**ANIMALS**

Six Kingdoms are usually recognized: Prokaryota, Archaea, Protoctista, Fungi, Plantae and Animalia.

The word **animal** comes from the Latin "anima", which means soul or breath.

The following notes have been taken from the book by Margulis and Schwartz, "Five Kingdoms", 3rd. Edition, 1998.

* Animals are heterotrophic, diploid, multicellular organisms that usually (except) sponges) develop from a blastula.
* The blastula, a multicellular embryo that develops from the diploid zygote produced by fertilization of a large diploid egg by a smaller haploid sperm, is unique to animals.
* The gametes of animals, eggs and sperms, differ in size and form and are called **anisogametes**.

Other characteristics that can be added to those above are: eukaryotes, with cells specialized and organized into tissues, organs, etc; they inhabit the sea, fresh water and land; most are capable of locomotion at some stage of their lives; most can respond adaptively to external stimuli and have well developed sense organs and nervous system; most reproduce sexually, with large non-motile eggs and small flagellated sperms. The diploid zygote produced by fertilization divides by mitotic divisions, resulting in a ball of cells that usually hollows out to become a blastula.

The kingdom Animalia is divided into about 35 phyla (sing. phylum).

Phyla are distinguished from each other by the body plan, the major features of its structural and functional design.

**THE ARCHITECTURE OF ANIMALS.**

Four features are commonly used to distinguish the body plan of animals:

1. The number of **tissue layers** found in the embryo: diploblast or triploblast.
2. The type of **body symmetry**: radial or bilateral.
3. Presence or absence of a body fluid-filled **body cavity**: acoelomates, pseudocoelomates, or coelomates.
4. The pattern of **early embryonic development**: protostomes or deuterostomes.

**Embryonic tissues.**

A tissue is an organized and functionally integrated group of cells.

**Diploblasts** have two embryonic layers of tissue, the endoderm and the ectoderm.

In **triploblasts** there are three layers present, the **endoderm**, the **mesoderm** and the **ectoderm**.

**Body symmetry.**

A body is symmetrical if it can be divided in a way that results in similar sides.

**Asymmetry**. They cannot be section in a way that produces similar parts. Some sponges are asymmetrical.

**Radial symmetry** has two planes of symmetry; the body is shaped like a cylinder or a disk with parts radiating from a central point.

**Bilateral symmetry** has only one plane of symmetry dividing the body into two sides, left and right; the body is usually long and narrow with a head and tail.

Types of sectioning a specimen:

* **Sagittal section** divides the body into **right and left parts**.
* **Cross or transverse section** divides the body into **anterior and posterior parts**.
* **Frontal section** divides the body into **dorsal and ventral parts**.

All triploblastic animals have bilateral symmetry, except the adult form of the echinoderms, e.g. starfish.

Bilateral symmetry is the most common. The reason for this is...

* Unidirectional movement of the animal for better sensing the environment (senses on the head), and easier to find food.
* With the mesoderm, nervous and muscular systems developed allowing directional movement possible.

**Body cavity**

Animals may be...

* **Acoelomate**: lack coelom or body cavity, e.g. cnidarians, ctenophores, flatworms..
* **Pseudocoelomate:** coelom is partially lined with mesoderm, e.g. roundworms, rotifers..
* **Coelomate**: coelom is completely lined with mesoderm.

Diploblast lack a body cavity. Triploblasts have either a false coelom or a true coelom.

Advantages of the coelom:

* Provides space for many organs to function with freedom, e.g. heart, gonads.
* Allows the digestive cavity to move independently of body movements.
* Hydrostatic skeleton.
* Coelomic fluid transports oxygen, wastes, etc. to organs and tissues.

**Early embryonic development in coelomates.**

Coelomate animals are bilaterally symmetrical, except adult echinoderms, and triploblastic.

Coelomates can be divided into protostomes and deuterostomes.

The vast majority of animals are protostomes, e. g. insects, mollusks, and segmented worms.

Protostomes...

* Have spiral cleavage of the very early embryo.
* The pore formed during gastrulation becomes the mouth.
* Coelom is formed in the mesoderm: schizocoely
* Protostomes also have a **determinate** cleavage in which the fate of the embryonic cells is fixed very early in development.

Deuterostomes...

* Have radial cleavage.
* The pore formed during gastrulation becomes the anus.
* Mesoderm forms pockets from the wall of the digestive cavity and pinch off to form the coelom: enterocoely.
* Deuterostomes have an **indeterminate** cleavage in which each cell keeps longer the capacity to develop into a full organism.

**Evolutionary hypothesis**

It is based on the sharing of the basic body plan characters.

Acoelomates evolved first, the pseudocoelomates and the coelomates.

After the coelom evolved, then the protostomes split from deuterostomes, then the echinoderms reverted to an adult with radial symmetry although the larva is bilateral.

Bilateral coelomates then split into protostomes and deuterostomes.

Segmentation evolved independently in both protostomes and deuterostomes.

**Molecular phylogenies**

Is based on rRNA data. It is still in progress.

Tentative results suggests that the branching based on rRNA studies is very similar to the branching of the phylogenetic tree based in body plan.

**FEEDING**

The feeding tactics observed in animals can be divided into five general types.

1. **Suspension feeding**.

The filtering of food suspended in water. It is found only in aquatic organisms.

It is find in a wide variety of animal groups, from shrimps, clams to whales.

This method of feeding has evolved many times in the animal kingdom.

1. **Deposit feeding**

Deposit feeders eat their way through the substrate.

There are many types of substrates: soil, mud, mesophyll of leaves, stem tissues, piles of feces, and carcasses of dead animals are but a few examples.

The food consists of bacteria, fungi, protists, and bits of organic material (detritus).

Deposit feeders are found in many groups of animals round worms, segmented worms, mollusks, insect larvae, etc.

1. **Herbivory**.

Herbivory means feeding on plants (syn. phytophagous).

* Herbivory includes defoliation and consumption of nectar, pollen, fruits and seeds.
* **Defoliation** is the destruction of leaves, bark, wood, roots and sap.
* It includes protozoans and animals that feed on bacteria and algae.

Animals that eat plant parts and algae are called **herbivores**.

There is a great diversity of mouthparts found in herbivores.

1. **Predation**

Predators are organisms that kill and eat animals.

Types of predation: Sit-and-wait method and prowler method.

Herbivores support carnivores.

1. **Parasitism**

Parasitism is an obligatory association between organism of two different species.

In this association one organism benefits, the **parasite**, and the other, the **host**, suffers but is seldom killed.

The parasite feeds off the body of the host, e.g. mosquito sucks blood, intestinal worms, etc.

A heavy load of parasites is an **infection** and the outcome of an infection is a **disease**.

* **Ectoparasites** live on their host, e.g. lice.
* **Endoparasites** live in their hosts, e.g. viruses.

Parasitism has evolved in a wide variety of taxonomic groups.

**KEY INNOVATIONS IN THE RADIATION OF ARTHROPODS.**

The largest and most diverse phylum with over one million species found in all habitats.

Over 1 million species have already been described and there are probably millions more still waiting discovery.

The number of insect species is not known; the estimates range from 3 to 30 million species.

Important characteristics:

1. Bilateral symmetry.
2. Body segmented into head, thorax and abdomen; in some head and thorax fuse into a cephalothorax.
3. Coelom small and filled with fluid and internal organs.
4. Jointed appendages that function in locomotion, feeding or copulatory organs.
5. Exoskeleton..

**Exoskeleton**

The exoskeleton is secreted by the epidermis, and made of protein, chitin, lipids and minerals.

In crustaceans the exoskeleton has deposits of calcium carbonate forming a shell around the animal.

Periodic molting of the exoskeleton allows growth.

The rigid exoskeleton provides attachment points to muscles.

Pairs of muscles that work antagonistically and are inserted at specific points move limbs and other parts.

**Limbs**

Arthropods use their limbs in locomotion of different types; walk, fly, swim, jump, burrow, etc.

They are made of cylindrical or flattened segments connected by joints.

The limbs of arthropods appear to be homologous. Their great diversification occurred through natural selection and other evolutionary processes.

**Insect metamorphosis.**

Metamorphosis is the change in structure and form undergone by an animal as it develops from embryo to adult.

Insects are a very successful group of organisms: exoskeleton, three body parts, three pairs of legs and the ability to fly.

Insects undergo metamorphosis. A series of molts allows the insect to grow and change.

Metamorphosis could be of two types:

* **Hemimetabolous**, in which the juvenile resembles the adult form, e.g. young cockroach and adult cockroach. The changes are minimal.
* **Holometabolous**, in which the early stages are very different from the adult, e.g. caterpillar to butterfly. It involves dramatic changes.

In holometabolous insects the different stages do not compete with each other because they occupy different environments.

Insect development is controlled by the interaction of various hormones.

* Generally an environmental factor affects neuroendocrine cells in the brain.
* Brain secretes BH hormone that stimulates the prothoracic gland to produce MH, **molting hormone or ecdysome**, which stimulates growth and molting.
* JH, juvenile hormone, maintains the larval stage and prevents metamorphosis.
* When the JH decreases the larva develops into a pupa.
* In the absence of JH, the pupa molts and becomes an adult.
* The amount of JH decreases with each successive molt.

**KEY INNOVATIONS IN THE RADIATION OF VERTEBRATES.**

Vertebrates are a subphylum members of phylum Chordata.

**Classification**

PHYLUM CHORDATA Subphylum Urochordata

Subphylum Cephalochordata

Subphylum Vertebrata

**Chordates** are coelomate animals with bilateral symmetry, segmented body, with a tube-within-a-tube body plan and three well-developed germ layers, an endoskeleton and closed circulatory system. There are about 42,000 extant species.

Chordates share with other phyla the following characteristics: coelomates with bilateral symmetry, a tube-within-a-tube body plan, endoskeleton, and a close circulatory system with a ventral heart.

Other important characteristics are the presence of jaws, membrane bound egg, limbs, and endothermy, the ability of maintain a constant body temperature by using the energy generated in metabolic reactions.

**Distinguishing characteristics of Chordates**

1. Notochord.

* Cartilaginous rod running underneath and supporting the nerve cord.
* Replaced by vertebrae in the adults of many groups.

1. Dorsal nerve cord.

* Single, hollow, dorsal, above the notochord.

1. Pharyngeal slits.

* Present in the embryo and adult of some species.

1. Post-anal tail.

* Prominent in embryos of all groups but not in all adults.

**Comparative approaches.**

**1. Hemichordata**

* Small soft-bodied coelomates with a proboscis, bilaterally symmetrical, unsegmented.
* Gill slits, with a nerve cord that is not homologous with that of chordates.
* They lack a true notochord.

**2. Urochordates or ascidians.**

* Larval stage is chordate with gills, notochord and dorsal nerve cord.
* These structures are lost in the adult stage except for the gill slits, which are present in the adult.

**3. Cephalochordates or lancelets.**

Share with the Vertebrata the following characteristics:

* Notochord, gill slits, dorsal nerve cord, metameric muscles, posterior direction of blood flow in the dorsal vessel and anterior blood flow in the ventral vessel, thyroid, homologous homeobox gene clusters. Larva similar to the Agnatha.

- Notochord extends to the anterior end (cephalochordates!) and does not end at a brain.

* Adults are suspension feeders burrowing in the sea bottom.
* Example: Branchiostoma (=Amphioxus), lancelet

**4. Vertebrates**

1. Vertebral column present; it replaces the notochord in most species.
2. Pronounce cephalization: well developed brain.
3. Cranium encloses and protects the brain.
4. Two pairs of appendages.
5. Muscles attached to the endoskeleton for movement.

**Molecular genetics**

A gene called Manx is involved in the development of the tail muscles, nerve cord and notochord.

**Jaws**

Agnathans (ostracoderms) appeared in the late Cambrian (505 m.y.a.) and did not have jaws.

The **Ostracoderms** were jawless fish, which lacked paired appendages and were encased in bony plates. Their internal skeleton was made of cartilage.

These fishes probably obtained their food by swallowing water rich in organisms and filtering it with the help of their gill.

New jawed and finned vertebrates arose during the mid-Devonian (~380 m.y.a.) using hard bony tissue for structure and defense.

Bone is made of a calcium phosphate salt

The jaws originated from gill arches.

Gill arches are bars of cartilage that support the gill tissue.

The gill-support hypothesis proposes that the first gill arch changed orientation and increased in size to produce the first jaw.

Jaws and gill support cartilage are derived from the same embryonic cells called the neural crest cells.

The muscles that move both structures are also derived from the same embryonic group of cells.

It is an evolutionary improvement that allows animal to hunt more efficiently.

**Limbs**

Fossils of fleshy-fined fish and early tetrapods are from the Devonian, about 375 million years ago.

Rhipidistians, a group of extinct fishes, evolved pectoral and pelvic appendages strong enough and flexible enough to enable them to leave drying pools to seek out those ponds that retained water.

Rhipidistians became extinct in the Permian (290-245 m.y.a.)

Data from comparative anatomy and genetics suggest that tetrapod limbs evolved from the fins of fish.

The number and arrangement of the limb bones in the limbs of fleshy-fined fossil fish and early tetrapod agree.

By the end of the Devonian (360 m.y.a.) the transition from rhipidistian fish to tetrapod amphibian had occurred.

Some similarities between early amphibians and Rhipidistians are similar shape and position of dermal skull bones and homologous fins and leg bones.

**The amniotic egg and endothermy**

The hard-shelled egg is a major evolutionary innovation that appeared in the Carboniferous.

* It first appeared in **reptiles**.
* It frees the reptiles from reproductive dependence on water and allowed them to become fully terrestrial.

Endothermy allows organisms to maintain a high body temperature using heat supplied by the oxidation of food.

It permits high level of activity in cold habitats and sustained fast movement.

Large amount of food is required.

Ectotherms are inactive or slow in cold weather and cannot maintain fast movement for a long time.

Genetic studies in endothermic fish suggest that endothermy evolved independently at least three times in fish and it is associated with cold habitats.

**HUMAN EVOLUTION**

Hominids are members of the **family Hominidae**, which includes several species of Australophithecus and Homo.

Humans (hominids) are adapted to bipedal terrestrial locomotion and have…

1. Longer hind limbs than forelimbs.
2. Free hands and refined manipulatory control.
3. Large brain relative to body size.
4. Small face.
5. Short canines.
6. Less body hair.
7. Other dental and skeletal features.

Three species of gracile australopithecines have been identified.

* They lived in East Africa from 4.1 to 2.4 million years ago.

About three species of robust australopithecines have been recognized.

* They lived in East Africa between 2.7 and 1.0 million years ago.
* These species had more massive teeth and jaws.

**Out of Africa**

The earliest species of Homo (H. habilis and H. erectus) date from 2.4 to 250,000 million years ago.

Modern man, Homo sapiens, dates from about 130,000 years ago.

* For about 80,000 years thereafter, H. sapiens resided in Africa, and H. erectus in Africa, and H. neanderthalensis in Europe.
* By about 40,000 years ago, H. erectus and H. neanderthalensis had disappeared, and H. sapiens occupied all of Eurasia and Australia.

Two theories:

1. Homo sapiens interbred with the other two species and modern H. sapiens is a blend of the three species, original H. sapiens, H. erectus and H. neanderthalensis.
2. Homo sapiens originated in Africa, then migrated to other parts of the world. There was no interbreeding with other species of Homo. H. sapiens outcompeted the other two species and remained the only surviving species.

DNA studies support the hypothesis that the genus Homo evolved in Africa and then migrated to Europe and Asia, eventually to the New World.

Chapter 38 **ANIMAL FORM AND FUNCTION**

**One definition of adaptation.**

An adaptation is a trait that allows individuals to produce more offspring in a particular environment than individuals without the trait.

Adaptations are the result of natural selection.

The environment does the selecting.

The genetic characteristics of the population changes with time; the genetic characteristics of the individual do not change with time.

Sometimes the phenotype of an individual changes with the environment. This is called acclimation.

* E.g. North America wood frogs produce molecules that protect their cells from being damaged by the formation of ice crystals. The ability to produce these molecules is an adaptation; the actual production of the molecules is an acclimation.

Organisms are adapted to their environment. All are successful. Human physiology is not better than clam physiology. There is no better physiology.

**NATURE OF ADAPTATION**

Not every structure and feature is adaptive. There are features that were present in ancestral population but are not currently adaptive.

* Vestigial structures e. g. tailbone, goose bumps, appendix in humans.
* Pelvic bones in whales, vestigial eyes in cave fish.
* Some structures appear early in the development and remain in the adult, e.g. human males have rudimentary mammary glands.

**Genetic constraints.**

Genetic correlation: selection on alleles for one trait (increased beak depth), caused a correlated and non-optimal increase in another trait (increase beak width).

Adaptations are constrained by genetic correlation with other traits, lack of genetic variations, historical constrains and historical constraints.

**Historical constraints**

Traits have evolved from previously existing traits., e. g. the ear bones evolved from part of the jaw and brain case in early mammals.

Natural selection act on structures that have a function and evolve them into structures with different functions.

**Trade-offs**

In reproduction, females make a trade off between the number of eggs and the size of the eggs they produce. If the number of offspring is large, the mother can provide less food.

It is not possible for an organism to be perfectly adapted to all aspects of the environment all the time, e.g. sweating to cool off may cause dehydration.

Adaptations are compromises limited by genetic and historical constraints.

**TISSUES, ORGANS AND SYSTEMS**

The form and function of body structures are correlated.

A **tissue** is made of a group of closely associated, similar cells adapted to carry out specific functions.

**1. Epithelial tissue** (epithelium) consists of fitted tightly together to form a continuous layer or sheet.

It covers body surfaces and lines cavities.

It functions in protection, absorption, secretion and sensation.

The outer surface of this tissue is typically exposed because it lines cavities.

The cell layer is attached to the underlying tissue by a non-cellular membrane, the **basement membrane**, made polysaccharides and fibers

Epithelial cells may be organized or differentiated into epidermis (skin), membranes, glands and sensory receptors.

Epithelial cells are **cuboidal, columnar** or **squamous**.

**2. Connective tissue** joins other tissues of the body, supports the body and its organs, and protects underlying organs.

It consists of relatively few cells, separated by an intercellular substance.

Typically the intercellular substance consists of fibers made of proteins, scattered through a matrix, a thin gel made of polysaccharides.

Different kinds of connective tissue will have different kinds of fibers and matrices.

The nature and function of each kind of connective tissue is determined in part by the structure and properties of the intercellular substance.

Intercellular substance contains...

1. **Collagen fibers** made of the protein **collagen**, the most abundant protein in the body.

* Collagen fibers are wavy, flexible and resistant to stretching.

1. **Elastic fibers** are made of the protein **elastin** and branch and fuse to form a network.

* They return to their original form after the stretching force is removed.

1. **Reticular fibers** are very small-branched fibers that form delicate networks.

* They are made of **collagen** and **glycoprotein**.

**Types of connective tissues**

1. **Loose (areolar) connective** tissue is found everywhere in the body. It supports organs and is a reservoir of salts and fluid. Together with adipose tissue, it forms the subcutaneous layer that attaches the skin to muscles and other structures beneath. The matrix is gel-like and contains all three fiber types, mast cells, fibroblasts and macrophages.
2. **Dense connective** tissue is found in the tendons, ligaments and dermis of the skin. It supports and transmits mechanical forces. Dense connective tissue may be **regular** or **irregular** depending on the arrangement of the collagen fibers. The matrix is made primarily of collagen fibers and a few elastin fibers. Fibroblasts are the major cellular component.
3. **Elastic connective** tissue is found in structures that must expand like lungs and large arteries. It consists of bundles of parallel elastic fibers. Fibroblasts present.
4. **Adipose tissue** is found in the subcutaneous layer and in patches around some internal organs. It stores food, insulates the body and provides additional support to organs like kidneys and mammary glands. Adipocytes store fat.
5. **Cartilage** makes the skeleton of chondrichthyes; it is found at the end of bones of other vertebrates, and provides flexible support to organs like the trachea, ears and nose. It resists compression.

* **Chondrocytes** (mature cells) found in lacunae.
* This tissue lacks nerves, lymph and blood vessels.
* Chondrocytes are nourished by diffusion through the matrix.
* Chondrocytes remain alive and lie in lacunae.

1. **Bone** makes the skeleton most vertebrates. It supports and protects internal organs, acts as a reservoir of calcium, and place for muscle attachment.

* **Osteocytes** (mature cells) are found in lacunae.
* In compact bone, the lacunae are arranged in concentric circles around the Haversian canal, through which capillaries and nerves pass.
* Compact bone consists of units called osteons.
* This tissue is rich in blood vessels.

1. **Blood** is found within the heart and blood vessels. In its liquid matrix transports cells (RBC, WBC, platelets) wastes, nutrients, and other materials.

**3. Muscle tissue** is specialized to contract.

Each cell is an elongated fiber containing many myofibrils.

**Myofibrils** are made of the protein **actin** and **myosin**.

* **Skeletal muscles** are striated and under voluntary control. Striations or bands reflect the alignment of the filaments responsible for contraction of the muscle cells. The cells are multinucleated.
* **Smooth muscles** contract involuntarily, lack striations and cells are uninucleate.
* **Cardiac muscles** are striated and act involuntarily. Cardiac muscle cells branch and the fibers are joined end to end at the intercalated disc. They are found only in the heart.

**4. Nervous tissue** is composed of **neurons**, which are cells specialized for conducting nerve impulses, and **glial cells**, which are supporting cells.

* A typical neuron consists of a cell body, dendrites and an axon.
* Neurons communicate at junctions called **synapses**.
* A nerve consists of many neurons bound together by connective tissue.
* The nervous tissue also contains various types of supporting cells that insulate and protect the delicate neurons.

**ORGANS AND SYSTEMS**

An **organ** consists of a group of tissues associated into a differentiated structure to perform a specific function or functions in the body.

Organs are associated together into **organ systems**. Organ systems perform together a specialized and vital function in the body.

Organs and organ systems work together to maintain appropriate conditions in the body, a constant internal environment called **homeostasis**.

**Homeostatic mechanisms** that maintain homeostasis may involve several organ systems that work together.

**BODY SIZE AND SCALING**

As cells become larger, the volume increases at a greater rate than the surface area.

Above a critical size, the number of molecules needed by the cell could not be transported into the cell fast enough to sustain its needs.

Once inside the cell molecules must be transported to their place of utilization.

Cells divide in order to maintain an optimal ratio of surface to volume.

Sizes and shape of cells are relate to the functions they perform.

The **micrometer** is the unit normally used to measure cells.

* 1μm = 1 millionth of a meter (10-6) or 1 thousandths of a millimeter (0.001 ml).
* The **nanometer** is used to measure cellular organelles.
* 1nm = 1 billionth of a meter (10-9) or 1 thousandths of a μm.
* Starting with the meter, the **ml**, **μm** and **nm** are 0.001 of the previous unit.

**Metabolic rate** is the overall rate of energy consumption by an individual.

Because energy production in animals depends on aerobic respiration, metabolic rate is often measured in terms of oxygen consumption; the units used are **ml O2 consumed per hour**.

**Basal metabolic rate** (BMR) is the rate at which oxygen is consumed at rest, with an empty stomach, in the absence of temperature or water stress.

**Mass-specific metabolic rate** is the rate per gram of tissue.

* It is expressed in **ml O2/gram of tissue/hour**.

Large animal have low metabolic rate because they have relatively small surface area for exchanging the oxygen and nutrients required to support metabolism.

The large surface area of small animals means that they lose heat very fast.

**Adaptations that increase the surface area**

Flattened, folded and branched structures have very high surface relative to its volume.

* Flattened surfaces: gills of fish.
* Folded surfaces: microvilli increase the surface area of the cell.
* Branched structures: capillary network increase diffusion.

**Allometry**

Allometry is the differential growth of body parts. It means that body size and some anatomical or physiological feature do not change in the same proportion.

* e. g. large animals have larger bones than small animals, but their bones are not only large but also disproportionately larger.

Allometry is an adaptation to certain environment or lifestyle. E. g. Dogs have larger hearts than cats of the same size. Dogs run down their prey while cats jump or sprint to hunt. Stamina requires a larger heart to pump blood to the muscles during long-distance chase.

**HOMEOSTASIS**

Homeostasis is the constant physical and chemical conditions in cells, tissues and the body in general.

There are many mechanisms for achieving homeostasis.

Animals have an optimal value or preferred point for functioning well.

Blood pH, nutrient availability, body temperature, etc. are some of the parameters that have to be maintained within certain range around the optimal point in order to maintain homeostasis.

Epithelial tissue is located at the interface between the external and internal environment.

Epithelial cell membranes have many embedded proteins that control the flow in and out of the cells.

Homeostasis is important to maintain the ideal conditions for enzyme function.

Temperature, pH, and other physical and chemical conditions have dramatic effects on protein structure. Enzymes work within a narrow range of conditions.

**Gaining and losing heat**

There are two general categories based on how animal obtain heat:

* **Endotherms** produce heat in their own tissues and have higher basal metabolic rate.
* **Ectotherms** obtain heat mostly from the environment and have low basal metabolic rate.

Some ectotherms can generate heat to keep warm certain organs of their body.

Many ectotherms and most endotherms have specialized heat-producing tissue called **brown adipose tissue**.

* This tissue has many mitochondria and large amount of stored fats.
* When fats are oxidized no ATP is produced but much heat is released.
* Brown adipose tissue releases about 10 times more heat than other body tissues.
* It is an adaptation of small endotherms to achieve the required body temperature.

**Exchanging heat with the environment**

Heat flows from areas of higher temperature to areas of lower temperature.

All organisms exchange heat with the environment.

There are four ways to exchange heat with the environment:

* **Conduction**: the direct transfer of heat between two objects that are in direct physical contact.

e.g. you sitting directly on a metal stand during a football game in winter.

* **Convection**: when air or water moves over the body, heat is removed from the body. The air or water in contact with the body is constantly replaced and not allowed to warm up.
* **Radiation**: the transfer of heat between two bodies that are not in direct contact.
* **Evaporation**: when a liquid is converted into a gas, e.g. when you sweat, the evaporation of the sweat removes heat from your skin.

Air is a poor conductor of heat and, therefore, it is a good insulator.

Animals have developed methods of trapping air to conserve heat, e. g. birds have feathers and mammals have fur.

In water there is no heat lost due to evaporation; radiation is poorly conducted in water.

To conserve heat,

* otters have water repellent fur that traps air next to the skin.
* whales, seals and other marine mammals have a thick layer of fat.

Countercurrent heat exchanger is found in several groups of aquatic animals and mammals and birds that live in cold habitats.

* The veins and arteries are next to each other in the limbs or tongue.
* Arteries carry warm blood from inside the body to the extremities.
* The heat flows from the arteries to the veins and is returned to the body instead of being lost to the surroundings.

To regulate body temperature, the body has a **sensor** that monitors some aspect of the environment.

An **integrator** is part of the nervous system that evaluates the incoming sensory information and decides if a response is necessary.

An **effector** is any structure that helps to restore the desired internal condition.

Endotherms maintain enzyme activities at all times. Mammals and birds remain active in winter and at night. They sustain high levels of aerobic activity like running and flying. This is done at a cost of energy. Endotherms need high levels of energy-rich food.

Ectotherms thrive with much less food. They can use a greater proportion of their total energy intake to support reproduction. They generally live in warm habitats.

Chapter 38 **WATER AND ELECTROLYTE BALANCE IN ANIMALS**

Maintaining water balance is an important element in homeostasis.

The most abundant solutes in many animals are Na+, K+, Cl-, and Ca2+.

These substances are called electrolytes because they become ionized when dissolved in water.

Maintaining electrolyte balance is essential to survival. In humans, electrolyte imbalance can result in muscle spasm, confusion, irregular heart rhythms, fatigue, or even paralysis.

**OSMOTIC STRESS AND OSMOREGULATION**

**Diffusion** is the movement of **solutes** from the region of higher concentration to the region of lower concentration.

**Osmosis** is the movement of **water** from the area of higher concentration to area of lower concentration.

**Osmolarity** is the concentration of a substance expressed in **moles per liter**, mol/l.

**WATER BALANCE IN FRESHWATER, MARINE, AND TERRESTRIAL ENVIRONMENTS.**

The epithelial cells on the surface of the gills are exposed to the surrounding water.

The exposed cell membranes are semipermeable.

There is great difference between the concentration of solutes in the cell and outside the cell.

**In freshwater fish...**

* The gill cells are hypertonic relative to the surrounding water, therefore, the cells gain water through osmosis.
* Cells and tissues that are gaining water are under **osmotic stress**.
* **Osmotic stress** means that the concentration of solutes in the cells and tissues is abnormal.
* The ability to achieve electrolyte balance is called **osmoregulation**.
* Freshwater fish excrete large amounts of water in the urine and do not drink water.

**In saltwater fish...**

* The cells are hypotonic relative to the surrounding seawater.
* Water tends to flow out of the gill cells.
* The cells run the risk of **plasmolysis**, which is shriveling and dying.
* Saltwater fish secrete large amounts of salt and drink lots of water.

**Land animals...**

Land animals constantly lose water to the environment through evaporation.

Gas exchange occurs through the wet surfaces of the lung epithelium.

Sweating and panting in order to keep their body cool also loses water.

**Electrolyte balance in freshwater, marine and terrestrial environments.**

1. **In freshwater fish...**

* Freshwater is hypotonic to the cell.
* Ions tend to move out of the cell into the surrounding water.
* Electrolytes lost must be replace by eating and by active transport from the surrounding water.

1. **In saltwater fish...**

* Seawater is hypertonic to the cells.
* Ions move in from the surrounding water. Most of this gain occurs in the gills.
* They also obtain many ions in their food and in the water they drink.
* Excess ions must secreted.

1. **Land animals...**

* Land animals gain electrolytes in food and lose electrolytes in sweat.
* Depending on conditions at the time, land animals must conserve or excrete electrolytes to maintain homeostasis.

**Water and electrolyte balance in aquatic environments.**

**Shark rectal gland**

Shark tissues are isotonic to the saltwater.

The cells and extracellular fluids contain large amounts of urea and trimethylamine oxide (TMAO), and moderate concentrations of sodium, potassium and chloride.

Sharks still have to excrete sodium and chloride because these substances diffuse through the gills.

Sodium-potassium pumps are located on the basolateral side of epithelial cells in this gland.

These pumps establish an electrochemical gradient that carries Na+ and Cl- from the blood into the lumen of the gland where it is excreted.

**The role of Na+/K+-ATPase**

Na+/K+-ATPase is found in the membranes of the epithelial cells lining the lumen of the shark's rectal gland.

* **Na+/K+-ATPase** pumps Na+ out of the cells and K+ into the cell.
* This activity creates an electrochemical gradient that favors the diffusion of Na+ back into the cell.
* **Cotransporters** are membrane proteins that transport more than one type of ions.
* A Na+/Cl- cotransporter brings these two ions from the extracellular fluid into the epithelial cells across their basolateral surfaces.
* Na+ are pumped back out of the cell. Cl- ions build up inside the cell.
* A chloride channel located in the apical membrane of the epithelial cells (facing the lumen) allows Cl- to diffuse out along its concentration gradient.
* Na+ diffuse into the lumen of the gland, following the concentration gradient by passing in between the spaces between the cells.
* The solution in the lumen, the interior cavity of the gland, empties into the environment.

The mechanism just described is widespread in animals.

Marine birds and reptiles have salt-excreting glands in their nostrils. These glands function much like the shark rectal gland.

Salt constantly diffuses into the cells of the gills of marine fishes. The cells are hypotonic to the salt water. Specialized salt-excreting cells similar to those found in the rectal gland, are found in the epithelium of the gills. These cells excrete excess salt.

The kidneys of mammals have cells with pumps, cotransporters and channels, which transport salt out of the kidney.

**Osmoregulation in salmons**

Freshwater fish do not drink and secrete large amounts of diluted urine.

Studies have shown that salmon species have two populations of cells in their gills

* Individuals living in saltwater have a large population of chloride-excreting cells at the base of the gill filaments.
* Salmon living in fresh water had salt-excreting cells in the lamellae that extend from the gill filaments.
* Salmon migrating into saltwater showed chloride-excreting cells at the base of the gill filaments.
* Salmon migrating into freshwater showed an increase of chloride-excreting cells in the gill lamellae.

The chloride-cell-switch hypothesis implies that salmon sense changes in the osmolarity of their environment and respond by producing or destroying the appropriate populations of chloride cells.

The actual mechanism is still to be elucidated.

**WATER AND ELECTROLYTE BALANCE IN TERRESTRIAL INVERTEBRATES.**

Invertebrates living in dry environment rarely drink water and are under water stress.

**Insects minimize water loss from their body surface**

Water loss is a byproduct of respiration.

Their exoskeleton is covered with a waxy substance that prevents evaporations.

The waxy layer is made of nitrogen-containing polysaccharides called **chitin**, and proteins.

Insects have a **tracheal system** of tubes used in respiration. This system connects to the atmosphere through openings called **spiracles**.

Muscles just inside the spiracle can open or close the pore depending on the atmospheric conditions.

**Types of nitrogenous wastes.**

Nitrogenous wastes are the products of deamination of amino acids.

* Ammonia is highly toxic and it is usually converted to uric acid or urea.
* Uric acid is the product of nucleic acid and amino acid breakdown. It is excreted in the form of a crystalline paste with little water loss.
* Birds, insects and some reptile excrete uric acid.
* Amphibians and mammals excrete urea.

The type of waste excrete by animals is correlated to the amount of water stress the animal has to endure.

* Animals living in dry habitats secrete uric acid because they must conserve water.

**The excretory system**

To maintain homeostasis, insects must regulate the electrolyte balance in their blood-like fluid called **hemolymph**.

Nutrients pass from the hemolymph into the cells and nitrogenous wastes pass from the cell to the hemolymph.

**Malpighian tubules** are found insects and spiders.

* Blind end tubules that stretch into the **hemocoel**, the body cavity.
* Their cells transfer wastes and salts from the hemolymph to the lumen of the tubule by diffusion and active transport.
* They empty into the intestine.
* Water and some salts are reabsorbed.

K+ concentration inside the tubules is high compared to the hemolymph. K+ accumulate against the concentration gradient.

The high concentration of potassium brings water into the tubules by osmosis.

The "pre-urine" in the tubules flows into the hindgut where it mixes with the material coming from the anterior digestive tract.

A large amount of water is reabsorbed in this part of the gut and the urine becomes very concentrated.

* In desert species up to 95% of the water is reabsorbed.

Na+/K+-ATPase moves ions from the lumen of the gut into the hemolymph.

There are also chloride pumps that transport Cl- against the concentration gradient.

The formation of the pre-urine is not selective, however, the formation of the urine through reabsorption is highly selective.

Water and electrolytes are reabsorbed in order to maintain homeostasis.

Waste products do not pass through the rectal membrane back into the hemolymph but remain in the urine and feces.

**WATER AND ELECTROLYTE BALANCE IN TERRESTRIAL VERTEBRATES.**

The functions of the excretory system are

* Regulation of body fluids by osmoregulation.
* Excretion of metabolic waste.

The body maintains a constant osmotic pressure by actively regulating the concentration of solutes in the body fluids: **osmoregulation**.

**Excretion** is the process of ridding the body of metabolic wastes including water.

* It is different from elimination of feces or defecation.

**MAMMALIAN URINARY SYSTEM**

**Kidney** produces urine.

**Ureter** brings urine to the urinary bladder.

**Urinary** bladder stores urine temporarily.

**Urethra** leads the urine to the outside.

The outer region of the kidney is called the **renal cortex** and the inner region the **renal medulla**.

The renal medulla contains a number of cone-shaped structures called **renal pyramids**.

At the tip of each renal pyramid is a **renal papilla** into which the collecting ducts open.

The **renal pelvis** is a pyramidal chamber that collects and leads the urine to the ureter.

The **nephron** is the functional unit of the kidney.

1. The filtrate passes from **capillaries → Bowman's capsule → proximal convoluted tubule → loop of Henle → distal convoluted tubule → collecting duct → renal pelvis.**

2. Blood circulates through the kidney in the following sequence:

**Renal artery → afferent arteriole → capillaries of glomerulus → efferent arteriole →**

**peritubular capillaries → small veins → renal veins.**

3. **Filtration**, **reabsorption** and **secretion** produce urine.

* Filtration is not selective with regard to ions and small molecules.
* Reabsorption is highly selective.
* Some substances are actively secreted from the blood.

Hydrostatic pressure in glomerular capillaries is higher than in other capillaries. Efferent arteriole is smaller than the afferent arteriole.

The high pressure forces about 10% of the plasma out of the capillaries into Bowman's capsule.

Glomerular capillaries are highly permeable with numerous small pores (fenestration) present between the endothelial cells.

There is a large permeable surface provided by the highly coiled capillaries.

Capillary epithelium and **podocytes** make up the filtration membrane.

Podocytes make the wall of Bowman's capsule and have elongated processes ("feet") which cover the surface of most capillaries.

**Filtration slits** separate the foot processes of adjacent podocytes.

The force to perform filtration comes from the blood pressure created by the heart and the closed circulatory system of vertebrates.

* The filtration membrane holds back large proteins and RBCs.
* Glucose, amino acids, ions and urea pass through and become part of the **filtrate**.

Reabsorption is highly selective.

The proximal tubule is involved in the active transport of molecules in and out of the filtrate.

**Microvilli** are present on the epithelial cells facing the lumen side.

Some substances are actively secreted from the blood into the filtrate.

Hydrogen, ammonium and potassium ions are actively secreted when their concentration is too high.

Filtrate is concentrated as it passes through the renal tubule.

The process depends on the salt concentration in the interstitial fluid in the kidney medulla.

The interstitial fluid has higher salt concentration around the loop of Henle.

There is a counterflow of fluid through the two limbs of the loop of Henle.

Water is drawn by osmosis from the filtrate as it passes through the collecting ducts and it concentrates the filtrate.

**Mechanism: reabsorption in the proximal tubule.**

The microvilli in the apical membrane contain several cotransporters and pumps including Na+/K+-ATPase.

Na+/K+-ATPase in the basolateral membrane, facing the blood vessels near the proximal tubule, pumps Na+ from the cell into the capillaries.

This creates a strong concentration gradient that brings Na+ into the cell from the filtrate, by means of cotransporters.

These cotransporters bind Na+ to glucose, amino acids or Cl-. The binding of sodium to these molecules allows them to flow into the cells against the concentration gradient.

Water follows the ions by osmosis.

Water leaves the proximal tubule through membrane proteins called **aquaporins**.

**Osmotic gradient in the loop of Henle.**

The filtrate then passes from the proximal tubule to the loop of Henle.

The osmolarity is low in the cortex of the kidney and high in the medulla. The osmolarity in the tissues surrounding the loop of Henle mirrors the osmolarity inside the tubule. There is a strong gradient between the two regions.

The descending portion of the loop is highly permeable to water but the ascending portion of the loop is impermeable to water.

The filtrate becomes more and more concentrated as it descends.

In the thin portion of the ascending limb, Na+ and Cl- are reabsorbed. These ions flow out of the tubule following the concentration gradient.

Na+ and Cl- are actively transported out of the thicker upper portion of the tubule.

Capillaries known as the **vasa recta** remove some of the water that diffuses from the filtrate into the interstitial fluid.

The vasa recta are extensions of the efferent arteriole that extend deeply into the medulla and then return fluid to the veins draining the kidney.

Urine is about 96% water, 2.5% urea, 1.5% salts and traces of other substances.

Urinalysis is the physical, chemical and microscopic examination of urine.

Filtration rate: 180 liter/day (45 gallons/day).

About 1.5 liter of urine is excrete every 24 hours. The rest of the fluid, about 99% of filtrate, is reabsorbed.

Urine volume is regulated by the hormone **ADH** (antidiuretic hormone), which is released by the posterior lobe of the pituitary gland in response to an increase in osmotic concentration of the blood, caused by dehydration.

* Low fluid intake decreases blood volume and increase osmotic pressure of blood.
* ADH increases the permeability of collecting ducts to water, increasing reabsorption and decreasing water excretion.

**Aldosterone** increases sodium reabsorption by distal and collecting ducts.

* Sodium is the most abundant extracellular ion.
* It is produced by the adrenal gland as a reaction to a drop in blood pressure.
* Decrease on blood pressure is caused by a decrease in blood volume due to dehydration.

Chapter 40 **ANIMAL NUTRITION**

As food moves down through the digestive system, its chemical and physical characteristics changes dramatically.

Complex raw materials are broken down into simpler usable components. Food is processed.

Processing food includes ingestion, digestion, absorption of wastes and elimination of wastes.

**NUTRITION REQUIREMENTS.**

**Nutrition** is processes of taking and assimilating food.

**Nutrients** are substances used as a source of energy, in metabolic processes and as building blocks in the growth and repair of tissues.

Animals need to general types of nutrients:

* reduced carbon compounds that can be oxidized to produce ATP,
* the elements and molecules that are needed to synthesize body components and sustain cells.

The Food and Nutrition Board of the National Academy of Sciences publishes the recommended daily allowances of essential nutrients (RDA).

**Proteins.** There are 20 amino acids required to manufacture proteins. Humans can synthesize 12. The other 8 must be obtained from food. These 8 AA are called essential amino acids.

**Vitamins.** Vitamins are essential for normal metabolism, growth and development of the body. They are required in minute. Some work as coenzymes in important reactions like the synthesis of DNA, clotting factors, collagen and hemoglobin. We do not understand all of the biochemical roles played by vitamins

**Essential minerals or elements**. Minerals are inorganic ions needed to maintain body fluid balance, components of proteins, cytochromes, hormones and other metabolites, activators of enzymes, involved in nerve impulse, and other functions. Some are needed in large amounts like Ca and P, other is small amounts like Fe and Mg.

**Electrolytes**. These substances are ionized in solution. They are involved in osmoregulation and are required for normal membrane function. Sodium, potassium and chloride are the most common ions in the body.

**Nutrition and athletic performance**

Glycogen is a polysaccharide of glucose.

Glucose is preferred starting compound for the production of ATP in aerobic respiration.

Most of the body glycogen is stored in the skeletal muscles and liver.

Glucose from the liver enters the blood stream and is delivered to cells that are doing work.

Glucose in the muscle cells is used to manufacture ATP.

Experiments have shown that a diet high in carbohydrates supports optimal performance.

Studies have rejected the hypothesis that ingesting sugars right before a contest improve performance.

**OBTAINING FOOD: THE STRUCTURE AND FUNCTION OF BEAKS, TEETH AND MOUTHPARTS**.

Among animal species there is a strong correlation between the size and shape of mouthparts and their function in capturing and processing food.

* Snake jaws are held together by elastic ligaments that allow the mouth to open very wide.
* Maggots lack mouth parts and swallow food whole.
* Insects show a large variety of mouthparts that allow them to exploit different food sources.
* The teeth of mammals are specialized for tearing, crushing and biting.
* Fish show a variety of mouthparts related to their diet: algae, fish, worms, plankton, etc.

**DIGESTION**

**Ingestion** is the process of taking food into the mouth and swallowing it.

**Digestion** breaks down food into simpler components.

Simpler molecules pass through the lining of the small intestine into the blood by **absorption**.

Undigested food is passed out through the process of **egestion** in simple animals or **elimination** in more complex animals.

MOUTH

Mechanical digestion and enzymatic digestion of food begins in the mouth.

Teeth are specialized to perform different functions in different animal groups.

* Fish, reptiles and amphibians do not have specialized teeth.
* Mammals have **incisors** for biting, **canines** for tearing, and **premolars** and **molars** for grinding.
* Each tooth consists of an outer coat of **enamel**, the inner **dentine** and the **pulp** cavity where capillaries and nerves are located.

Three pairs of **salivary glands** in the mouth region secrete about a liter of saliva containing **salivary amylase**, which begins starch digestion.

Salivary amylase breaks down polysaccharides (starch, glycogen, etc.) into maltose and small polysaccharides.

PHARYNX AND ESOPHAGUS

The pharynx or throat and the esophagus conduct food to the stomach.

The pharynx is a muscular tube that connects the mouth with the esophagus.

The esophagus is long muscular organ. The upper third is made of skeletal muscles, the lower third of smooth muscles, and the middle third is a mixture of the two kinds of muscles.

Peristaltic movements push the food **bolus** toward the stomach.

During swallowing, the **epiglottis** closes the entrance to the larynx.

STOMACH

The stomach is muscular, distensible bag-like portion of the alimentary canal

Mechanical and chemical digestion continues in the stomach.

A sphincter or ring of muscles normally closes the entrance to the stomach.

Folds in the stomach wall are called **rugae** and are lined with a simple columnar epithelium.

Rugae smooth out when food enters the stomach to increase its capacity.

Tiny gastric glands in the stomach wall secrete chemicals:

* **Parietal cells** secrete **HCl** and **intrinsic factor** for the absorption of vitamin B.
* **Chief cells** secrete **pepsinogen** which is converted to **pepsin** when comes in contact with HCl.
* **Pepsin** breaks down proteins.

Parietal cells contain the enzyme carbonic anhydrase, which catalyzes the formation of H2CO3 from CO2 and H2O

H2CO3 dissociates immediately into HCO3- and H+.

HCO3- passes to the blood stream and H+ passes to the stomach lumen by means of a proton pump.

Cl- found in the blood pass into the parietal cells and from there into the lumen via chloride channels

The gastric mucosa secretes an alkaline mucous that protects the stomach.

Epithelial cells of the lining of the stomach fit tightly together preventing gastric juice from leaking between them.

When part of the stomach is digested, a **peptic ulcer** develops. These sores or ulcers can also occur in the esophagus or in the duodenum.

**Chyme** is partially digested food in the stomach.

When digestion is finished in the stomach, peristaltic movements propel the chyme through the exit opening controlled by a sphincter, the **pylorus**.

SMALL INTESTINE

Most enzymatic digestion takes place in the small intestine.

The wall consists of folds (**plicae**) and tiny finger-like projections called **villi**.

**Microvilli** are elongations of the cell membrane of the villi. There are about 600 microvilli on each villus.

It consists of three regions:

1. **Duodenum** is the ~25 cm closest to the stomach.

* It receives the chyme from the stomach and secretions from the pancreas and liver.

2. **Jejunum** begins at an abrupt bend of the small intestine.

* ~2.5 m (8 ft) long.
* Most absorption occurs here.
* Plicae and villi are prominent but gradually decrease along its length.

3. **Ileum** is about ~3.2 m long and continues absorption.

The **ileocecal valve** controls the passage of the remnant of digestion into the large intestine.

LARGE INTESTINE or COLON

The large intestine is about 1.3 to 1.5 m long.

Most of the nutrients in the chyme have been absorbed by the time it reaches the large intestine.

Large intestine absorbs water, vitamins and sodium ions, and eliminates wastes (defecation).

Bacteria act on the unabsorbed material and produce vitamins K and B, which are also absorbed.

The **caecum** and **vermiform appendix** are located below the junction of the small and large intestine.

* Their functions are unknown in humans.
* Both are functional in some herbivores.

The parts of the large intestine are known as the caecum, ascending colon, transverse colon, descending colon, sigmoid colon, rectum and anus.

**Elimination** is the term used for getting rid of digestive waste.

**Excretion** is the process of getting rid of metabolic waste. In mammals it mostly happens in the kidneys and lungs.

DIGESTIVE GLANDS

**Liver**

It is the largest and most complex organ of the body.

A liver cell carries more than 500 metabolic reactions.

Digestive functions:

1. Produces bile.
2. Helps in homeostasis by adding and removing nutrients from the blood.
3. Converts excess glucose to glycogen, and stores it.
4. Converts amino acids to fatty acids and urea.
5. Stores iron and certain vitamins.
6. Detoxifies drugs and poisons that enter the blood.

**Bile** consists of water, salts, pigments, cholesterol, and the phospholipid lethicin.

* Bile is stored in the gall bladder, which releases it into the duodenum as needed.
* Bile emulsifies fats so they can be acted upon by lipase.

**Pancreas**

Pancreas secretes digestive enzymes and hormones that regulate the level of glucose in the blood.

**Protein digestion**.

* **Trypsinogen** is an inactive enzyme that is acted upon by **enterokinase** and forms trypsin.
* **Trypsin** then activates chymotrypsin and carboxypeptidase.
* **Pepsin, trypsin** and **chymotrypsin** break the internal bonds of proteins and polypeptides resulting into dipeptides.
* **Carboxypeptidases** remove amino acids from the carboxyl end of polypeptide chains.
* **Aminopeptidases** and **dipeptidases** remove amino acids from the amino end of the chain or split small peptides to amino acids.

**Lipid digestion.**

* **Lipases** break down fats into monoglycerides, diglycerides, glycerol and fatty acids.
* Undigested triacylglycerols (triglycerides) are absorbed in small amounts.

**Carbohydrate digestion**

* **Pancreatic amylase** converts undigested polysaccharides to maltose.
* **Maltase** splits the disaccharide maltose into two glucose molecules.
* **Sucrase** converts the disaccharide sucrose to glucose and fructose.
* **Lactase** splits the milk sugar lactose, a disaccharide, into glucose and galactose.

Most digestive enzymes are produced only when food is present in the digestive tract.

Salivary secretion is controlled entirely by the nervous system.

The nervous system and hormones control secretion of other digestive enzymes.

ABSORPTION

Only a few substances like water, simple sugars, salts, alcohol and certain drugs are small enough to be absorbed through the stomach wall.

Most absorption occurs in the small intestine.

To reach the blood, a nutrient molecule must pass through an epithelial cell in the wall of the small intestine and through a cell of the blood or lymph vessel lining.

The absorption of glucose and amino acids is coupled with the active transport of sodium.

**Na+/glucose cotransporters** are found on the apical membrane of the microvilli.

* Na+ follow a concentration gradient from the lumen of the intestine into the epithelial cells on the intestinal wall by means of the Na+/glucose cotransporters.
* Water follows by osmosis.

Absorption of fats.

* **Micelles** are soluble complexes of fatty acids and monoacyl-glycerols combined with bile salts.
* Micelles transport the fatty acid to the epithelium. Micelles are soluble in the phospholips of the plasma membrane.
* Glycerol, fatty acids and monoacylglycerols are absorbed into the epithelial cells by diffusion. Micelles become free to pick up more fatty acids and glycerol.
* In the epithelial cell, glycerol and fatty acids resynthesize to form triacylglycerols, which along with phospholipids and cholesterol form protein covered globules called **chylomicrons**.
* Chylomicrons pass out of the cell into the **lacteal** by diffusion.
* The lymph transports the chylomicrons to the blood.

**NUTRITIONAL HOMEOSTASIS**

**Glucose, a case study**

* About 1 million little clusters of cells scattered throughout the pancreas.
* **Alpha cells** secrete the hormone **glucagon**, which increases the concentration of glucose in the blood by breaking down glycogen in the liver and skeletal muscles.
* Cells that store lipids break down fatty acids in response to glucagon
* **Beta cells** secrete the hormone **insulin**, which lowers the concentration of glucose in the blood.
* Insulin stimulates cells to take up glucose, inhibits the release of glucose from the liver, stimulates the deposit of fat in the adipose tissue, and inhibits the use of amino acids.
* Insulin binds to receptors in the cell membrane and glucose uptake increases.
* Glucose concentration regulates the secretion of glucagon and insulin.

**Diabetes mellitus** is an endocrine disorder.

* Type II diabetics produce enough insulin but the receptors on target cells cannot bind to it.
* Type I diabetics do not produce enough insulin. The immune system or a virus destroys beta cells.

Chapter 41 **GAS ESCHANGE AND CIRCULATION**

The production of ATP in the mitochondria requires oxygen and the elimination of carbon dioxide.

**AIR AND WATER AS A RESPIRATORY MEDIA**

**In the air.**

Gas exchange between the environment and mitochondria depends on diffusion.

* Under normal conditions, oxygen concentration is relatively high in the environment and low in the cells.
* Under normal conditions, carbon dioxide concentration is relatively high in the cells and low in the environment.

Oxygen makes 21% of the atmosphere.

The % of oxygen does not change with altitude.

The difference in partial pressure of oxygen between the inhaled air and the blood allows the oxygen to diffuse.

* At sea level, Pox= 160 mm Hg in air and Pox= 40 mm Hg in venous blood.
* Therefore oxygen diffuses into the blood.
* Pox= 100 mm Hg in arterial blood; Pox= 0- 40 mm Hg in tissues.
* Therefore oxygen diffuses into the tissues.
* On top of Mount Everest, the atmospheric pressure is 250 mm Hg.
* To find the partial pressure of oxygen: 250 mm x 0.21 % = 53 mm Hg.
* On top of Mount Everest, Pox= 53 mm Hg.

There is a greater difference at sea level between the partial pressure of oxygen in the environment and the blood: 160 mm and 40 mm.

On Mount Everest, the difference is between 53 mm and 43 mm.

**In water.**

Gases are soluble in liquids, but the amount of gas that dissolves depend on:

1. The solubility of the gas in the liquid, e. g CO2 is 30 times more soluble in water than O2. It is easier to rid of CO2 than of O2.
2. The temperature of the liquid. As temperature increases the amount of gas in solution decreases.
3. The presence of other solutes. The more solutes there are in the solution, the lesser the amount of dissolved gases. Freshwater habitats are more oxygen-rich than sea water habitats.

Mixing also helps the solubility of gases.

Air contains more oxygen than does water.

* 1 liter of air contain 208 ml of O2
* 1 liter of water contains 7 ml of O2
* an animal must process 30 times more water than air to obtain the same amount of O2

Land organisms have more difficulty in eliminating CO2 from the blood than do aquatic organisms.

* CO2 has a very high solubility in water and blood.

Water is more viscous and dense than air and the aquatic animal must spend a lot of its energy moving water over the gills.

Aquatic animals spend 20% of its energy while terrestrial animals spend 1 -2 % of its total energy.

**ORGANS OF GAS EXCHANGE**

Unicellular and small multicellular organisms obtain O2 and eliminate CO2 by diffusion.

**The Law of Diffusion.**

**Fick's law**: the rate of diffusion of a gas depends on five parameters: the solubility of the gas being considered, the temperature, the surface area available for diffusion, the difference in partial pressures of the gas across the respiratory surface, and the thickness of the barrier to diffusion.

* The greater the partial pressure difference and the larger the surface area, the faster the gas will diffuse.
* If the respiratory epithelium of the two human lungs was spread flat it would cover an area of 100 m2, one quarter of a football field.

**The gill**

* Gills containing capillaries.
* Echinoderms have dermal gills.
* Chordates usually have internal gills.
* In bony fish, a bony plate, the **operculum**, protects the gills.
* Fast swimmers get additional oxygen by swimming with their mouth open, this is called **ram ventilation.**
* Counter current system is an efficient method of obtaining oxygen.
* Countercurrent maintains a large difference in the amount of O2 and CO2 in the blood and the water.

**The insect tracheal system**.

* Tracheal tubes that deliver oxygen to all parts of the body.
* It consists of a network of **tracheal tubes** that open on the body surface through up to 20 tiny openings called **spiracles**.
* The tracheal tubes are sandwiched between muscles. When the muscles contract and expand when the insect beats its wings, the tubes constrict and expand in response improving ventilation.

**Lungs**

Amphibians and reptiles have simple lungs.

* The lungs of toads and frogs are simple sacs with ridges that increase the respiratory surface.
* Some amphibians do not have lungs and exchange gases through the skin.
* Reptiles have sacs with folding of the wall to increase the respiratory surface.

Birds have the most efficient respiratory system of any living vertebrate.

Their lungs have air sac extensions that reach into many parts of the bird's body.

**HUMAN RESPIRATORY SYSTEM**

The human respiratory system is typical of air-breathing vertebrates.

**Nostrils** are the opening of the nose.

**Nasal cavities** moisten, warm and filter the air.

**Pharynx** or throat is used also by the digestive system.

**Larynx** also called "voice box" contains the vocal cords and is supported by a cartilage.

**Epiglottis** is a small flap of tissue that closes the larynx during swallowing.

**Trachea** or windpipe is supported by rings of cartilage.

**Bronchi** are branches of the trachea that lead to each lung.

* Both trachea and bronchi are lined with a mucous membrane containing ciliated cells.

**Bronchioles** and **alveoli** make most the **lungs**.

Each lung is covered with a **pleural membrane**, which also lines the thoracic cavity.

**Pleural cavity** is the space in between the pleural membranes and it is filled with a fluid.

* The pleural fluid provides lubrication between the lungs and the body wall.

The alveoli are tiny air sacs at the end of the bronchioles and are lined with a very thin epithelium.

Capillaries surround the alveoli.

Gas exchange occurs in the alveoli of the lungs.

The lungs as such consist mostly of air tubes and elastic tissue with a very large internal surface.

Passage of air:

**Nostrils → nasal cavities → pharynx → larynx → trachea → bronchi→ bronchioles → alveoli.**

**BREATHING**

Ventilation is accomplished by breathing.

**Breathing** is the mechanical processes of moving air from he environment into the lungs (**inspiration**) and expelling the air from the lungs (**expiration**).

During inspiration, the volume of the thoracic cavity is increased by contraction of the **diaphragm**.

* Contraction moves the diaphragm downward increasing the volume of the thoracic cavity.
* The pressure of the air in the lungs decreases by 2 or 3 mm Hg below the atmospheric pressure.

With the increase in volume in the thoracic cavity, the pressure drops and air is forced in by the atmospheric pressure.

Expiration occurs when the diaphragm relaxes.

The normal amount of air inhaled at rest is called **tidal volume**: ~ 500 ml.

The **vital capacity** is the maximum amount of air a person can exhale after filling the lungs to the maximum extent.

O2 and CO2 are exchanged between alveoli and blood by diffusion.

The difference in partial pressure of oxygen between the inhaled air and the blood allows the oxygen to diffuse.

**BLOOD**

Blood is a type of connective tissue containing different kinds of cells suspended in a liquid matrix , the **plasma**.

Plasma makes about 55% of the blood. The remaining 45% are made up of blood cells and platelets.

**Plasma** is about 92% water, 7% proteins and the rest consists of nutrients, organic wastes and electrolytes (ions).

Blood makes up about 8% of the body weight.

Humans have 4 to 6 liters of blood.

The plasma contains nutrients, wastes, hormones and respiratory gases.

The plasma and interstitial fluid are similar in composition except that the plasma contains a higher protein concentration than the interstitial fluid.

When proteins involved in blood clotting have been removed from the blood; the remaining liquid is called **serum**.

Plasma proteins:

**1. Globulins** are of three kinds:

* Alpha globulins include certain hormones and proteins involved in their transport. HDL, high-density lipoproteins transport fats and cholesterol.
* Beta globulins are lipoproteins that bind to minerals, vitamins, lipids and cholesterol to dissolve and transport.
* Gamma globulins are antibodies that provide immunity against certain diseases.
* Globulins make up 33% of the plasma proteins.

**2. Albumins** help to regulate the amount of fluid in the plasma and interstitial fluid and help maintain osmotic pressure and proper blood volume. They constitute 60% of plasma proteins.

**3. Fibrinogen** and **prothrombin** function in the clotting reaction.

Plasma proteins act as buffers in order to maintain a constant **pH of 7.4**.

The liver synthesizes more than 90% of the blood proteins: all of albumin and fibrinogen and most of the globulins.

Immunoglobulins are produced by plasma cells (a type of white blood cell).

Protein hormones are produced in endocrine glands.

Red blood or **erythrocytes** cells (RBC) transport oxygen and carbon dioxide.

* Made in the bone marrow ribs, long bones, vertebrae and skull bones.
* 5.4 million/ μl (mm3) in men and 5.0 million/ μl (mm3) in women.
* Lack nucleus and live for about 120 days.
* Liver and spleen remove old RBC from circulation.
* **Hemoglobin** is the oxygen transporting protein; contains Fe.
* Fe deficiency causes anemia, a decrease production of hemoglobin and RBCs.
* **Anemia** is a deficiency in hemoglobin.
* Hemolytic anemia is due to an increase rate of RBC destruction. Hemorrhage decrease RBC production is other causes of anemia.
* RBC production is regulated by the protein **erythropoietin**, which is released by the kidneys in response to a decrease in oxygen.

Birds have large, oval, nucleated RBCs.

White blood cells or **leukocytes** (WBC) defend the body against disease-causing microorganisms.

**Bohr Effect**

The binding of oxygen to a subunit of a hemoglobin molecule causes a conformation change in the molecule that makes the other three subunits much more likely to bind to oxygen.

* This is called **cooperative binding**.

**CO2 exchange and the regulation of blood pH.**

Carbon dioxide is transported mainly as bicarbonate ions.

* About 70% of the CO2 dissolves in the plasma and forms HCO3- and H+ lowering the pH.
* About 7% - 10% dissolves in the plasma.
* About 20% - 23% enter the red blood cells and combines with hemoglobin forming carbaminohemoglobin.
* Carbonic anhydrase is responsible for maintaining a strong partial pressure gradient favoring the entry of CO2 into the RBCs.

This reaction occurs in the RBC catalyzed by carbonic anhydrase.

Carbonic

anhydrase

**CO2 + H2O -------→ H2CO3 → H+ + HCO3-**

Most of the H+ released from carbonic acid combine with hemoglobin and do not change the pH of the blood.

Many of the bicarbonate ions leave the RBCs and diffuse into the plasma.

Chloride ions diffuse into the RBC to replace the bicarbonate ions. This is known as the **chloride shift**.

When hemoglobin is carrying oxygen, it has a great affinity for protons. In this way hemoglobin acts as a buffer.

As CO2 diffuses out of the alveolar capillaries, the resulting lower CO2 concentration reverses the previous reaction.

CO2 and H2O are the products of formed by the dissociation of bicarbonate and the protons in the hemoglobin.

**THE CIRCULATORY SYSTEM**

**FUNCTION**

To supply cells with all the necessary materials for metabolism, and to remove wastes products.

The human circulatory system is also known as the **cardiovascular system**.

**Circulatory systems** consists of

1. **Blood**, a connective tissue made of cells, cell fragments and a fluid known as plasma.
2. A pumping organ, usually a **heart**.
3. A system of blood **vessels or spaces** through which the blood circulates.

**Open circulatory system**

In all animals fluid between the cell, called **interstitial fluid** or tissue fluid, bathes the cells and provides a medium for diffusion of oxygen and nutrients.

Sponges, cnidarians, ctenophorans, platyhelminthes, etc. depend on **diffusion** for internal transport.

Arthropods and mollusks have an **open circulatory** **system**.

* Blood flows into a **hemocoel** bathing the tissues directly.
* The hemocoel is made of spaces or sinuses. The hemocoel is not part of the coelom.
* **Hemolymph**: blood and interstitial fluid are indistinguishable.
* **Hemocyanin**: an oxygen-transporting pigment found in **some** mollusks (cephalopods) and arthropods (crustaceans); contains copper.
* One or several hearts pump the hemolymph into an artery that empties into an open, fluid filled cavity, the hemocoel.
* The hemolymph returns to the heart when the heart relaxes and creates suction.
* Hemolymph is under low pressure.

**Closed circulatory system**

Some invertebrates (e.g. cephalopods, echinoderms, annelids) and vertebrates have a closed circulatory system

Nemerteans have a primitive circulatory system that is closed but does not have a pumping organ. Blood moves depending on the movements of the animal and contractions in the wall of the large blood vessels.

Earthworms have **hemoglobin** dissolved in the blood plasma.

**Functions** of the vertebrate circulatory system:

1. Transports oxygen, metabolic wastes, nutrients and hormones.
2. Helps maintain fluid balance.
3. Defends the body against invading microorganisms.
4. Distributes metabolic heat to maintain normal body temperature.
5. Helps maintain appropriate pH.

Exchange of materials occur through the thin wall of capillaries.

**BLOOD VESSELS**

1. **Arteries** carry blood away from the heart.
2. **Veins** carry blood to the heart.
3. **Capillaries** are thin-walled vessels through which materials pass back and forth between blood and tissues.
4. Smaller secondary branches of arteries are called **arterioles**, and of veins **venules**.

Notice that arteries and veins are distinguished by the direction in which they carry blood and not by the characteristics of the blood.

Veins and arteries have three layers of tissues.

* **Tunica intima** consists of squamous epithelium (**endothelium**).
* **Tunica media** is made of connective tissue and smooth muscle.
* **Tunica adventitia** consists of connective tissue rich in elastic and collagen fibers.

The smooth muscle in the wall of arteries can constrict (**vasoconstriction**) or dilate (**vasodilation**).

The thick wall of the arteries and veins prevent gases from passing through.

Capillaries form a network between arterioles and venules.

**Metarterioles** connect directly an arteriole with a venule.

Capillaries branch off metarterioles.

**Precapillary sphincters** are located whenever a capillary branches off a metarteriole. These sphincters open and close continuously to direct blood to needed sectors of the tissues.

Vasoconstriction and vasodilation help maintain the appropriate blood pressure and control the volume of blood passing to a particular tissue.

Changes in blood flow are regulated by the autonomic nervous system in response to metabolic needs of tissues.

**HEART**

In vertebrates, the heart consists of one or two atria, which receive the blood, and one or two ventricles, which pump the blood.

1. **In fish** there is one atrium and one ventricle and blood flows in a **single circuit**.

Atrium → ventricle → conus arteriosus → aorta → gill capillaries → organ capillaries →sinus venosus → atrium

1. **In amphibians** there are two atria and one ventricle.

* Systemic and pulmonary circulation, a double circuit.

Ventricle → aorta → body capillaries → veins → sinus venosus → right atrium → ventricle → pulmonary artery → lung and skin capillaries → veins → left atrium → ventricle

* Oxygen-poor blood is pumped out the ventricle before the oxygen-rich blood enters it.

1. **Reptiles** have a double circuit blood flow and the ventricle is partly divided.

* Some mixing of blood occurs.
* Ventricle sides contract at different times.
* Crocodiles have two ventricles.

1. **In birds and mammals** the heart ventricles are separated. There are two ventricles.

The conus arteriosus becomes the base of the aorta and pulmonary artery.

Body capillaries → veins → right atrium → right ventricle → pulmonary arteries → lung capillaries → pulmonary veins → left atrium → left ventricle → aorta → body organs → veins → right atrium...

A sac of connective tissue, the **pericardium**, protects human heart.

The inner surface of the pericardium and outer surface of the heart are covered by a smooth layer of endothelium.

The space in between, the pericardial cavity, is filled with a fluid, which reduces friction during heartbeats.

The **fossa ovalis** is located on the **interatrial septum**. It marks the location of the **foramen ovalis** in the fetus.

On the upper surface of each atria lies a small muscular pouch called the **auricle**.

The right **atrio-ventricular valve (AV)** or **tricuspid valve** controls the blood flow between the right atrium and right ventricle.

The left AV is called the **mitral valve**.

The **cordae tendinae** attach the valves to the papillary muscles of the heart.

The **semilunar valves** guard the exits from the heart: aortic and pulmonary valves.

**HEARTBEAT**

The heart is capable of beating independently of the nervous system.

The contraction of the heart is called **systole**, and the relaxation of the heart is known as **diastole**.

At the end of cardiac muscle cells there are dense bands called **intercalated discs**, gap junctions in which two cells are connected through pores.

* The **sinoatrial node (SA)** or **pacemaker** initiates the heartbeat. It is located near the point where the superior vena cava enters the right atrium.
* Because cardiac muscle cells are coupled by the gap junctions of the intercalated discs, the electrical impulse they produce spread rapidly through the wall of the atria making them contract in unison.
* Atrial muscle fibers conduct the action potential to the **atrioventricular node** located in the right atrium, on the lower part of the septum.
* From the AV node, the action potential travels into the **AV bundle**, also known as the **bundle of His**, made of the **Purkinje fibers**.
* The AV bundle branches into sending branches into each ventricle.
* From the AV bundle, the action potential spreads through the ordinary cardiac muscle fibers.

When the semilunar valves do not close tightly during diastole, the blood flows back with a hiss known as a **heart murmur**.

The electrical activity of the heart spreads through the body fluids to the body surface and can be recorded in a graph called the **electrocardiogram (ECG or EKG)**.

**Heart rate.**

The SA sets the tempo for the entire heart and it is influenced by several factors:

* Hormones like epinephrine secreted by the adrenal gland.
* Nicotine has a direct effect on the heart, and also influences the release of epinephrine and norepinephrine from the adrenal glands.
* Nicotine blocks the K+ of the cardiac muscles and throws off the heart rhythm by interfering with electrical transmission.
* Body temperature. An increase of body temperature by 1°C, increases the heart rate by 10beats/min.
* Exercise in order to bring enough oxygen to the muscles.

**Cardiac output** is the volume of blood pumped by the left ventricle into the aorta in one minute.

The **stroke volume** is the volume of blood pumped into the aorta during one beat, ml/stroke.

**Heart rate** is the number of contractions per minute, strokes/min.

Cardiac output = stroke volume X heart rate, ml/min.

**Blood pressure**

**Blood pressure** is the force exerted by the blood against the inner walls of the blood vessel.

* It is determined by cardiac output, blood volume and resistance to blood flow.
* Resistance to flow is caused by the viscosity of the blood and by friction against the wall of blood vessels.
* A change in the diameter of a blood vessel affects blood pressure significantly.
* It is greatest in arteries and decreases as blood flows through the capillaries.
* Blood pressure increases during systole and decrease during diastole.
* **Baroreceptors** located on the walls of certain vessels and heart chambers are sensitive to blood pressure.

* Baroreceptors send messages to the **cardiac** and **vasomotor centers** of the medulla when the pressure increases.
* The cardiac center stimulate the parasympathetic NS that slows the heart rate and the vasomotor center inhibits the sympathetic NS that constricts the blood vessels. All these reduces blood pressure.
* **Angiotensins** are hormones that act as vasoconstrictors and increase blood pressure.
* Blood pressure rises during systole and drops during diastole. For a young adult male is 120/80 mm Hg as measured by the **sphygmomanometer**.

**BLOOD CIRCULATION**

**Pulmonary circulation** oxygenates the blood.

**Systemic circulation** delivers blood to the tissues.

* **Coronary** arteries feed the heart.
* **Carotid** arteries bring blood to the brain.
* **Subclavian** arteries to the shoulder region and arms.
* **Mesenteric** arteries to the intestines.
* **Renal** arteries to the kidneys.
* **Iliac** arteries to the legs.

Blood returns to the heart in veins.

* The **superior vena cava** collects blood from j**ugular** and **subclavian veins** drain the brain and arms.
* **Renal**, **iliac** and **hepatic** veins empty into the **inferior vena cava**.
* Coronary capillaries empty in the coronary veins, which in turn join to form a large vein, the **coronary sinus** that empties directly into the right atrium.

The **hepatic portal system** delivers nutrients to the liver.

* The hepatic portal system delivers blood rich in nutrients to the liver.
* Blood flows from the liver to the small intestine through the **superior mesenteric artery**.
* Blood flows through the capillaries of the intestine and collect glucose, amino acids and other nutrients.
* This blood passes to the mesenteric vein and then into the **hepatic portal vein**, which delivers the nutrient rich blood to the liver.

Four arteries deliver blood to the brain: two **carotids** and two **vertebral** arteries.

At the base of the brain these arteries branch and fuse again forming the **circle of Willis**.

**LYMPHATIC SYSTEM**

The lymphatic system is an accessory circulatory system which...

1. Collects and returns interstitial fluid to the blood.
2. Defends against disease-causing organisms.
3. Absorb lipids from the small intestine.

The lymphatic system consists of...

* Lymphatic vessels that conduct **lymph**.
* Lymphatic tissue organized into **lymph nodes** and **nodules**.
* Tonsils, thymus gland and spleen.

Interstitial fluid enters the lymph capillaries and is called lymph.

Lymph capillaries are dead-end and extend into almost all tissues of the body.

Lymph capillaries join to form large **lymphatics** (lymph veins).

* **Thoracic duct** empties the lymph into the left subclavian vein.
* **Right lymphatic duct** empties into the right subclavian vein

Valves within the lymph veins prevent the lymph from flowing backwards.

Tonsils are lymphatic tissue that protects the respiratory system from infections.

They are found at the back of the nose and on the throat.

When enlarged, the tonsils found at the back of the nose is called adenoids.

When blood enters the capillaries under pressure some plasma and proteins filters out into the tissues forming the **interstitial fluid**.

Only about one fourth of the blood proteins pass into the tissues.

Lymph capillaries are made of overlapping cells that separate under pressure allowing excess interstitial fluid and proteins in it to enter and drain the tissue.

Obstruction of the lymph vessels causes **edema**, the swelling that occurs due to the accumulation of interstitial fluid.

Chapter 42 **ELECTROCAL SIGNALS IN ANIMALS**

The ability of an organism to survive and maintain homeostasis depends largely on how it responds to internal and external stimuli.

A **stimulus** is an agent or a change within the body that can be detected by an organism.

Nerve cells are called neurons. These cells are specialized for transmitting electrical and chemical signals through a network.

The nervous system consists of this network of neurons and supporting cells.

**Neurotransmitters** are chemical messengers used by neurons to signal other neurons and that allows the nerve impulse to be transmitted across a synapse or connection between neurons and/or receptors.

**FUNCTION OF THE NERVOUS SYSTEM**

The nervous system is the master controlling and communicating system of the body.

It is responsible for behavior, thought, actions, emotions, and maintaining homeostasis (together with the endocrine system).

**Principles of electrical signaling.**

Reactions to stimulus depends on four processes:

1. **Reception**: afferent or sensory neurons and sense organs detect the stimulus.
2. **Transmission**: messages are transmitted from neuron to neuron, to organs, and to the Central Nervous System, **CNS**.
3. **Integration**: involves sorting and interpreting information and determining proper response.
4. **Response**: efferent neurons bring the proper message to muscles and glands.

The CNS is made of the brain and the spinal cord.

Neurons that transmit messages to the CNS are called **afferent** or **sensory** neurons.

Neural messages are transmitted from the CNS by **efferent** neurons or **motor** neurons, to **effectors**, muscles or glands.

The action by effectors is the response to the stimulus.

All other components of the nervous system that are outside of the CNS are considered part of the **peripheral nervous system or PNS**.

**The anatomy of a Neuron**

**Nerve cells** are called **neurons**.

* A typical neuron has **cell body**, **dendrites** and an **axon**.
* **Dendrites** are short, highly branched cytoplasmic extensions specialized to receive stimuli and send nerve impulses to the cell body.
* In many brain areas, the finer dendrites have thorny projections called **dendrite spines**.
* The **axon** is a long extension sometime more than 1 meter long, and conducts impulses away from the cell body.
* The axon ends in many terminal branches called **axon terminals** with a **synaptic terminal** or **knob** at the very end that releases **neurotransmitters**.
* Axons may branch forming **axon collaterals**.
* Axons outside the CNS and more than 2 μm in diameter are myelinated.

The junction between a synaptic terminal and another neuron is called a **synapse**.

A **nerve** consists of hundreds or thousands of axons wrapped together in connective tissue.

Within the CNS, bundles of axons are called **tracts** or **pathways**.

Outside the CNS, cells bodies form masses called **ganglia**.

Inside the CNS, groups of cell bodies are referred to as **nuclei** rather than ganglia.

**Schwann cells** are found outside the CNS and form an outer cellular sheath around the axon called **neurilemma**, and an inner myelin sheath.

* The plasma membrane of the Schwann cell is rich in **myelin**, a white fatty substance that acts as an insulator.
* Gaps in the myelin sheath are called **nodes of Ranvier**.

**MEMBRANE POTENTIALS**

A separation of charge across a cell membrane is called a **membrane potential**.

**Resting Potential**

Most animal cells have a difference in electrical charge across the plasma membrane: more negative on the inside and more positive on the outside of the cell, in the fluid.

The plasma membrane is said to be polarized when one side or pole has a different charge from the other side.

When this occurs, a potential energy difference exists across the membrane.

If the charges are allowed to come together they have the **potential to do work**.

Neurons use electrical signals to transmit information.

A resting neuron is the one not transmitting an impulse.

For an impulse to be fired, the plasma membrane of the neuron must maintain a **resting potential**. It must be **polarized**.

The **resting potential** is the difference in electrical charge across the plasma membrane.

* The inner surface of the membrane is negative.
* The interstitial fluid surrounding the neuron is positive.
* An electrical potential difference exists across the membrane. It is called the **resting or membrane potential.**

The resting potential of a neuron is **70 mV** (millivolts).

By convention it is expressed as -70mV because the inner side is negatively charged relative to the interstitial fluid.

The resting potential develops **by transporting Na+ out of the neuron and K+ into the neuron** using sodium-potassium pumps.

* The concentration of K+ is about three times greater inside the cell than outside.
* The concentration of Na+ is about ten times greater outside the cell than inside the cell.

**Na+/K+-ATPase** pumps work against concentration gradient and require ATP.

For every three Na+ pumped out of the cell, two K+ are pumped in.

More positive ions are pumped out than in.

Proteins in the plasma membrane form specific passive ion channels.

Ions also flow through these channels down the concentration gradient, passive transport.

K+ channels are the most common and they make the membrane more permeable to potassium than to sodium.

K+ leak out more rapidly than Na+ can leak into the cell. The membrane is about 100 times more permeable to K+ than to Na+.

Na+ pumped out of the neuron cannot easily pass back into the cell but the potassium ions pumped into the neuron can diffuse out.

The flow of K+ ions in and out of the cell eventually reaches a flow equilibrium **called equilibrium potential**, at -70mV (resting potential).

Some Cl- ions also diffuse into the cell and contribute to the inner negative charge.

Negatively charged proteins and organic phosphates contribute to the negative charge inside the membrane.

An electrical imbalance is created mostly due to...

* Negative protein anions inside the cell.
* Outward diffusion of K+.
* Inward diffusion of Cl-.

**THE NERVE IMPULSE**

**What is an action potential?**

The nerve impulse is an **action potential**.

Electrical, chemical or mechanical stimulus may alter the membrane's permeability to Na+.

The axon contains specific **voltage-gated ion channels** that open when they detect a change in the resting potential of the membrane.

**Voltage-gated ion channels** are of two kinds, potassium channels and sodium channels.

When the change reaches threshold levels, the protein changes shape, the channels open and Na+ flows into the cell. Na+ channels stay open for about one millisecond then close.

The membrane of a neuron can depolarize by about 15mV without initiating an impulse

The threshold to open the voltage-activated sodium-ion channels is -55mV.

The inside of the cells becomes positive.

These causes a momentary reversal of polarity as the membrane depolarizes and overshoots to +35 mV, creating a **spike**.

After a certain time, the sodium-ion channels close. The closing depends on time rather than on voltage.

K+ channels also open but more slowly and remain open until the resting potential has been restored.

Once depolarization occurred in one portion of the membrane, the adjacent areas also become depolarize and the ion gates open. This is done by a **positive feedback mechanism**.

This process is repeated creating a **wave of depolarization** until the depolarization reaches the end of the axon.

**Repolarization** occurs in less than one millisecond later when the channels close and the membrane becomes impermeable to Na+.

Leakage of K+ out of the cell also occurs and restores the interior of the membrane to its negative state.

Sodium-potassium pumps begin to function again.

When the membrane is depolarized, it cannot transmit another impulse no matter how great stimulus is applied.

**Summary**

1. In the **resting state**, both sodium and potassium channels are closed, and membrane's resting potential is maintained.

2. **Depolarization phase**. Sodium channels open and Na+ rush into the cell and the interior of the cell becomes more positive. Potassium channels remain closed.

3. **Repolarization phase**. Sodium channels close and potassium channels open. Leakage of K+ out of the cell occurs. The loss of positive charges restores the interior of the membrane to its negative state.

4. During **hyperpolarization**, the sodium channels are closed. The potassium gates are slow to close and remain open for a millisecond more allowing the continuous leakage of K+ to the outside of the cell.

**The role of the sodium-potassium pump**

**Na+/K+-ATPase** transports three sodium ions out and two potassium ions in. this activity maintains the resting potential by restoring the potassium ions that leak out of the neuron.

**Propagation of the action potential**.

The action potential starts with the inflow of sodium ions into the cell.

This rush of positive charges repulses other positive charges in side the cell, which spread away from the channel where the sodium ions came in and depolarize nearby areas of the membrane.

In myelinated axons, no charge leaks across the membrane as it spreads down the axon. The action potentials jump down the axon from node to node.

Myelination acts as insulation. It prevents the influx of sodium ions into the cell.

The action potential spreads until it hits an unmyelinated area, the node of Ranvier.

The node has a high concentration of voltage-gated channels and supports action potential.

If myelination decreases, the spread of the nerve impulse (the action potential) slows down considerably.

The disease multiple sclerosis, MS, develops as a result of the loss of myelination and the impaired electrical signaling.

The cause of MS is a mystery but there is some evidence that indicates that it is an autoimmune disease.

**SYNAPTIC TRANSMISSION**

A synapse is the junction between two neurons or between a neuron and an effector:

* **Neuromuscular junction** or motor end plate is the synapse between a muscle and a neuron.
* **Presynaptic** neuron and **postsynaptic** neuron.

Signals across the synapse can electrical or chemical.

**Electrical synapses** occur when the neurons are very close together (synaptic cleft less than 2 nm).

* It allows the passage of ions from one neuron to the next and the impulse is directly transmitted.
* Between axons and cell body, cell body to cell body, dendrites and axons, dendrites and dendrites.
* For quick communication and coordination between many neurons.

**Chemical synapses** are separated by the **synaptic cleft**, about 20 nm wide.

* Most synapses are chemical.
* Chemical messengers or **neurotransmitters** conduct the message.

More than 40 different chemicals are known or suspected to function as neurotransmitters.

Each type of neuron is thought to release one type of neurotransmitter.

A postsynaptic neuron may have more than one type of receptors for neurotransmitters.

When depolarization reaches the end of the axon it cannot jump across the cleft.

The electrical signal is converted to a chemical one.

Neurotransmitters are the chemicals that conduct the signal across the synapse and bind to chemically activated ion channels in the membrane of the postsynaptic neuron.

Neurotransmitters are stored in the synaptic terminals within membrane-bound sacs called **synaptic vesicles**.

Neurotransmitters are produced in the terminal knobs of the presynaptic axon.

* Action potential upon reaching the synaptic terminal activates voltage-sensitive Ca+ channels.
* Ca+ from the surrounding interstitial fluid pass into the synaptic terminal.
* Ca+ cause the synaptic vesicles to fuse with the presynaptic membrane and release neurotransmitters into the synaptic cleft by exocytosis.
* Diffuse across the synaptic cleft and combines with specific receptors on the postsynaptic neuron.
* Receptors are proteins that control chemically activated ion channels. They are called **ligand-gated ion channels**.
* The neurotransmitter, the **ligand**, binds to the receptor and the ion channel opens.
* Opening of the channels may cause a depolarization of the postsynaptic membrane.
* Neurotransmitter must be removed enzymatically for repolarization to occur.

**Postsynaptic potentials, summation and integration.**

A single neuron may receive information from many neighboring neurons via thousands of synapses. Some of the information is excitatory and other inhibitory.

At an **excitatory synapse**, neurotransmitters receptors control gated channels that allow the sodium ions to enter the cell and the potassium ions to leave bringing the neuron closer to the threshold voltage making it more likely that the postsynaptic neuron will generate an action potential.

* This new state is called an **excitatory postsynaptic potential or EPSP**.

At an **inhibitory synapse**, the binding of neurotransmitter s to the postsynaptic membrane hyperpolarizes the membrane by opening ion channels that make the membrane more permeable to K+, which leave the cell, or to Cl- the enter the cells. This flow of ions makes the inside of the cell more negative through the loss of positive charges or the gain of negative charges.

* This hyperpolarized state is called an inhibitory postsynaptic potential or IPSP.

A single EPSP at one synapse is not strong enough to trigger an action potential.

Several synaptic terminals acting simultaneously on the same postsynaptic cell, can have a cumulative impact on the membrane potential. This is called **summation**.

The **action hillock** is the region of the postsynaptic neuron where voltage-gated sodium channels open and generate and action potential when some stimulus ha depolarized the membrane to the threshold.

**THE VERTEBRATE NERVOUS SYSTEM**

**DIVISIONS OF THE VERTEBRATE NERVOUS SYSTEM**

brain

Central

spinal cord

Vertebrate

Nervous receptors

System Somatic afferent nerves (receptors to CNS)

efferent nerves (CNS to skeletal muscles)

Peripheral

Receptors

Autonomic afferent n. (receptors to CNS)

efferent n. (CNS to organs) sympathetic

parasympathetic

**The spinal cord.**

Function so the spinal cord:

1. Transmits impulses to the from the brain
2. Controls many reflex activities.

The spinal cord extends from the base of the brain to the second lumbar vertebrae.

The spinal cord consists of gray matter and white matter.

* It has a small central canal.
* The white matter surrounds the gray matter.
* The gray matter has the shape of an H.
* The **gray matter consists of cell bodies**, **dendrites and unmyelinated axons**.
* The **white matter is made of myelinated axons** arranged into tracts or pathways.

A reflex action or withdrawal reflex is a fixed response to a simple stimulus.

A message is also send to the cerebrum and pain, touch, etc. is felt.

Many activities such as breathing are controlled by reflex action.

**The cerebrum.**

The cerebrum is the largest and most prominent part of the human brain.

Cerebral cortex is made of gray matter arranged into sulci.

* **Sensory** areas receive information from senses and receptors.
* **Motor** areas control the movement of voluntary muscles.
* **Association** areas are the site of intellect, learning, memory, language, and emotion; interprets sensory information.

The cortex has been mapped into areas responsible for certain functions:

* Occipital lobe: visual centers.
* Temporal lobes: auditory centers.
* Parietal lobes receive information about heat, touch and pressure.
* Other areas are involved in complex integrative activities.

The size of the motor area in the brain for any given part of the body is proportional to the complexity of movement involved and not to the amount of muscle.

White matter lies beneath the cerebral cortex.

* **Corpus callosum** connects right and left hemispheres.
* Axons are arranged into bundles (tracts).

**Learning and memory.**

Learning and memory are based on modifications of synapses, e.g. number of synapses, or in the amount of neurotransmitter produced..

After learning has taken place, some neurons release more or less neurotransmitter in response to stimulation.

In the case of long term memory, these changes depend on changes in gene expression.

Chapter 43 **ANIMAL SENSORY SYSTEMS AND MOVEMENT**

**Sensory receptors** are structures specialized to respond to stimuli and changes in the external environment.

Sensory receptors consists of

* Neuron endings.
* Specialized cells in close contact with neurons.

These receptors **transduce** (convert) the energy of the stimulus into electrical signals that are then transmitted by the neurons.

Sensory receptors and other types of cells make the sense organs: eyes, ears, nose, taste buds.

There are six senses recognized by biologists: sight, hearing, smell, taste, touch and balance.

**CLASSIFICATION OF RECEPTORS**

Receptors are classified according to the source or type of stimulus.

According to location:

1. **Exteroceptors** receive stimuli from outside the body.
2. **Proprioceptors** are located within muscles, tendons, and joints and enable the animal to perceive the position of arms, legs, etc. and the orientation of the body as a whole.
3. **Interoceptors** are located within body organs and detect physiological changes, e.g. pH, temperature, chemicals in blood.

According to types of stimuli to which they respond.

1. **Mechanoreceptors** respond to mechanical energy, e.g. pressure, touch, and gravity.
2. **Chemoreceptors** respond to chemicals, e.g. odors.
3. **Thermoreceptors** detect changes in temperature.
4. **Photoreceptors** respond to light.
5. **Electroreceptors** detect electrical energy.

**RECEPTOR POTENTIAL**

Sensory receptors maintain a resting potential: a difference in charge between the inside and the outside of the cell membrane.

Receptor cells absorb energy, converts (transduce) that energy into electrical energy, and produce a **receptor potential** that may result in an action potential.

Each receptor is sensitive to a particular type of energy.

A stimulus causes changes in the permeability of the membrane and specific ion channels open or close.

If the difference in charge is increased, the receptor becomes hyperpolarized.

If the potential decreases, the receptor becomes depolarized.

**Stimulus → transduction into electrical energy → receptor potential → action potential**

Sensory receptors perform three important functions:

1. Detect the stimulus in the environment by absorbing energy;
2. Converts the energy of the stimulus into 3electrical energy (transduction);
3. Produces a receptor potential that may become an action potential

**SENSE OF HEARING AND BALANCE**

Functions in hearing and maintaining equilibrium or balance.

Three regions:

1.External ear: ear and ear canal in some vertebrates.

2. Middle ear: **tympanic membrane** and **auditory bones**.

3. Inner ear: **semicircular canals, vestibule** and **cochlea.**

All vertebrates have inner ears. Outer and middle ears may be absent in some groups.

Auditory bones are the **malleus**, **incus** and **stapes**.

The vestibule consists of two chambers, the **saccule** and the **utricle**.

The vestibule and semicircular canals are also known as the **labyrinth**.

The inner ear is made of a membrane that fits inside the skull bone

**1. EQUILIBRIUM**

**Equilibrium** in humans depends on the proper functioning of the labyrinth and proprioceptors, the sense of vision, and stimulus coming from the soles of the feet.

The saccule and utricle of vertebrates contain **otoliths** (CaCO3) that change position when the head is tilted or when the body is moving in straight line.

* Hair cells are located in the saccule and utricle.
* Hair cells surrounded at their tips by a gelatinous **cupula**.
* Hair cells send information to the brain about the direction of gravity.
* Each cell has a **cilium** and several small **stereocilia**.

The semicircular canals inform the brain about turning movements (linear acceleration).

Each canal is hollow, connected to the utricle and at right angle to the other two.

* Filled with **endolymph**.
* At one of the openings of each semicircular canal there is a bulb-like enlargement, the **ampulla**.
* Each ampulla contains a cluster of hair cells called the **crista** .
* Each hair cell has a cilium and stereocilia.
* Endolymph movement stimulates the cristae.
* No otoliths are present in the ampulla.

**2. AUDITORY RECEPTION**

Auditory receptors are located in the cochlea.

A spiral tube consisting of three canals separated by membranes.

* Canals are filled with the **perilymph**.
* **Vestibular canal** and **tympanic canal** are connected at the apex of the cochlea.
* The **middle canal** is filled with **endolymph** and contains the **organ of Corti**.
* **Basilar membrane** separates the tympanic canal from the medial canal.
* Above the organ of Corti is the **tectorial membrane**.

Distortion of the basilar membrane causes the organ of Corti to rub against the tectorial membrane.

Loud sounds cause waves of greater amplitude resulting in greater stimulation of hair cells and transmission of greater number of impulses per second.

Pitch depends on the frequency of the sound waves; e.g., high frequency results in high pitch.

**PHOTORECEPTORS**

Most animals have photoreceptors that use a group of the pigments called **rhodopsins** to absorb light.

Invertebrates have eyespots, simple eyes and compound eyes.

* Simplest are found in some cnidarians and flatworms.
* Eyespots are called **ocelli**, a bowl shaped cluster of light sensitive cells within the epidermis.
* They detect light intensity and direction but no images.

Effective image formation requires a **lens** that concentrates light on photoreceptors.

The brain interprets the message of the photoreceptors - **VISION**.

It integrates information about brightness, location, position and shape of the stimulus.

**THE COMPOUND EYE**

Compound eyes are found in crustaceans and insects.

They consist of **ommatidia**, which collectively produce a mosaic image.

* Some crustaceans have 20 ommatidia and dragonflies have 28,000.

Each ommatidium has a convex lens and a crystalline cone.

These structures focus light on retinular cells.

Rhodopsin is located in microvilli found in the membranes of the retinular cells.

Adjacent cells fuse their membrane and form the rod-shaped **rhabdome**.

Compound eyes form a mosaic image based on the message sent by each ommatidium.

The eye is sensitive to flickers of high frequencies; e.g. a fly can follow flickers of about 265 flickers/second.

Compound eyes are sensitive to wavelengths from red to UV.

**THE VERTEBRATE EYE**

Position of the eye offers different advantages; e.g. lateral eyes of grazers allow them to detect predators.

Humans have binocular vision useful in judging distance and depth.

Two layers of tissue protect the eye:

* **Choroid**, cells contain black pigment that absorbs extra light and prevents internally reflected light from blurring the image.
* **Sclera**, the outer coat of the eye, is a tough layer of connective tissue that protects and helps maintain the rigidity of the eyeball.

The thin, transparent **cornea** is the continuation of the sclera on the front of the eye.

**Iris** controls the amount of light entering the eye.

**Ciliary muscles** adjust the lens to focus for near or far vision.

The **lens** of the eye is a transparent, elastic ball immediately behind the iris.

The **anterior cavity** between the cornea and the lens is filled with a watery substance, the **aqueous fluid**.

The larger **posterior cavity** between the lens and the retina is filled with viscous fluid called the **vitreous body**.

The anterior margin of the choroid is thick and forms the **ciliary processes**, glandlike structures that secrete the aqueous fluid.

The **retina** contains light-sensitive **rods** (125 million in humans) and **cones** (6.5 million).

* Rods are for dim-light vision and allow detecting shape and movement.
* Rods are more numerous in the periphery of the retina.
* Cones are responsible for color, fine detail and bright-light vision.
* Cones are concentrated in the **fovea**, a small depressed area in the center of the retina.

Light must pass through several layers of connecting neurons in the retina to reach the rods and cones.

The retina has five main types of neurons:

* Photoreceptors: rods and cones.
* Bipolar cells, which make synaptic contact with...
* Ganglion cells. Their axons form the optic nerve.
* Horizontal cells receive information from photoreceptors.
* Amacrine cells receive messages from bipolar cells and send signals to ganglion cells.

**Vision events**: Light passes through...

* Cornea → aqueous fluid → lens → vitreous body→ image forms on the retina (rods, cones) → impulses in bipolar cells → impulses in ganglion cells → optic nerve transmits nerve impulses to thalamus → integration by visual areas of cerebral cortex.

**Rhodopsin** in the rod cells and other related pigments in the cones are responsible for the ability to see.

A chemical change in rhodopsin leads to the response of a rod to light.

Rhodopsin is made of **opsin** (polypeptide) and **retinal** (pigment from vitamin A).

Two isomers of retinal exist: cis and trans forms.

* In the dark, the photoreceptors have the Na+ channels open and are depolarized.
* The photoreceptors are releasing glutamate, an inhibitory neurotransmitters.
* Retinal binds to opsin in the cis form to make rhodopsin.
* Cyclic GMP, guanosine monophosphate, maintains the Na+ open.
* The release of neurotransmitter is graded according to the degree of depolarization.
* When light strikes rhodopsin, rhodopsin breaks down into opsin and retinal.
* Cis retinal changes to trans-retinal.
* Opsin then becomes activated as an enzyme.
* The opsin molecule activates a G protein called **transducin**.
* In turn transducin activates and enzyme that converts **cGMP** to GMP.
* Sodium channels must be bound to cGMP to remain open.
* When cGMP decreases and GMP increases, the Na+ channels begin to close and the cell becomes polarized.
* The rate of neurotransmitters declines.
* The release of glutamate hyperpolarizes the bipolar cells.
* A decrease in glutamate thus results in depolarization.
* Depolarized bipolar cells **release neurotransmitters that stimulate the ganglion cell**, which sends its axon to the brain in the optic nerve.

**COLOR VISION**

There are three types of cones: **blue, red and green absorbing cones**.

Each type has a different photopigment

The retinal is the same as in rhodopsin but the opsin is slightly different in each type.

All three types respond to a wide range of wavelengths.

The three types are named according to the wavelength that its pigment responds more strongly.

Ganglion cells transmit specific types of visual stimuli such color, brightness and motion.

The **optic nerves** cross the floor of the hypothalamus and form the **optic chiasm**.

Some axons crossover to the other side of the brain.

Axons end and transmit information to the **lateral geniculate nuclei** in the thalamus.

From there neurons bring information to the **primary visual cortex** in the **occipital lobe** of the cerebrum.

Information is then transmitted to other cortical areas for further integration.

The mechanism involved in the integration of visual information is not well understood.

**CHEMORECEPTORS**

The senses of smell and taste use chemoreceptors.

**1. TASTE (gustation)**

Taste receptors are specialized epithelial cells in the taste buds located in the mouth.

In humans, taste buds are located on the tongue, in tiny elevations or papillae.

There are about 3,000 papillae on the human tongue.

Each taste bud is an epithelial capsule containing about 100 taste receptor cells interspersed with supporting cells.

Tips of the taste receptor cells have microvilli that extend into the taste pore on the tongue's surface.

These receptors detect food molecules dissolved in saliva.

There are four basic tastes: salty, sweet, sour and bitter.

Flavor depends on the four tastes in combination with smell, texture, and temperature.

The ability to taste certain chemicals is inherited.

**2. SMELL (olfaction)**

In humans, the olfactory epithelium is found on the roof of the nasal cavity.

It contains about 100 million specialized olfactory cells with ciliated tips.

The cilia extend into the layer of mucus on the epithelial surface of the nasal passageway.

Receptor molecules on the cilia bind to compounds that dissolve in the mucus.

The other end of each olfactory cell is an axon that extends directly into the brain.

These axons make the first cranial nerve.

Messages travel to the olfactory bulb in the brain then to the olfactory cortex, to the limbic system and finally to other areas of the cortex by way of the thalamus.

The number of odorous molecules determines the intensity of the receptor potential.

Humans can detect seven main groups of odors.

Each odor is made of several components and each component may bind with a particular type of receptor.

The combination of receptors activated determines the odor we perceive.

Olfactory organs react to a very small amount of stimulant; ionone (odor of violet) can be detected at 1 in 30 billion parts.

Olfactory sense adapts very quickly.

**MUSCLE**

Prefixes **myo** or **mys** = muscle; the prefix **sarco** = flesh.

A muscle is an organ made of contractile cells that allow movement.

**FUNCTIONS OF MUSCLES**

1. Produce movement of body parts, circulation of blood, passing of food through the digestive system, and manipulation of objects.
2. Maintain posture.
3. Stabilize joints of the skeleton that do not have complementary articular surfaces.
4. Generate heat.

There are three types of muscles: striated, smooth and cardiac.

**MUSCLE STRUCTURE**

In vertebrates, muscles are organs.

Muscle cells are called **fibers.**

Muscle fibers are huge cells ranging between 10 and 100 μm (10-6 m), up to 10x that of an average body cell; their length could reach 30 cm (12 inches).

Muscle fibers are multinucleate.

Muscle fibers originate from the fusion of hundreds of embryonic cells.

**Actin** is a contractile protein found in all eukaryotic cells.

In most cells, **myosin** is associated with actin.

1. Fibers are grouped into bundles called **fascicles**.
2. Fascicles are wrapped by connective tissue making the muscle.
3. Plasma membrane or **sarcolemma** has many inward extensions called **T tubules** (transverse tubules).

* Cytoplasm or **sarcoplasm**.
* ER of **sarcoplasmic reticulum**.

1. **Myofibrils** run the length of the muscle fiber.
2. Myofibrils are made of two kinds of myofilaments:

* Thick myofilaments made of myosin.
* Thin myofilaments made of actin.
* The proteins tropomyosin and troponin complex are also present.

1. Myofilaments are organized into repeating and contractile units called **sarcomeres**.
2. Sarcomeres are joined end to end at the **Z line**.

* The Z line is made of a protein that anchors the thin filaments and connects each myofibril to the next

1. Hundreds of sarcomeres connected end-to-end make up the myofibril.

Contraction occurs when actin and myosin filaments slide past each other.

**MUSCLE CONTRACTION**

During muscle contraction the thin actin filaments are pulled between the myosin filaments toward the center of the sarcomere.

**Sequence of events**:

1. Motor neuron releases acetylcholine into the cleft between the neuron and muscle fiber.
2. Acetylcholine causes the depolarization of the sarcolemma and the transmission of an action potential.
3. The impulse spreads through the T tubules and stimulates Ca2+ ion release from the sarcoplasmic reticulum.
4. Ca2+ ions initiate a process that uncovers the active sites of the actin filaments. Ca2+ bind to troponin causing a change in shape.
5. Troponin pushes tropomyosin away exposing the active sites on actin filaments.
6. Myosin molecules is made of a folded into two globular structures called heads and a long tail.
7. ATP is bound to myosin when the fiber is at rest. Myosin heads have the ability to breakdown ATP in the presence of Ca2+.
8. Cross bridges form, linking the myosin and actin filaments. ADP and Pi are released.
9. Cross bridges flex utilizing the energy released by ATP, and the filaments are pulled past one another. The muscle shortens.
10. The actin-myosin complex binds to ATP again and myosin separates from actin.
11. This series of events takes milliseconds.

**ENERGY SOURCE**.

ATP provides energy for the first few seconds of strenuous activity.

**Creatine phosphate** is an energy storing compound found in the sarcoplasm.

The energy stored in the creatine phosphate is passed on to ATP as needed.

**Glycogen**, a glucose polymer, releases glucose and restores the supply of creatine phosphate and ATP as they become depleted.

**MUSCLE ACTION.**

Muscle tone is the state of partial contraction characteristic of muscles.

Skeletal muscles produce movements by pulling on **tendon**, cords of connective tissue that attach muscles to bones.

Smooth muscles are not attached to bone. They form tubes and squeeze the contents of the tube, e.g. blood and food.

Muscles can only pull; they cannot push.

Muscles act antagonistically to one another:

* **Agonist**, the contracting muscle.
* **Antagonist** muscle causes the opposite movement.

Not all muscular activity is the same.

**White fibers** are specialized for quick response and **red fibers** for slower, longer response.

White fibers obtain most of its energy from glycolysis.

White fibers use glycogen quickly and fatigue rapidly.

Red fibers are rich in myoglobin, a red pigment similar to hemoglobin.

There are two types of red fibers:

* fast-twitching fibers specialized for quick response, and slow-twitching fibers specialized for slow response.

**Myoglobin** is a protein that stores oxygen within the muscle fiber; it is similar to hemoglobin.

**SKELETON**

Main functions of the human skeleton are:

1. Transmit mechanical forces created by muscles (levers).
2. Support internal organs and tissues.
3. Protect internal organs.
4. Storage of calcium salts.
5. Blood cell production (hematopoiesis).

Vertebrate endoskeleton consists of two portions:

1. **Axial skeleton**: skull, vertebrae, ribs and sternum.
2. **Appendicular skeleton**: bones of arms, legs, pectoral girdle and pelvic girdle.

Skull consists of 8 **cranial bones** and 14 **facial bones**.

Vertebral column is made of 24 vertebrae and two fused bones, the **sacrum** and **coccyx**.

* 7 cervical, 12 thoracic, 5 lumbar, 5 sacral, 4 coccygeal

Chapter 45 **REPRODUCTIVE SYSTEM**

In **asexual reproduction** a single parent produces an offspring that is genetically identical to the parent.

In **sexual reproduction** there is a fusion of gametes (fertilization) each provided by a different parent.

**REPRODUCTION IN INVERTEBRATES**

Sponges and cnidarians reproduce by **budding**.

Some echinoderms reproduce by **fragmentation**.

In **parthenogenesis** the unfertilized egg develops into a new individual, e.g. Daphnia in spring and early summer.

* Parthenogenesis occurs in some insects, mollusks, and some reptiles.
* In some fish, eggs do not develop unless fertilized by a sperm but none of the father's genes are incorporated into the offspring.
* In ants, honeybees and other insects, males are produced by parthenogenesis; but females develop from fertilized eggs produced through sexual reproduction.

**SEXUAL REPRODUCTION**

It is the most common type of animal reproduction.

* In external fertilization gametes are released into the water and meet outside the body.
* In internal fertilization, the sperms are delivered into the body of the female.

Some animals are hermaphrodites and posses both male and female reproductive systems.

Sex organs are called gonads; testes are the male gonads and ovaries are the female gonads.

The male gamete is called sperm or spermatozoid.

The female gamete is called ovum (pl. ova).

The fusion of gametes is called **fertilization** and produces the first cell of the new individual, the **zygote**.

**External fertilization** is common among aquatic animals. Gametes from both sexes are released synchronously into the environment. This is controlled by environmental cues like light and temperature.

**Internal fertilization** is an adaptation to life on land. Males deposit sperm directly into the female reproductive tract with the aid of a copulatory organ, the penis.

In some species, the sperm is deposited in a structure called the **spermatophore**, which is then placed inside the female track by the male or the female.

**Oviparity**: the embryo develops in the outside environment, e.g. birds.

**Viviparity**: the embryo develops inside the mother, e.g. humans.

**MALE REPRODUCTIVE SYSTEM**

SPERMATOGENESIS.

Sperms are produced in the testes through a process called **spermatogenesis**.

**Spermatogenesis** occurs in the **seminiferous tubules** of the testes.

It begins with the undifferentiated cells, spermatogonia, in the walls of the tubules.

Spermatogonia divide by mitosis to produce more spermatogonia.

Some enlarge and become **primary spermatocytes** and undergo meiosis.

Spermatogonium (2N) → primary spermatocyte (2N) → two secondary spermatocytes (N) → four spermatids (N) → four sperms (N).

Each sperm consists of a head, midpiece or neck and a flagellum.

The head contains the nucleus and a cap or **acrosome**.

* The **acrosome** helps the sperm penetrate the egg.

During its development, the sperm cytoplasm is discarded and phagocytized by the **Sertoli cells** of the tubules.

Testes develop inside the body of fetus and descend into the scrotum two months before birth.

Sperms cannot develop at body temperature.

The testes are kept in the **scrotum,** which maintains a temperature of a few degrees below body temperature.

The scrotum is connected to the pelvic cavity by the inguinal canal.

A series of ducts transport the sperm.

Seminiferous tubules → epididymis → vas deferens → ejaculatory duct → urethra → outside

ACCESSORY GLANDS

Accessory glands produce the fluid portion of the **semen**.

The normal ejaculate is about 3.5 ml of semen containing some 400 million sperms.

1. **Seminal vesicles** secrete a nutritive fluid rich in fructose and prostaglandins.
2. The **prostate** gland secretes an alkaline fluid containing prostaglandins, which neutralizes the acidic medium in the vagina and increases sperm motility.

* Prostaglandins stimulate contractions of the uterus that help propel the sperms deeper into the reproductive tract.

1. The **bulbourethral glands**, located on each side of the urethra, secrete a mucus that lubricates the penis.

A major cause of male infertility is insufficient sperm production.

* A man with less than 35 million sperm/ml is considered sterile.

TRANSPORT AND DELIVERY

**Penis** consists of three columns of erectile tissue called **cavernous bodies**.

This tissue becomes engorged with blood and the penis grows erect.

Hypothalamus releases gonadotropin-releasing hormone (GnRH) that acts on the anterior pituitary.

Anterior pituitary releases **follicle-stimulating hormone** (FSH) and **luteinizing hormone** (LH).

* FSH stimulates development of the seminiferous tubules and spermatogenesis..
* LH stimulates interstitial cells in the seminiferous tubules to release testosterone.
* Testosterone stimulates spermatogenesis and maintains the secondary sexual characteristics.

Sertoli cells produce the hormone **inhibin**, which inhibits the production of FSH by the anterior pituitary.

In a negative feedback mechanism, FSH stimulates inhibin secretion which in turn inhibit FSH production.

Testosterone is responsible for the **primary sex characteristics** in the male: descent of testes into the scrotum, growth of reproductive organs, sperm production.

**Secondary sex characteristics** include facial and body hair distribution, vocal cord length and thickness and muscle development.

**FEMALE REPRODUCTIVE SYSTEM**

The female produces ova, incubates the embryo, gives birth, and produces milk for the young after birth.

**Ovaries** produce gametes and sex hormones.

**Oogenesis** is the process of ovum production.

All female gametes originate during embryonic development.

By the time of birth they are in prophase of the first meiotic division. At this point they enter a resting stage that lasts through childhood and into adult life.

A **follicle** consists of the primary oocyte and the cells surrounding it.

At puberty, one follicle develops every month in response to FSH from the anterior pituitary.

The maturing follicle completes its first meiotic division and produces a polar body and a secondary oocyte.

* The secondary oocyte continues into the second phase of meiosis but remains in metaphase until it is fertilized.
* **Polar bodies** are small and may or may not divide, eventually disintegrating.

Oogonium (2N) → primary oocyte (2N) → secondary oocyte and polar body (N) → ovum and polar body (N).

As the oocyte matures it becomes separated from the surrounding follicle cells by a layer of glycoproteins called the **zona pellucida**.

Fluid collects in the **antrum** or space between the zona pellucida and the wall of the follicle.

Follicle cells also secrete estrogens, female sex hormones.

As the follicle matures, it moves closer to the surface of the ovary, eventually forming a bulge on the ovary surface.

During **ovulation** the secondary oocyte is ejected through the wall of the ovary into the pelvic cavity.

The follicle then becomes the **corpus luteum**, a temporary endocrine gland that secretes **progesterone**.

The **oviduct** (**fallopian tube, uterine duct**) transports the secondary oocyte.

**Fertilization** takes place in the oviduct.

Oviducts open into the **uterus**, which is lined with a mucous membrane, the **endometrium**.

The lower portion of the uterus, the **cervix**, projects into the **vagina**.

The vagina is an elastic muscular organ that receives the penis and sperm.

The external genitalia are called collectively the **vulva**.

It consists of the **labia majora**, **labia minora**, **clitoris** and **mons pubis.**

The **hymen** is an thin membrane that forms a ring around the opening of the vagina.

Breasts function in lactation, the production and secretion of milk

After giving birth, the hormone prolactin stimulates milk production.

**Colostrum** is produced for a few days after giving birth

* It contains protein and lactose but little fat.

As the baby suckles, the posterior pituitary releases **oxytocin**, which stimulates ejection of mil into the breasts.

Oxytocin also stimulates the uterus to contract to nonpregnant size.

**MENSTRUAL CYCLE**

**Menstrual phase - 5 days**

Begins with the first day of menstrual bleeding.

Gonadotropin-releasing hormone, GnRH, from the hypothalamus stimulates the anterior pituitary to release FSH and LH.

Follicles are stimulated to develop.

**Preovulatory or follicular phase - 8 days**

Developing follicles secrete estrogens.

Estrogens stimulate the growth of the endometrium and the production of more estrogens (autocrine regulation).

Rise of estrogens signal the pituitary to increase the level of LH, a surge necessary for the final maturation of the follicle and ovulation.

**Ovulation - 1 day** Occurs on the fourteenth day of the cycle.

**Postovulatory or luteal phase - 14 days**

LH stimulates the development of the corpus luteum, which secretes large amounts of **progesterone** for about two weeks.

Progesterone stimulates glands in the endometrium to secrete a nutritive fluid

Estrogens stimulate the production of GnRH, FSH and LH in the preovulatory phase but inhibit their production in the postovulatory phase.

This different effect may be due to a change in the sensitivity of the hypothalamus to these hormones.

If the secondary oocyte is not fertilized, the corpus luteum degenerates after two weeks and ceases to produce progesterone.

Lack of progesterone brings about menstruation.

Premenstrual syndrome (PMS) occurs in some women and is cause is unknown.

* Anxiety, depression, irritability, fatigue, edema, headache.

If fertilization occurs, the zygote becomes implanted about the seventh day.

Membranes that develop around the embryo secrete the human chorionic gonadotropin hormone (hCG) that maintains the corpus luteum producing progesterone.

**SEXUAL RESPONSE**

During copulation or **coitus**, the male deposits the semen into the upper end of the vagina near the cervix.

Vasocongestion and increase muscle tension are physiological responses to sexual stimulation.

* The four phases are sexual desire, excitement, orgasm and resolution.
* Heart rate and blood pressure rises and more than doubles during orgasm.

Fertilization is fusion of the two gametes.

**Conception** is the establishment of pregnancy.

Several hormones, including oxytocin and prostaglandins, regulate parturition, the birth process.

Labor can be divided into three stages:

* Contraction of the uterus move the baby down toward the cervix; amnion ruptures.
* The fetus passes through the cervix and vagina; it is "delivered".
* The placenta and fetal membranes, the afterbirth, are expelled.

**GESTATION PERIOD**

Development begins in the oviduct.

The embryo enters the uterus on about the fifth day and floats there. Its cells form the blastula or blastocyst.

The outer layer of the embryo, the trophoblast, will eventually form the chorion and amnion.

The embryo implants in the endometrium on about the seventh day.

Once implanted, the trophoblast produces the **human chorionic gonadotropin hormone** (hCG) that signals the corpus luteum that pregnancy has begun.

The corpus luteum responds by releasing large amounts of progesterone and estrogen.

Without the hCG, the corpus luteum will degenerate and the embryo would be aborted and flushed out with the menstrual flow.

The placenta is the organ of exchange between the mother and the embryo.

* It provides nutrients and oxygen to the fetus and removes wastes.
* It functions as an endocrine organ that maintains pregnancy.

The chorion invades the endometrium and develops the chorionic villi, which become vascularized.

The umbilical cord has two umbilical arteries and one umbilical vein.

Blood flows from the embryo through the arteries to the villi and returns to the embryo through the umbilical vein.

After 2 months of development, the embryo is referred as a fetus.

The blood of the fetus and the mother do not mix.

The duration of pregnancy averages 280 days (40 weeks) from the time of the mother's last menstrual period to the birth of the baby or 266 days from the time of conception.

The mother changes her physiology to accommodate the demands of the fetus:

* The heart enlarges and beats faster to increase the stroke volume and heart rate.
* The breathing rate and breathing volume increases to supply the fetus' demand for oxygen and its release of carbon dioxide.
* Fetal hemoglobin has greater affinity for oxygen than the mother's. This ensures that the fetus will get enough oxygen no matter what the concentration of oxygen is in the mother's blood.

Chapter 46 **THE IMMUNE SYSTEM IN ANIMALS**

Disease-causing microorganisms are called **pathogens**.

They include bacteria, viruses, protozoans and fungi.

Internal defense depends on the ability of the organisms t distinguish between its own cells and those of foreign organisms - between self and nonself.

Cells have surface proteins different from those of other organisms.

Pathogens have macromolecules on their cell surfaces that the body recognizes as foreign.

These foreign substances stimulate an immune response. They are called **antigens**.

An immune response involves the recognition of the foreign substance and a response aimed at eliminating it.

Antigenic molecules (antigens) include DNA, RNA, proteins, and some carbohydrates.

**Immunology** is the study of specific defense mechanisms.

There are **Specific defense mechanisms** and **Nonspecific defense mechanisms** also known as **innate immune response**.

Specific defense responses are known as adaptive or acquired immune responses.

**Acquired immunity** happens when cells of the immune system become activated.

**Innate immunity** occurs when cells of the immune system react readily to a pathogen without need of activation.

BARRIERS

**Nonspecific defense mechanisms** include mechanical and chemical barriers.

* Mechanical barriers include skin, hair, mucous.
* Chemical barriers include sweat, sebum, tears, and stomach acid.

**Lysozymes** are enzymes found in tears, sebum and tissues that attack the cell wall of bacteria.

**Cytokines** are regulatory proteins (interferons and interleukins) secreted by cells of the immune system. They are important signaling cells during immune responses.

Cytokines can influence nearby cells and modify their functions.

* **Interferons** are proteins produced by virus infected cells. Some, produced by macrophages or fibroblasts, inhibit viral replication and kill tumor cells, Type I, and stimulate macrophages, Type II interferons.
* **Interleukins** are secreted mostly by macrophages and leukocytes. They regulate the interaction between leukocytes and other cells and can cause fever, kill tumor cells and cause other responses.

**Inflammation** is a protective mechanism.

* Damage to tissue by physical injury or by infection triggers the inflammatory response.
* It is regulated by proteins in the plasma, by cytokines, and by substances called **histamines** released by platelets, by basophils (WBC), and by mast cells.
* Blood flow increases bringing phagocytic cells to the site of infection. This is probably the most important element of inflammation.
* Histamines cause vasodilation and make capillaries more permeable allowing antibodies to enter the tissues.
* Leukocytes release **prostaglandins** that increase blood flow to the injured area.
* Blood flow to the injured area brings clotting elements to initiate tissue repair, makes the skin feel warm, and may causes redness.
* Edema (swelling) occurs.

**Fever** is a widespread inflammatory response.

* Pathogens may trigger fever.
* Some leukocytes release interleukins and reset the body thermostat in the hypothalamus.
* Fever interferes with the growth and replication of microorganisms.
* It may kill some microorganisms.
* Causes lysosomes to break and destroy infected cells.
* Promotes activity of lymphocytes (T cells), antibody production and phagocytosis.

**Leukocytes or Phagocytes** destroy bacteria and other cells.

* **Neutrophils** are the first phagocytes to arrive usually within an hour of injury.
* Monocytes arrive next and become large **macrophages**.
* Both phagocytize pathogens, their products and dead and injured cells.
* A neutrophil can phagocytize about 20 cells and a macrophage 100 cells before they become inactive and die.
* Pus consists of dead phagocytic cell, fluid and proteins leaked out of capillaries.
* Leukocytes circulate between the blood and tissues.

**INTRODUCTION TO LYMPHOCYTES AND THE IMMUNE SYSTEM**

Cells involved in the acquired immune response are called **lymphocytes**.

Lymphocytes are produced and mature in the bone marrow and the thymus gland.

Lymphocytes circulate through the blood and the lymph nodes, spleen and lymphatic ducts.

Lymphocytes encounter antigens in the lymph nodes.

Circulating lymphocytes are in an inactive state.

Antigens activate lymphocytes. It has to be the appropriate antigen to activate a lymphocyte.

T lymphocytes and B lymphocytes target specific invaders.

**Antigen recognition and clonal selection**.

An antibody is specific for an antigen.

Antibodies to many antigens can be produced.

The clonal selection theory states that...

1. Lymphocytes have unique receptors on their surfaces that recognize the antigen.
2. Lymphocytes are activated when a receptor binds to an antigen then it divides and makes many clonal copies of itself.
3. Some of these copies persist after the pathogen is eliminated and allow for a quick respond in future infections.

**B cells**

* Responsible for **antibody-mediated immunity**.
* Produced in the bone marrow daily by the millions.
* They mature in the bone marrow.
* Carry specific glycoprotein receptor to bind to a specific antigen.
* When a B cell comes into contact with an antigen that binds to its receptors, it clones identical cells, and produces **plasma** cells that manufacture antibodies.
* BCR receptors have "Y" shape, with a light and heavy chain.
* Also produce **memory B cells** that continue to produce small amounts of antibody after an infection.
* Plasma cells remain in the lymph nodes and secrete **specific antibodies**.
* Antibodies are transported via lymph and blood to the infected region.
* Antibodies form complexes with antigens on the surface of the pathogen.
* BCR receptors and antibodies secreted by B cells are immunoglobulins (gamma globulins).

**T lymphocytes or T cells:**

* Responsible for **cellular immunity**.
* Originate in the bone marrow.
* In the **thymus** they become immunocompetent that is capable of immune response.
* In the thymus they divide many times and some develop specific surface proteins with receptor sites. These cells are selected to divide: positive selection.
* T cells that react to self-antigens undergo **apoptosis**. In this way T cells can distinguish between foreign antigens and the body's own antigens.
* They produce different kinds of cytokines that affect T cell development, B cell development, NK development and the action of macrophages.
* There are several types and subtypes of T cells.

**Antibody-antigen specificity.**

Antibodies and antigen receptors do not bind to the entire antigen but to a selected region called the **epitope**.

An antigen may have different epitopes where binding by antibodies and receptors occur.

Gene recombination allows for millions of possible antibodies and receptors.

**Antigen presentation by MHC proteins: activating T cells.**

* Pathogen invades the body and infects cells.
* Dendritic leukocytes (macrophages) engulf pathogen.
* Antigens are broken into segments.
* Antigen segments form complex with the class I MHC protein.
* Macrophages displays MHC-antigen complex on its cell surface.
* Helper T cells recognize the foreign antigen-MHC complex and secrete IL-2. These cytokines can activate T cells.
* Competent T cells are in turn activated, increase in size and divide mitotically.
* Clones of competent T cells are produced.
* Clones differentiate into helper T cells (CD4+), cytotoxic lymphocytes (CD8+) and other types of cells.
* Cytotoxic T cells leave the lymph nodes and migrate to the area of infection.

**B cell activation and antibody secretion.**

B cells are responsible for antibody-mediated immunity, also called humoral immunity.

Antibody molecules serve as cell surface receptors that combine with antigens.

Only B cells bearing a matching receptor on its surface can bind a particular antigen.

B cell must be activated.

* Macrophage engulfs bacterium.
* Antigen forms complex with the class II MHC protein.
* Macrophage displays MHC-antigen complex on its cell surface.
* Helper T cells are activated when their receptors combine with the MHC-antigen complex.
* Interaction between helper T cells and MHC-antigen complex stimulate B cells to divide and differentiate.
* Some differentiate into plasma cells and produce large quantities of antibodies.
* IL-2 also stimulates cytotoxic T cells to become active killers.

Activated B cells form many clones, some of which differentiate into **plasma cells**, and some into **memory B cells**.

Plasma cells remain in the lymph nodes and secrete specific antibodies.

Antibodies are transported via lymph and blood to the infected region.

Antibodies form complexes with antigens on the surface of the pathogen and mark them for destruction.

Memory cells survive for a long time and continue to produce small amounts of antibody long after the infection has been overcome.

Memory cells when stimulated can produce clones of plasma cells.

**Killing bacteria**

Macrophages ingest some of the infecting bacteria at the site of infection and display epitopes on it surface.

Helper T cells recognize and bind to the displayed epitopes.

The attachment of helper T cells to macrophages enhances the phagocytic activity of the macrophages.

The helper T cells secrete cytokines that kill bacteria and viruses, recruit additional phagocytic cells to the site of infection and increase the inflammatory response.

Bacteria are also tagged for destruction by macrophages or by the destruction of the cell wall.

Antibody-antigen complexes stimulate complement proteins that punch holes on the bacterium cell membrane.

**Destroying viruses.**

Cytotoxic lymphocytes recognize and bind to viral epitopes displayed by the infected cell. The cytotoxic cell then inject molecules that induce a self-destruction of the infected cell. The spread of infection is limited this way.

Plasma cells produce antibodies that bind to the virus and prevent the virus from binding and infecting other cells. Macrophages recognized the tagged virus and phagocytose them.

**Immunological memory**.

Activated B and T cells also produce **memory cells**.

Memory cells circulate through blood and tissue for years or decades, ready to provide an extremely rapid response should an infection with the same antigen recur.

If the same antigen reenters the body, memory cells recognize the antigen aand trigger a secondary acquired immune response.

Secondary response is faster because the antigen-specific receptors are already present and increase the likelihood

**Somatic hypermutation.**

Some B memory cells go to an area of the lymph nodes called the germinal center.

In the germinal center the DNA of the memory cells undergo rapid mutation in the V (variable) region of the immunoglobulin gene, producing point mutations.

Some of the newly produced receptors and antibodies bind better to the antigen and are more effective in destroying the pathogen.