in the population are: **p + q = 1.** At equilibrium, the frequencies of the genotypic classes are:

$$p^2 (AA), 2pq (Aa), q^2 (aa)$$

$$p^2 + 2pq + q^2 = 1$$

The Hardy-Weinberg equilibrium will be maintained in nature only if all five following conditions are met:
- the population is very large,
- the population is isolated; that is, there is no migration of individuals or alleles they carry, in or out of the population,
- mutations do not alter the gene pool,
- mating is random,
- all individuals are equal in reproductive success; that is, natural selection does not occur.

In medicine the H.-W. equilibrium allows us to determine the probability of recessive allele frequency for a given trait in a heterozygote.

Medical Relevance of Genetics

The interaction between the basic science of genetics and the clinical science of medicine has been bi-directional and highly productive over the past several decades. Medical genetics deals with human diseases at the most fundamental level – that of the gene itself.

The essential areas of medical genetics are:
- recognition of the role of genetic factors in causation of human disease,
- molecular genetics which facilitates a better understanding of the pathogenesis of disease and improves their diagnosis and management,
- **genetic prognosis in preventive health care,**
- new genetic knowledge applied to genetic screening programmes, genetic counselling and prenatal diagnosis,
- advances in human cancer genetics; it has been demonstrated that human cells carry a variety of genes called "protooncogenes" which normally participate in growth control but whose mutations can contribute to uncontrolled growth; the discovery of oncogenes showed an unexpected link between cancer, virology and genetics.

7 EVOLUTION

The Origins of Cellular Life

The Earth formed approximately 4.6 billion years ago. The surface of the young Earth was too chaotic, temperature too extreme, oxygen too scarce and radiation too intense for life to develop.
The scientific concept is that life forms defined as enclosed chemical systems with self-maintaining properties, evolved from inorganic matter.

Early Evolutionary Stages

Chemical evolution resulted in the formation of organic compounds that accumulated in the oceans. Some of the small organic molecules (amino acids, sugars, lipids and nitrogen bases) may have combined to form more complex compounds such as proteins or nucleic acids. The first life forms to evolve may have been **coacervates** (according to Oparin) or **microspheres** consisting of **protenoids** (according to Fox). Both are hypothetical models for a pre-cell. The first life forms were probably **heterotrophs.**
The next evolution to a **prokaryotic cell** went through **eobionts** and through the development of **membranes.**
Evolution of genetic information. The first genes were probably short strands of RNA that replicated themselves and acted as enzymes catalysing RNA splicing.
Evolution of metabolism includes using **ATP** as the main energy source and the ability to synthesize **enzymes.** The result may have been the step-by-step evolution of **glycolysis.**
Evolution of prokaryotic and eukaryotic cells.

Possibilities of Life in the Universe

Exobiology is a science studying the possibilities for the existence of life in any part of the Universe and for transfer of living organisms through the universe. Two methods of study are used: indirect and direct observations.
Indirect research is based on **astronomical observations** and **spectral analysis** of distant sky bodies. These have gained an insight into chemical composition, temperature and other physical characteristics which would be necessary for the existence of life. Studies of Earth's organisms in extreme **physical conditions,** such as very low or high temperature, high pressure, vacuum or different kinds of radiation, can also provide indirect evidence. Essential factors for any form of life are the **presence of water** and the **chemical composition** of the atmosphere.
Direct methods attempt to find any traces of life in accessible parts of the Universe. **Meteorites** and other debris fall down to the Earths surface. Some organic compounds have been found there but they are believed to be abiogenic in origin. Samples brought to Earth by **astronauts or probes from other planets** of our planetary systems have also been analysed.
Scientists have also been interested in the very remote cosmic bodies which are estimated to number around 10^{22} in the observable universe. From these, about 10^{16} are thought to have conditions capable of supporting life: 10^{11} are in our galaxy and a further 10^{5} are in the Milky Way. However, these bodies are so remote that any contact is unlikely in the present state of our knowledge.

Geological Development and Evolution of Independent Life

The geological time scale consists of major groupings, **eras,** subdivided into **periods.** The boundaries between the eras and, to some extent periods, mark major transitions in the forms of fossilised life found in rocks.

Paleontological Evidence of the Earliest Forms of Life

Fossils – remnants or imprints of ancient organisms – have much to tell us about the life history of extinct organisms. They are found mainly in sedimentary rock strata. The sequence of strata indicates relative age. **Radioactive dating,** which measures the decay of radioactive isotopes, can gauge the actual ages of fossils. The fossil record chronicles **macroevolution,** the main events in the history of life.

Animals and plants can be preserved as fossils in several ways: freezing in ice and soil, enclosure in rocks, tar, amber or oil-impregnated soils, burial in quicksand or swamps.
When the skeletal structure of an organism is preserved, it retains its original shape but loses its organic material. Animals and plants may be enclosed by incrustations of calcium carbonate or silica. In **petrification,** the organisms have been mineralised, with lime, silica, iron oxides or iron pyrites replacing the original material while retaining the original shape.
Paleontology, the science studying fossils, reveals many trends in the evolution of species and lineage, such as the gradual increase in size in the evolution of dinosaurs, evolution of birds from reptile-like ancestors, evolution of the horse through a series of successive changes or evolution of wheat, one of the earliest plants cultivated by man. Certain types of fossils indicate the boundaries and extent of former lands and waters. Certain fossils are known as **index fossils,** because through them it is possible to determine particular geological ages and periods.

Darwin's Theory of Evolution

The ideas on the role of evolution had existed before **Darwin (1809-1882)**. His contribution was in stating the **theory of natural selection** and supporting it with massive evidence. On the basis of extensive research, Darwin published a book entitled *The Origin of Species by Means of Natural Selection* in 1859. He maintained that the living species were the descendants of similar but slightly different forms that had lived in the past. Darwin's theory was based on observations and studies of many plants and animals all over the world.
Darwin noted two important conditions of natural selection – **variations** amongst living individuals and a great reproductive potential of any species. He described the former as a continuous process in both plants and animals. He noticed the fact that offspring of a pair of individuals were not all alike and that this could be used in breeding for certain desirable traits and production of new kinds of domestic animals and plants. He found support for his theory of natural selection in studies of fossils, comparative anatomy and embryology, geology and geographic distribution of species and provided proof for it by breeding experiments which produced variations in animals and plants.
The **reproductive potential** of all species is more than sufficient to replace the existing population. More offspring may be produced than can possibly survive and, therefore, they must compete with each other for existence. As a result, individuals best adapted usually survive (survival of the fittest). Some of the differences amongst individuals result in a largely unobserved selective mortality or **"struggle for life"**. Thus, over a period of many generations, **new species originate by natural selection** of the best fitted individuals.

The Geological Time Scale

Era	Period	Epoch	Millions of years ago	Some important events in the history of life
		Recent		Historic time
	Quaternary	Pleistocene	0.01	Ice ages; humans appear
CENOZOIC	Tertiary	Pliocene	1.8	Apelike ancestors of humans appear.
		Miocene	5	Further spreading of mammals and angiosperms.
		Oligocene	24	Origins of many primate groups, including apes.
		Eocene	38	Angiosperm dominance increases; origin of most modern mammalian orders.
		Paleocene	54	Major spreading of mammals, birds and pollinating insects.
MESOZOIC	Cretaceous		65	Flowering plants (angiosperms) appear; dinosaurs become extinct.
	Jurassic		144	Gymnosperms continue as dominant plants, dinosaurs as dominant animals.
	Triassic		213	Cone-bearing plants (gymno-sperms) dominate landscape; first dinosaurs, mammals, birds.
PALEOZOIC	Permian		248	Spread of reptiles; origin of mammal-like reptiles and most orders of insects; extinction of marine invertebrates.
	Carboniferous		286	Extensive forests of vascular plants; origin of reptiles; amphibians dominant.
	Devonian		360	Diversification of bony fishes; first amphibians and insects.
	Silurian		408	Diversity of jawless fish; first jawless fish; colonization of land by vascular plants and arthropods.
	Ordovician		438	Marine algae abundant.
	Cambrian		505	Origin of most invertebrates; first vertebrates (jawless fish); diverse algae.
PRECAMBRIAN			670	Diverse invertebrate animals, mostly soft-bodied.
			700	Origin of first animals.
			1500	Oldest eukaryotic fossils.
			2500	Oxygen begins accumulating in atmosphere.
			3500	Oldest definite fossils known (prokaryotes).
			4600	Approximate time of origin of the Earth.

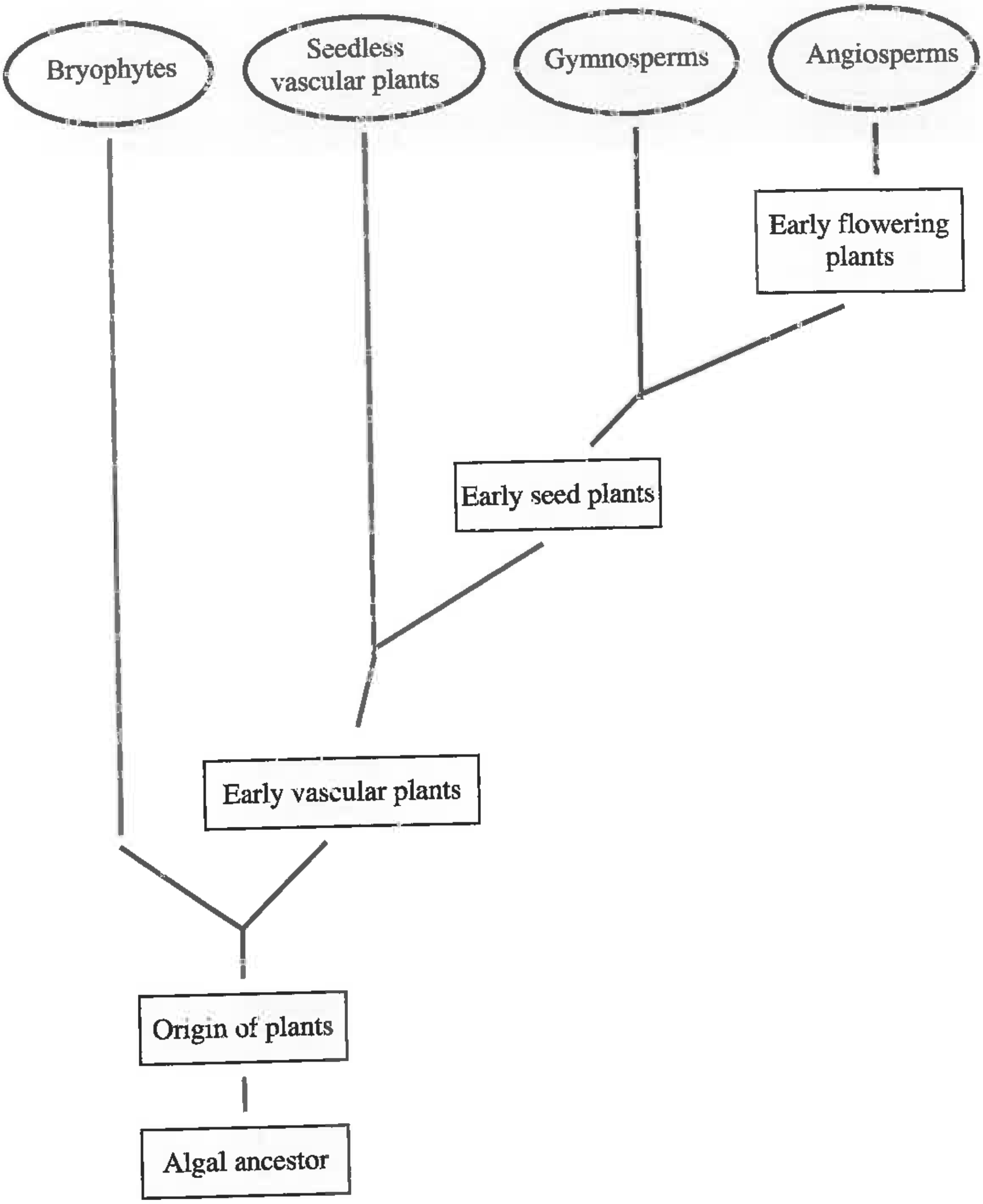
Evolution of Plants and Fungi

The movement of plants and fungi onto the land was the major event in the history of life. This involved profound changes in plant and green algae structures and functions, such as the development of roots, stems and leaves for absorption of nutrients, photosynthesis and mechanical support. In most plants, vascular systems and special jacked organs (gametangia) which protect gametes and embryos have developed.
Plants, which probably evolved from green algae, later split into two major lineages: one without vessels, **bryophytes**, and one with vascular tissues. **Seedless vascular plants**, such as ferns, as well as **seed plants** have well-developed roots and rigid stems. The appearance of seed plants, i.e., **gymnosperms**, such as **conifers**, **angiosperms** and **flowering plants**, was the major step in plant evolution.
The association of plant roots with fungi, **mycorhizae**, helped make colonisation of the land by plants possible. Conversely, this connection with plants probably helped fungi to move onto the land. The first fungi on dry land may have been the mycorhizal partners of the first land plants.

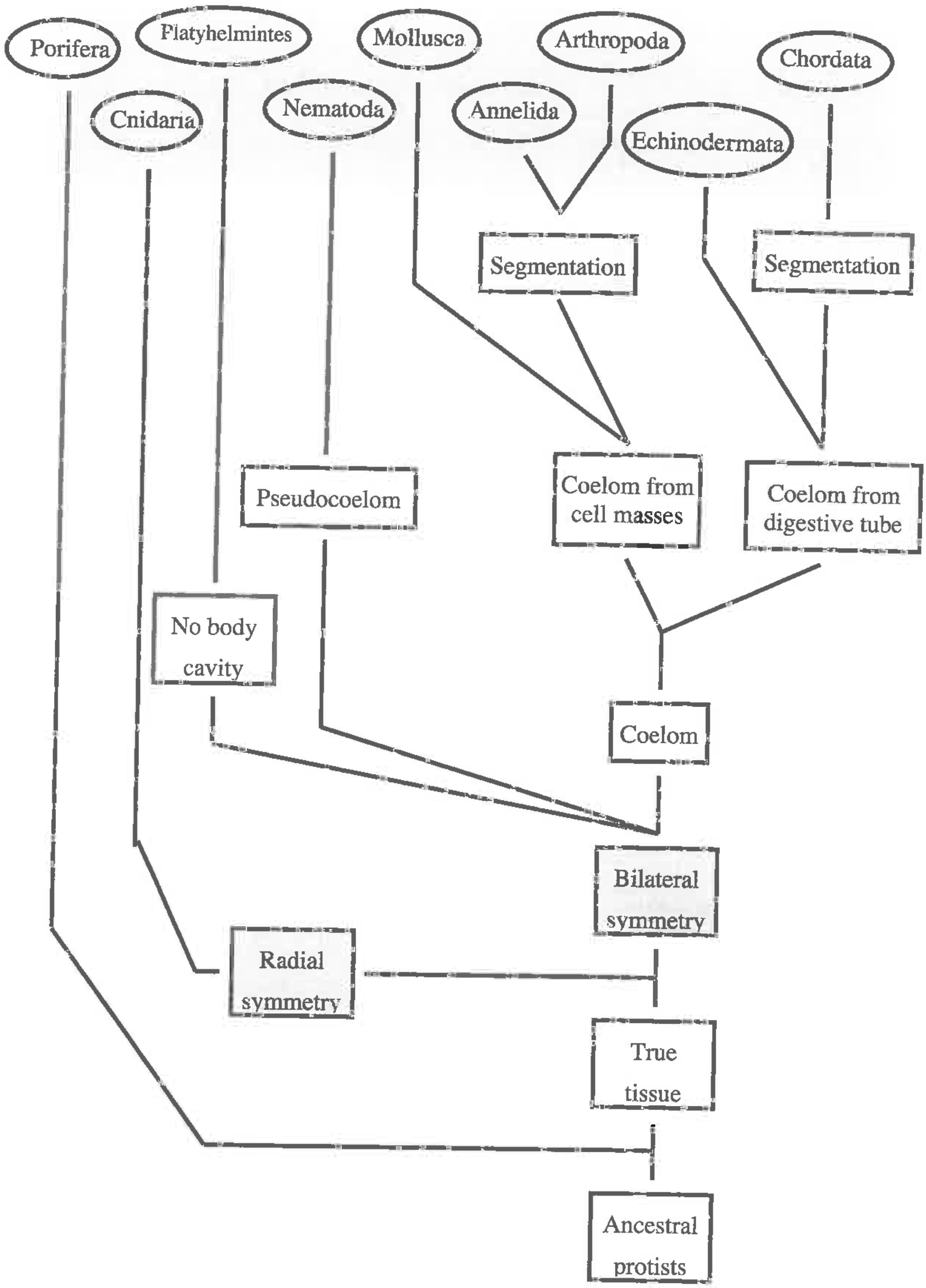
Evolution of animals

The earliest animals probably arose from **colonial protists** because **Porifera** (sponges), which are at the lowest level of the evolutionary tree, bear some similarities to protists, such as a relatively simple body and the lack of true tissues. Above this branch, the main trunk of the animal kingdom tree includes ancestral animals whose body consisted of specialized true tissues. These "tissue-level" animals gave rise to two distinct lineages: one developed the **radial symmetry** (now the phylum *Cnidaria*) and the other, the main stream of the animal kingdom, gave rise to the **bilateral symmetry** in animals.
Bilaterally symmetrical animals have a head with sensory structures. They move head first in their environment. The simplest bilateral animals are flatworms (*Platyhelmintes*). Above them, the bilateral animal phyla are classified by the kind of their body cavity. The presence of the **pseudocoelem** makes the roundworms (*Nematoda*) fundamentally different from the other phyla and thus they constitute a separate branch of the tree.
Above the Nematoda branch, the main trunk of the pylogenetic tree involves animals which posses a **coelom**, a body cavity lined with a sheet of tissue which also wraps around the digestive tract and other internal organs. Animals with a coelom are classified into two groups, according to the way their body develops, each splitting into two branches. In one, the coelom develops from solid masses of cells which form between the digestive tube and the embryonic body wall (*Mollusca, Annelida* and *Arthropoda*). In the other, the coelom develops from the hollow outgrowth of the digestive tube of the early embryo (*Echinodermata* and *Chordata*). One of the major evolutionary factors was **segmentation** which affected three important phyla: *Annelida, Arthropoda* and *Chordata.*
The phylogenetic tree allows us to trace evolutionary relationships amongst the animal phyla. These relationships are based on fundamental structural features of adult animals and on the patterns of embryonic development. The phylogenetic tree also reflects the effects of chance events and evolutionary processes on the history of life.

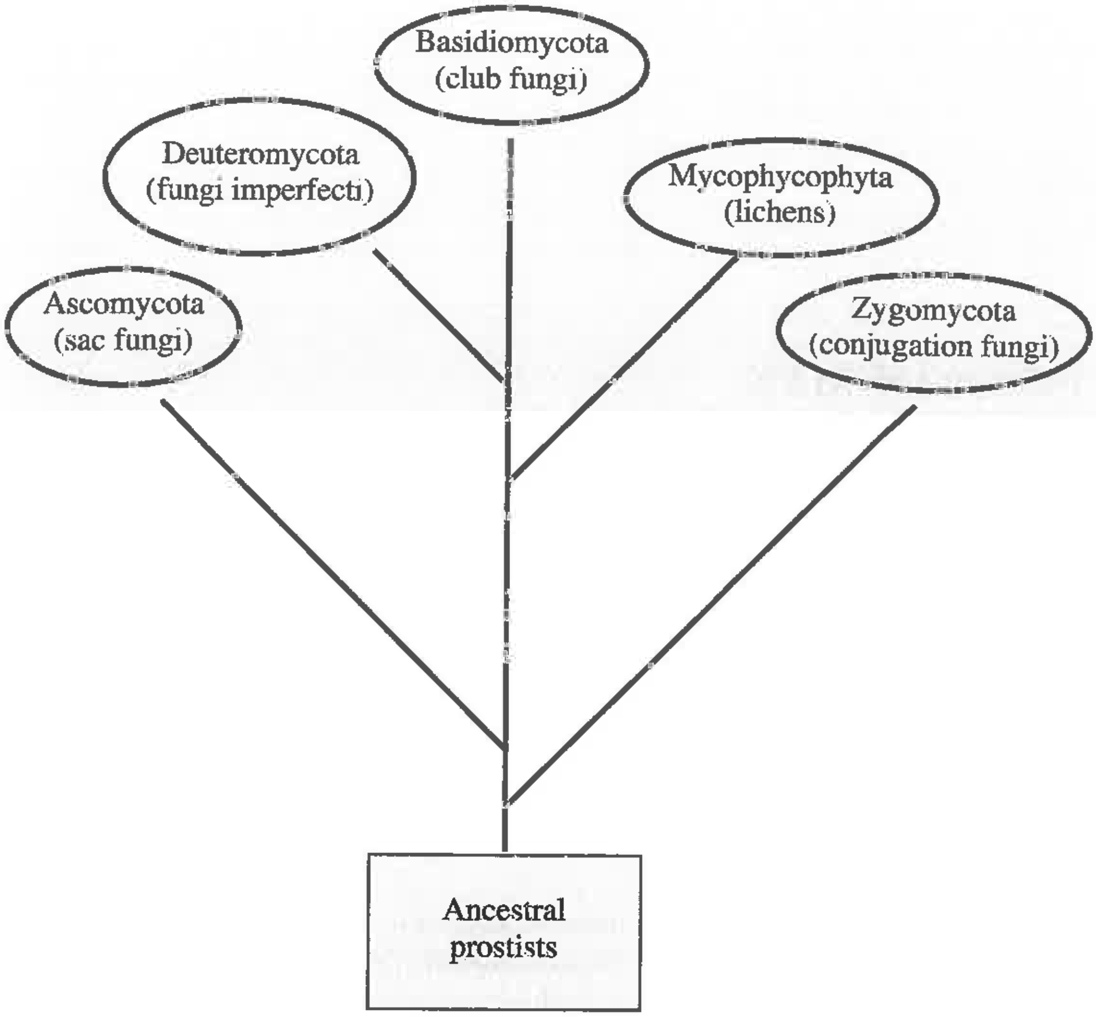
The Phylogenetic Tree of the Plant Kingdom
(For geological time scale see Table pp. 52–53)



Phylogenetic tree of the animal kingdom
(For geological time scale see Table pp. 52–53)



Phylogenetic tree of the fungal kingdom (For geological time scale see Table pp. 53–54)



The Evolution of Man

Humans, apes, monkeys and lemurs all gorilla belong to the mammalian order **Primates**. Monkeys, apes and hominids are grouped into **anthropoids**.
Apes, including gibbon, orangutan, gorilla and chimpanzee, are closely related to humans. **Apes and hominids diverged** from a common, ape-like ancestor **about 20 or 25 million years ago.**
Main groups in the human branch of the primate tree:
Ramapithecus, appeared 12–14 million years ago in Africa, Europe and Asia. Average height was 100–120 cm, cranial capacity was about 350 ml, it moved quadripedally, ate fruit, seeds and tubers.
Australopithecus, appeared 2–3.5 million years ago in Africa, was 115 - 125 cm tall, cranial capacity was about 490 ml and he was bipedal (erect-walking). He used sharpened sticks and stones for tools, and ate meat.
Homo erectus, lived 1-1.5 million years ago in the Old World. Height was 155-160 cm, brain size 950 ml. He lived in caves, built fires, wore clothes and designed stone tools.

Homo sapiens, the oldest fossils date back over 300.000 years in Africa. By about 100.000 years ago, this archaic type had spread throughout the Old World and three forms are known:
- **H. sapiens steinheimensis** (200.000-300.000 years ago)
- **H. sapiens neanderthalensis** (100.000-150.000 years ago)
- **H. sapiens sapiens** (25.000-40.000 years ago).

Major milestones in human evolution:
- evolution of erect stance (remodelling of skeleton),
- enlargement of brain,
- prolonged period of parental care.

8 BIOLOGY OF MAN

Tissues of the Human Body

A **tissue** is a unit of similar cells which performs a specific function. The major categories of human body tissues are: epithelial, connective, muscle and nervous tissues and body fluids. The latter do not form compact tissues but are whole systems containing special cells, e.g., blood, which have specific functions.
Epithelial tissues occur as sheets of closely packed cells that cover body surfaces or line internal organs. They are classified according to the number of layers (**simple** or **stratified epithelia**) and according to their cell shape (**squamous, cuboidal** or **columnar**).
Connective tissue consists of a sparse population of cells scattered throughout a non-living material (**matrix**). Some cells form a web of fibres embedded in a liquid, jelly or solid.

Connective tissues are:
- loose connective tissue with strong collagen fibres, serving mainly as a binding and packing material and holding other tissues and organs in place; it is located under the skin,
- adipose tissue contains fat, it pads and insulates the body and stores energy,
- fibrous connective tissue has a matrix of densely packed parallel bundles of collagen fibres; it forms tendons and ligaments,
- cartilage forms a strong but flexible skeletal material with an abundance of collagen fibres embedded in a rubbery matrix; it surrounds ends of bones and supports the nose and ears,
- bone is the most rigid connective tissue with a matrix of collagen fibres embedded in calcium salts.

Muscle tissues in vertebrates are: skeletal, cardiac and smooth muscle.
Skeletal muscles are attached to bones by tendons. They are responsible for voluntary body movements. They are composed of **striated** muscle fibres in the form of bands which are involved in muscle contraction.
Cardiac muscles are the contractile tissue of the heart. They are striated like the skeletal muscle, their fibres are branched. Muscle contraction is involuntary.
Smooth muscles lack striation and are found in the walls of inner tubular or hollow organs, such as digestive tract, urinary bladder, arteries, etc. The cells are spindle-shaped. Smooth muscle contraction is slower than in striated muscles and is involuntary.
Nervous tissues form internal communication and coordination systems. They receive stimuli and transmit signals from one part of the organism to another, making it possible for all the body parts to function as a coordinated whole. The structural and functional unit of nervous tissue is the nerve cell - **neuron,** which, by means of extensions, **dentrites** and the **axon**, can conduct nerve signals. Nervous tissue also contains **glial cells** or **neuroglia** which performs supportive and protective roles for neurons.

Musculoskeletal System

Movement is one of the most distinctive features of animals. It is facilitated by the **musculoskeletal** system. The muscular system exerts the force that makes an animal or its parts move while the skeletal system provides the firm structure against which the force exerted by muscles produces movement. The human skeleton is made up of more than 200 bones.

The human skeleton consists of:
- **axial skeleton** (a skull which surrounds and protects the brain, a backbone which encloses the spinal cord and a rib cage which protects the lungs and heart)
- **appendicular skeleton** (upper and lower extremities).

The **skull** consists of more than 20 bones (some of them in pairs) firmly interlocked: frontal (1), parietal (2), temporal (2), occipital (1), ethmoid (1), sphenoid (1), maxilla (2), lacrimal (2), nasal (2), vomer (1), palate (2), zygoma (2), and mandible (1).
The **backbone** or **vertebral** column consists of 26 bones: cervical (neck) (7), thoracic (chest) (12), lumbar (lower trunk) (5), sacral (sacrum) (5 bones fused), and coccygeal (caudal or tail) (3-5 bones fused).
The **rib cage** consists of 24 ribs and one sternum (breastbone).
The **upper extremity:** shoulder girdle (clavicle – collarbone, and scapula – shoulder blade), humerus, radius, ulna, carpals (wrist) (8), metacarpals (hand) (5), and phalanges (fingers) (14).
The **lower extremity:** pelvic girdle (hip), femur (thigh), tibia (shin), fibula, tarsals (ankle and heel) (7), metatarsals (foot) (5), and phalanges (toes) (14).
The adult skeleton has more than **200 bones** of various shapes and sizes.
Bones are made up of hard osseous tissue and are described as **long** (humerus and femur), **short** (carpals and tarsals), **flat** (scapula) and **irregular** (maxilla).
Long bones consist of: **periosteum** (surface sensitive membrane), **two ends** (sponge bone covered by articular cartilage), **shaft** (compact bone) and **medullary** or **marrow cavity** (containing marrow).
The points where two or more bones meet is a **joint** or **articulation,** which may be **ball-and-socket** (humerus and scapula), **hinge** (between phalanges) or **pivot** (ulna and radius at the elbow).
Joints consist of **ligaments** (attaching bones to bones), two or more **bone ends** (covered by cartilage layers) and **joint cavity** (filled with lubricating, **synovial fluid**).
The **skeletal muscles** functioning in movement are attached to two bones across a joint; contraction then pulls one bone toward or away from the other. Muscle is the most abundant tissue in the body. It accounts for some two fifths of the body weight and is represented by more than 600 skeletal muscles. Their scientific names are applied in relation to the number of "heads" (biceps, triceps, quadriceps), in reference to their shape (deltoid – the delta-shaped muscle on the top of the shoulder), in reference to the direction in which they run (external oblique, rectus abdominus), in reference to their location (internal or external intercostals, pectoralis), in reference to their function (flexors or extensors of wrist and hand, that bands or straightens hand) and in reference to their length or size (peroneus longus or brevis, and gluteus maximus, medius or minimus).

Respiratory System and its Function

Respiration includes:
- **breathing**, passage of air from the atmosphere into the lungs,
- **gas exchange**, transfer of oxygen and carbon dioxide between the lungs and blood and between the blood and tissues,

- **gas transport**, various processes involved in movement of these gases,
- **cellular respiration**, biochemical activity of cells generating ATP.

The system is composed of a respiratory tract and the lungs.

The **respiratory tract:** nose, pharynx, larynx, trachea and bronchi. The **nose** is divided by a partition into two wedge-shaped cavities, connected to sinuses of adjacent bones, lined by ciliated epithelium.

Functions of the **nasal cavity**:

- to remove dust and other foreign materials by hairs, cilia and mucus secreted by goblet cells
- to warm and moisture to inhaled air
- to detect odours by means of receptor cells situated on the roof of the nasal cavity
- to act as a sounding board for the voice.

The **pharynx** is a common cavity that connects the nasal cavities with the larynx and the mouth with the oesophagus. **Eustachian tubes** connect to the middle ear cavity. The pharynx contains **lymphoid tissue – adenoids** and **tonsils** involved in defence mechanisms against microbes.

The **larynx** is a cartilaginous organ – **voice box** which forms the upper part of the **windpipe.** It contains two membranes, **vocal cords** which produce sound as air passes between them. The entrance to the larynx is covered by the **epiglottis** when food is swallowed.

The **trachea** is a membranous tube located in front of the oesophagus. Its walls are supported by cartilaginous C-shaped rings. The lower end branches into two **bronchi**. Each bronchus divides and subdivides, the smallest branches being **bronchioles**. Each bronchiole terminates in a series of sac-like, thin-walled **alveoli** surrounded by thin-walled capillaries through which the exchange of gasses occurs.

The **lungs** are cone-shaped organs separated by **mediastinum** from the cavity of the thorax which also contains the heart, larger blood vessels and trachea. The left lung is smaller then right one because the heart occupies part of this space. Each lung is enclosed in a serous sac, **pleura,** consisting of an outer layer, parietal pleura, which adheres closely to the **diaphragm** and walls of the **thorax** and a visceral pleura which covers the lungs. The two pleurae are separated by a thin layer of serum to reduce friction.

Breathing is rhythmical **inhalation** and **exhalation** of air produced by contractions of intercostal muscles and the diaphragm. About 500 ml of air is moved with each breath. The maximum amount of air involved is about 4000 ml and is called the **vital capacity** of the person. The normal breathing rate is about 16 per minute. The breathing control centres in the medulla oblongata of the brain keep breathing in time with the body's need to remove carbon dioxide from blood.

In the alveoli, oxygen and carbon dioxide are transferred through thin-walled air sacs of the lungs (about 5% of oxygen from inhaled air is taken up, and about 4% of carbon dioxide is eliminated).

Blood

Blood consists of cells (about 45% of volume) and plasma.

Plasma consists of:

- **water** carrying various salts,
- **proteins,** albumin, immunoglobulins, and fibrinogen,
- **substances transported by blood,** nutrients, waste products of metabolism, etc.,
- **hormones,**
- **respiratory gasses.**

Cellular elements (blood cells) are: red blood cells or erythrocytes, white blood cells or leucocytes and thrombocytes (platelets).

Erythrocytes are round, anuclear, biconcave, haemoglobin-containing discs, **7.2 µm** in diameter, numbering **4-5 million/µl. Haemoglobin** is respiratory pigment conveying oxygen. The life span of erythrocytes is about

120 days. They are produced in red bone marrow – **haemopoesis. Polycythaemia** is an excess of erythrocytes. **Anaemia** is a deficiency of erythrocytes.
Leucocytes are nucleated cells numbering about **10, 000/µl.** They have a **protective role,** engulfing and destroying bacteria by phagocytosis. The leucocytes are: **granulocytes,** (neutrophils, eosinophils and basophils), and **agranulocytes** (lymphocytes and monocytes). **Leucopenia** is a deficiency of leucocytes. **Leucocytosis** is an excess of leucocytes due to **infection** and is a symptom of **inflammation. Leucaemia** is an uncontrolled proliferation of leucocytes (**cancer**).
Lymphocytes produce the **immune response. T lymphocytes** pass through the thymus, circulate in the blood and attack bacteria or virus-infected body cells. They are involved in **cell-mediated immunity. B lymphocytes** continue their development in bone marrow and then secrete antibodies dissolved in the blood. They function in **humoral immunity**. Lymphocytes are eventually lodged in secondary **lymphoid tissues,** such as **spleen, lymph nodes** and **tonsils.**
Thrombocytes or **blood platelets** are non-nucleated fragments derived from large cells of bone marrow numbering about 300,000/µl. They are important in **blood clotting** (blood coagulation) – the reaction in which the plasma protein **fibrinogen** is converted into a thread-like protein, **fibrin.** Threads of fibrin trap blood cells and form a **fibrin clot,** an important agent of **haemostasis. Haemorrhagic** (excessive bleeding) occurs in **haemophilia, vitamin K deficiency** or similar disorders.

Defense Mechanisms of the Organism

The body has two main defence systems. The first line of defence includes non-specific barriers to infection; undamaged skin with its secretions, stomach acids, white blood cells and the inflammatory response.
The second line of defence is the **immune system**. This responds to specific foreign macromolecules, **antigens**, by producing specific proteins, **antibodies**, which react to antigens and "remember" the invasive agent. Two kinds of lymphocytes, B cells and T cells, carry out the immune response. **B cells** are responsible for humoral immunity, i.e., antibodies circulating in body fluids. Antigens on the surface of microbes trigger the B cells to differentiate into plasma cells which secrete antibodies. Antibodies bind to the antigen and help to destroy or eliminate it by different means, such as blocking, clumping or precipitating harmful antigens. They also activate complement proteins which kill bacteria and enhance inflammation. **T cells** are produced in the marrow and then travel to the thymus, were they continue to divide and mature. There are different types of T cells. **Killer T cells** are responsible for cell-mediated immunity. **Helper T cells** interact with B cells to help them make antibody molecules. **Suppressor T cells** interact with B cells to suppress their production of antibody.
The immune system sometimes fails. In **autoimmune diseases**, the immune system turns against the body's own molecules. In **immunodeficiency diseases**, some immune components are lacking and infection recurs. Allergies are abnormal sensitivities to antigens, **allergens**, in the immediate environment. Both physical and emotional stress weakens the immune system.

Blood Groups and Blood Transfusion

The most important of the blood groups is the **ABO system**. The principle of **erythrocyte-plasma agglutination** (clumping together) was explained by the Czech physician Jan Jansky in 1907. The surface of red blood cells carries two types of **antigens,** glycoprotein molecules, **agglutinogens**, designated as **A** or **B**. There are four possible combinations which define **blood groups A, B, AB or 0**. Blood plasma contains specific **antibodies – agglutinins** designated **as anti-A** and **anti-B.** Blood group A has agglutinin anti-B in its plasma and blood group B has anti-A. The **clumping of red cells** occurs when agglutinogen **A** reacts with agglutinin anti-A or agglutinogen B reacts with anti-B.

Blood transfusion is the intravenous replacement of lost or destroyed blood by compatible, citrated human blood. Fresh or stored blood may be used as:
- whole blood,
- blood with some plasma removed, "packed-cell" transfusion,
- plasma only.

Precise knowledge of **blood group compatibility** is essential for a successful transfusion. Donor blood can be transfused only to a recipient of the same blood group. The donor's and the recipient's blood must be carefully cross-matched by means of the **slide agglutination test.**

Circulatory System and its Function

Internal transport of oxygen, carbon dioxide, nutrients, wastes and hormones in humans is accomplished by a closed circulatory system, the **cardiovascular system,** consisting of the **heart, blood vessels and blood.**
The heart has a specialised striated muscle, **myocardium.** It consists of four cavities, two **atria** receiving returning blood and two **ventricles** pumping blood out. The direction of blood flow is regulated by the **valves.** The cavities are lined with a smooth membrane, **endocardium,** the heart itself is enclosed inside the **pericardium.**
Vessels in the closed circulatory system are:
- **arteries**, carry blood away from the heart to organs,
- **veins**, return blood to the heart,
- **capillaries**, convey blood between arteries and veins within each organ.

The human circulatory system:
- **pulmonary circuit**, carries blood between the heart and the gas-exchange tissues in the lungs,
- **systemic circuit**, carries blood between the heart and the rest of the body.

Part of the deoxygenated blood returning from the abdominal organs is deflected through the **portal circulatory branch.**
Heart function:
Alternating relaxation, **diastole,** and contraction, **systole,** make up the **cardiac cycle.** The volume of blood pumped by either ventricle is the **stroke volume** and it ranges from **70-200 ml.** The volume of blood per minute which the left ventricle pumps into the aorta, **cardiac output,** is about 5.25 L/min in an average person at rest. Cardiac output varies with body activity.
The heart's pumping rhythm is maintained by a specialized region of cardiac muscles, **pacemaker** or **sinoatrial node**, together with the **atrioventricular node.** The **heart rate** is measured by counting the **pulse,** which is the rhythmic stretching of the arteries caused by powerful contractions of the ventricles during systole. An average heart rate at rest is about **70 beats per minute.**
Blood pressure is the force that blood exerts against the walls of the blood vessels; it's normal values are:
- **systolic pressure** is 14-16 kP,
- **diastolic pressure** is 9-12 kP.

High blood pressure, **hypertension,** is defined as a persistent systolic/diastolic blood pressure of **21/12 kP or higher** and low blood pressure, **hypotension,** is defined as a systolic/diastolic pressure persistently **below 13/9 kP.**
Cardiac muscle cells are nourished and supplied with oxygen by blood vessels, **coronary arteries,** arising from the root of the aorta. If these arteries become clogged, the heart muscle suffers from a lack of oxygen, manifested as a **heart attack.**

Lymph and its Circulation

The lymphatic system circulates a fluid, **lymph**, which is similar to interstitial fluid but contains less oxygen and fewer nutrients. The lymphatic system consists of a branching network of lymphatic vessels with numerous lymph nodes, as well as the thymus, tonsils, appendix, spleen and bone marrow.

About 1% of the fluid that enters the tissue spaces from the blood in a capillary bed does not re-enter the blood capillaries. This small amount of fluid is taken up by **lymphatic capillaries** from which it is drained into progressively larger lymphatic vessels. The largest lymphatic vessels are the thoracic duct and right lymphatic duct by which lymph re-enters the veins. Lymphatic vessels resemble veins in having valves.

Lymph nodes and the other lymphatic organs are responsible for the defensive functions of the system. They are densely packed with lymphocytes and macrophages. As lymph flows through the lymphatic organs, macrophages ingest infectious microorganisms.

Gastrointestinal System and its Function

The human body requires nutrients for energy and for building cellular materials. Food is ingested, digested and absorbed, and the undigested wastes are eliminated. The human **digestive tract** consists of an **alimentary canal** and **accessory glands.**

Digestion begins in the **oral cavity** which is bounded by **teeth, tongue** and **palate.** The teeth break up food, saliva moistens it and salivary enzymes begin the hydrolysis of starch. The **tongue** pushes the chewed food into the **pharynx,** and the swallowing reflex moves it into the **oesophagus.** Peristaltic movements push food into the stomach.

The **stomach** is a dilated part of the alimentary canal with muscular walls in which food is mixed with **gastric juices.** Its **cardiac orifice** opens into the oesophagus and its **pyloric orifice** into the duodenum. Hydrochloric acid and pepsin in the gastric juice begin the hydrolysis of protein. The stomach churns the food and the gastric juice to form a mixture called **acid chyme.** Occasional backflow of acid chyme into the lower end of the oesophagus causes the feeling we call heartburn. During vomiting, peristalsis reverses direction and the stomach contents are forced upward into the oral cavity.

Digestion and nutrient absorption mainly occur in the **intestine,** the longest organ of the alimentary canal, extending from the pylorus to the anus. It consists of the **small intestine – duodenum, jejunum** and **ileum,** and the **large intestine – ascending colon, caecum** with **vermiform appendix, transverse colon, descending colon, pelvic colon** and **rectum.** Two large glandular organs, **pancreas** and **liver,** are attached to the duodenum.

The **pancreas** is a dual-purpose gland leading by the **pancreatic duct** into Vater's papilla in the duodenum. Alkaline **pancreatic juice** neutralizes stomach acid. Its enzymes break down polysaccharides, proteins, nucleic acids and fats. **Insulin,** secreted by the **islets of Langerhans,** regulates blood glucose level.

The **liver** is the largest gland in the body. It is essential to life in several ways including the secretion of bile and many other metabolic functions, such as protein synthesis, glucose storage and poison neutralisation. **Bile,** stored in the **gall-bladder,** emulsifies fat droplets to aid digestion by pancreatic enzymes.

Enzymes from the walls of the **small intestine** complete the digestion of many nutrients. The mucosa of the small intestine is covered with thread-like projections, **villi,** which increase its absorptive surface. Nutrients pass through the epithelium of the villi into the blood which flows to the liver. The liver stores nutrients and converts them to other substances utilised by the body.

Undigested material passes to the **large intestine** in which water is absorbed and faeces are produced. The first part of the large intestine is the **caecum** with an extension, **appendix,** containing a mass of white blood cells. The appendix is prone to infection (appendicitis). As water is absorbed, the remains become more solid (faeces) and consist of indigestible cellulose fibres and bacteria, such as *Escherichia coli.* This bacterium is important for decomposing waste materials and producing vitamins in the intestine.

Nutrition: Transformation of Substances and Energy

Nutrition is the study of the requirements and use of nutrients – saccharides, fats, proteins, vitamins and minerals. The human diet provides fuel for cellular metabolism which generates ATP by oxidising nutrient molecules. The energy required by a resting human adult, **basal metabolic rate**, amounts to 5,500-7,500 kJ per day. An active life requires much more energy. **Saccharides** and **fats** are the main sources of energy. Saccharides supply cca 17 kJ, fats about 39 kJ of energy per gram. **Proteins**, which supply the amino acids needed for cell and tissue growth, development and maintenance, can also supply about 17 kJ energy per gram. Dietary proteins are the starting materials in the production of 11 out of the 20 amino acids needed to build human proteins. The other 9 required amino acids cannot be synthesised in human cells and must, therefore, be provided by the diet. They are called **essential amino acids**. Some forms of dietary protein, primarily from plants, do not contain all essential amino acids whereas proteins, such as those from meat and soybeans, supply all the essential amino acids in the correct dietary proportions.
Vitamins are nutrients required in relatively small amounts. They do not supply energy but are essential in the regulation of cell chemistry, building bones and tissues, blood clotting, etc. There are two categories of vitamins, depending on their water-solubility. **Water-soluble** vitamins are the **B-complex vitamins** and **vitamin C**; **fat-soluble** vitamins are **A, D, E** and **K.**
Inorganic elements, such as iron, zinc or iodine, are important in human metabolism, others, such as calcium and phosphorus, are important in building tissue.

Body Temperature and its Maintenance

Normal body temperature is controlled by a centre in the hypothalamus of the brain. It is maintained within a narrow range varying according to the body region, time of day, etc. The average temperature measured in the armpit is about **36.5° C**, whereas in the mouth and rectum it is slightly higher. It also fluctuates, in the range of 0.5-1°C, during the day, being lowest in the morning and highest in the evening. In women, temperature varies with the menstrual cycle, being lowest at menstruation and highest at ovulation.
The body loses heat to the environment by **conduction**, **radiation** and **evaporation of water** from the skin. Air movement increases conduction from the body. Heat is gained by the combustion of fuel derived from food and by muscular activity. Temperature is further regulated by changes in blood flow in the skin. Warmth provided by clothing depends on a layer of entrapped, still air.
A raised body temperature, **fever** or **pyrexia**, is usually associated with infection. In fever, the temperature setting of the brain centre is altered by chemical actions of substances formed either by destruction of bacteria or by damage to body tissues. The accelerated chemical turnover may contribute to natural defence against infection.

Excretory System

The excretory organs of humans are the **kidneys** responsible for processing the waste products of cellular respiration. Blood is cycled through the kidneys and **nitrogenous wastes** are removed.
There are two kidneys at the back of the abdominal cavity, one on each side of the vertebral column. Each kidney consists of an outer **cortex**, an inner **medulla** and a **renal pelvis**. The cortex contains approximately a million long, coiled, renal corpuscles, **nephrons**. One end of the nephron is a cup-shaped **glomerular** or **Bowman's capsule,** in which there is a ball of thin-walled capillaries. This part of nephron lies in the outer cortex. The

other end of the nephron is a convoluted renal tubule, located in the medulla, which is in direct contact with the web of capillaries. Each tubule has a U-shaped section, the nephron loop – **loop of Henle**, leading out into a collecting duct which, in turn, leads to a larger duct and, finally, empties into the renal pelvis.

Nephrons have three functions: filtration, re-absorption and secretion. **Filtration** occurs in the glomerulus where blood is forced into the glomerular capsule. The filtrate includes blood plasma, cellular nitrogenous wastes, urea, salts, ions, glucose and amino acids. Approximately 180 L of fluid circulate through the nephron each day. **Re-absorption** and **secretion** take place in the tubules. Some 99% of fluid and salt is re-absorbed into the blood. Water is returned by osmosis but active transport is necessary for the re-absorption of sodium and potassium ions, glucose and amino acids. As a result of this process, only 1.5 L of fluid, **urine**, is eliminated per day. The urine from the renal pelvis passes out through **ureters** towards the muscular **bladder** located in the pelvic cavity. The bladder empties to the exterior through the tubular **urethra.**

Aldosterone, a hormone of the adrenal gland, functions together with nephrons in regulating the secretion and re-absorption of potassium and sodium ions in the blood. An anti-diuretic hormone of the pituitary gland, acts with the collecting ducts in regulating the re-absorption of water.

Skin and its Functions

The skin is a protective, elastic, waterproof, sensitive organ covering the entire body surface. It consists of epidermis, dermis and subcutaneous tissue.

The **epidermis** is free from blood vessels and nerves and has an outer layer of dry, dead cells that are constantly shed and replaced from the growing, basal layer. The cells of the basal layer include melanocytes containing **melanin**, the pigment responsible for skin colour.

The **dermis** is an acellular, predominantly fibrous layer with collagen and elastic fibres. It contains blood vessels, nerves, sensory corpuscles, sebaceous and sweat glands and hair follicles with attached hair muscles.

The **subcutaneous tissue** is a kind of connective tissue rich in fat in some parts of the body. It serves as an insulator and shock-absorber and can be mobilised as a fuel at any time.

The skin is more than a waterproof jacket for the body; it is an active and versatile sensory organ assisting in adaptation to a changing environment. The sensations of touch, pressure, warmth, cold and pain provide much information about the environment and provide warning of certain dangers. The skin also functions in maintenance of the internal body temperature.

In the pubertal female, adipose tissue under the skin of the chest develops into a pair of breasts under the influence of ovarian sex hormones. Towards the end of pregnancy, pituitary gland hormones stimulate milk secretion.

Endocrine Glands

The **endocrine** (ductless) **glands** play a significant role in maintaining body **homeostasis.** They secrete biologically active chemicals – **chemical signals,** called **hormones.** They are carried by the circulatory system and affect only specific **target organs**. They are potent substances which, in minute concentrations, control metabolic processes.

The main mechanism controlling hormone secretion is the **negative or positive feedback system**. Negative feedback decreases, positive feedback increases the rate of secretion.

The endocrine system often collaborates with the nervous system. Some nerve cells are specialized as **neurosecretory cells** which, in addition to conducting nerve signals, make and secrete hormones into the blood. When a nerve signal reaches the end of a nerve cell, it triggers the secretion of **neurotransmitters**. These are also chemical messengers but, unlike hormones, do not travel in the bloodstream.

Endocrine glands: pituitary gland, thyroid gland, parathyroid gland, adrenal glands, pancreas, gonads, placenta.

The **pituitary** is cherry-shaped, about 1.5 cm in diameter, and is described as the master gland of the body. It is formed of **anterior and posterior lobes.**

The **anterior lobe** is responsible for the production of:
- **growth hormone** (GH) promoting protein synthesis and breakdown of fats; **pituitary dwarfism** is a result of hypofunction, **gigantism** follows hyperfunction in childhood, **acromegaly** results from hyperfunction in adult life,
- **adrenocorticotropic hormone (ACTH)** stimulating the adrenal cortex,
- **thyroid-stimulating hormone (TSH)** regulating the functional activity of the thyroid gland,
- **follicle-stimulating hormone (FSH)** governing the development of ovarian follicles and spermatogenesis in the testes,
- **luteinizing hormone (LH)** stimulating sex hormone secretion,
- **prolactin** inducing secretion of milk.

The **posterior lobe** produces:
- **antidiuretic hormone** causing retention of water by the kidneys; its deficiency causes **diabetes insipidus,**
- **oxytocin** acting on smooth muscles of the uterus at parturition.

The **thyroid**, consisting of two lobes in the anterior part of the neck, produces **thyroxin** influencing basal metabolic rate and, indirectly, growth and nutrition. The hormone contains **iodine**.
Disorders are:
- **cretinism** resulting from congenital failure of the gland to develop,
- **myxoedema** due to deficiency starting in adult life,
- **goitre**, an enlargement of the thyroid due to lack of iodine in the diet,
- **Basedow's disease** (toxic goitre or hyperthyroidism) marked by overactivity of the thyroid and increased energy consumption.

The **parathyroid** glands produce **parathormone** regulating the **concentration of calcium** in the blood. Disorders are **tetany** due to hypofunction and **resorption of bone** due to excess.

The **adrenal glands** consist of a **cortex** and **medulla.**
The **adrenal cortex** is responsible for secretion of **corticosteroids**:
- **mineralocorticoids** have an effect on salt and water balance,
- **glucocorticoids** promote the synthesis of glucose from proteins and fat.

The **adrenal medulla** is responsible for secretion of **adrenalin** and **noradrenalin** acting as vasoconstrictors and cardiac stimulants. Both hormones contribute to the **short-term stress response**.

The **gonads, ovaries or testes**, produce sex hormones: oestrogens and progesterone (female) and androgens (male).

In the **pancreas,** the **islets of Langerhans** produce **insulin** and **glucagon,** antagonists regulating the concentration of glucose in the blood.

The endocrine glands do not act independently of each other. The optimal levels of hormones are maintained by the feedback system, ultimately controlled by the central nervous system. Hormones constitute a highly specialised and most efficient type of humoral regulation in which even a very low concentration is enough to produce a profound effect on certain physiological processes, particularly metabolic rate. Conversely, endocrine dysfunctions invariably result in severe pathological conditions.

Nervous System

Anatomy

The nervous system consists of the **central nervous system – CNS** (brain and spinal cord), the **peripheral nerves** related to the central system, the **autonomic nervous system** and **sense receptors**. The basic unit of the whole nervous system is the nerve cell (**neuron**). In nervous tissue, nerve cell bodies form the **grey matter**, nerve fibres the **white matter**.

The human **brain**, enclosed in the skull, consists of:
- **brain stem**, medulla oblongata, pons and midbrain,
- **cerebellum,**
- **forebrain**, thalamus, hypothalamus and cerebrum.

The **medulla oblongata** regulates vital functions, such as heart rate, breathing or blood pressure. The **midbrain** contains the reticular formation, a criss-cross arrangement of grey and white matter, acting as a central switchboard for the whole brain.
The **cerebellum** is involved in voluntary movement, muscle tone, balance and posture.
The **thalamus** is a mass of grey matter in which sensations of all kinds are received and relayed to reflex pathways or to the cerebral cortex.
The **hypothalamus** is the highest centre of the autonomic nervous system to which the pituitary gland is attached.
The **cerebrum** consists of two **cerebral hemispheres**, each covered with a layer of **grey matter, cerebral cortex.** The surface of the cerebral cortex, both the right and left hemispheres, has four discrete lobes (frontal, parietal, temporal and occipital), Below this layer, there is a broad zone of **white matter**.
The **spinal cord** is a column of nervous tissue enclosed in the spinal canal of the backbone. It is a conductor between the brain and the rest of the body. It also deals with many reflex actions without reference to the brain, such as knee-jerk reflex or passing urine.
The **peripheral nerves** comprise 12 pairs of **cranial nerves** and 31 pairs of **spinal nerves**.
The **autonomic nervous system** consists of nerves regulating internal organs and their involuntary functions. Functionally, the system is in two parts: the **sympathetic system**, arising from the thoracic and upper lumbar spinal nerves, and the **parasympathetic system** from certain cranial nerves. The two divisions are antagonistic since they are responsible for opposite actions in various organs. The sympathetic system secretes adrenalin and is described as **adrenergic**; the parasympathetic system secretes acetylcholine and is called **cholinergic**,.

Function

The nervous system controls the organism's activities. Nerve fibres, enclosed in an insulating sheath of myelin, transmit impulses between the periphery and the nerve centres. **Afferent nerves** convey impulses from tissues to nerve centres, while **efferent nerves** act in the opposite direction. Neurons communicate at **synapses**, junctions or relay points between two neurons. Synapses are either electrical or chemical.
Electrical synapses are action potentials which pass directly from one neuron to the next. They are common in the heart and digestive tract. **Chemical synapses** have a narrow gap, **synaptic cleft**, separating a **synaptic knob** of the transmitting neuron from the receiving neuron. **Chemical signals,** also called **neurotransmitters** (acetylcholine, adrenalin, serotonin), are transferred by **exocytosis** and by **passage through canals** in the plasma membrane of a receiving cell.

A nerve impulse is a wave of depolarization started by various kinds of stimuli, e. g., electric current, heat, pressure or certain chemicals. The depolarization of any part of the neuron travels as an impulse to the end of the nerve fibre. Nerve cells generate small electric currents and brain electrical activity can be recorded by electroencephalography (EEG).

Reflexes

The nervous system functions largely by reflex action. A nerve reflex involves the transmission of an impulse, initiated in a receptor, causing a response in an effector. It involves receptors, sensory neurons, centres in the spinal cord or brain, motor neurons and effectors. Some reflexes can be complex, involving one or more interneurons. Reflexes may be inborn or conditioned.

Inborn reflexes control various body functions, such as, dilatation of blood vessels in the skin, sweating or constriction of pupils in response to bright light. The effectors are muscles or glands. Some reflexes, such as breathing or passing urine, can be modified temporarily by nerves under voluntary control but eventually the reflex action overrides this control. Inborn reflexes are standard equipment which everyone inherits and transmits to their offspring.

Conditioned reflexes are either modifications of inborn reflexes or completely new automatic responses developed as a result of the individual's experience. These reflexes are acquired by each generation in response to the environment.

Higher nervous activity

Special functional association areas were identified within each of the four lobes of the cerebral cortex. A large association area in the **frontal lobe** uses varied inputs from many other areas of the brain to evaluate consequences, make considered judgements and plans for the future. Language abilities result from very complex interactions amongst several association areas, e.g., reading and speech require association areas in the **parietal lobe**.

Sleep

Humans spend about a third of their lives asleep. During sleep, brain activity is altered but not suppressed. The cerebral cortex is electrically active but this activity is not under conscious control. In **deep sleep**, electrical waves recorded in EEG are slow, regular and large. In very **light sleep**, the wavers are smaller and slower. When awake, brain waves are rapid and irregular.

The state of being awake or sleeping is controlled by the **reticular formation** in the midbrain. When this is switched to sleep, nervous impulses continue to circulate in the cortex and the rest of the brain but they are no longer dependent on incoming impulses from the sense organs.

Changes during sleep are not confined to the brain. The chemical processes of the body are slowed and the flow of saliva, tears, mucus and urine decreases.

Sense Organs

A change in the external environment that may cause an organism to respond is called a **stimulus**. Stimuli are received through **sensory receptors** which are specialized to detect various stimuli:

- pain receptors (skin, internal organs),
- thermoreceptors (skin, circulatory system),
- mechanoreceptors (skin, muscles, hair cells in the ear),
- chemoreceptors (nose, taste buds, arteries),
- photoreceptors (eye retina).

Reception of Pain

Most pain arises from direct mechanical injury to the **specific terminal ends of dendrites** caused, for instance, by a blow, wound or burn. Pain may also be caused by chemical irritation. Not all tissues are sensitive to pain. The skin with its underlying connective tissue, muscle, linings of body cavities (peritoneum and pleura) and periosteum covering bones are very sensitive whereas the bone itself, the liver and brain are not.

Thermoreceptors

Receptors for differences in skin temperature are of two kinds. **Heat receptors – Ruffini's corpuscle**, are stimulated by a temperature higher than that of skin; **cold receptors – end bulb of Krause,** are stimulated by a temperature lower than that of skin. The most sensitive thermoreceptors are those of the tongue, less sensitive are those of the face and least sensitive are those of the trunk and limbs.

Mechanoreceptors

Mechanoreceptors (respond to mechanical energy) are the most diverse of sensory receptors. Most of them are in the skin where they detect touch and pressure or are sensitive to movements of hair. In skeletal muscles, there are stretch receptors which monitor changes in muscle length and in the position of body parts. Other types are found in the hair cells of the organ of Corti and in the organ of balance in the inner ear.

Human ear

The ear consists of **two separate organs**, one for **hearing** and the other for **maintaining balance**.
The **auditory apparatus** consists of the outer, middle and inner ears.
The **outer ear** consists of the flap-like pinna, and the auditory canal ending in the **eardrum – tympanum,** which separates it from the middle ear.
The **middle ear** contains three ossicles: **hammer** (malleus), **anvil** (incus) and **stirrup** (stapes). These pass sound waves into the inner ear through the oval window containing the stapes. The **Eustachian tube** conducts air between the middle ear and the pharynx, ensuring that air pressure is equalised on either side of the eardrum.
The inner ear consists of several structures embedded in the temporal bone of the skull. One of these is the **cochlea**, a snail-shaped container for the **organ of Corti,** in which sound vibrations create nervous impulses for transmission to the brain. The human hearing receptor can detect sound vibration frequencies ranging from **16 to 20,000 Hz.**

The **organ of balance** consists of two parts:
- three **semicircular canals** detect changes in the rate and direction of head movement,
- two chambers (**utricle** and **saccule**) detect the position of the head with respect to gravity.

Chemoreceptors

Chemoreceptors include sensory cells in the nose and tongue and internal receptors in some arteries.
The **sense of smell** depends on olfactory cells in the upper portion of the nasal cavity.
The **sense of taste** depends on taste buds on the tongue. They detect four categories of taste: sweet, sour, salty and bitter.
Internal chemoreceptors in some arteries monitor the level of carbon dioxide in the blood.

Photoreceptors

Photoreceptors in the visual apparatus detect the electromagnetic energy that we call light. This apparatus consists of two **eyes** with their associated **muscles, tear glands** and **eyelids**.
The human **eyeball is** composed of the **sclera, cornea, choroid, iris** with **pupil, lens, retina, aqueous humour** in the front chamber, and **vitreous humour** in the large chamber.
The human eye is of the **camera type** in which a lens focuses light onto the retina. Rods and cones in the retina receive stimuli from incoming light waves. **Rods** are responsible for peripheral vision and respond to dim light, **black-and-white vision. Cones** are responsible for daylight **colour vision**. Visual receptors respond to **light waves** ranging from **350** to **750 nm**.
Lens shape is controlled by muscles attached to the choroid. Focusing, **accommodation,** is achieved by change in lens shape.
There are three common visual problems:
Nearsightedness or **myopia** is a failure to focus well on distant objects, the eyeball being longer than normal. The error is corrected by spectacle lenses thinner in the centre than at the outside edge.
Farsightedness or **hyperopia** occurs when the eyeball is shorter than normal. Corrective lenses are thicker in the middle than at the outside edge.
Blurred vision or **astigmatism** is caused by unequal curvature of lens or cornea.

Reproductive Systems in Males and Females

The reproductive systems consists of a pair of ovaries (in females) or testes (in males), ducts that carry gametes and structures for copulation.
In females, **ovaries** contain follicles which produce ova (eggs) by **oogenesis** and sex hormones. **Oviducts** convey eggs to the **uterus** where they may be fertilised. The uterus opens into the **vagina (birth canal)** which receives the penis during intercourse.
A woman's ovaries contain her lifetime supply of primary oocytes at birth. Cyclic changes in the ovaries and uterus are synchronised by hormones. Every 28 days, the follicle-stimulating (FSH) and luteinizing (LH) hormones the of anterior pituitary trigger the growth of a follicle and ovulation (egg release). The follicle secretes oestrogen and, after ovulation, becomes the corpus luteum which produces progesterone. These hormones stimulate the uterine lining (**endometrium**) to thicken, preparing it for implantation of a fertilised egg. If the egg is not fertilised, the corpus luteum and its hormones decline, which triggers **menstruation**, the break down of the endometrium. If fertilisation has occurred, a hormone from the developing embryo maintains the uterine lining and prevents menstruation.
In males, **testes** produce sperm by **spermatogenesis**. Several glands, including the **prostate**, contribute to the formation of fluid that carries, nourishes and protects sperm. This fluid and the sperm constitute **semen** expelled through ducts during **ejaculation.**
Human sexual behaviour is designed to achieve the union of egg and sperm, **fertilisation**, and may promote bonding between mates. The human sexual response occurs in four phases: excitement, plateau, orgasm and resolution. Sexual intercourse may carry risk of sexually transmitted diseases and unwanted pregnancy. Contraception prevents pregnancy by blocking the release of gametes, preventing fertilisation or implantation.

Ontogenesis and Intrauterine Development

Ontogenesis is the development of an individual, beginning with the **fertilisation** of an egg, which includes cleavage, gastrulation and organogenesis. (See I.9, p.7)

Cells begin to differentiate or specialise to different functions. In a process called induction, adjacent cell layers may influence each other's differentiation via chemical signals. Pattern formation, the emergence of all parts of a structure in the correct relative positions, seems to involve the response of genes to spatial variations of chemicals in the embryo.

Function of Placenta

During the first months of embryo development, a special organ, the **placenta,** develops from the layer of cells surrounding the embryo. This organ provides nourishment and oxygen to the embryo and helps dispose of its metabolic wastes. The placenta consists of both embryonic and maternal tissues.
The **embryonic part** of placenta consists of chorionic villi containing vessels communicating, by umbilical veins and arteries, with the infant's own circulation. The villi are bathed in tiny pools of maternal blood in the lining of the **mother's uterus**. There is no direct contact between mother's and embryo's blood. However, the chorionic villi absorb nutrients and oxygen from mother's blood and pass them to the embryo, while carbon dioxide and other waste products diffuse in the opposite direction. The placenta allows protective antibodies to pass from mother to foetus but also a number of harmful materials, such as viruses (German measles, AIDS, etc.), prescription drugs, antibiotics and alcohol, can pass across the placenta.

Pregnancy

Pregnancy or **gestation** is the condition of carrying a developing young in the female reproductive tract, the uterus. It begins at fertilisation of an egg by a sperm cell – **conception,** and continues until birth.
The average **gestation period** is about **270 days**. By the fourth or fifth days after fertilisation, the embryo reaches the uterus as a blast cyst containing about 100 cells.
The outer layer of the blast cyst (**trophoblast**) later becomes a part of the **placenta.**
After seven days, the embryo is a two-layered plate of cells called an **embryonic disc**.
Development of **embryo length**:

- one month-old, 1 cm,
- two months, 4 cm,
- three months, 9 cm ,
- four months, 16 cm ,
- five months, 25 cm,
- at birth (9 month), about 50 cm.

Human embryonic development is divided into **three trimesters** of about three months each. The most rapid changes occur during the first trimester. **By 9 weeks, all organs are formed** and the embryo is called a foetus. The second and third trimesters are periods of growth and preparation for birth.

Procedures in Human Genetics

The study of human genetics is much more difficult than the study of inheritance in other animal or plants. The generation time of humans is approximately 20 years as compared with a few months or weeks, and human parents produce only a few children each, unlike the hundreds of offspring in some animals or plants. Controlled breeding experiments would be ethically unacceptable in man, the only tools, therefore, available for genetic investigation are pedigrees and twin studies.
A **pedigree** is a chart that illustrates a family history for a particular trait. Dominant, recessive or X-linked traits show distinctive patterns of inheritance. Mendel's principles allow us to analyse and deduce the genotypes for

each of the people in the pedigree. A pedigree not only helps us understand the past, it can help us predict the future and assist in genetic counselling.

In human genetics, it is difficult to separate the effects of genetic inheritance from the effects of the environment. **Studies of identical twins** provide an opportunity to examine the influence of heredity and environment. Identical twins develop when a cell arising from a single fertilised egg separates and forms two complete embryos which have exactly the same genetic information. If these twins differ from one another in the expression of a particular trait, this would imply a major influence of the environment.

Genetic counselling can help prospective parents. Counsellors gather information about the family history of a couple, analyse this information and then advise the couple about their risk of having an affected child. They also provide information about possible medical tests for defining the risk more precisely, the disorder itself and the resources available for dealing with an affected child.

Hereditary diseases. Over 1000 human genetic disorders are known to be inherited as Mendelian traits. They are controlled by a single gene locus and show a simple inheritance pattern. Most of these are autosomal recessives: albinism, cystic fibrosis, phenylketonuria, sickle-cell anaemia, etc. A few disorders, such as achondroplasia and Huntington's disease, are caused by autosomal dominant alleles. Most sex-linked disorders, like red-green colour blindness and haemophilia, are due to X-linked recessive alleles.

Many genetic disorders can be detected before birth. Blood and biochemical tests and karyotyping, made in conjunction with techniques of **amniocentesis** and **chorionic villi sampling**, can determine whether the developing foetus has the condition. With other techniques, such as ultrasound imaging and foetoscopy, the foetus can be examined directly for anatomical deformities. If foetal tests reveal a serious genetic disorder, the parents must choose between terminating the pregnancy and preparing themselves for a baby with the birth defect.

The key to assessing genetic risk for a recessive disease is to determine if the prospective parents are heterozygous carries of the recessive trait. Sometimes this can be answered by **analysis of the pedigree**. In most cases, however, the family pedigrees do not show their genotypes clearly. For some heritable disorders, there are tests which can distinguish between heterozygotes and normal homozygotes. New methods allow researchers to **examine the DNA** of a suspected carrier for harmful alleles.

Human Diet

A **healthy balanced diet** provides:

- fuel for cellular metabolism,
- organic raw materials needed to build the body's own molecules,
- essential nutrients, substances which must be obtained directly from food because the body itself cannot produce them.

When a human body takes in more energy than needed to meet its energy requirements, the extra energy is stored as glycogen in liver and muscles and, when these are full, the excess energy is stored as fat. This happens even if the diet contains only little fat because the liver converts excess carbohydrates or proteins into fat.

Adult humans cannot make nine of the **essential amino acids** needed to synthesise proteins. A diet low in one or more of the essential amino acids results in **protein deficiency**, a serious type of **malnutrition**. All essential amino acids are present in meat and animal by-products such as eggs, milk and cheese. In contrast, most plant proteins are incomplete or deficient in some of the essential amino acids.

A healthy diet also includes **13 vitamins**, most of which function as coenzymes. Some of the diseases due to lack of particular vitamins have been known for a long time, such as beriberi in Asia (lack of vitamin B_1), scurvy among sailors (lack of vitamin C) or rickets (lack of vitamin D).

A number of **minerals**, some in minute amounts, are essential for body function.

Undigested roughage, such as vegetable fibres, improves the mechanical efficiency of the intestine.

Millions of people in underdeveloped countries suffer from an inadequate diet. **Malnutrition** is especially serious in children. In developed countries, malnutrition is more often due to illness than lack of food. **Malabsorption**, failure to assimilate food from the intestine is a symptom of various disorders. A special diet with additional proteins and vitamins is required during pregnancy and lactation.

Work and Rest in Human Life

Work is an important part of human life. The difference between **mechanical and mental work** is gradually disappearing. The most important conditions of healthy life is the physiological and temporal organisation of work (work load within the body's capabilities, regular work pattern, inclusion of breaks and regular rest). Important **environmental factors** in work include temperature, humidity, light, noise and the presence of dust and toxic substances. Physiological body posture during work is also important.

A **healthy daily regimen** should be based on balanced **alternation of activity and rest**, with an emphasis on regular routine (waking and sleep patterns, feeding habits, leisure activity, physical exercise, etc.). The lack of sleep results in reduced efficiency in both physical and mental performance and increases risks of accidents.

In modern society, stress is a very important factor affecting the quality of life. There are many **stress factors**: overwork or strain, rush to meet deadlines, noise, inter-personal relationships, abundance of information to be absorbed, lack of sleep, repetitive actions, etc. Persistent stress may lead to a variety of **psychosomatic diseases** (cardiovascular, digestive, mental, etc.)

Drug Addiction

Drug addiction has become a major world problem in recent years. The frequent and regular use of drugs or pharmacological preparations leads to a **chronic toxic state**. The initiation of the drug-taking habit may result from increased personal, health or social problems or may merely be a response to peer pressure, particularly in young people. The habit is **self-perpetuating**, once the initial effect wears off, the taker craves for another dose.

The long-term usage of drugs is harmful for both physical and psychical health and also creates social problems, such as an increase in crime, violence and suicide rates. Cures for drug addiction are very unpleasant and take much longer than the development of the drug-taking habit.

In the recent period, the dependence of the population on tranquilisers and sleeping pills as well as alcohol has increased. Smoking and drinking black coffee can also be included as minor addictive behaviour.

9 ECOLOGY

Fundamental Concepts of Ecology

Ecology is the science of **inter-relationships between organisms and their environment**. The distribution of extremely diverse forms of life on Earth is a result of the nature of the environment and the ways in which the organisms interact with it. Ecology deals with the effects the environment has on organisms which live in it, their special adaptations to that environment and the way in which all the organisms are dependent upon each other. It also explains how the **flow of energy** and the **cycling of matter** combine to support the diversity of life.

Interactions between organisms and their environment are two-way processes. Organisms are affected by their environment, their presence and activities, in turn, change the environment, often dramatically, and directly or indirectly they affect other organisms. Human beings are the most environmentally destructive animals ever to live. No part of the biosphere remains untouched by human activities and many people are now concerned about the destructive impact of **human populations** and **technology**. Some of the problems which must be solved include: misuse of natural resources, localised famine aggravated by land exploitation, the expanding global population, the number of species extinguished or endangered and poisoning of soil and water with toxic wastes.

Ecology has close connection to **behavioural biology**. The search for evolutionary causes of behaviour, called also ultimate causes, is essential to the understanding of a species' evolutionary and ecological role.

Study of ecology. Ecological studies are carried out at four levels: organism, population, community and ecosystem. Ecological research at any level employs the usual methods of science: observation, hypothesis, prediction and testing. However, in contrast to the laboratory, ecological experiments cannot be precisely controlled since environments are very complex.

At the **organism** level, ecology studies how an individual organism meets the challenges of its environment, e.g., adaptation to the extreme temperatures, pollution, etc. At the **population** level, ecology is concerned with the dynamics of whole populations in changing environmental conditions: population growth rate, genetic differences within populations, migration and their evolution. At the third level ecology focuses on interactions amongst **communities** inhabiting a particular area, studying the effects of predation, symbiosis, competition, outside disturbances and a trophic structure on the structure of communities. An **ecosystem** includes all the life forms existing in a particular area together with all the non-living factors. At this level, ecology is interested in an important global problem – how do energy and chemicals flow within an ecosystem?

The **global ecosystem** is called the **biosphere.** It includes all life on Earth. The environment of an organism includes various non-living – **abiotic factors** as well as other organisms – **biotic factors.** An organism's ability to survive and reproduce in a particular environment results from natural selection. By eliminating the least fit individuals in a population, environmental forces help adapt species to the mix of abiotic and biotic factors which they encounter. Organisms vary a great deal in their ability to **tolerate fluctuations** and **long-term changes** in their environments. They can usually tolerate environmental fluctuations only within the set of conditions to which they are adapted.

Interactions amongst species in communities involve interspecific competition, predation and symbiosis. These are the forces which hold the population of a species together as a community. Outside disturbances, including human activities, may drastically change a community. Increasing human interference in ecosystems threatens global climate and the existence of thousands of species.

Feeding Relationships

The community has a **trophic structure,** a pattern of feeding relationships, consisting of several different levels. The trophic structure determines the route that energy takes in flowing through the ecosystem, as well as the pattern of chemical cycling.

An **ecosystem** can be divided into:

- **producers**, organisms manufacturing organic compounds from inorganic,
- **consumers**, organisms consuming other organisms; they can be **herbivorous** (plant-eating or primary consumers) or **carnivorous** (flesh-eating, secondary or higher-level consumers),
- **decomposers**, organisms as **bacteria** or **fungi** decomposing or breaking down organic compounds of dead organisms into substances which can be re-used,
- **non-living components,** acting as reservoirs from which constituents can be drawn and to which they may be returned.

Biocenosis is a group of plant species – **phytocenosis** or animal species – **zoocenosis,** living together as a community in a particular habitat, **biotope**. A biocenosis interacts with abiotic factors, forming an **ecosystem.** **Biotope**, the environment of a biocenosis, is the complex of abiotic factors including solar energy, temperature, water, soil and wind. Special biotopes and biocenosis are: rivers, ponds, benthic zone, tropical forests, savannas, deserts, temperate grasslands, taiga, tundra.

Abiotic and Biotic Factors

Abiotic factors, including solar energy, temperature, water, soil, chemical compounds, pH, wind and catastrophes, both natural and human, create the biosphere's diverse habitats. The complex of physical factors, such as sunlight, temperature, moisture, rainfall, winds, landform, associated with climate influence the distribution of biological communities – **biomes**. Most climatic variations are due to uneven heating of Earth's surface.
The main biomes are:
- **tropical forests**, in the warm, moist belt along the equator,
- **savannas**, drier tropical and some non-tropical areas, grassland with scattered trees,
- **deserts**, driest regions developed because of misuse of the surrounding land,
- **chaparral**, shrubland with cool, rainy winters and dry, hot summers during which fires often occur,
- **temperate grasslands**, in the interior of continents where winters are cold,
- **temperate deciduous forest**, in areas where rainfall is more abundant and winters are cold,
- **taiga**, coniferous forests of the far north and high mountains with short summers and long, snowy winters,
- **tundra**, treeless plain, where it is too cold for large trees to survive; it occurs between taiga and the permanently frozen polar regions, and above the tree line on high mountains,
- **polar and high-mountain ice**, permanently frozen regions.

Biotic factors are based on either **intraspecific** or **interspecific inter-relationships**. Intraspecific inter-relationships are important particularly in the life of populations, interspecific in both populations and communities. There are three main categories of these interactions: **competition, predation**, and **symbiosis**.

Biosphere

This is the most complex level of ecology with three physical layers:
- **atmosphere**, gaseous envelope around the Earth,
- **hydrosphere**, including all water mass on the Earth's surface, particularly oceans, lakes and streams,
- **lithosphere**, the land mass of the continents.

Another feature of the biosphere is its **patchiness**, as seen on several levels. On a global scale, it is shown in the distribution of continents and oceans. On a regional scale, it occurs in the distribution of deserts, grasslands, forests, lakes and streams, for example. Within any patch it is possible to find several different habitats, each with a characteristic community of organisms determined by the characteristic abiotic factors.

Life and the Biosphere

Solar Radiation

Ecosystems are powered primarily by sunlight. **Photosynthetic organisms** use sunlight to manufacture molecules which store energy needed by all organisms. In most terrestrial environments, light is not a limiting factor but, in ponds, lakes and oceans, as the intensity and quality of light decreases with depth, the distribution and

numbers of photosynthetic organisms is reduced. Most photosynthesis in aquatic environments occurs near the surface. Some **plants** require maximum light, others require less. Photosynthetic reactions use only certain components of visible light. The light-absorbing molecules of chlorophyll take up mainly the blue-violet and red-orange wavelengths. Plants tend to locate in areas that contain the optimum light factors for their needs. Similarly, some **animals** cannot tolerate excess light, whereas others require large quantities. Some species require the stimulation provided by light in order to carry on many of their metabolic activities, including reproduction. The distribution of certain species is quite different in daylight from that at night.
Some activities of plants and animals fluctuate rhythmically with time of day. A biological cycle of about 24 hours is called a circadian rhythm. This rhythm persists even when the organism is sheltered from environmental cues. Circadian rhythms are controlled by internal timekeepers called biological clocks.

Atmosphere

The atmosphere is the layer of air around the whole surface of the Earth, consisting of three sub-layers:
- **troposphere**, up to an altitude of 12 km, which is the highest boundary of any free forms of life,
- **stratosphere**, up to 80 km; at an altitude of 40–50 km there is the ozone layer shielding the Earth's surface from an excess of ultraviolet radiation,
- **ionosphere**, with very low concentration of gaseous particles.

The limiting factors for life in the atmosphere are: temperature, water, chemical composition (particularly, the presence of oxygen and carbon dioxide in a suitable ratio, and nitrogen, an inert gas) and a low level of short-wave radiation.
Temperature is an important abiotic factor because of its effect on metabolism. Few organisms can maintain a sufficiently active metabolism at temperature close to 0°C; temperatures above 50°C destroy enzymes in most organisms.
Plants gain the heat form infrared radiation and lose it by transpiration. The highest viable temperature for most plants is between 40°C to 45°C. Only some succulents in desert conditions can survive at 80°C. The majority of plants keep their living activity at the lowest temperature near the freezing point. Higher animals, such as mammals and birds, are **endotherms** and control their internal temperature. Many animals can tolerate wide fluctuations in their body temperature. Temperature often affects the behaviour of animals. Many animals change body heat simply by relocation, some species migrate to a more suitable climate.
Air is a mixture of gasses of which the most important are oxygen and carbon dioxide. **Oxygen** is plentiful in the atmosphere and rarely limits the rate of cellular respiration in terrestrial organisms. In contrast, dissolved oxygen is often in short supply for aquatic organisms. **Carbon dioxide** has an important role in the carbon cycle in ecosystems. On a global scale, the return of CO_2 to the atmosphere by respiration is closely balanced by its removal by photosythesis. However, the burning of wood and fossil fuels (coal and petroleum) is steadily increasing the amount of CO_2 in the atmosphere, causing significant environmental problems, such as global warming.
Wind is an important abiotic factor. Some small organisms, such as bacteria or many insects, depend on nutrients blown to them by winds. Local damage caused by wind often creates openings in forests, contributing to the patchiness of ecosystems. In an organism, wind increases the rate of water loss by evaporation, which may have cooling effects.

Hydrosphere

About two thirds of the Earth's surface is hydrosphere contained mainly in the oceans. Their evaporation provides most of the world's rainfall and their temperature has a major effect on climate and wind pattern. Photosynthesis of marine algae supplies a substantial portion of the biosphere's oxygen.

Fresh water constitutes about 3% of the hydrosphere. Areas where fresh and sea water merges are called estuaries – the most productive environments on Earth. The narrow zone where **estuarine** or **sea water** meets land is called the **intertidal zone**, a type of wetland intermediate between an aquatic ecosystem and a terrestrial one. The ocean water itself is termed the **pelagic zone** and the seafloor is the **benthic zone**. These zones are also grouped according to light intensity, the illuminated stratum is the **photic zone** and the underlying, dark region is **aphotic zone**.
Freshwater resources include lakes, ponds, rivers and streams. Light, temperature, currents, water clarity and availability of nutrients and dissolved oxygen determine the communities which inhabit them.
Aquatic organisms are classified into four basic communities:
- **plankton**, small algae and cyanobacteria (phytoplankton) and small animals, protozoa and small arthropods (zooplankton),
- **nekton**, highly motile animals, such as fish and marine mammals,
- **neuston**, staying on the water surface, such as some algae,
- **benthos**, living on the seafloor itself, often firmly attached to the bottom, such as algae, fungi, sponges, burrowing worms, sea anemones and crabs.

Lithosphere and Pedosphere

The lithosphere is a compact layer of the Earth's surface; the upper portion containing living organisms is called pedosphere. It is the **soil layer**, within which it is possible to distinguish three horizons:
- **topsoil**, subject to extensive weathering (freezing, drying, erosion), containing decomposing organic material (humus) and living organisms,
- **lower horizon**, subject to less weathering, containing fewer organisms and much less organic matter,
- **lowerest horizon**, composed mainly of slightly eroded rock, containing only some anaerobic microorganisms.

Fertile topsoil contains a mixture of fine rock particles and clays, providing an extensive surface area that retains water, inorganic nutrients, humus, and living organisms, teeming numbers of bacteria, protozoans, fungi and small animals, such as earthworms, roundworms and burrowing insects. Together with plant roots, these organisms loosen and aerate the soil and contribute organic matter to it.
Soil – its structure, pH and inorganic nutrients – is an important environmental factor limiting the distribution of plants and thus the animals that feed on them. Soil water is a solution containing dissolved oxygen and inorganic ions. It may take centuries for a new soil to become fertile. The global loss of soil fertility is one of the most pressing environmental problems because survival of the human species depends on soil.

Populations

A population is defined as an **interbreeding group of individuals** of a particular species which are more or less isolated from other such groups; it can also be limited by a common resource base or by geographical boundaries. Population dynamics is concerned with changes in population size and the factors which regulate them over time.
Density and **dispersion pattern** are two important characteristics used to analyse and compare populations. Population density is the number of individuals in a given area or volume. Dispersion pattern is the mode of spacing, which may be clumped, uniform or random.
In idealised models of populations it is possible to distinguish two kinds of population growth. **Exponential growth** is the accelerating increase that occurs during a time period when growth is unregulated. In nature, it occurs only for short periods. **Logistic growth** is modified by population-limiting factors and tends to level

off at a carrying capacity based on the number of individuals the environment can support. Natural selection influences the life history of a species between two hypothetical extremes. **Opportunistic populations** produce many offspring and grow exponentially in unpredictable environments. **Equilibrial populations** raise fewer offspring and maintain relatively stable populations in stable environments.

The **age structure** of a population depends on the proportions of **pre-reproductive, reproductive** and **post-reproductive individuals.** A human population with a large percentage of pre-reproductive and reproductive individuals (as in developing nations) will grow more rapidly and have different social needs than populations whose age groups are nearly balanced or are skewed towards the post-reproductive groups (as in developed nations).

Population Explosion

The **human population** as a whole is growing exponentially and faces an uncertain future because no population can continue to grow indefinitely. Each population will stop growing when birth rates and death rates are equal. A unique feature of human reproduction is that it can be controlled by either contraception or government activities. Social changes also affect birth rates. It is more desirable for population control to result from a decrease in birth rate by social change or individual choice than by an increase in death rate, especially in the young, pre-reproductive group.

Communities (associations)

All the organisms in a particular area make up a community. A **biotic community** is also called a **biocoenosis**. Plants usually live in **phytocoenotic** and animals in **zoocoenotic** communities. These communities are characterised by diversity of species, relative dominance of different organisms, stability and adaptability, and a trophic structure.

A community interacts with abiotic factors, forming an ecosystem. **Energy flows** from the sun through living organisms and is lost as heat. **Chemicals are recycled** amongst air, water, soil and organisms. **Food chains** and **food webs** map the flow of energy and nutrients from plants - **producers** to **herbivores** – **primary consumers,** then to **carnivores – secondary** and **higher-level consumer**. **Dentrivores** (scavegeres, fungi and bacteria) decompose waste matter and recycle nutrients.

Interactions amongst Populations

Species are linked together in communities by **interspecific competition**, **predation,** and **symbiosis.**

Interspecific competition can inhibit the growth of the involved populations, sometimes to the extent of elimination of one of the populations, thereby playing a major role in structuring the community. The way a population "fits into" its environment, i.e., the total of the population's use of biotic and abiotic resources, is defined as a niche. Populations of two species cannot comfortably coexist in a community if they share the same niche.

Predation represents an interaction where one species eats another; the consumer is the predator and the food species, plant or animal, is the prey. Defence mechanisms are extremely diverse. Plants use chemical toxins, spines and thorns. Animals use both mechanical and chemical defences. **Camouflage** is an especially common type of defence, in which an animal becomes almost invisible against its background. In the case of **Batesian mimicry**, a palatable species mimics an unpalatable one. Another kind of mimicry, **Müllerian mimicry**, involves two unpalatable species, which co-exist in the same community, that mimic each other.

In some cases, as the predator adapts to its prey, natural selection adapts the prey's defences against the predator. This process of **reciprocal adaptation** is known as **co-evolution.**

A **keystone predator** is a species that reduces the density of the strongest competitors in the community and helps maintain species diversity by preventing competitive exclusion of weaker competitors.

A **symbiotic relationship** is an interaction between two or more species in which one lives in or on the other. Three types of symbiotic relationships exist in communities: parasitism, commensalism, and mutualisms. **Parasitism** is a kind of predator-prey relationship in which one organism (parasite) derives its food at the expense of its symbiotic associate (host). Parasites are usually smaller than their hosts. In **commensalism**, one partner benefits without significantly affecting the other. There are probably only few cases of absolute commensalism, because it is unlikely that one of the partners will be completely unaffected. **Mutualism** is the type of symbiosis which benefits both partners in the relationship.

Changes to Ecosystems

Communities may change drastically after events such as flood, fire, glacial advance or retreat, volcanic eruption, etc. The disturbed area may be re-colonised by the original species or these may be replaced by other species which colonise the area. Such transition in the species composition of a community is called **ecological succession.** Human disturbance has the greatest impact on community change and succession.
Altered ecosystems trigger changes in other ecosystems. Any major change in a terrestrial ecosystem disrupts chemical cycling and moves large amounts of chemical nutrients to other areas. Most of the nutrients lost from deforested lands and agricultural areas are highly soluble in water and readily pass into an aquatic ecosystem. When a freshwater lake receives an overload of nutrients from surrounding terrestrial ecosystems, it may gradually undergo **eutrophication.** It becomes increasingly more productive, particularly in algal and bacterial populations, and it loses most of its species diversity, with only the most tolerant organisms surviving.

Human Population and the Environment

Although growth of human populations varies widely in different societies, the human population as a whole is **growing exponentially**. It has doubled three times in the last three centuries and now stands at over 5.6 billion; it may reach 8 billion by the year 2020. Most of the increase is due to improved health and technology which have decreased death rates. The underlying reason for this population explosion is the human ability to manipulate nature in order to change it rapidly and drastically to suit our needs.
The **alteration of ecosystems by human activities** threatens the **global climate** and the existence of thousands of species. Accelerated **eutrophication** reduces species diversity in rivers and lakes. Large tracts of forest in taiga biomes are still being clear-felled to satisfy demands for lumber and urban development and tropical forests continue to be converted into farmland.. To diminish the disruption of these ecosystems, some nations are establishing **mega-reserves** or **undisturbed wild lands.**
The explosive growth of human population and technology continues today. Populations of developing nations are growing the fastest and their technology and resource consumption increases the strain on the biosphere. Oil spills, acid rain, ozone depletion, and chemical pesticides and fertilisers affect the entire world. Burning of fossil fuels is increasing the amount of CO_2 and other green-house gases in the air. This, in turn, is warming Earth, changing climate patterns, melting polar ice and flooding coastal regions. Logging and clearing of forests, especially the tropical rain forests, for farming also contributes to global warming by reducing the uptake of CO_2 by plants. Continued destruction of the tropical rain forests, currently the home to perhaps 80% of the world's plants and animals, could further reduce the number of species on Earth. Habitat destruction, overhunting and introduction of new species could alter the biosphere to such an extent that we are threatening our own survival.
Human intelligence enables man to manipulate nature on a global scale, but he has only **created global** environmental problems. This intelligence should have enabled man to better understand the living world and live more harmoniously with nature.

Effect of the environment on health

The direct environment has a significant influence on human health and mental balance. These effects are studied by the branch of medicine called **preventive medicine**.

The **environmental factors** affecting human health may be either **positive** or **negative**. Positive changes improve the working environment, improve quality of life and have a stimulating influence on both physical and mental states. Negative factors can be physical, chemical and biological and have adverse effects on health.

Physical negative factors include temperature, noise, dust and radiation; chemical factors include a much greater range of substances, the most common of which are oxides of sulphur, carbon and nitrogen, detergents and phenols. Biological factors, such as pathogenic microbes, can cause serious viral or bacterial diseases and epidemics. Some environmental factors are sociobiological or psychosocial in character: ethnic culture, human inter-relations, aesthetics, etc.

All these types of factors affect the human species as a whole and their effect depends on man's ability to respond and adapt to them.

Environmental protection

The present state of global ecosystems results from long-term developments in human populations and is particularly influenced by recent progress in science and technology. The alteration of ecosystems by human activities threatens global climatic change, the existence of thousands of species and, finally, the existence of man himself as a biological species.

In an attempt to slow down the disruption of ecosystems, some countries are setting up mega-reserves. A **mega-reserve** is an extensive region of land which includes areas undisturbed by human occupation. The undisturbed areas may be surrounded by land which has already been changed by human activity and is used for economic production. These areas will continue to be used to support the human population but they will be protected from extensive alteration. As a result, they will serve as a buffer zone, or shield, against further intrusion into the undisturbed areas.

TEST BANK FOR GENERAL BIOLOGY

The tests are based on the knowledge of grammar school biology. The questions are phrased to show that the student not only is familiar with the whole range of biological concepts and findings, but also can use them to solve basic biological problems. This also requires adequate knowledge of chemistry and physics. The number of questions in each section is related to the relevance of this issue to medical studies.

General Characteristics of Living Systems
Important Discoveries in Biology

1. Which is the fundamental difference between prokaryotic and eukaryotic cells?
a) Presence of the cell wall
b) Coding for genetic information
c) Presence of the nucleus enveloped by a membrane
d) Biomembrane structure

2. Which of the following historical dates is correct?
a) Robert Koch discovered the causative agent of tuberculosis in 1952.
b) Human genome project was completed in 1990.
c) The birth of the first cloned animal –Dolly the sheep – was published in 1997.
d) Luis Pasteur found out in 1776 that fermentation is produced by microorganisms.

3. The structure of deoxyribonucleic acid was discovered in 1953 by:
a) H. Krebs
b) J.D. Watson and F. Crick
c) L.C. Pauling
d) M.W. Nirenberg and H.G. Khorana

4. The ability to reproduce themselves is a property that viruses share with living systems. Viruses can therefore replicate
a) in vitro in the presence of nucleotides and amino acids
b) in vitro in the presence of nucleotides, amino acids and ATP
c) both in a living and a dead cell
d) only in a metabolically active cell

5. Which order of living systems by their level of organisation is correct?
a) Organ→tissue→cell→organism.
b) Cell→organ→tissue→organ system.
c) Cell→organ→organism→community of organisms.
d) Tissue→organ→organism→cell.

6. Which of the following are classified as non-cellular organisms?
a) Mycoplasmas
b) Rickettsias.
c) Bacteriophages.
d) Spirilla.

7. Which of the following statements on HIV and its hosts *is false*?
a) HIV belongs to retroviruses, i.e., its virions possess the enzyme reverse transcriptase.
b) HIV infects T-lymphocytes, i.e., the cells releasing antibodies into blood plasma.
c) HIV causes the disease called acquired immunodeficiency syndrome (AIDS).
d) HIV can be transmitted by blood, semen and vaginal fluid.

8. Which of the following statements *is false* ?

a) Laws of inheritance were discovered by Johann Gregor Mendel.
b) The cell theory was postulated by M. J. Schleiden and Th. Schwann.
c) The principle of vaccination was discovered by L. Pasteur.
d) The closed blood circulation system was discovered by K. Landsteiner.

Cell Biology

1. The rate of simple diffusion across the plasma membrane depends on:

a) ATP concentration in the cytoplasm b) concentration gradient
c) transport protein activity d) membrane enzyme activity

2. DNA is present in:

a) mitochondria b) lysosomes c) ribosomes d) endoplasmic reticulum

3. A differentiated cell of an organisms and the zygote this organism developed from are characterised by:

a) different genomes b) identical genomes
c) identical mRNA molecules d) identical phenotypes

4. Which of the following mechanisms of neural excitation is true?

a) Increased flow of protons through the plasma membrane of an axon.
b) Change in orientation of neuron membrane phospholipids.
c) Changes in neuron plasma membrane permeability for Na^+ and K^+ ions.
d) Changes in membrane potential due to an increase in cytoplasmic Ca^{++} concentration in the neuron.

5. Which of the following is the regular component of a bacterial cell?

a) Cell wall. b) Mitochondria. c) Membrane-enveloped nucleus. d) Vacuoles.

6. Which is the correct order of cell cycle phases?

a) $G1 \rightarrow G2 \rightarrow S \rightarrow M$ b) $S \rightarrow G1 \rightarrow G2 \rightarrow M$ c) $M \rightarrow G1 \rightarrow G2 \rightarrow S$ d) $G1 \rightarrow S \rightarrow G2 \rightarrow M$

7. Thickness of the plasma membrane is

a) 0.75 nm b) 7.5 nm c) 75 nm d) 7.5 µm

8. The flagellum of a eukaryotic cell is similar in ultrastructure to

a) flagellum of a bacterial cell b) a bundle of microfilaments
c) flagellum of a bacteriophage d) cilium

9. Which of the following is not the product of transcription?

a) mRNA b) tRNA c) rRNA d) DNA

10. Which of the human body cells could be visible with the naked eye?

a) Striated muscle cell.
b) Motor neurone.
c) Mature oocyte.
d) Macrophage.

11.In which of the following cell structures does protein synthesis take place?
a) Lysosomes and chloroplasts. b) Plant cell vacuoles and mitochondria.
c) Mitochondria and chloroplasts. d) Plasma membrane and Golgi bodies.

12.In which of the cell cycle phases does nuclear DNA replicate?
a) G1 b) G2 c) M d) S

13.Which of the statements concerning viruses is true?
a) Viruses include only one kind of nucleic acid, either DNA or RNA.
b) Viruses usually contain all known types of nucleic acids (DNA, mRNA, rRNA, tRNA).
c) Viral particles are capable of ATP synthesis.
d) Synthesis of viral proteins takes place on specific viral ribosomes.

14. The primary structure of a protein molecule is determined by a sequence of:
a) single nucleotides in mRNA b) nucleotide triplets in tRNA
c) nucleotide triplets in mRN d) nucleotides in rRNA

15.Which of the following statements on the biosynthesis of nucleic acids and proteins *is false*?
a) Incorporation of each amino acid into a newly synthesised polypeptide is defined by a nucleotide triplet in mRNA.
b) The set of rules which match appropriate amino acids to individual codons is known as the genetic code.
c) The end of a translation process is signalled by a termination codon.
d) A sequence of amino acids in a polypeptide chain is termed a structural gene.

16.Translation is a process by which genetic information is translated from
a) DNA into rRNA b) DNA into mRNA c) mRNA into proteins d) proteins into tRNA

17.Which of the following deoxyribonucleotides is complementary to T during DNA replication?
a) U b) T c) A d) C

18.Both the alpha helix and the beta sheet are involved in the arrangement of
a) primary structure of proteins b) secondary structure of proteins
c) linear polysaccharides d) nucleic acids

19.RNA synthesis takes place in:
a) lysosomes and peroxisomes
b) mitochondria and chloroplasts
c) ribosomes and centrioles
d) rough endoplasmic reticulum

20.Transcription is a process by which genetic information is transferred from
a) tRNA to peptide b) DNA to DNA c) mRNA to peptide d) DNA to mRNA

21.On transcription of an AAC triplet from DNA, which triplet is formed on a corresponding mRNA?
a) UUC b) UAA c) UUG d) CCA

22. A bacteriophage is:

a) term for a special macrophage
b) white blood cell capable of phagocytosis of bacteria
c) virus that lyses bacteria
d) bacterium capable of phagocytosis

23. Cell structures, biochemical components and biochemical functions are presented in the following three columns. Select a meaningful triad:

a) nucleus	chlorophyll	ATP synthesis
b) cytoplasm	methionine	protein synthesis
c) Golgi complex	uracil	RNA synthesis
d) vacuole	vitamin C	cellular oxidation

24. A flagellum composed of microtubular bundles is responsible for locomotion of:

a) bacteriophages b) sperm cells c) bacteria d) amoebae

25. DNA polymerase is an enzyme that

a) is localised in the nucleolus of eukaryotic cells
b) is bound to nuclear ribosomes
c) is present in the cytoplasm of eukaryotic cells
d) functions in chloroplasts and mitochondria

Physiology of Higher Plants and Animals

1. When both male and female gonads are present in one and the same organism, we talk about:

a) gonochorism b) cryptorchism c) hermaphroditism d) bisexualism

2. The ladder-like nervous system is found in

a) Flatworms b) Rhizopoda c) Mollusca d) cartilaginous fish

3. Amnion is:

a) endoderm b) inner foetal membrane c) ectoderm d) outer foetal membrane

4. Which of the following images is projected on the retina of a vertebrate eye?

a) Reverse, enlarged. b) Direct, reduced. c) Reverse, reduced. d) Direct, enlarged.

5. Transmission of a nerve impulse across a synapse is facilitated

a) by mechanical irritation of adjoining cells
b) in a chemical way by means of ATP
c) in a chemical way using a mediator
d) by means of the sodium-potassium pump

6. Which of the following statements on fungi *is not in agreement* with the current knowledge?

a) Fungi are eukaryotic organisms.
b) Chitin is a typical polysaccharide of the fungal cell wall.
c) Production of conidia is the most common way of asexual reproduction in fungi.
d) Amitosis is the form of nuclear division typical of fungal cells.

9. The alleles of a given gene differ from each other in that
a) they are localized on chromosomes of different pairs
b) they carry information for different proteins with the same function
c) they are localized on different loci of the same chromosome
d) each carries a different mutation of a given gene

10. Homologous chromosomes
a) are identical in shape and have different loci
b) differ in shape and size and have identical loci
c) pair during meiosis
d) pair during mitosis

11. An allele is
a) always found in two forms
b) a unit of the phenotype
c) an alternative form of a gene found at the same locus on homologous chromosomes
d) an alternative form of a gene found in genomes of different organisms

12. One of Mendel's key discoveries was that
a) organisms had two hereditary factors for all traits
b) blending was a common occurrence in sexually reproducing organisms
c) gametes contained two heredity factors for each trait
d) ova were larger than sperms

13. Which of the following is true?
a) Alleles are similar forms of the same gene found on different chromosomes.
b) An individual containing two recessive alleles for the same trait is considered to be homozygous-dominant.
c) The recessive allele is expressed only when the dominant allele is missing.
d) In an individual who is heterozygous for a given trait, the recessive allele is missing.

14. Which of the following is true?
a) Human cells contain one pair of sex chromosomes and 23 pairs of autosomes.
b) Chromosome banding is a procedure for identification of structural abnormalities in chromosomes.
c) Hemophilia is an autosomal-dominant trait.
d) Chromosomal constitution of the sperm is XY.

15. Chromosomes line up in the center of the cell during
a) prophase b) metaphase c) anaphase d) telophase

16. In the complete dominance of A over a, the heterozygote Aa has a phenotype
a) identical with AA
b) identical with aa
c) between AA and aa
d) different from both parents (AA, aa)

7. Antibiotics are the products of
a) bacteria and moulds b) bacteria and higher plants
c) bacteria and protozoa d) bacteria and parasitic worms

8. Which of the following diseases is transmitted by the tse-tse fly?
a) Malaria. b) Dysentery. c) Sleeping sickness. d) Typhoid fever.

Genetics

1. In his experiments leading to the discovery of genetic laws, J.G. Mendel used the following organism:
a) Arabidopsis thaliana b) Pisum sativum c) Drosophila melanogaster d) Zea mays

2. Which of the following types of nucleic acids is a carrier of anticodon:
a) mtDNA b) mRNA c) tRNA d) rRNA

3. Loss of one nucleotide in a DNA molecule has generally
a) milder effect than nucleotide substitution
b) no effect at all
c) greater effect than nucleotide substitution
d) lesser consequence than a loss of three nucleotides

4. When crossing individuals with genotypes AaBb and AaBb, the ratio of phenotypes (A,B dominant alleles, a,b, recessive alleles) will be as follows:
a) 9:3:3:1 b) 3:1 c) 1:2:2:1 d) 1:1:1:1

5. A chromosome of prokaryotic cells
a) is made of one, usually circular double-stranded DNA molecule
b) is enclosed in a nuclear envelope
c) consists of a circular single-stranded DNA molecule
d) consists of a circular double-stranded RNA molecule

6. Parthenogenesis
a) is a form of sexual reproduction in ciliate protozoa
b) is a form of sexual reproduction in hermaphrodites
c) is a form of asexual reproduction in which females produce eggs that develop without fertilisation
d) is a form of asexual reproduction in lower organisms by which progeny arises from fragmentation of a parent organism

7. Transduction is the process by which DNA is transferred from one bacterium to another by:
a) cell fusion b) phage c) isolated nucleus d) single deoxyribonucleotide

8. A phenotype is
a) usually determined by two alleles
b) independent of genotype
c) a synonym for genotype in haploid organisms
d) a set of all observable traits of a cell or an organism resulting from an interaction of the environment and the genotype

17. The number of different phenotypes in F2 generation of dihybrids with complete dominance (AaBb x AaBb) is:
a) 1 b) 2 c) 3 d) 4

18. Gene mutations
a) result in alterations of the karyotype
b) can be a results of a change in the nucleotide number of a gene
c) prevent separation of mitotic chromosomes
d) are manifested as polyploidy

19. A relationship between A and B alleles for the ABO blood group is
a) recessive and dominant b) semidominance c) codominance d) superdominance

20. Which blood types can be found in the children whose both parents have O blood groups?
a) O b) O, A c) O, A, AB d) O, A, AB, B

21. A genotype is
a) strongly dependent on the phenotype b) the set of all genes of the organism
c) a typical gene d) a synonym for the karyotype

22. Which of the following statements concerning the genetic code *is false*?
a) Genetic code is the system of rules governing the translation of genetic information.
b) Genetic code is based on nucleotide triplets.
c) Genetic code includes 64 codons.
d) Genetic code includes 20 codons to specify 20 amino acids found in proteins.

23. Plasmids are
a) synonymous with thylacoids in a chloroplast
b) carriers of a part of genetic information in bacteria
c) linear DNA molecules in the cytoplasm
d) granular bodies in the cytoplasm

24. The karyotype in Down syndrome is characterised by the presence of an extra copy of genetic material on the
a) chromosome 21 b) chromosome 22
c) chromosome 12 d) chromosome 18

25. Genetic transformation is
a) alteration of genetic information of a cell due to environmental factors
b) transfer of genetic information between bacteria by means of a bacteriophage
c) alteration of genetic information of a cell following incorporation of foreign DNA
d) restructuring of the cell's genome by a recombinant process

26. Crossing-over is
a) random combination of chromosomes of the maternal and paternal sets
b) synonym for the segregation of chromosomes
c) exchange of genetic material between homologous chromosomes
d) process by which the number of chromosomes in a set is reduced

Human Biology

1. The part of the human digestive system engaged in food digestion and absorption of nutrients is:
a) stomach b) large intestine c) small intestine d) appendix

2. Human saliva contains enzymes that digest
a) proteins b) starch c) saccharose d) glucose

3) What is the role for red blood cells?
a) Participation in blood clotting to stop bleeding.
b) Involvement in immunological defence.
c) Oxygen transfer.
d) Iron transfer.

4) In the human heart, semilunar valves are found between
a) the right and the left ventricle
b) the right and the left atrium
c) the right atrium and the right ventricle
d) the ventricles and the major arteries

5. Insulin is a hormone that
a) facilitates glucose metabolism in cells
b) participates in protein metabolism
c) is involved in urinary excretion of glucose
d) increases the level of blood acetone

6. The nerve centre controlling many autonomous functions is located to
a) cerebellum b) medulla oblongata
c) thoracic region of the spinal cord d) hypothalamus

7. The human eye can perceive light waves in the range of
a) 400–600 μm b) 400–750 nm c) 40–70 nm d) 40–60 μm

8. The full prenatal development in humans lasts for
a) 300 days b) 290 days c) 270 days d) 250 days

9. The human thorax has
a) 10 pairs of ribs b) 8 pairs of ribs c) 12 pairs of ribs d) 14 pairs of ribs

10. Which of the following responds to a change in body position?
a) Chemoreceptors. b) Radioreceptors. c) Mechanoreceptors. d) Free nerve endings.

11. The cancer disease of white blood cells is called
a) carcinoma b) leukemia c) hemophilia d) leucocytosis

12. One mm^3 of human blood contains
a) 5.10^6 leukocytes b) 5.10^9 erythrocytes c) 5.10^6 lymphocytes d) 5.10^6 erythrocytes

13. Insulin is produced in the pancreas in response to
a) an increase in body temperature
b) a hormonal signal from the pituitary gland
c) an increase in the glucose plasma level
d) a decrease in the glucose blood level

14. Cell-mediated immunity is provided by
a) B-lymphocytes b) plasma cells c) T-lymphocytes d) macrophages

15. The human spinal column consists of the following vertebrae:

a) 5 cervical	12 thoracic	7 lumbar	5 sacral and coccyx
b) 7 cervical	10 thoracic	7 lumbar	5 sacral and coccyx
c) 7 cervical	12 thoracic	5 lumbar	7 sacral and coccyx
d) 7 cervical	12 thoracic	5 lumbar	5 sacral and coccyx

16. Which of the following statements *is false*?
a) The human hand has five metacarpal bones
b) The human hand has eight carpal bones
c) The human skeleton is made up of more than 300 bones of all shapes and sizes
d) There are seven metatarsal bones.

17. Human being can perceive sound at frequencies
a) below 16 Hz b) up to 100 000 Hz c) between 16 and 20 000 Hz d) above 20 000 Hz

18. The principle of blood clotting in vertebrates is based on
a) conversion of soluble fibrinogen into insoluble fibrin
b) conversion of soluble fibrin into insoluble fibrinogen
c) contraction of muscles at the site of injury
d) production of a glycogen gel-like substance that seals a damaged blood vessel

19. Platelets are
a) specialised cells with non-functional nuclei
b) specialised anucleated cells
c) cytoplasmic fragments of large bone marrow cells
d) erythrocytes free of haemoglobin

20. What blood volume the heart of a human adult at rest can pump into the pulmonary circulation in one minute?
a) 0.5 L b) 5 L c) 1.5 L d) 15 L

21. A direct source of energy for muscle contraction comes from:
a) cytochromoxidase b) fatty acids c) lactic acid d) glucose

22. The most important immediate source of energy for humans includes
a) proteins b) sugars c) fats d) amino acids

23. Amylase is the enzyme that digests
a) fats b) starch c) proteins d) cellulose

24. Which of the following statements concerning the lymph fluid *is false?*

a) Some of the lymph fluid is produced during absorption of substances from the intestine.
b) About 3 litres of lymph fluid is produced every day.
c) Lymphatic vessels empty into veins of the circulatory system.
d) Lymph fluid is produced in lymph nodes.

25. Bile is produced in

a) liver b) pancreas c) gall bladder d) duodenum

Evolutionary Biology

1. **The oldest paleontological evidence suggesting the existence of living cells is found in sediments:**

a) 1 million years old b) 100 million years old
c) 3.7 billion years old d) 5 billion years old

2. **Homo sapiens neanderthalensis lived**

a) 2–1.5 million years ago b) 1- 0.5 million years ago
c) 200,000–30,000 years ago d) 40,000 years ago

3. **The human species continues to exist owing to:**

a) evolution b) mutations
c) reproduction of individuals d) longevity of its individuals

4. **Darwin postulated that the major factor influencing evolution**

a) are mutations b) is migration
c) are evolutionary leaps d) is natural selection

5. **The first eukaryotic cells appeared about 1.5 billion years ago. This conclusion was drawn from**

a) results of measuring ^{14}C radioactivity in the fossils remains of blue-green algae
b) age of the sediments in which the fossil remains of algal cells were detected by microscopy
c) estimates based on the rate of evolution of multicellular organisms.
d) estimates based on the frequency of base substitution in DNA in fossil cells as compared with that of current cells

6. **Darwin's Theory of Evolution is concerned primarily with**

a) origin of species
b) origin of life
c) mechanism of adaptation to changing environmental conditions
d) origin of diversity

7. **Australopithecus africanus is thought to have been a direct ancestor of <u>modern humans</u>. Which of the following facts concerning Australopithecus *is not in agreement* with paleontological evidence?**

a) Hiscranium about 500 cm³ in volume. b) He showed bipedal movement.
c) He used of stone tools. d) He lived between 3 and 2.3 million years ago.

Environmental Science

1. Ecological niche of a species
a) describes the relational position of a species in its ecosystem
b) is defined by abiotic components of the biosphere only
c) is defined by biotic components of the biosphere only
d) is a space which the species occupies in its ecosystem

2. All organisms living together in an area constitute
a) zoocenose b) biocenose c) phytocenose d) ecosystem

3. Plants utilise for photosynthesis
a) visible light b) ultraviolet light
c) infrared light d) radiation of all wavelengths

4. Which of the following gases is responsible for the greenhouse effect?
a) CO_2 b) SO_2 c) O_2 d) H_2O vapour

Test Bank Answers

GENERAL CHARACTERISTICS OF LIVING SYSTEMS. IMPORTANT DISCOVERIES IN BIOLOGY
1c, 2c, 3b, 4d, 5c, 6c, 7b, 8d

CELL BIOLOGY
1b 2a 3b 4c 5a 6d 7b 8d 9d 10c 11c 12d 13a 14c 15d 16c 17c 18b 19b 20d 21c 22c 23b 24b 25d

PHYSIOLOGY OF HIGHER PLANTS AND ANIMALS
1c 2a 3b 4c 5c 6d 7a 8c

GENETICS
1b 2c 3c 4a 5a 6c 7b 8d 9d 10c 11c 12a 13c 14b 15b 16a 17d 18b 19c 20a 21b 22d 23b 24a 25c 26c

HUMAN BIOLOGY
1c 2b 3c 4d 5a 6d 7b 8c 9c 10c 11b 12d 13c 14c 15d 16c 17c 18a 19c 20b 21d 22b 23b 24d 25a

EVOLUTIONARY BIOLOGY
1c 2c 3c 4d 5b 6a 7c

ENVIRONMENTAL SCIENCE
1d 2b 3a 4a

OVERVIEW
OF GENERAL BIOLOGY

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