CHAPTER-2

Chemical and Cellular Organisation

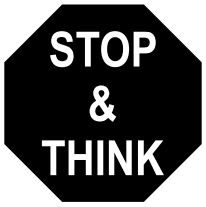
Core Resources

Tortora and Grabowski- Principles of Anatomy and Physiology

Chapters 2, 3, 4

Introduction

This section will introduce you to the chemicals involved in life, and to the cells, which form the basic building blocks of the human body.



Learning outcomes

At the end of this module you should:

- Know the basic elements present in the human body
- Understand how atoms bond to form molecules
- Know the basics of organic chemicals
- Know the various parts of the cells
- Understand, and know the differences between meiosis and mitosis

Chemical Organisation

Whilst the chemical systems that compose the human body may seem very complicated, there are some simple underlying patterns:

- The human body is made up of a large range of macromolecules, which are built up from a smaller range of small molecules.
- The information contained in DNA determines the characteristics of the human body.
- The cell uses information in the DNA to make proteins, including enzymes…
- Enzymes control most of the physical and chemical activities of the human body.
- Metabolism is the term for the sum of all the chemical activities within the human body. It is divided into two types of reaction; anabolic (building up) and catabolic (breaking down).
- Anabolic reactions usually involve condensation reactions, where molecules are joined together with a water molecule being released
- Catabolic reactions usually involve hydrolysis reactions, where molecules are split as they react with water.

- Energy is obtained by respiration. In respiration organic molecules are oxidised into smaller molecules, usually carbon dioxide and water. The energy produced is used to fuel the processes of the body.

You will be covering the chemical organisation of the human body fully in the biochemistry module, therefore only a brief overview will be provided here.

Chemical elements and atoms

All forms of matter are composed of chemical elements, which are substances that cannot normally be split into simpler substances. They are given letter abbreviations called chemical symbols, and all the known elements, with their chemical symbol, can be seen presented on the periodic table.
Each element is made up of atoms, which are the smallest units of matter that retain the properties of the element.

Ions

If an atom gains or loses an electron(s) it becomes an ion. Ions are either positively or negatively charged, termed **cation** and **anion** respectively. An ion of an atom is symbolised by either a + or – symbol after its chemical symbol to denote whether it is positive (lost electrons) or negative (gained electrons), and the number of electrons involved is also written in superscript. E.g. $Ca^{2}+$ indicates a calcium ion that has lost two electrons.

Molecules

Molecules are the combination of two or more atoms. They are formed when atoms share electrons, and can be formed from atoms from the same or different elements. If formed from different elements they are called compound molecules. The molecular formula indicates the elements and number of atoms, which make up a molecule. E.g. the formula for an oxygen molecule, O_2 shows that it contains only oxygen atoms, and the subscript 2 shows that there are two of them. The formula for water, H_2O, shows that it contains two hydrogen atoms and a single oxygen atom.

Free radicals

Free radicals are atoms or parts of molecules with an unpaired electron in the outer shell. They seek to become stable by either gaining an electron or by giving the electron from atoms around them. This can break apart molecules, potentially damaging important molecules of the body

Chemical bonds

Chemical bonds are the forces that hold atoms in a molecule together. The three most important for your understanding are; ionic, covalent and hydrogen bonds.

Task: read and understand the differences between Ionic, covalent and hydrogen bonds

Chemical reactions

Every time a bond is formed or broken, this is termed a chemical reaction. As has been mentioned metabolism refers to all the chemical reactions that occur in the human body.
The types of chemical reaction are:

- **Synthesis**- atoms, ions or molecules combine to form larger molecules. These are anabolic reactions, and condensation reactions (water released are an example).
- **Decomposition**- a molecule is split into smaller parts. These are catabolic reactions, and hydrolysis reactions (reaction with water).
- **Exchange**- the replacement of atom(s) with different atom(s)
- **Reversible**- where the end products can recombine to form the original molecules
- **Reduction-oxidation** (Redox)- electrons taken from the atom being oxidised by atom being reduced.
    - **Oxidation**- loss of electrons from a molecule, resulting in a decrease in potential energy of the molecule
    - **Reduction**- gain of electrons by a molecule resulting in an increase in potential energy of the molecule.

Acids, bases and salts

An **acid** is a substance that dissociates in water to produce one or more hydrogen ions (H+) and one or more anions. Because H+ is a single proton with one positive charge, acids are also known as proton donors.

A **base** dissociates in water into one or more hydroxide ions (OH-) and one or more cations. Bases are alkali.

Acids and bases react with each other to form salts. Salts dissociates into cations and anions neither of which is H^+ or OH^-.

Acid-base balance- pH

A solutions acidity or alkalinity is expressed on the pH scale. The scale is based upon the concentration of H+ in a solution:

- A pH of 7 means that the concentration of H+ and OH- are equal

- A pH of less than 7 means that there are more H+ than OH+ in the solution, and it is therefore acidic
- A pH of greater than 7 means there are less H+ than OH- and the solution is therefore alkali
- Each change of one whole number on the scale represents a tenfold change in the amount of H+

Buffer systems

Acids and bases are continually being taken in and formed by the body, but the fluids in the body need to contain specific quantities of H+ and OH- within narrow ranges.
The pH of fluids in and around cells remains almost constant, through homeostatic mechanisms such as buffer systems. Buffer systems convert strong acids into weak acids and strong bases into weak bases, and therefore reduce the effect on pH.

- An important buffer system is the carbonic acid-bicarbonate buffer system which helps keep the pH of blood between 7.35 and 7.45

Organic molecules

Organic molecules are compound molecules that contain carbon. Hydrogen, oxygen, nitrogen, sulphur and phosphorus are the other elements most commonly found in organic molecules. Smaller organic molecules can combine to form larger macromolecules.

Nomenclature:

- A single molecule is termed a **monomer**
- Two monomers linked together are called a **dimer**
- Three or more monomers linked together is called a **polymer**
- **Macromolecules** are usually polymers, formed by the covalent bonding of similar monomers

Monomers are usually joined together by a condensation reaction (also called a dehydration reaction), where an H from one and an OH from another is removed to release a molecule of water H_2O when they are joined. Condensation reactions form covalent bonds.

- Macromolecules such as carbohydrates, lipids, proteins and nucleic acids are formed through condensation reactions

Isomers are molecules that have the same molecular formula i.e the same number of each type of atom, but are structured differently. E.g. fructose and glucose have the same formula- $C_6H_{12}O_6$, but the various atoms are located in different positions in its structure.

Carbohydrates

Carbohydrates are sugars and starches and contain only the elements carbon, oxygen and hydrogen. They normally contain oxygen and hydrogen in the ratio 1:2 (the same as water) and carbon in the ratio 1:1 with oxygen.

They are classified according to structure and size into **monosaccharides**, **disaccharides** and **polysaccharides.**

- Monosaccharides and disaccharides are classed as simple sugars and usually have names ending in –ose. Monosaccharides and disaccharides taste sweet.

Monosaccharides

- Contain 3-7 carbon atoms
- They are termed according to the number of carbon atoms; trioses have 3 carbon atoms, tetroses 4, pentoses 5, hexoses 6 and heptoses have 7.
- Glucose, a hexose, is the main source of energy in the human body, and many common polysaccharides are glucose polymers.

Disaccharides

- Are two monosaccharides joined by a condensation reaction. E.g. Sucrose is a disaccharide formed by the linking of glucose and fructose.
- The condensation bonds between monosaccharides are called glycosidic bonds
- Disaccharides can be split by a hydrolysis reaction, where a water molecule is added, separating the monosaccharides

Polysaccharides

- Unlike monosaccharides and disaccharides, polysaccharides are usually insoluable in water, and do not taste sweet
- Polysaccharides are primarily used for storage.
- Glycogen is the main storage polysaccharide in humans, whilst starch is the main polysaccharide in plants.

Lipids

Like carbohydrates, lipids, normally only contain carbon, oxygen and hydrogen, although sometimes they also contain phosphorous or nitrogen. They have fewer electronegative oxygen atoms than carbohydrates, and therefore fewer polar covalent bonds. Most lipids are therefore insoluble in polar solvents such as water, and are termed hydrophobic as a result. Groups of lipids include **triglycerides**, **phospholipids** and **steroids.**

Triglycerides:

- Are formed of one molecule of glycerol and three fatty acid chains
- Act as energy stores
- They may be either solid at room temperature (fats) or liquid (oils)
- Provide twice as much energy per gram as either carbohydrates or proteins

- Excess dietary carbohydrates, proteins or lipids are stored in adipose tissue as triglycerides.

There are three main types: saturated, monounsaturated and polyunsaturated:

1. **Saturated fats** are triglycerides, whose fatty acid chains have no double bond between any carbon atoms. Every spare bond of the carbon chain is occupied by a hydrogen atom- i.e. they are **saturated with hydrogen atoms**. They are usually solid at room temperature, and are found in animal tissues and coconut oil, amongst others.
2. **Monounsaturated fats** have a single double bond between carbon atoms. Olive oil and peanut oils are rich in monounsaturated fatty acids.
3. **Polyunsaturated fats** have more than one double bond between carbon atoms. Sunflower and safflower oils are rich in polyunsaturated fats.

Phospholipids:

- Have a similar structure to triglycerides. They have a glycerol head and two fatty acid chains, but have a phosphoric acid head which is polar, instead of a third fatty acid chain.
- This gives them a polar head and a non-polar chain.
- If placed in water they will group together in balls, with the polar head facing out into the water, and their non-polar tails pointing in.
- This property is used by the body to form phospholipid bilayer membranes, separating one aqueous solution from another.
- Phospholipids form the basis of all biological membranes.

Steroids:

- Have a very different structure to triglycerides.
- Cholesterol is the steroid from which all other steroids in the body are made.
- Cholesterol is either derived from the diet or produced by the liver.
- Like cholesterol, all steroids have four rings of carbon atoms as their backbone.
- Some important hormones such as oestrogen and testosterone are examples of steroids.

Proteins

Proteins contain the elements carbon, hydrogen, oxygen and nitrogen. They are large molecules, with much more complex structures than lipids or carbohydrates. The monomers of proteins are amino acids. There are 20 different amino acids, which make up all the proteins in the human body.

Amino acids have an amine group ($-NH_2$) and a carboxylic acid group (-COOH) both attached to a central carbon atom. The backbone of an amino acid is carbon-carbon-nitrogen (C-C-N). Amino acids also have a side chain also attached to the central carbon atom. In diagrams the letter R usually

represents this chain. This is because the side chain varies between the different amino acids. Amino acids are linked by condensation reactions with covalent bonds called peptide bonds.

- Short chains of amino acids are termed **peptides**, larger chains are termed **polypeptides**, and the term **protein** refers to a finished functioning molecule.
- Some proteins consist of a single polypeptide, whilst others consist of two or more polypeptides folded together.
- Amino acids act as buffers in the body either accepting or releasing hydrogen (H+) or hydroxl (OH+) ions.

Proteins have either three or four levels of structural organisation:

1. **The primary structure** is the sequence of amino acids in that protein. This is determined by the gene which codes for that specific protein.

2. **The secondary structure** is the pattern that the amino acids make as they fold and twist to form the most stable arrangement of hydrogen bonds.α -Helixes and β-pleated sheets are the most common arrangements.

3. **The tertiary structure** is the overall three dimensional shape that results from the secondary structures and if in an aqueous solution from the hydrophobic nature of many amino acid side chains. A variety of bonds, dictated by the secondary structure, maintain the tertiary structure. Sulphur to sulphur bonds, known as disulphide bridges are the strongest bonds, but are generally only found in structural proteins. The specific tertiary structure is vitally important for the protein function. Functional proteins, such as enzymes must have an exact shape to fulfil their role, whilst structural proteins, such as keratin depend upon their tertiary structure for strength.

4. **The quarternary structure** occurs if the protein contains more than one polypeptide. It is the three dimensional structure formed when the polypeptides combine to form the functional protein. Because reasonably weak bonds maintain the shape of proteins, they are sensitive to changes in temperature and environment, which may break some of the bonds, causing it to change shape. If this happens the protein is called **denatured**, and is no longer functional.

Enzymes

Enzymes are globular proteins with complex tertiary structures that act as biological catalysts. Without enzymes biological processes would be too slow to sustain life. They are **highly specific**, interacting only with specific substrates. Enzymes have an **active site**, which binds to that of a particular part of the substrate, thereby having its effect. Enzymes lower the **activation energy** needed to allow reactions (bond breaking/building) to take place. They are very **efficient**, catalysing reactions up to millions of times faster than if the reactions were to occur without enzymes.

They are closely **controlled** by substances in the cell, which either enhance or inhibit their activity. If an enzyme is denatured the shape of its active site is irreversibly changed and it no longer fulfils its function.

Some substances mimic the substrate that an enzyme acts upon. If the substance binds but then releases from the active site it is called a **competitive inhibitor** (competing with the substrate). If it binds but releases from the active site it is a **reversible inhibitor** that simply slows down the enzymes activity. If it binds, but does not release it is called an **irreversible inhibitor**, and it renders the enzyme useless.
The theoretical models of how enzymes work are known as the **lock and key theory** and the **induced fit theory.**

Nucleic Acids

There are two types of nucleic acid deoxyribonucleic acid (**DNA**) and ribonucleic acid (**RNA**). They contain the elements carbon, hydrogen, oxygen, nitrogen and phosphorus. The monomers of nucleic acids are called nucleotides. A nucleic acid is a sequential chain of nucleotides. Each nucleotide has three parts, a nitrogenous base, a pentose sugar and a phosphate group.
DNA has four different nitrogenous bases; Adenine (A) Guanine (G) Thymine (T) and Cytosine (C). RNA has the same bases, except thymine is substituted for Uracil (U).

DNA

- DNA contains the genetic code for the whole body. Each gene is a segment of DNA which codes for a specific protein, and as a result determines inherited traits.
- DNA has a double helix structure consisting of two nucleic acid chains, whilst RNA is just a single chain.
- The structure of DNA allows it to copy itself and thereby pass the genetic code to new cells. It also allows it pass information on to RNA to synthesize proteins.

RNA

- RNA has three forms messenger RNA (mRNA), transfer RNA (tRNA) and ribosomal RNA (rRNA).
- mRNA forms a copy of the gene to be used as a template for protein synthesis.
- tRNA brings the specific amino acids to the ribosome during protein synthesis.
- rRNA is a major structural component of ribosomes.

Cellular organisation

The cell is the basic living, structural, and functional unit of the body, although they may vary widely in shape and size.

For learning purposes the cell can be divided into 3 sections:

1. Plasma/cell membrane
2. Cytoplasm including organelles
3. Nucleus

The Structure of the Cell Membrane

The cell membrane surrounds all living cells, and is the cell's most important organelle. It controls how substances can move in and out of the cell and is responsible for many other properties of the cell as well. The membranes that surround the nucleus and other organelles are almost identical to the cell membrane.

The fluid mosaic model is currently considered to be the most accurate description of the plasma membrane. According to this model the membrane consists of three types of lipids (phospholipids, cholesterol and glycolipids) within which proteins are inserted. Carbohydrates are also present attached either to lipids (glycolipids) or proteins (glycoproteins).

The foundation of the membrane is a phospholipid bilayer, which is considered ‘fluid’ in the sense that the phospholipids and other components are generally free to move around the membrane. The membrane is interspersed with proteins giving a ‘mosaic’ effect.
In the cell membrane phospholipid molecules create a spherical three dimensional lipid bilayer shell around the cell.

Phospholipids

The phospholipids form a thin, flexible sheet, while the proteins float in the phospholipid sheet, and the carbohydrates extend out from the proteins. The phospholipids are arranged in two layers, with their polar, hydrophilic phosphate heads facing outwards either into or away from the cell, and their non-polar, hydrophobic fatty acid tails facing each other in the middle to form the ‘bi-layer’.

The hydrophobic layer acts as a barrier to all but the smallest molecules, effectively isolating both sides of the membrane. Human cell membranes also contain cholesterol, which links the fatty acid tails together and so stabilises and strengthens the membrane.

Proteins

- Proteins in the membrane either span the phosphlipid bilayer or sit on one surface or the other.

- The proteins that span the phospholipid bilayer are called integral proteins, whilst those that sit on one of the surfaces are called peripheral proteins. Peripheral proteins can be stripped from the membrane without disturbing its integrity.

- Most proteins are free to slide around the membrane, but can never flip from one side to the other. However, many proteins are not free to diffuse.

- The cytoskeleton supports the cell membrane and provides anchoring points for integral membrane proteins. Anchoring restricts them to a particular cell face or surface and limits how far they may diffuse within the bilayer. Therefore, rather than presenting always a formless and fluid contour, the plasma membrane surface of cells may show structure.

- The proteins have hydrophilic amino acids in contact with the water on the outside of membranes, and hydrophobic amino acids in contact with the fatty chains inside the membrane. Proteins comprise about 50% of the mass of membranes, and are responsible for most of the membrane's properties.

- Integral proteins are usually involved in transporting substances across the membrane.

- Proteins on the inside surface of cell membranes are often attached to the cytoskeleton and are involved in maintaining the cell's shape, or in cell motility. They may also be enzymes, catalysing reactions in the cytoplasm.

- Proteins on the outside surface of cell membranes can act as receptors by having a specific binding site where hormones or other chemicals can bind. This binding then triggers other events in the cell. They may also be involved in cell signalling and cell recognition, or they can also be enzymes.

Carbohydrates

- The carbohydrates are found on the outer surface of all human and other eukaryotic cell membranes.
- The carbohydrates form a layer or glycocalyx outside the cell membrane. The glycocalyx is involved in cell recognition, and antigens are usually cell-surface glycoproteins.

Remember that a membrane is not just a phospholipid bilayer, but that it also contains protein and carbohydrate parts.

Function of the cell membrane

Cell membranes are a barrier to most substances, and this property allows materials to be concentrated inside cells, excluded from cells, or simply separated from the outside environment. This compartmentalisation is essential for life, as it enables reactions to take place that would otherwise be impossible. Eukaryotic (including human) cells can also compartmentalise materials inside organelles.

Transportation across the membrane

Materials need to be able to enter and leave cells, and there are five main methods by which substances can move across a cell membrane:

1. Diffusion
2. Facilitated diffusion
3. Osmosis
4. Active Transport
5. Vesicles (endocytosis and exocytosis)

Apart from active transport none of the methods use energy.

Diffusion

Diffusion is the movement of a substance down a concentration gradient. In other words a substance will always move from an area of high concentration to an area of low concentration seeking to establish equilibrium. Diffusion is a passive process, and therefore the cell uses no energy. Simple diffusion cannot be controlled by the cell, in the sense of being switched on or off.

Few substances can diffuse directly through the lipid bilayer part of the membrane. The only substances that can do this are lipid-soluble molecules such as steroids, or very small molecules, such as H_2O, O_2 and CO_2. For these molecules the membrane is no barrier at all.

Osmosis

Osmosis is effectively simple diffusion, but since water is so important and so abundant in cells, the diffusion of water has its own process. The contents of cells are essentially solutions of numerous different solutes, and the more concentrated the solution, the more solute molecules there are in a given volume, so the fewer water molecules there are.

- Water molecules can diffuse freely across a membrane, but always down the concentration gradient, so water therefore diffuses **from a dilute to a concentrated solution**.
- Osmosis can be quantified using water potential.
- Water potential (Ψ) is simply the effective concentration of water.
- It is measured in units of pressure (Pa, or usually kPa), and the rule is that **water always "falls" from a high to a low water potential**.

- 100% pure water has $\Psi = 0$, which is the highest possible water potential, so all solutions have $\Psi < 0$, and you cannot get $\Psi > 0$.

Facilitated diffusion

Facilitated diffusion is the transport of substances across a membrane by a trans-membrane **transport protein** molecule. The transport proteins tend to be specific for one molecule (a bit like enzymes), so certain substances can only cross a membrane if the membrane contains the appropriate protein. This is a passive diffusion process, so no energy is involved and substances can only move down their concentration gradient.

There are two kinds of transport protein:

1. **Channel Proteins** form a water-filled pore or channel in the membrane. This allows charged substances (usually ions) to diffuse across membranes. Most channels can be **gated** (opened or closed), allowing the cell to control the entry and exit of ions.
2. **Carrier Proteins** have a binding site for a specific solute and constantly flip between two states so that the site is alternately open to opposite sides of the membrane. The substance will bind on the side where there is a high concentration and be released where there is a low concentration.

Active Transport

Active transport is the pumping of substances across a membrane by a trans-membrane **protein pump** molecule. The protein binds to a molecule of the substance to be transported on one side of the membrane, changes shape, and releases it on the other side. The proteins are highly specific, so there is a different protein pump for each molecule to be transported.

The protein pumps are also **ATPase enzymes**, since they catalyse the splitting of ATP and use the energy released to change shape and pump the molecule. Pumping is therefore an **active process**, and is the only transport mechanism that can transport substances against or up the concentration gradient.

Vesicles

Large molecules such as proteins, polysaccharides and nucleotides and even whole cells are moved in and out of cells by using membrane vesicles.

Endocytosis is the transport of materials into a cell.

- Materials are enclosed by a fold of the cell membrane, which then pinches shut to form a closed vesicle.
- Strictly speaking the material has not yet crossed the membrane, so it is usually digested and the small product molecules are absorbed by the methods above.
- When the materials and the vesicles are small (such as a protein molecule) the process is known as pinocytosis (cell drinking), and if the materials are large (such as a white blood cell ingesting a bacterial cell) the process is known as phagocytosis (cell eating).

Exocytosis is the transport of materials out of a cell and it is the exact reverse of endocytosis.

- Materials to be exported must first be enclosed in a membrane vesicle, usually produced from the Rough Endoplasmic Reticulum (RER) and Golgi Body.
- Hormones and digestive enzymes are secreted by exocytosis from the secretory cells of the intestine and endocrine glands.
- Sometimes materials can pass straight through cells without ever making contact with the cytoplasm by being taken in by endocytosis at one end of a cell and passing out by exocytosis at the other end.

Cytoplasm

- The cytoplasm consists of the **cytosol** and a variety of **organelles**
- The cytoskeleton is a network of protein filaments that extends throughout the cytosol that provide structure and aid movement of organelles through the cell, as well as aiding the movement of the cell as a whole.
- The **cytosol** is the fluid portion of the cytoplasm.
- It consists of 70-90% water, with various solutes. The composition varies between different types of cell. Solutes include ions, glucose, amino acids, lipds and ATP amongst others.
- It is the site for many of the necessary chemical reactions usually involving enzymes.
- **Organelles** are specialised structure that have characteristic shapes that perform specific functions within the cell.
- The number and types of organelles found within specific cells vary depending upon the cells function.

Organelles

- **Mitochondria** are often called the ‘powerhouse’ of the cell because they produce the ATP that the cell uses as energy. They are especially abundant in metabolically active cells such as muscles and those involved in active transport.

- **Endoplasmic reticulum** (ER) is a series of complex tunnels that spread throughout the cell.

- Often the ER has ribosomes attached to its surface giving it a ‘rough’ appearance, and it is called rough ER (RER) if this is the case. Their primary function is to transport proteins synthesised by ribosomes through the cell to the ER lumen where they can assume their tertiary structure. It is abundant in cells that make large amounts of protein.

- Smooth ER (without ribosomes) is not involved in protein synthesis, but is the site of steroid synthesis, and contains enzymes which detoxify many organic molecules, as well as acting as a storage sit of calcium in skeletal muscle cells.

- **Ribosomes** are composed of RNA and protein, and are usually attached to the RER, although some are free within the cytosol. They assemble amino acids to synthesise new proteins.

- The **Golgi complex** is a tightly packed group of flattened vesicles. It is involved in the synthesis and modification of proteins, lipids and carbohydrates, which are then secreted in vesicles to exit the cell.

- **Lysosomes** are membrane-enclosed vesicles that contain a mixture of digestive enzymes. They digest materials within the cell, such as unwanted organelles or substances absorbed by the cell such as bacteria. Sometimes they are used to digest whole unwanted cells once they have performed their function.

- The cell membrane and nucleus are also considered organelles.

Nucleus

- Is the largest and most prominent organelle in cells (except in red blood cells, where it is absent).
- It is surrounded by a nuclear envelope, which consists of two membranes. The envelope has pores which allow entry and exit of certain substances.
- It contains the cells DNA.
- When the cell is not dividing the DNA is spread throughout the nucleus as chromatin.
- The nucleus also has nucleoli which produces ribosomes.

Cell division

Cell division is the process by which cells reproduce themselves. Cell division that results in an increase in body cells involves a nuclear division known as mitosis, whilst cell division that results in the production of gametes (sperm and ova) involves a nuclear division known as meiosis.
Meiosis

- Produces four non-identical cells
- Cells have half the number of chromosomes
- When gametes combine they will have the whole compliment

The cell cycle is the length of time between one cell division therefore and the next. It consists of **interphase** followed by mitosis or meiosis.

Interphase

During interphase the cell is engaged in metabolic activity and preparing for division and performs every life process except division, carrying out its functions as normal. Chromosomes are not clearly discerned in the nucleus, although a dark spot called the nucleolus may be visible. The cell may contain a pair of centrioles, which are organizational sites for microtubules.

Interphase encompasses stages G1, S, and G2 of the cell cycle.

- G1- the cell is metabolically active, organelles, and cystolic components (except DNA) are replicated.
- S- Chromosomes are replicated.
- G2- cell growth continues and preparations for division is completed.

Mitosis

Mitosis is nuclear division plus cytokinesis, and produces two identical daughter cells from a single parent cell.

Mitosis can be divided into four principals stages:

1. **Prophase**: The chromatin diffuse in interphase and condenses into chromosomes visible under a microscope. The nucleolus disappears and the nuclear envelope disintegrates. Centrioles migrate to opposite poles of the cell and spindle fibres form.

2. **Metaphase**: The chromosomes align at the equator and are held in place by microtubules attached to the spindle and the centromere. This line is referred to as the metaphase plate.

3. **Anaphase**: The centromeres split, and the sister chromatids separate and move toward the corresponding poles, as the spindle fibres contract.

4. **Telophase**: The chromatids arrive at the poles, and two new nuclei are formed. Cytokinesis or the partitioning of the cell may also begin during this stage.

Cytokinesis
Following mitosis cytokinesis occurs. In human cells, cytokinesis results when a fibre ring composed of a protein called actin around the equator of the cell contracts pinching the cell into two daughter cells, each with one nucleus.

Meiosis

Meiosis is the type of cell division by which gametes (eggs and sperm) are produced. Gametes have 23 chromosomes, rather than the 46 (23 pairs) present in other cells. When fertilisation takes place the gametes fuse and the resultant cell has the full compliment of chromosomes.

Meiosis comprises two successive nuclear divisions with DNA replication only happening once. The two divisions are termed **meiosis I** and **meiosis II**. There are four stages in both.

Homologous chromosomes are pairs of chromosomes that have the same size and shape, and the same genes at the same loci (position of gene on chromosome), but different alleles. Alleles are genes that have different forms e.g. blue or brown eyes.

Before meiosis interphase occurs, the same as in mitosis, with genetic material being duplicated.

Meiosis I - first nuclear division.

Prophase 1 the chromosomes become visible and **homologous** pairs of chromosomes pair up and form **bivalents** in a process termed **synapsis.** Chiasmata, the point of contact between chromatids becomes visible. The centrioles migrate to the poles and begin to form spindles, as in mitosis.
Metaphase 1 the bivalents align on spindles at the equator. Some exchange of genetic material may take place (called crossing-over) at the chiasmata.
Anaphase 1 the pairs of chromosomes split, with one of each pair pulled towards opposite poles as the spindle fibres contract.
Telophase 1 two nuclei form and the cell begins cytokinesis.

Cytokinesis occurs, the same as in mitosis.

Meiosis II- second nuclear division.

Between meiosis I and meiosis II, there is a resting period often termed interphase, but DNA replication does not occur. Meiosis II is very similar to mitosis

Prophase 2 this is the same as prophase I, except that chromosomes do not pair up.
Metaphase 2 Chromosomes align at the equator.
Anaphase 2 Centromeres split and the sister chromatids are pulled towards the poles as the fibres contract.
Telophase 2 new nuclei form and the cells begin cytokinesis.

Cytokinesis occurs again.

One parent cell therefore produces four haploid daughter cells. Daughter cells have half the number of chromosomes found in the original parent cell and with crossing-over, are genetically different.

Meiosis differs from mitosis primarily because there are two cell divisions in meiosis, resulting in cells with a haploid number of chromosomes.

Activity- you will find it both necessary and helpful to know the definitions of the following terms.

- Homologous
- Gene
- Loci
- Chiasmata
- Allele
- Diploid
- Haploid
- Chromosome
- Chromatid
- Centromere

Self-assessment questions

Chapter-2

1. Discuss the importance of acid-base balance and how this is achieved and maintained.

2. Describe the structure and role of carbohydrates.

3. Describe the structure of proteins.

4. Identify the different organelles found within a typical cell and briefly state their function.

5. Describe the steps in mitotic division of a cell.

6. Define meiotic division.