

Physiological Mechanisms

Basic concepts in physiology

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External link: e-book

http://www.mhhe.com/biosci/esp/2002_general/Esp/default.htm

Physiology is the study of how living organisms function. Life, as we know, is living matter (made of organic molecules) with functional manifestations, such as cellular-organization, reproducibility, growth, dependence on nutrition, metabolism, respiration, movement, tendency for evolutionary modification.

The simplest organisms are unicellular (i.e. made up of one *cell*— the basic building blocks of all organisms), living in a “constant state” with respect to their external environment despite their conflicting requirements of exchanging substances with (deriving nutrition, eliminating wastes, exchanging heat and oxygen) and protecting themselves (through the partially permeable cell membrane) from the external surroundings.

In the evolutionary progression to a multicellular organism, cells have undergone functional specialization. Cells performing similar functions are organized in groups in a nonliving intracellular matrix — tissues. Each tissue also has a specialized function, e.g. the four groups of tissues are: (1) *epithelial tissue* that covers and lines other organs, (2) *connective tissue* that constitutes blood, bones ligaments and tendons, (3) *muscle tissue*, such as skeletal, cardiac and smooth muscle, and (4) *nervous tissue*, e.g. brain and spinal cord. Tissues are further grouped together to form organs that are distinct structures with specialized functions, e.g. kidneys. Organs group together to form organ systems, e.g. the excretory system. Organ systems deal with various specialized functions required for survival (i.e. digestion, support, excretion, reproduction, movement, circulation, respiration, hormonal control) and together form the whole organism. Thus, the body is a complex system and daily life activities (such as movement, sight, hearing, smelling, eating, breathing among others) require specific physiological mechanisms with a high level of coordination and functional synchronization between the various functional units of the body.

All these physiological mechanisms are governed by the basic principles of physics and chemistry. To understand physiological mechanisms it is important to understand some basic concepts that are relevant to biological systems.

Chemical foundations of physiology

Atoms are the building blocks of matter. All living matter is composed essentially of atoms of carbon (the fundamental element in organic molecules) together with hydrogen, oxygen as well as nitrogen, phosphorus, calcium and sulphur, and to a lesser degree other elements, such as iron, magnesium, chromium, etc. All living things have **biomolecules** that are made up of these atoms. Examples of biomolecules include carbohydrates, proteins, lipids and nucleic acids.

Solutions

Solutions are a mixture of solutes dissolved in a solvent. Solutions have various functional specialties—solutions with ions conduct electricity (e.g. those in intracellular fluid (fluid within cells) and interstitial fluid (fluid between cells), while others help deliver food (e.g. blood) and remove wastes (e.g. urine). The most abundant solvent in biological systems is **water**. Water is an ideal solvent for these systems because of its special properties.

Water

It is the most abundant inorganic substance that is important to living organisms. It constitutes 60%–80% of the human body.

Special properties of water

- It is an excellent solvent: Thus it is good for chemical reactions, waste removal, and delivery of food materials.

- It stays liquid over a wide temperature range: Thus chemical reactions can take place readily. It is useful for circulatory systems.
- It acts as a lubricant with proteins, e.g. in joints, ligaments, tendons, etc.
- It is an ionizing solvent (with a high dielectric constant): Thus it ionizes salts and makes conductive solutions that are useful for nerves and other excitable tissues.
- It has a low viscosity (i.e., it flows readily), which is important for circulatory systems and thus less work for the heart.
- It has a high surface tension and adhesion: This causes water molecules to stick together, e.g. the pleural membranes of the lungs stick to one another making inspiration and expiration possible.
- It has a high heat of vaporization (large amount of heat is removed when water evaporates). This helps maintain body temperature in mammals by sweating.
- It has high heat conduction. This prevents overheating of the body as heat generated from biological processes gets removed from the body.
- It has a high heat capacity (large amount of heat is required to raise water temperature). This is useful for moving large amounts of heat in the circulatory system without any change in body temperature.
- It has a high heat of fusion. This means that a lot of heat has to be lost to convert water into ice. This property prevents the formation of ice crystals in cells, which could be fatal.

Transport mechanisms

The functional synchronization of physiological mechanisms is achieved by fluid transport of hormones over long distances by the [circulatory system](#) <See circulation chapter>, and conduction of ions across the cell membranes in the [nervous system](#) <See excitable tissues chapter>, among others.

The body of a multicellular organism can be thought of as divided into three main solution-filled compartments: *intracellular*, *interstitial* and *blood* and living cells may be thought of as very small bags of solutions contained within semi-permeable membranes.

Chemical substances need to move from one place to another to keep organisms alive and growing. For example, food substances must move from one cell to another; move in and out of the cell; and move from one part of the cell to another. Thus, physiological mechanisms (acquisition of nutrients, gases, and water, and the elimination of wastes) depend on the movement (transport) of ions and water between these compartments (across cell membranes).

There are two main transport mechanisms in the body: **passive** and **active**. <Also see “active transport” in chapters on digestion, excretion, excitable tissues>

Passive transport

This is the movement of (bio) chemicals, and other ions or molecular substances, across membranes. The process does not require chemical energy and depends on the permeability of the cell membrane. The four main kinds of passive transport are diffusion (simple), facilitated diffusion, filtration and osmosis.

Diffusion (simple) is an important process by which molecules and ions randomly move (This random mixing of ions and molecules in a solution is due to their kinetic energy.) from its region of high concentration to its region of low concentration. The greater the concentration gradient (i.e. difference between the higher concentration and lower concentration), faster is the

diffusion/movement. One example of diffusion in the human body is the movement of oxygen and carbon dioxide between the air within the lungs and blood capillaries as well as between the blood and body cells.

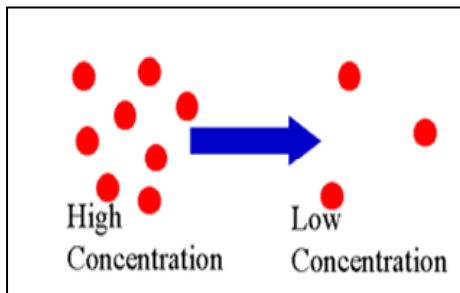


Fig. 1: Principle of diffusion

Facilitated diffusion occurs where molecules diffuse across membranes from a region of high concentration to low concentration, with the assistance of *transport proteins*. These molecules (e.g. many ions, urea, glucose, fructose, galactose and certain vitamins) being lipid insoluble cannot diffuse through the cell/plasma membrane. Transport proteins are integral proteins of the cell membrane that act as water-filled carriers for each type of molecule.

Substances enter the cell through facilitated diffusion by the following process:

Molecule attaches to the carrier protein on the outside of the cell membrane



Because of the binding of the molecule, the carrier protein changes shape forming a conduit



The molecule passes through the carrier protein conduit and is released inside the cell.

Fig. 2: Simple diffusion

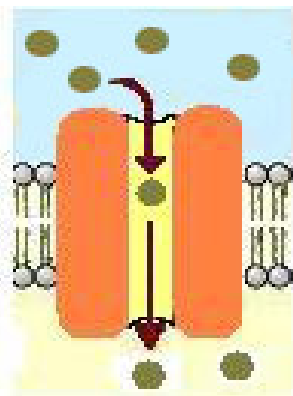
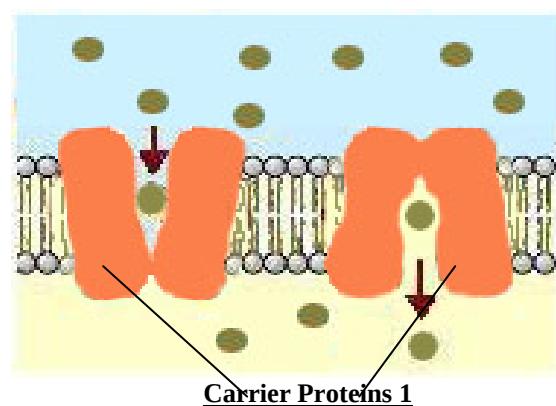


Fig 2b: Facilitated diffusion



Filtration is the movement of water and solute molecules across the cell membrane due to hydrostatic pressure generated by the cardiovascular system. The movement depends on the size of the membrane pores. For example, in capillaries only the fluid part of blood with solutes can move out into the interstitial spaces, while the blood cells and proteins cannot.

Osmosis is the diffusion of water from its area of high concentration to its region of low concentration (i.e. from a dilute solution to a concentrated solution) through a semi-permeable membrane (the cell membrane). Osmosis is important in biological systems as many biological membranes are semi-permeable, i.e. they are impermeable to organic solutes and large molecules, such as polysaccharides, while permeable to water and small, uncharged solutes.

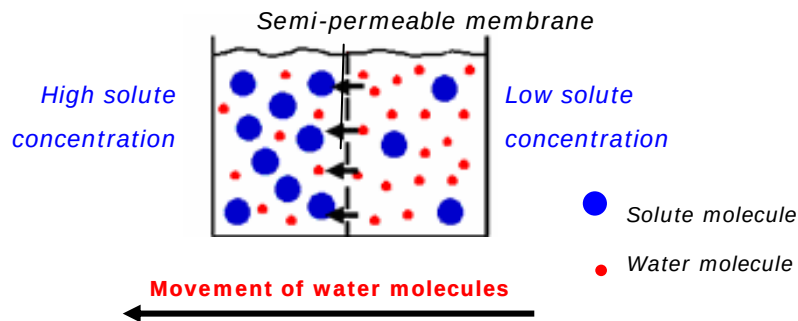


Fig. 3: Osmosis

Osmosis is driven by the solute concentration. Solute concentrations are defined as:

- *Isotonic* if the solutions being compared have equal concentration of solutes.
- *Hypertonic* if one solution has a higher concentration of solutes than the other (the other solution with lower concentration of solutes is known as hypotonic solution).
- *Hypotonic* if one solution has a lower concentration of solutes than the other (the other solution with higher concentration of solutes is known as hypertonic solution).

Flash animation: <http://www.stolaf.edu/people/giannini/flashanimat/transport/osmosis.swf>

The concentration of solute generates a pressure across the plasma membrane called *osmotic pressure*, which tends to draw in water, and is equal to the hydrostatic pressure required to stop the flow of water. Osmotic pressure is an important mechanism for the flow of water between the various compartments of the body. Under normal conditions, the osmotic pressure within the cells is equal to that outside, so the cells retain their water content and intracellular fluid constitution, while the osmotic pressure in blood at the venous end of the capillaries is more than the interstitial fluid causing fluid to enter the capillaries (absorption). <See circulation>

Active transport

This is achieved by utilizing energy in the form of ATP (adenosine triphosphate, the energy currency of living organisms) molecules. There are “pumps” located in the cell membrane that transport a substance across a membrane by utilizing energy, e.g. the $\text{Na}^+\text{-K}^+\text{-ATPase}$ pump that throws three Na^+ ions out of the cell and brings two K^+ ions inside the cell, while converting one ATP into ADP (adenosine diphosphate) and utilizing the energy released for this work.

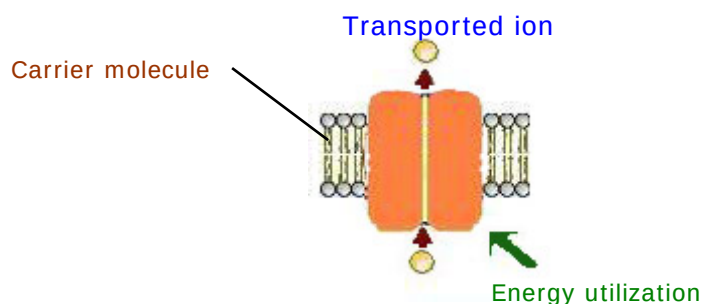


Fig. 4: Active transport

Inorganic constituents

In addition to the organic biomolecules, certain inorganic substances are essential for life. Inorganic compounds are small in size and do not contain carbon as the major constituent. Examples of common inorganic compounds in the body include oxygen, carbon dioxide, water and many salts ([Table](#)). Inorganic salts and minerals amount to about 6 per cent of the entire body weight. One of the most important inorganic salts in the body is sodium chloride (absolutely necessary for continued existence) which is found in all the tissues and fluids. Various phosphates are formed by the combination of phosphorus with sodium, potassium, calcium, and magnesium. The most abundant phosphates are of lime. They form more than half the material of the bones, and are found in teeth, other solids and fluids of the body. Iron is also an important inorganic substance as it is an essential constituent of blood and of enzymes required for production of energy.

Table: Important inorganic elements in the body

Element	Concentration in the body	Functions
Oxygen	65%	It is a component of water and other compounds; oxygen gas is essential for respiration.
Carbon	18%	It is found in all organic molecules.
Hydrogen	10%	It is a component of water and most other compounds in the body.
Nitrogen	3%	It is found in proteins, nucleic acids, and other organic compounds; 78% of the respired air is nitrogen while only 21% is oxygen.
Calcium	1.5%	It is found mainly in bones and teeth, and important for membrane function, nerve impulses, muscle contractions, and blood clotting.

Element	Concentration in the body	Functions
Boron	Traces	It assists and improves retention of calcium, magnesium, and phosphorus; necessary for brain function, memory and alertness as well as for the activation of vitamin D.
Chlorine	0.70%	It is important for membrane function and water absorption; chloride is the major anion in body fluids and part of hydrochloric acid (HCl) in gastric juices.
Chromium	Traces	It is the most important regulator of insulin; is a potent metabolic hormone in the metabolism of proteins, carbohydrates, and fats; assists neurotransmitters; helps with the function of the brain, thyroid, and hormonal balance.
Cobalt	0.70%	It is a vital part of vitamin B12; stimulates numerous enzymes; helps build red blood cells and with iron absorption.
Copper	0.70%	It is involved in the synthesis of haemoglobin, melanin, and elastin; is an enzyme cofactor; part of some cytochromes in cell respiration; assists in phospholipid synthesis, protein metabolism, vitamin C oxidation, and the formation of RNA.
Germanium	Traces	It helps activate various organs to attract more oxygen; expels harmful pollutants and pathogens from the body; helps maintain a strong immune system by assisting in the production of killer cells and T-suppressor cells; assists in electron transmissions.
Iodine	0.70%	It is a major component of thyroid hormones (thyroxine and T3); necessary for the metabolism of fats and such minerals as calcium, silica, and phosphorus; essential for spleen, liver, and brain function.
Iron	0.70%	It is essential for oxygen transport and energy production; component of haemoglobin, myoglobin, and cytochromes in cell respiration.
Magnesium	0.05%	It is required for activation of several enzymes; vital for strong bones and teeth; essential for brain and liver function; calms nerves; promotes cell growth; increases tissue elasticity; necessary for metabolism of ATP–ADP.
Manganese	0.70%	It is a cofactor for some enzymes; because it is found

Element	Concentration in the body	Functions
		with lecithin, it is involved in the synthesis of fatty acids and cholesterol; strengthens nerves and thought processes; element in body linings and connective tissues; helps with eyesight; enhances body's recuperative abilities and resistance to disease.
Phosphorus	1.0%	It is found in the nucleus of every cell in the body (including white blood cells), nucleic acids, high-energy compounds, and phosphate buffer system; a major component of outer bone; combines with such elements as iron, potassium, sodium, magnesium and calcium; necessary for the reproductive system and sexual function; necessary for muscle tissue and growth; an essential nutrient for the nerves.
Potassium	0.35%	It is important for proper membrane function, nerve impulses, and muscle contractions; major cation in cytoplasm; a primary electrolyte; attracts oxygen to tissues; helps eliminate toxins from the body.
Selenium	0.70%	It is a powerful antioxidant; vital to the immune system; major part of apoptosis (normal cell death in the body); helps maintain cell integrity; supports heart function; helps slow the ageing process; delays oxidation of polyunsaturated fatty acids.
Sodium	0.15%	It is stored in stomach walls, joints, and gallbladder; important for membrane function, nerve impulses, and muscle contractions; major cation in body fluids; contributes to the alkalinity of the lymph and blood; works with the bicarbonate buffer system in the digestive tract to prevent hydrochloric acid from burning stomach walls; helps retain calcium and cholesterol liquid in the body.
Sulphur	0.25%	It is found in many amino acids as well as thiamine and biotin; necessary for developmental and neurological processes and for synthesis of collagen; detoxifies; increases blood circulation; reduces muscle cramping and back pain; removes inflammation; assists in the healing of muscles; helps the liver produce choline; an important element in nerves and the myelin sheath; stimulates flow of bile; regulates heart and brain function; promotes healthy skin, nails, and hair; helps lubricate joints.
Zinc	0.70%	It is found in all body fluids, including urine as well as

Element	Concentration in the body	Functions
		the moisture found in the eyes, mouth, lungs, and nose; a cofactor for enzyme function, especially carbonic anhydrase needed for carbon dioxide transport; part of peptidases needed for protein digestion; necessary for normal taste sensation; important in wound healing; necessary for hormone production and for the prostate gland; and a vital part of the immune system.

Molecules of inorganic compounds dissociate into ions when dissolved in water. The ionic concentration of H^+ or OH^- ions defines the kind of solution that is formed—acidic or basic. Substances that donate H^+ ions to a solution are acids while substances that donate OH^- ions to a solution are bases.

pH and pKa

Since all living things are water-based, biological functions are extremely sensitive to pH. pH is defined as a measure of the acidity or alkalinity of a solution (or “fluid” in biological systems). A pH of less than seven is considered acidic while pH greater than seven is basic (alkaline). The cell environment is always buffered at approximately pH 7, which is neutral.

The most reactive ions, hydrogen ions (H^+) and hydroxyl ions (OH^-), are the basis for the pH value of a substance/solution. pH is denoted as a logarithmic unit, $pH = -\log [H^+]$, where $[H^+]$ is the H^+ ion concentration in moles/litre (a high pH indicates low concentration of H^+ ions and a low pH indicates a high concentration of H^+ ions).

pH in biological systems is important as proton dissociable groups are found in [bio/macromolecules](#) (such as proteins). These biological macromolecules act as acids and bases by donating or accepting protons. However, due to the size of these molecules, they often contain several different groups and act as weak acids or bases that accept or donate protons. This leads to another important concept in chemical physiology, the *acid dissociation constant* denoted by K_a . It is the equilibrium constant for the dissociation of a weak acid. The pK_a values ($pK_a = -\log K_a$) of proteins and amino acid side chains are important for the activity of enzymes and the stability of proteins because the ionization of a compound governs its physical behaviour and properties, such as solubility and hydrophobicity.

Regulation of pH: Buffers

As all biological processes are extremely sensitive to pH, organisms need to maintain a specific and constant pH. The body regulates pH through a buffer system. **Buffers** are weak acid mixtures, which minimize pH change by converting strong acids or bases, which are unstable and ionize easily, into relatively stable weak acids and bases. A buffer system consists of a mixture of two compounds, one that takes up H^+ ions (H^+ acceptor) if there are too many H^+ ions and another that releases H^+ ions (H^+ donor) if there are not enough H^+ ions (such as bicarbonate/ CO_2).

The various buffer systems operating in the body are:

Bicarbonate buffer	$\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-$	In blood plasma
Haemoglobin	$\text{Hb-H} \rightleftharpoons \text{Hb}^- + \text{H}^+$	Interior of red blood cells
Phosphate buffer	$\text{H}_2\text{PO}_4^- \rightleftharpoons \text{H}^+ + \text{HPO}_4^{2-}$	Important in acid–base balance by kidneys
Protein (Pr)	$\text{Pr-H} \rightleftharpoons \text{Pr}^- + \text{H}^+$	Intracellular fluid

[Buffer \(animation\)](http://www.mhhe.com/physsci/chemistry/essentialchemistry/flash/buffer12.swf)

<http://www.mhhe.com/physsci/chemistry/essentialchemistry/flash/buffer12.swf>

Homeostatic mechanisms

All living cells need to maintain stable conditions for effective functioning of the body and its survival. Homeostasis is the means by which multicellular organisms maintain a constant internal environment which is less vulnerable to changes in the external environment. The processes and activities that help to maintain homeostasis are referred to as **homeostatic mechanisms**, for example sweating or shivering in response to temperature changes, osmotic regulation and blood sugar level regulation.

A system as complicated as the human body (or any multicellular organism), can function effectively only if factors such as blood volume, blood pressure, muscle movements, body temperature, blood sugar level, are regulated. Regulation is a two-way exchange of information between a factor/variable and the body's control centre for making adequate adjustments to achieve homeostasis.

The most common regulatory process for achieving homeostasis is **negative feedback control** ("negative" means that any deviation from the normal is reduced or resisted) which occurs through three components: receptor, control centre and effector.

Receptor detects the stimulus (change in internal environment may be caused by an external factor) and informs the control centre.



The control centre analyses the signal from the receptor and sends output to the effector



The effector produces a response which opposes the initial change



The internal environment reverts to its original state (or near its original state)

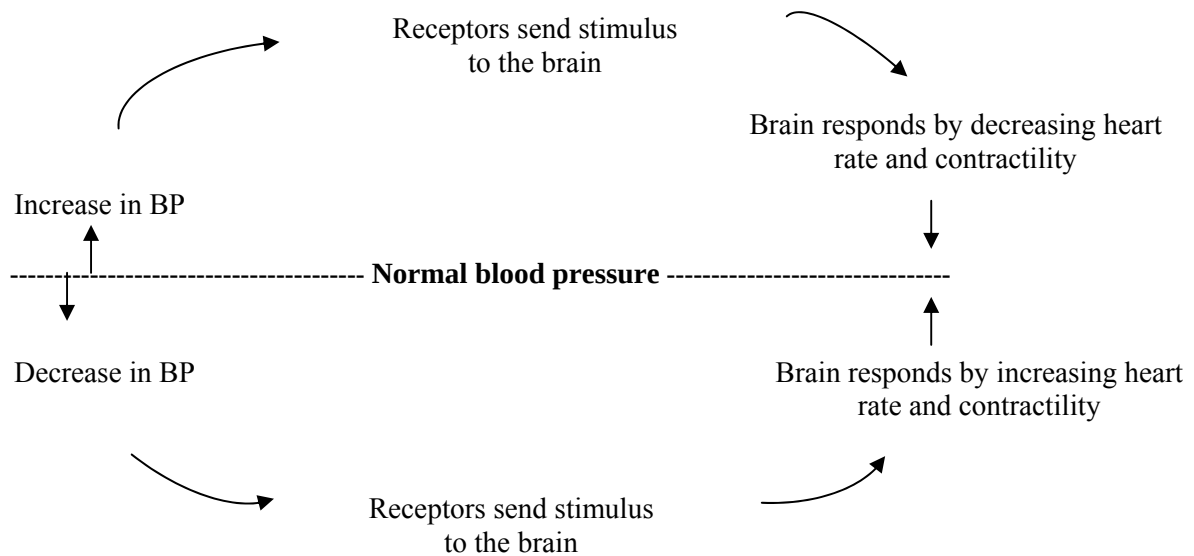
Some examples of homeostatic mechanisms

Blood pressure regulation

Regulation occurs through change in heart rate and contractility that allows blood pressure to fluctuate within a narrow normal range.

- Receptors are located in the large blood vessels near the heart

- Control centre is the brain
- The effector is the heart



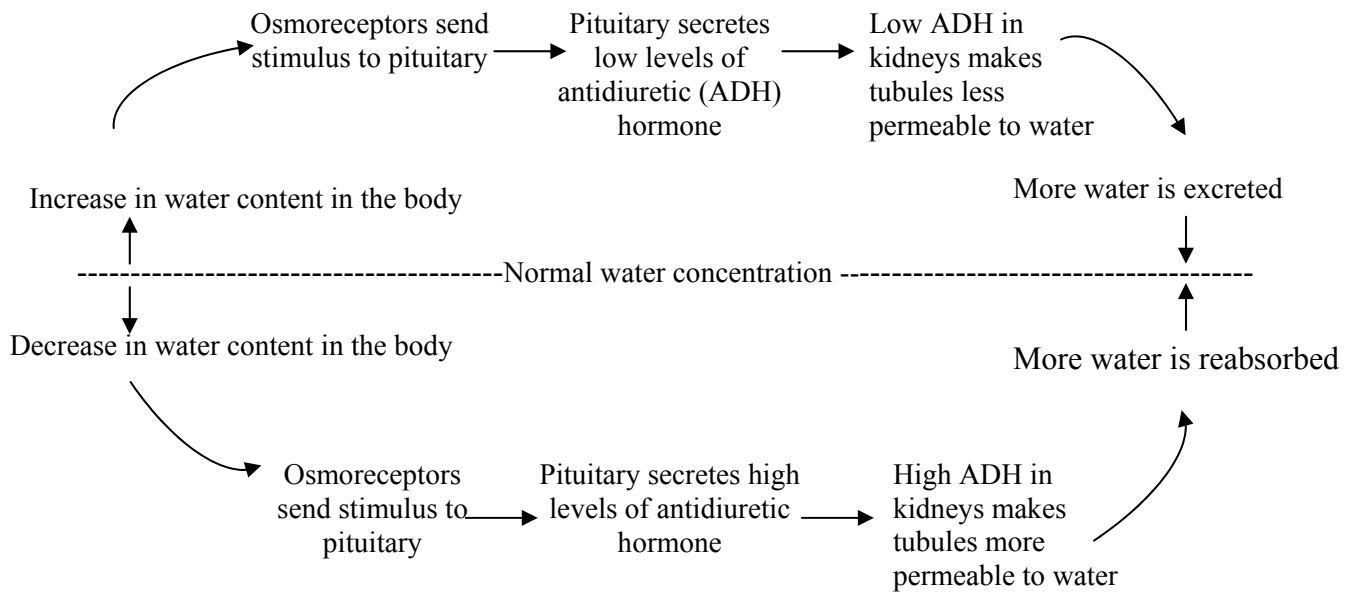
Thermoregulation

This is the regulation of body temperature at 37°C, despite fluctuations in heat production and heat loss and also the external temperature. Thermoreceptors located in the skin (that detect the temperature of the external environment) as well as those present in the hypothalamus send information to the hypothalamus (control centre).

Process of regulation of body temperature	
<i>Very cold environment (when body's core temperature decreases)</i>	<i>Very warm environment (when body's core temperature increases)</i>
1. Muscles begin to contract involuntarily due to shivering reflex thus producing heat. 2. Vasoconstriction of blood vessels minimizes heat loss from the body. 3. The hairs on the body 'stand on end', and trap a layer of air between the hair and the skin. This insulation of warmer air next to the skin reduces heat loss. 4. Increase in metabolic rate is caused by increased secretion of thyroid hormone resulting in increased heat production.	1. Vasodilation (i.e. the blood vessels close to the skin surface become more dilated, increasing their surface area) maximizes heat loss to the external environment. 2. Increased sweating reduces the body temperature.

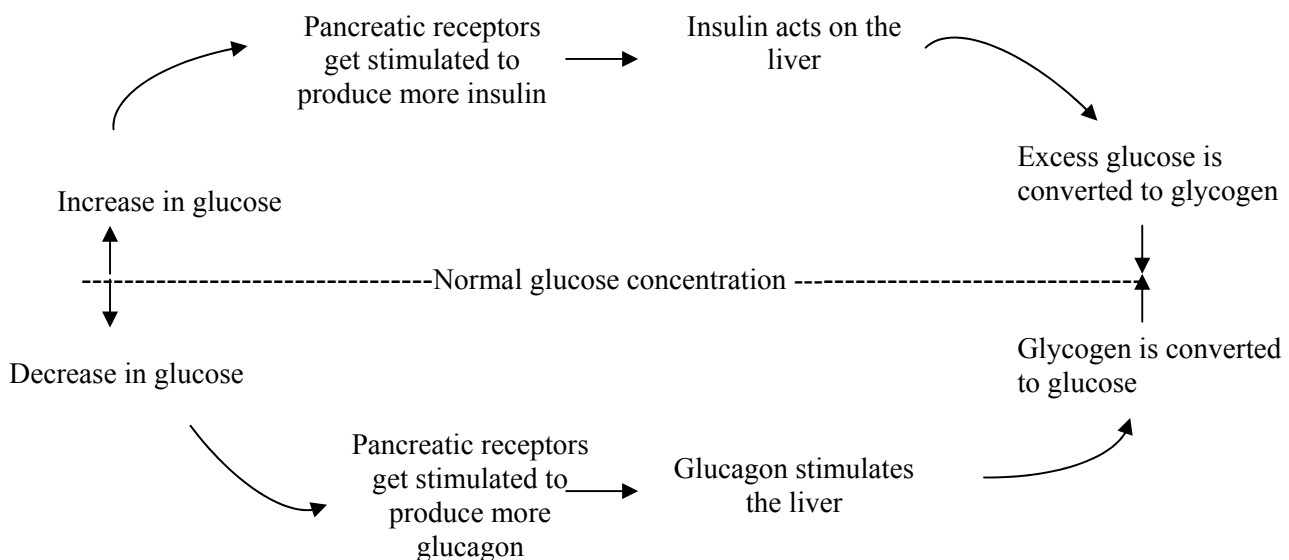
Osmoregulation

This is the regulation of water concentration in the body fluids.



Blood sugar regulation

This is important for the body's energy needs. The body requires lots of glucose to create adenosine triphosphate (ATP; the energy molecule). The amount of ATP needed fluctuates, and therefore the body regulates the availability of glucose to maximise its energy making potential. Blood sugar regulation occurs through [hormonal control](#).



Fight/flight situations and homeostasis

In an emergency situation, the body reacts by releasing adrenaline (from the adrenal glands) which overrides the homeostatic control of glucose thus promoting the breakdown of glycogen into glucose for energy. The secretion of adrenalin causes increased metabolism, breathing and heart rate.

When the emergency is over, adrenaline levels drop causing the homeostatic controls to revert to normal state.

Biomolecules

Biomolecules include:

[Carbohydrates](#)

[Lipids](#)

[Proteins](#)

[Nucleic acids](#)

What makes carbon the ideal atom for making biomolecules?

- It is a relatively small atom with a low mass.
- It has the ability to form 4 strong covalent bonds.
- It can react with other carbon atoms to form large molecules of varied shapes.
- Large sized carbon-containing compounds being insoluble are basic units for body structures.

Carbohydrates

Carbohydrates are made up of carbon, hydrogen, and oxygen. These include starches, sugars, glycogen and cellulose. Carbohydrates are classified as,

- [monosaccharides](#) (simple sugars with ring structures, e.g. glucose and fructose),
- [disaccharides](#) (contain two monosaccharides together, e.g. sucrose, maltose and lactose), and
- [polysaccharides](#) (contain many monosaccharides together, e.g. glycogen and cellulose).

Monosaccharides are aldehyde or ketone compounds with multiple hydroxyl groups. They contain one sugar molecule, are water-soluble and sweet in taste. They contain 3 (trioses), 4 (tetroses), 5 (pentoses), 6 (hexoses), 7 (heptoses) or more carbon atoms. Common hexoses are glucose and fructose, while pentoses include ribose and

Fig. 5: Hexose sugars

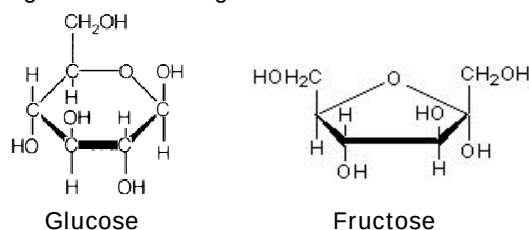
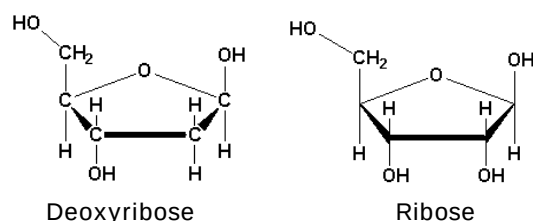


Fig. 6: Pentose sugars



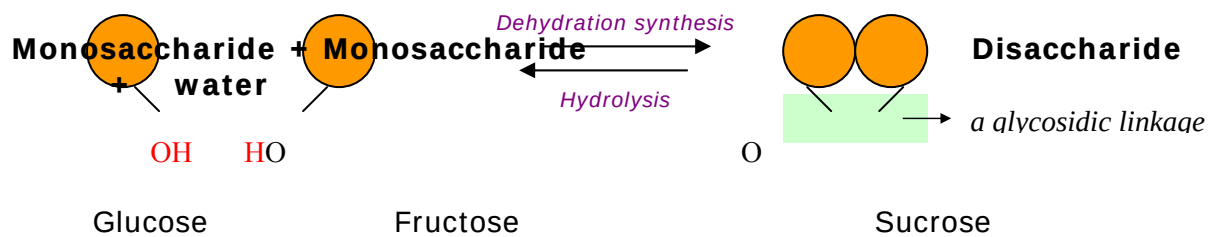
deoxyribose. They are the building blocks for disaccharides and polysaccharides. Most monosaccharide molecules have cyclic structure.

Disaccharides contain two monosaccharide molecules joined by glycosidic linkages. Two monosaccharide molecules unite through dehydration synthesis to form one disaccharide molecule and one water

molecule (Fig. 7 below). Depending on the constituent monosaccharide these may be crystalline, water-soluble, and sweet-tasting. Most common disaccharides are sucrose (table sugar, consisting of a glucose and fructose molecule), lactose (milk sugar, consisting of two glucose molecules), and maltose (consisting of a glucose and a galactose molecule). They form a part of our diet.

Disaccharides can be broken down by the addition of a water molecule through hydrolysis (Fig. 7 below).

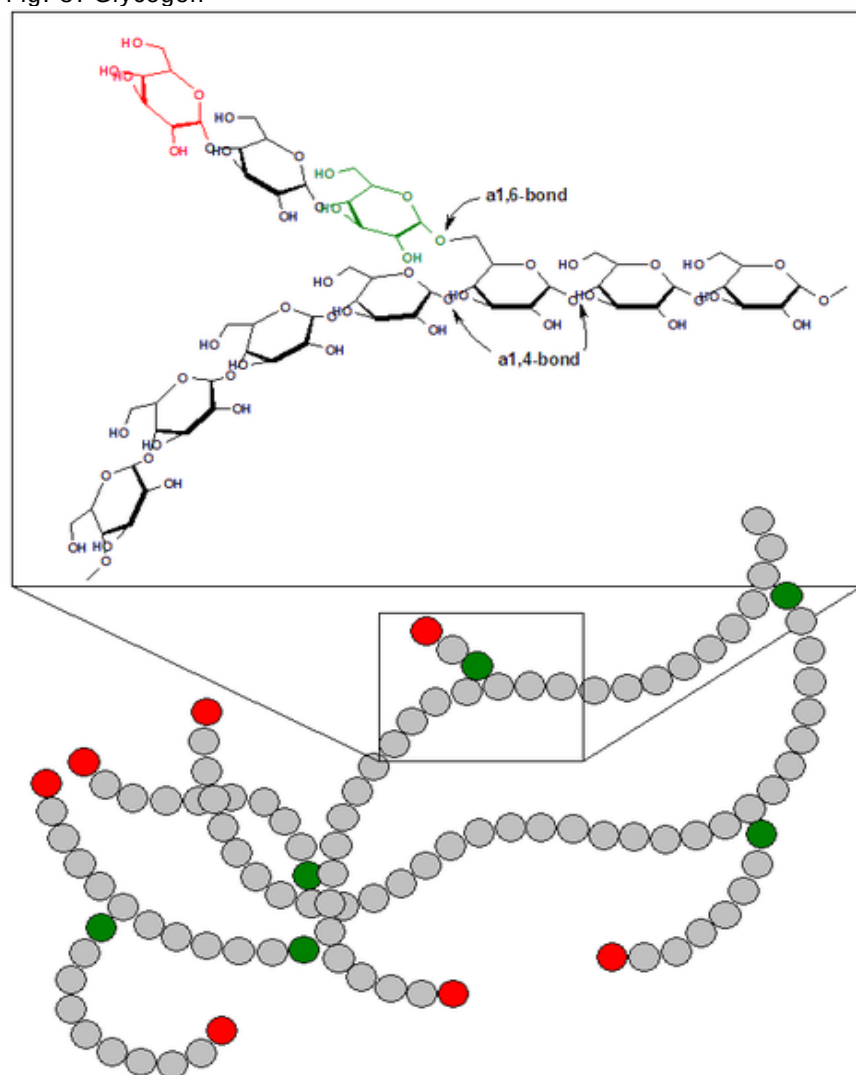
Fig. 7: Dehydration synthesis and hydrolysis mechanisms



Polysaccharides are large carbohydrates made up of hundreds of monosaccharide molecules (joined by glycosidic linkages). They are formed by dehydration synthesis. They tend to be amorphous, insoluble in water, and have no sweet taste. Polysaccharides can be broken down to its monomer units by hydrolysis. Most common polysaccharides are starch and glycogen (Fig. 8).

Polysaccharides serve as energy stores. Liver stores energy in the form of the polysaccharide glycogen, which is broken down to monosaccharide glucose when blood sugar levels fall so that cells can use it to

Fig. 8: Glycogen



Source: <http://en.wikipedia.org/wiki/Image:Glycogen.png#file>

generate energy. Polysaccharides also serve as physiologically active components (heparin and polysaccharides of blood groups).

Functions of carbohydrates

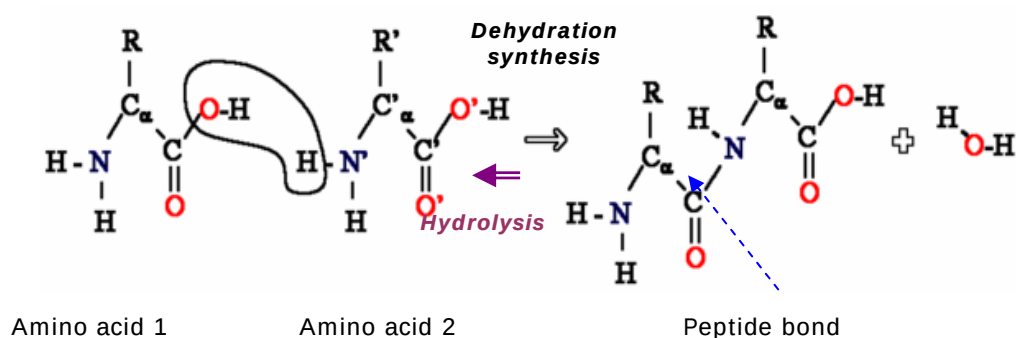
Carbohydrates are an important source of energy for cells serving as energy stores, fuels and metabolic intermediates. Specific functions include:

- Glycogen (polysaccharide) is rapidly metabolized to glucose which is the primary fuel for generation of energy (ATP)
- Ribose and deoxyribose (monosaccharides) form the structural framework of RNA and DNA, respectively.
- Glycoprotein complexes are important in molecular targeting and cell–cell recognition.
- Phosphorylated sugars are key intermediates in energy generation and biosynthesis.
- Derivatives of sugars participate in the formation of various materials, e.g. glucosamine in cartilage.
- They are components of some coenzymes, e.g. nicotinamide adenine dinucleotide (NAD), nicotinamide adenine dinucleotide phosphate (NADP), coenzyme A, flavin adenine dinucleotide (FAD) and flavin mononucleotide (FMN).
- Vitamin C is a derivative of a hexose.
- They form a component of the “lubricants” found in joints and vitreous humor of the eye.
- Heparin, an anticoagulant, is a sugar derivative.

Proteins

Proteins are large organic molecules made up of alpha amino acids that are arranged linearly and linked together by peptide bonds (by dehydration synthesis) to form polypeptide chains. Alpha amino acids have an amino group (NH_2), a carboxyl group (COOH), a hydrogen atom and a distinctive side-chain (R-group) attached to the central carbon.

Fig. 9: Dehydration synthesis and hydrolysis mechanisms



There are twenty amino acids depending on the specific R-group and each protein has a unique sequence of amino acid residues forming its **primary structure**.

Secondary structure refers to the regular folding of these polypeptide chains. Two types of secondary structures exist.

1. α -helix where the polypeptide coils to form a rod-like cylindrical structure which is stabilized by hydrogen bonds.
2. β -pleated sheet, where the polypeptide chain runs parallel (or anti-parallel if in opposite directions) to each other and is held by hydrogen bonds.

Tertiary structure in a protein is the three dimensional arrangement of amino acids in a polypeptide. Tertiary structure is formed by ionic hydrogen and disulphide bonds as well as hydrophobic interactions and it confers biological activity upon a protein.

Quaternary structure is the spatial rearrangement of multiple polypeptides (e.g. in haemoglobin) and the interactions between them.

Functions of proteins

- Bring about enzymatic catalysis. Most enzymes are proteins, which catalyse the various chemical reactions in the body.
- Transport and storage: e.g. myoglobin transports oxygen in muscle, transferrin carries iron in plasma of blood and another protein stores it.
- Bring about coordinated motion, as in muscle contraction due to actin and myosin (which are proteins that cause muscle contraction) as well as movement of chromosomes during cell division.
- Provide mechanical support: collagen in skin and bones and keratin in hair and nails.
- Provide immune protection: antibodies and interleukins fight against invading pathogens.
- Regulate hormone secretion and physiological processes: e.g. regulation of secretion of thyroid hormones from the thyroid gland by the thyroid stimulating hormone (a protein), growth and development by the growth hormone, and blood glucose level regulation by insulin.
- Facilitate generation and transmission of nerve impulses by receptor proteins that bind to neurotransmitters.

Fig. 10: Primary structure of protein

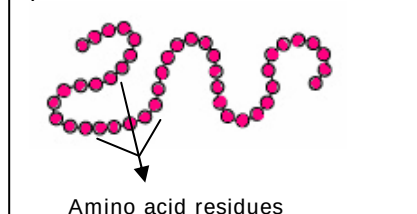


Fig. 11: Secondary structure of protein

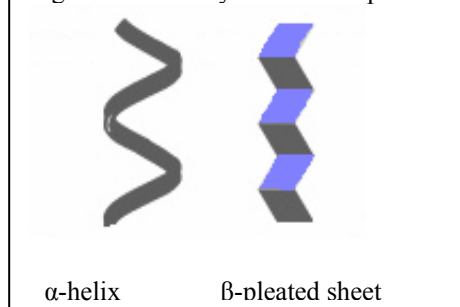


Fig. 12: Tertiary structure of protein

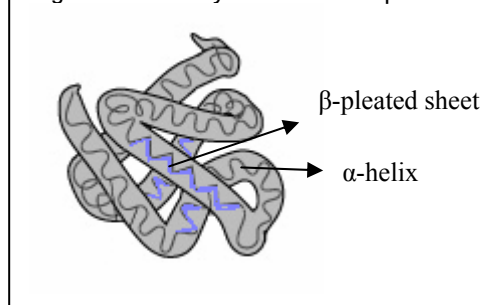


Fig. 13: Quaternary structure of protein



- Bring about growth and differentiation by specific growth factors which are proteins, e.g. formation of neural networks is controlled by nerve growth factors.
- Control transcription and translation, e.g. repressor proteins suppress a portion of the DNA molecule.

Lipids

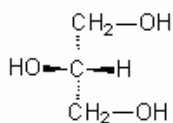
Lipids are directly or indirectly related to fatty acids. They are usually esters of fatty acids and alcohol. Fatty acids are long chains of hydrocarbons with a terminal carboxylic acid (COOH) group.

Naturally occurring fatty acids have an even number of carbon atoms arranged in a straight chain (because they are synthesized from 2-carbon units). Chain length usually ranges from 14–24 carbon atoms with the most common being those with 16 or 18 carbon atoms. Fatty acids are said to be saturated when there are no double bonds in the straight chain and unsaturated when there are double bonds in the straight chain (monounsaturated when there is a single double bond and polyunsaturated when there are more than one double bonds).

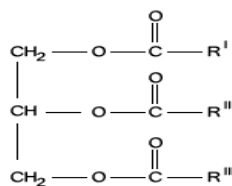
Types of lipids

Simple lipids are esters of fatty acids with various alcohols. These include:

- *Fats (triacylglycerol or triglycerides)*. These are esters of fatty acids with glycerol.

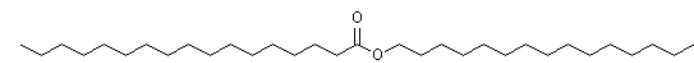


Glycerol



Triglyceride (R', R'', R''' — fatty acids)

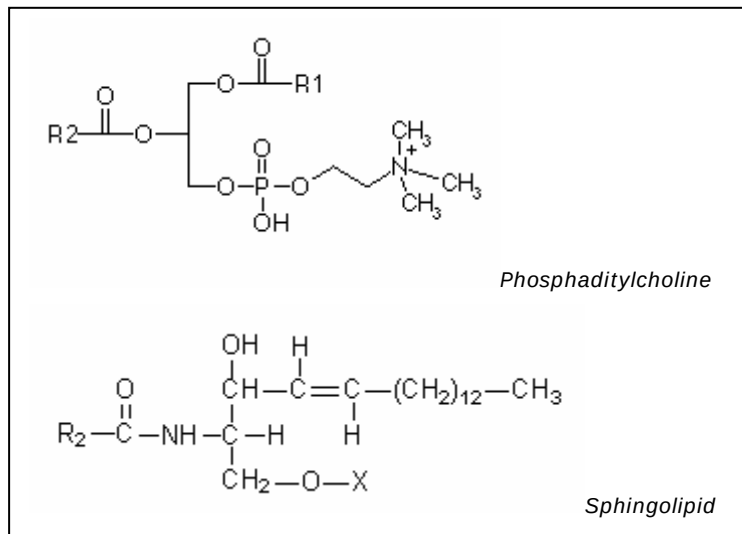
- *Waxes*. These are esters of fatty acids with a monohydric alcohol of a high molecular weight.



Wax

Compound lipids are esters of fatty acids with alcohol with some additional groups. These include:

- Phospholipids, which contain phosphoric acid, nitrogen-containing bases and other substitutes in addition to the fatty acid and alcohol, e.g. phosphoglycerides derived from glycerol and sphingophospholipids derived from sphingosine.



- Cerebrosides or glycolipids. These are esters of fatty acid with a sugar residue as an additional group and no phosphorylated group.

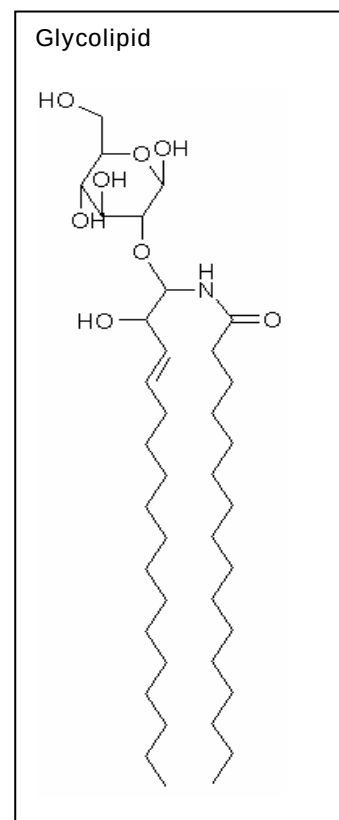
Functions of lipids

- Fatty acids act as fuel molecules and as reserve fat in the form of triacylglycerols in adipose tissue.
- Phospholipids are components of biological membranes.
- They act as hormones which regulate various physiological activities, e.g. sex steroids and adrenocorticosteroids.
- They act as paracrine agents, e.g. prostaglandins and thromboxane A2 (derived from the 20-carbon atom fatty acid, arachidonic acid).
- They act as intracellular messengers, e.g. inositol phosphate (IP₃) and diacylglycerol (DAG).
- Bile salts, derived from cholesterol (a lipid), help in emulsification and absorption of fat molecules in the alimentary canal.
- Vitamin D, which is essential for calcium absorption in the alimentary canal, is a form of lipid.

Nucleic acids

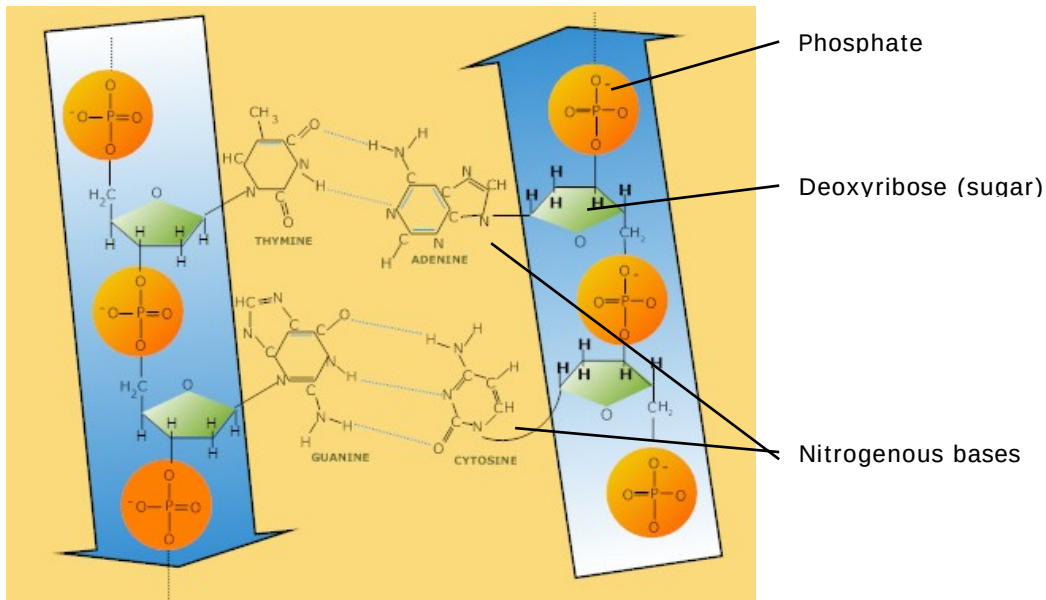
These constitute the genetic material in all living cells. These include the **deoxyribonucleic acid** (DNA) and the **ribonucleic acid** (RNA). They are polymers of nucleotides. A nucleotide consists of a pentose sugar, a nitrogenous base and phosphoric acid.

- Sugar.** Ribose sugar is present in RNA and deoxyribose sugar is present in DNA.



- **Nitrogenous base.** Two types of bases, the purines (with two rings) or pyrimidines (with one ring) form the nitrogenous base. Purines are adenine (A) and guanine (G) and pyrimidines are thymine (T) in DNA and uracil (U) in RNA and cytosine.
- **Phosphoric acid.** This gives the nucleic acids their acidic character.

Fig. 14: Nucleic acid structure



The sugar and nitrogenous base combine by a condensation reaction to form a *nucleoside*. A nucleoside combines with the phosphoric acid forming a phosphodiester link to give rise to a nucleotide. Two nucleotides join to form a dinucleotide by condensation between the phosphate group of one with the sugar of the other. A polymer of nucleotides is formed to give rise to nucleic acids.

Functions of nucleic acids

In eukaryotes:

- DNA stores genetic information.
- RNA is responsible for protein synthesis based on the information present in DNA.