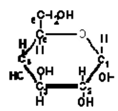
(B) Biological Molecules

Chapter 2

AICE Biology



(B) Biological molecules

Content

- Structure of carbohydrates, lipids and proteins and their roles in living organisms
- Water and living organisms

Learning Outcomes

(a) **[PA] carry out tests for reducing and non-reducing sugars (including using colour standards as a semi-quantitative use of the Benedict's test),** the iodine in potassium iodide solution test for starch, the emulsion test for lipids and the biuret test for proteins;

(b) describe the ring forms of α-glucose and β-glucose;

(c) describe the formation and breakage of a glycosidic bond with reference both to polysaccharides and to disaccharides including sucrose;

(d) describe the molecular structure of polysaccharides including starch (amylose and amylopectin), glycogen and cellulose and relate these structures to their functions in living organisms;

(e) describe the molecular structure of a triglyceride and a phospholipid and relate these structures to their functions in living organisms;

(f) describe the structure of an amino acid and the formation and breakage of a peptide bond;

(g) explain the meaning of the terms *primary structure, secondary structure, tertiary structure and quaternary structure of proteins and describe the types of bonding (hydrogen, ionic, disulfide and* hydrophobic interactions) that hold the molecule in shape;

(h) describe the molecular structure of haemoglobin as an example of a globular protein, and of collagen as an example of a fibrous protein and relate these structures to their functions (the importance of iron in the haemoglobin molecule should be emphasised);

(i) describe and explain the roles of water in living organisms and as an environment for organisms;

(j) use the knowledge gained in this section in new situations or to solve related problems.

Molecular Biology

- Study of structure & function of bio. molecules
- Closely linked to biochemistry
  - Chemical rxns of biological molecules
  - Sum total of all biochemical rxns in body called **metabolism**

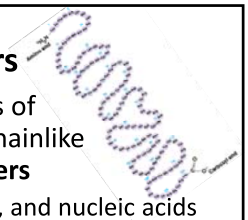
Four most common elements in living organisms:

- Hydrogen:
  - Hydrocarbons will have more H than C
- Carbon:
  - Basis of organic chemistry
  - Remarkable ability to form ring and other structures
- Oxygen:
  - Atmospheric and water
- Nitrogen:
  - proteins

Biological Molecules

- Formed from smaller organic molecules (**polymers**) bonded together to form larger molecules
  - *Repeating subunits* bonded together end to end; like beads/pearls on a string
- These larger molecules (**macromolecules**) may be composed of thousands of atoms
  - Polysaccharides, proteins (polypeptides) and nucleic acids (polynucleotides)
  - Process called polymerisation

Polymers

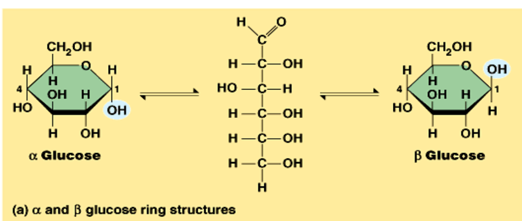


- Three of the four classes of macromolecules form chainlike molecules called **polymers**
  - carbohydrates, proteins, and nucleic acids
- Polymers consist of many similar or identical building blocks linked by *covalent bonds*.
  - The repeated units are small molecules called **monomers**

Carbohydrates

- Sugar & starch
- All contain carbon
- General formula: $\mathbf{C_x(H_20)_y}$
  - 3 main groups: monosaccharides, disaccharides, and polysaccharides

- Monosaccharides are the smallest carbohydrate units
  - Glucose most common
  - Important energy sources
- Straight chain or rings

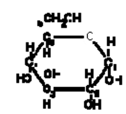


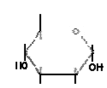
(a) α and β glucose ring structures

α-glucose and β-glucose

α-glucose

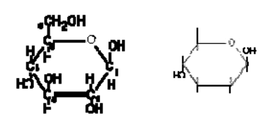
- used to make starch and glycogen





β-glucose

- used to make cellulose



Monosaccharides

Simple sugars

- General molecular formula $(CH_2O)_n$
- Dissolve easily in water – form sweet solutions
- Classified based on # of carbons
  - Triose, 3C $(CH_2O)_3$
  - Pentose, 5C $(CH_2O)_5$
  - Hexose, 6C $(CH_2O)_6$

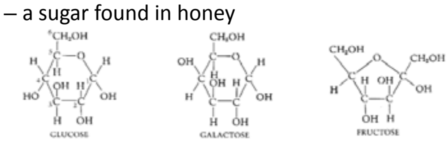
Monosaccharides

Have 2 major functions

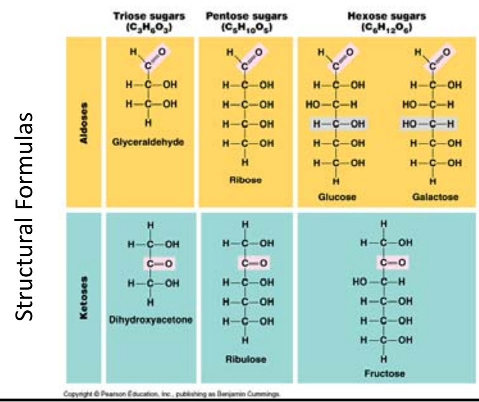
- Source of energy in ***respiration***
  - Broken O-H bonds release energy (ATP from ADP)
- The most common and important monosaccharide in ***energy metabolism*** is **glucose**
  - Which is a six-carbon (hexose) sugar, formula $C_6H_{12}O_6$

Hexose Sugars

- **Glucose**
  - "blood sugar", the immediate source of energy for cellular respiration
- **Galactose**
  - a sugar in milk and yogurt
- **Fructose**
  - a sugar found in honey



Monosaccharides



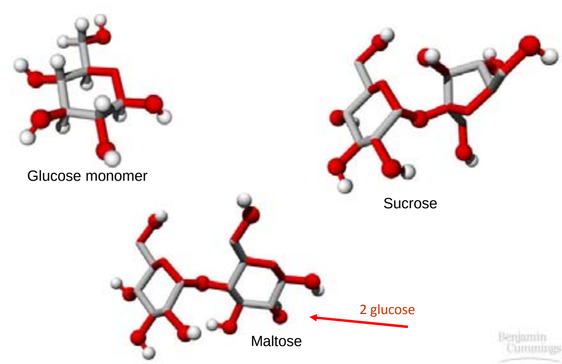
Disaccharides

Three common disaccharides

- **sucrose**
  - common table sugar = glucose + fructose
- **lactose**
  - major sugar in milk = glucose + galactose
- **maltose**
  - product of starch digestion = glucose + glucose

Bond that joins together is called a **glycosidic bond**

Glucose monomer and disaccharides

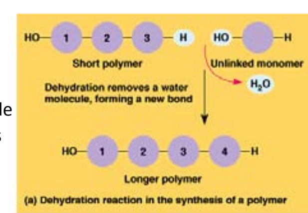


Condensation Reaction

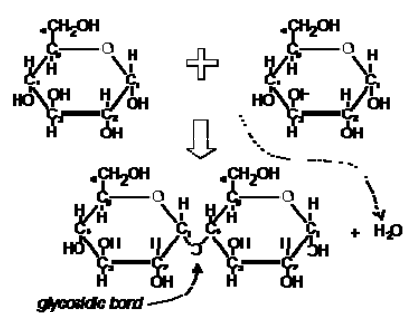
(or Dehydration Synthesis)

When two monosaccharides react and a glycosidic bond forms, water is released.
This type of rxn is called a condensation reaction.

- The process of connecting monomers to make a polymer.
  - process requires energy and is aided by enzymes
  - Removes water molecule
  - One monomer provides a hydroxyl group and the other provides a hydrogen



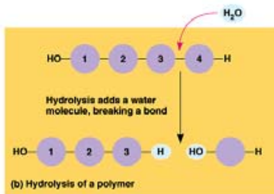
Condensation Reaction



Hydrolysis Reaction

Process of breaking a polymer with water

- Reverse of condensation rxn
- As the *glycosidic bond* is broken a hydrogen atom and hydroxyl group from a split water molecule attaches where the *glycosidic* bond used to be
- Hydrolysis reactions dominate the digestive process, guided by specific enzymes



Functions of **Monosaccharides & Disaccharides**

- Good sources of energy in living organisms
- Used to make ATP
- Soluble in water, so they are the form in which carbohydrates are transported through an organism's body
  - Animals: glucose trans. dissolved in blood plasma
  - Plants: sucrose is trans. in phloem sap

- All monosaccharides and some disaccharides act as reducing agents and will reduce blue Benedict's solution to produce an orange-red precipitate.
- They are called **reducing** sugars.
- Sucrose is a **non-reducing** sugar.

Polysaccharides

- Substances whose molecules are made up of hundreds or thousands of monosaccharides linked in long chains
  - Due to large size, majority don't dissolve in H_20
  - This makes them good for **storing energy** (starch and glycogen) or **forming strong structures** (cellulose).

Glycogen

- Storage polysaccharide in animals and fungi
- Made of α-glucose link by glycosidic bonds
  - 1-4 links, some 1-6 links
- Bonds can be hydrolyzed by carbohydrase enzymes to form monosaccharides; used in respiration
- Highly branched, used for energy reserves in human (animal) muscles and the liver
- **GLYCOGEN IN LIVER CELLS**
  Stained with carmin, nuclei are stained with haematoxylin

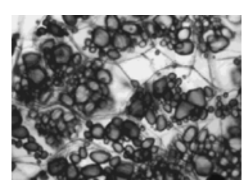
(Gunin, 2009)

Polysaccharides in Plants

not sugars

Starches
- Polymers of α-glucose; subunits are monosaccharides
- Mixture of two substances: *amylose* and *amylopectin*

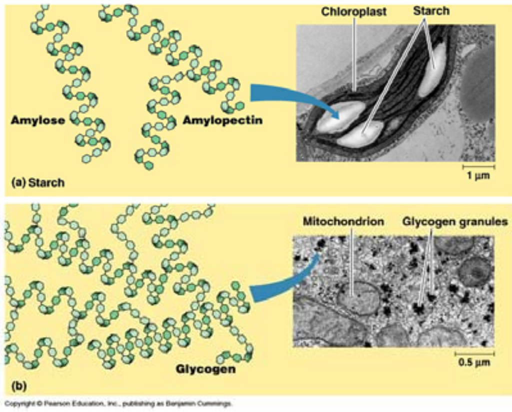
Amylose
- Linear unbranched chains of several hundred glucose units
- Coils into a spiral, very compact



(Kimball, 2004)

Plants convert excess glucose into starch for storage

Amylopectin
- Highly branched with side chains, similar to glycogen

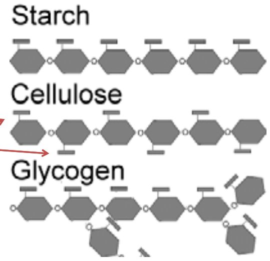


Cellulose

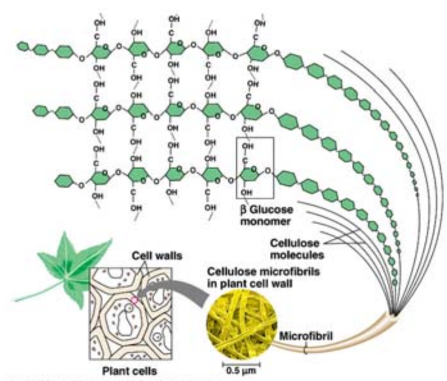
- Most abundant organic molecule
- Major component of plant cell walls
  - Uses **β glucose** *1-4* linkages
    - Many glucose molecules linked by glycosidic bonds
  - Cellulose difficult to digest
    - Few organisms have an enzyme that can break β 1-4 glycosidic bonds, therefore it passes through the intestine
  - Many microbes can digest cellulose
    - Herbivores (cows and termites) have symbiotic relationships with these microbes and can digest cellulose

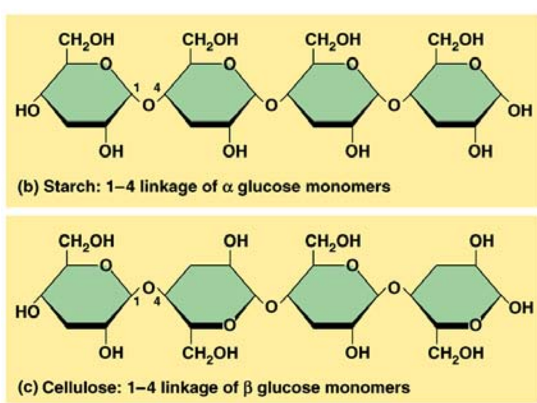
Cellulose

- Notice **β glucose** *1-4*
- Adjacent glucose molecules in chain are upside-down in relation to one another
- Straight chain rather than spiral
- Forms bundles called *microfibrils*
  - *Very strong*
  - *Excellent for cell walls*
  - *Won't break when plant cell swells with water*



The arrangement of cellulose in plant cell walls





Tests for Carbohydrates

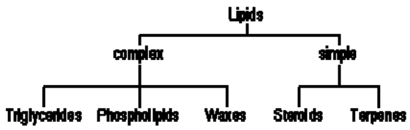
- **Reducing sugar**
  - Benedict's reagent and heat
  - **Orange** precipitate indicates the presence of reducing sugar

- **Non-reducing sugar**
  - Test done on solutions known **not** to contain reducing sugars
  - Hydrolyze by heating with dilute HCl, then neutralize with sodium hydrogen carbonate, then carry out the test for reducing sugar

- **Starch**
  - Use iodine in potassium iodide solution
  - **Blue-black** color indicates the presence of starch

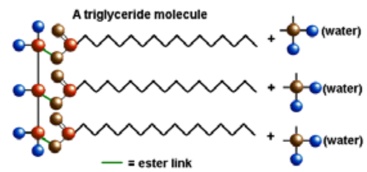
Lipids

- Contain Carbon, hydrogen and oxygen
- Triglycerides and phospholipids
  - All insoluble in water
- Excellent energy reserves



Triglycerides

- Most common: Triglycerides
  - Three fatty acid molecules (hydrocarbons) with one glycerol molecule
  - Each fatty acid is joined to glycerol by an ester bond
  - Joined by condensation reaction



Triglycerides

- **saturated** fatty acids have a high melting point and tend to be found in warm-blooded animals.
  - Hydrocarbon with **single** bonds
  - At room temperature they are solids (fats), e.g. butter, lard
- **unsaturated** fatty acids have a low melting point and tend to be found in plants and cold-blooded animals.
  - Hydrocarbon with both **single and double** bonds
  - At room temperature they are liquids (oils), e.g. fish oil, vegetable oils

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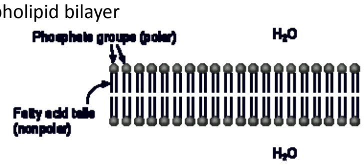
- Used for storage, insulation and protection in fatty tissue (adipose tissue) found under the skin (sub-cutaneous) or surrounding organs
  - Cells in adipose tissue contain oil droplets made of triglycerides
  - Protects against heat loss
  - Low density tissue- increases buoyancy; ie. Whales and seals

- Contain more energy per unit mass than other compounds so are good for energy storage
  - Can store energy in less mass
  - Carbohydrates can be mobilized more quickly, and glycogen is stored in muscles and liver for immediate energy requirements
  - Energy store in seeds

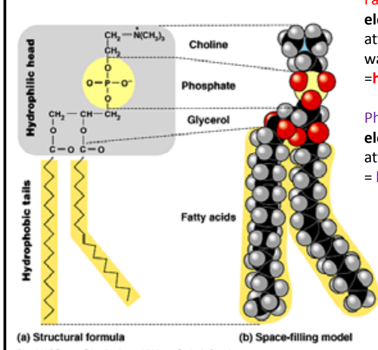
Phospholipids

- Special type of lipid
- One end soluble in water
- Phospholipids have a similar structure to triglycerides, with one fatty acid chain replaced by a phosphate group

- Phospholipid bilayer

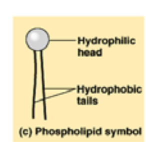


The structure of a phospholipid



Fatty acid chains have **no electrical charge** and are not attracted to the dipoles of water molecules =**hydrophobic**

Phosphate group **has an electrical charge** and is attracted to water molecules = **hydrophilic**



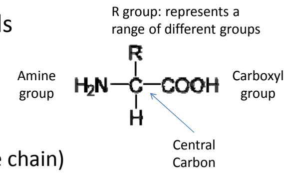
Test for Lipids

- Mix the substance to be tested with absolute ethanol.
- Decant the ethanol into water
- A milky emulsion indicates the presence of lipid

Proteins: Amino Acids

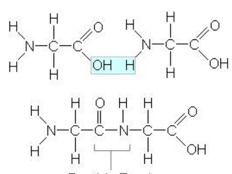
- *Proteins are large molecules made of long chains of **amino acids***
- 20 different amino acids

  Each has:
  - Amine group
  - Carboxyl group
  - A variable **R group** (side chain)
    - The R group determines the characteristics of the amino acid
  - All are attached to a central carbon



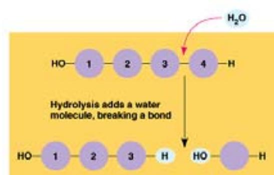
Amino Acids

- Two amino acids can link together
  - Condensation reaction
  - Forms a dipeptide
  - *Bond* is called a ***peptide bond***



Amino Acids

- Dipeptide can be broken with hydrolysis reaction
  - Bond breaks by adding water molecule



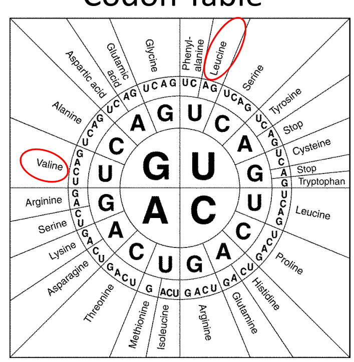
Structure of Protein Molecules

- Amino acids are linked together in long chains called **polypeptides**
  - May form from a protein molecule on its own or associate with other polypeptides to form a protein molecule
- Sequence
  - called primary structure
  - 3 letters = first 3 letters of amino acid

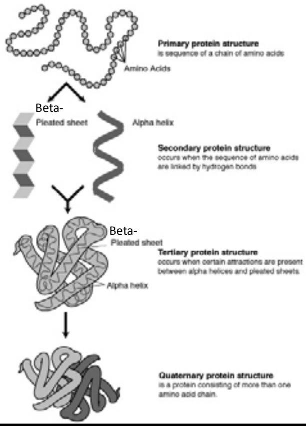
Val – Leu – Ser – Pro – Ala – Asp – Val – Lys – Thr

- Val is valine, Leu is leucine

Codon Table



- Chain of amino acids often folds or curls to form a 3D shape
- Secondary structure
  - Alpha helix
  - Held together by hydrogen bonds
- Tertiary
  - Held together by hydrogen bonds as well as
    - Ionic bonds
    - Disulfide bonds
    - Hydrophobic interactions
  - Globular structure
- Quaternary
  - Same bonds as tertiary



Quartnary Structure

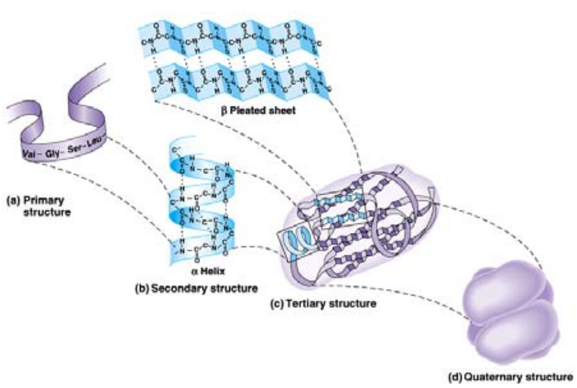
Haemoglobin, the oxygen-carrying protein in red blood cells, consists of four globular subunits arranged in a tetrahedral (pyramid) structure. Each subunit contains one iron atom and can bind one molecule of oxygen.

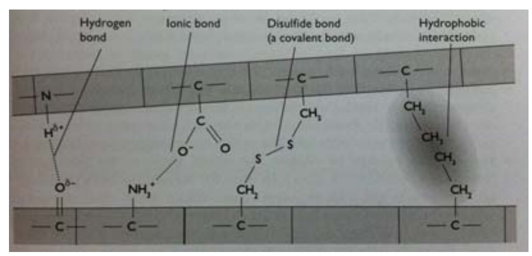
Immunoglobulins, the proteins that make antibodies, comprise four polypeptide chains arranged in a Y-shape. The chains are held together by sulphur bridges. This shape allows antibodies to link antigens together, causing them to clump.

Actin, one of the proteins found in muscles, consists of many globular subunits arranged in a double helix to form long filaments.

Tubulin is a globular protein that polymerizes to form hollow tubes called microtubules. These form part of the cytoskeleton, and make cilia and flagella move.

Proteins continued





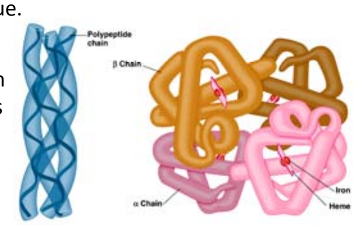
(Jones, 2010)

- Bonds involved in structure of proteins

Globular and fibrous proteins

- Globular
  - Spherical 3D shape
  - Hemoglobin, insulin, enzymes
  - Often soluble in water
- Fibrous
  - Molecules do not curl up into a ball
  - Long thin molecules, lie side by side to form fibres
    - Keratin (hair) and collagen (skin, bone)
  - **Not** soluble in water

- **Collagen**
  - fibrous protein of three polypeptides super-coiled like a rope.
  - Provides the structural strength for their role in connective tissue.
- **Hemoglobin**
  - globular protein with two copies of two kinds of polypeptides



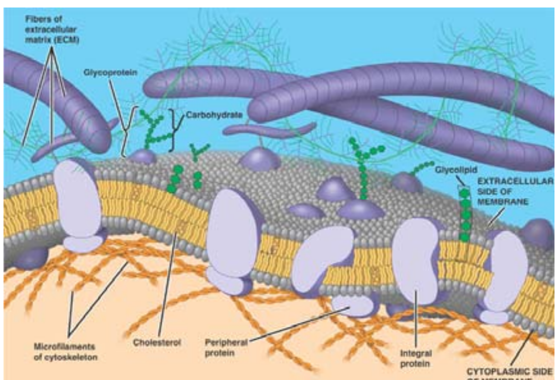
Test for proteins

- Add **biuret solution**.
- **Purple** color indicates presence of a protein

Protein Functions

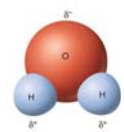
Table 5.1 An Overview of Protein Functions

Type of Protein	Function	Examples
Structural proteins	Support	Insects and spiders use silk fibers to make their cocoons and webs, respectively. Collagen and elastin provide a fibrous framework in animal connective tissues. Keratin is the protein of hair, horns, feathers, and other skin appendages.
Storage proteins	Storage of amino acids	Ovalbumin is the protein of egg white, used as an amino acid source for the developing embryo. Casein, the protein of milk, is the major source of amino acids for baby mammals. Plants have storage proteins in their seeds.
Transport proteins	Transport of other substances	Hemoglobin, the iron-containing protein of vertebrate blood, transports oxygen from the lungs to other parts of the body. Other proteins transport molecules across cell membranes.
Hormonal proteins	Coordination of an organism's activities	Insulin, a hormone secreted by the pancreas, helps regulate the concentration of sugar in the blood of vertebrates.
Receptor proteins	Response of cell to chemical stimuli	Receptors built into the membrane of a nerve cell detect chemical signals released by other nerve cells.
Contractile proteins	Movement	Actin and myosin are responsible for the movement of muscles. Other proteins are responsible for the undulations of the organelles called cilia and flagella.
Defensive proteins	Protection against disease	Antibodies combat bacteria and viruses.
Enzymatic proteins	Selective acceleration of chemical reactions	Digestive enzymes catalyze the hydrolysis of the polymers in food.



Water

- About 80% of an organism's body is water
- Molecule
  - Slightly negative } dipole
  - Slightly positive
  - Hydrogen bonds between molecules
- Universal solvent
  - Dipoles make it an excellent solvent
- Transport medium



(b) Distribution of partial charges in a water molecule

Water

- Thermal properties
  - Liquid at normal temp
  - High latent heat of evaporation
    - Kinetic energy
  - Specific heat capacity
    - A lot of heat energy is needed to raise temp of water
  - Freezes from top down
- Density & freezing properties
- High surface tension and cohesion

Inorganic ions in living organisms

Inorganic ion	Examples of functions
Calcium	• as calcium phosphate, provides a hard, strong insoluble matrix in bones and teeth in mammals • required for blood clotting in mammals • as calcium pectate in plant cell walls, forms a matrix in which cellulose fibres lie • involved in the transmission of action potentials from one neurone to another, and in muscle contraction
Sodium	• constantly pumped out of cells by active transport in exchange for potassium ions, providing a positive charge outside the cell which is important in the transmission of nerve impulses
Potassium	• constantly pumped into cells by active transport in exchange for sodium ions; important in the transmission of nerve impulses
Magnesium	• forms part of the chlorophyll molecule in plants, important for the absorption of light energy to drive the reactions of photosynthesis
Chloride	• moved out of cells lining the lungs and digestive system to provide a low water potential outside the cell, causing water to follow so that mucus is not too thick and stiff (failure of this mechanism is the cause of cystic fibrosis)
Nitrate	• used to produce amino acids (and therefore proteins) from the carbohydrates made in plants by photosynthesis
Phosphate	• the production of nucleic acids (DNA and RNA) in cells • the production of ATP (the energy currency of all cells) • the production of phospholipids, essential in cell membranes

(Jones, 2010)

Resources

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