Edexcel (A) Biology A-level

Topic 2: Genes and Health

Notes

Gas Exchange

The rate of **gas exchange** by diffusion is increased by:

- **Surface area** exchanged across increase
- **Diffusion distance** decrease
- **Diffusion gradient** made more steep

Fick's Law is used to determine the rate of diffusion and it states that **the larger the surface area, difference in concentration and shorter the diffusion distance the quicker the rate.**

$$\text{Rate of Diffusion } \alpha \frac{\text{surface area} \times \text{concentration difference}}{\text{distance}}$$

In mammals, **lungs** are adapted for **rapid gas exchange** in the following ways:

- They have a **large surface area** due to the presence of many **alveoli** which increase the surface area
- **Good supply of circulating blood** to the lungs which carries carbon dioxide to the lungs and oxygen away from them ensures that the concentration gradient is steep – high concentration of oxygen and low concentration of carbon dioxide is maintained by mechanical ventilation
- They have a **short diffusion distance** as the alveoli are just **one cell thick** thus reducing the diffusion distance

Cell Membrane and Transport of Substances

All cells and organelles are surrounded by a **partially permeable membrane** composed of a sea of **phospholipids** with **protein molecules** between phospholipid molecules. Membrane proteins consist of transport proteins, receptor proteins, enzymes, structural and recognition proteins.

The main function of the membrane is **controlling the movement of substances** in and out of the cell/organelle. It also contains **receptors** for other molecules such as hormones, and enables **adjacent cells to stick together**.

The fluidity of the membrane and the mosaic arrangement of the protein give the structure of the membrane its name – the **fluid mosaic model**.

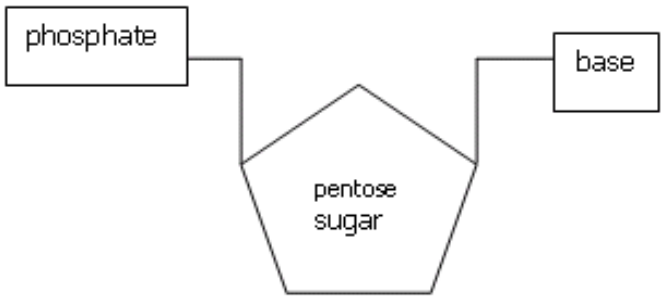
The movement of molecules through cell membrane depends on the properties of the molecule as well as the requirements of the cell. There are several types of movement:

- **Diffusion** – the **passive** movement of **small, non-polar, lipid-soluble molecules**, such as carbon dioxide and oxygen, from an area of **high concentration to an area of low concentration**. The molecules move directly through the phospholipid bilayer. The rate of gas exchange by diffusion becomes more rapid as:
    - **the surface area** increases
    - **the diffusion distance** decreases
    - **the diffusion gradient** becomes more steep.
- **Facilitated Diffusion** – requires a **channel protein** in the cell membrane to transport **polar, charged and water-soluble** molecules across the membrane.
- **Osmosis** – the movement of water molecules from an area of **low solute concentration to an area to high solute concentration** through a **partially permeable membrane**.
- **Active Transport** – can transport all types of molecules through **carrier proteins**. Movement may be either down the concentration gradient, as with diffusion, or against the concentration gradient (such as in many neurones). This process requires energy in the form of **ATP**. Hydrolysis of ATP provides an accessible store of energy for biological processes. Phosphorylation of ATP requires energy.
- **Endocytosis/Exocytosis** – transport large particles. In endocytosis, particles are enclosed in **vesicles** made from cell surface membrane and transported into the cell. In exocytosis, vesicles containing large particles are fused with the cell surface membrane and transported out of the cells. These are both active processes.

DNA

Structure of a mononucleotide

- Bases:
    - **Purine** (two nitrogen-containing rings): adenine, guanine
    - **Pyrimidine** (one nitrogen-containing rings): cytosine, thymine
- Pairing:
    - A-T
    - C-G
- Sugar: **deoxyribose** (hydroxyl group replaced by hydrogen on Carbon-2)
- Bonding:
    - **Phosphodiester bonds** between phosphate group and Carbon-5
    - Hydrogen bonds between the bases



- Hydrogen bonds holding the structure together

- Structure: double-stranded, alpha double helix with a sugar-phosphate backbone on each strand

mRNA

- Bases:
  - Purine: adenine, guanine
  - Pyrimidine: cytosine, **uracil**
- Pairing:
  - A-U
  - C-G
- Sugar: **ribose**
- Bonding: same as DNA
- Structure: **single-stranded**, not usually folded, carries codons (triplets of bases) which attach to tRNA via **hydrogen bonds**

tRNA

- Bases, pairing, sugar, bonding: same as mRNA
- Structure: single-stranded, folded into a specific pattern held together by hydrogen bonds, carries **anticodons** complementary to mRNA codons, bonded via hydrogen bonds.

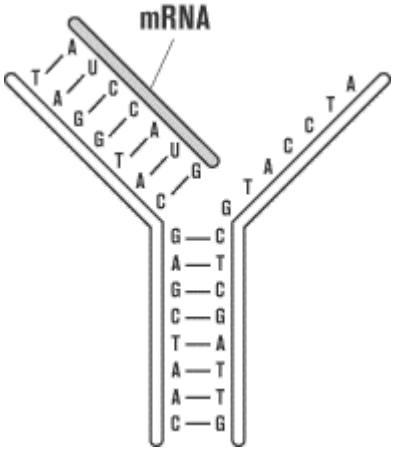
Protein Synthesis

There are two stages of **protein synthesis**. **Transcription,** which occurs in the nucleus and involves **DNA and mRNA** and **translation**, which occurs at the ribosomes and involves **mRNA and tRNA**. During transcription the DNA strand is transcribed into mRNA and during translation the amino acids are assembled together to form a polypeptide chain/protein.

Transcription

During transcription, a molecule of mRNA is made in the nucleus:

1. The **hydrogen bonds** between the complementary bases break and **DNA uncoils**, thus separating the two strands.
2. One of the DNA strands is used as a **template** to make the mRNA molecule. The template is called the **antisense strand**.



Free nucleotides line up by **complementary base pairing** and adjacent nucleotides are joined by phosphodiester bonds, thus forming a molecule of mRNA. This is catalysed by RNA polymerase.

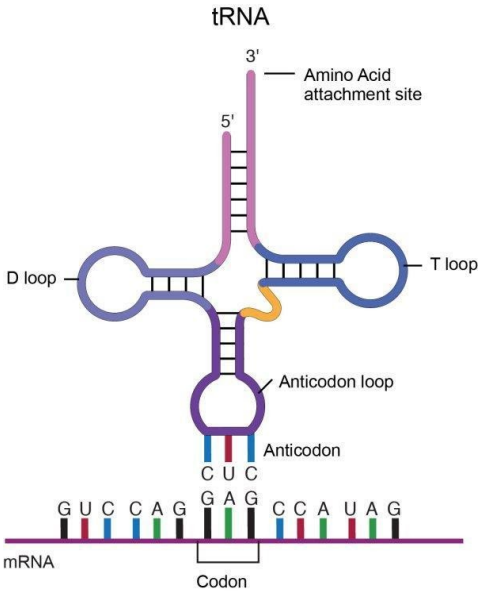
3. mRNA then moves out of the nucleus through a **pore** and attaches to a **ribosome** in the cytoplasm which is the site of the next stage of protein synthesis.

Translation:

During translation amino acids join together to form a polypeptide chain:

- **mRNA** attaches to a ribosome tRNA is a **single stranded** molecule with an amino acid **binding site**. **tRNA** binds to specific amino acids from the cytoplasm depending on its anti-codon, this is known as activation.
- Complementary anticodons of **tRNA** bind to mRNA codons and are held in place by hydrogen bonds.
- The ribosome joins the amino acids attached to two tRNA molecules by a **peptide bond** and then **tRNA molecules detach** from the amino acids.

This process is repeated thus leading to the formation of a **polypeptide chain** until a **stop codon** is reached on mRNA.



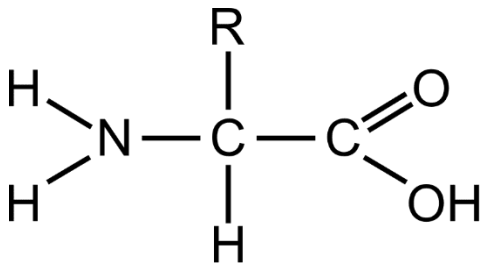
Genetic Code

A **gene** is a series of bases on a DNA molecule which codes for a series of amino acids in a polypeptide chain. The order of bases on DNA is called the **genetic code,** which consists of **triplets of bases**. Each triplet of bases codes for a particular amino acid. The amino acids are then joined together by **peptide bonds** and form a polypeptide chain. Therefore, a **gene** is a sequence of bases on a DNA molecule coding for a sequence of amino acids in a polypeptide chain. However, not all of the genome codes for proteins – the non-coding sections of DNA are called **introns** and the coding regions are called **exons**.

Features of the genetic code:

- The genetic code is **non-overlapping**, meaning that each triplet is only read once and triplets don't share any bases.
- The genetic code is **degenerate,** meaning that more than one triplet codes for the same amino acid.
- The genetic code is a **triplet code** - each three bases codes for one amino acid.
  It also contains **start and stop codons** which either start or stop protein synthesis.

Proteins



Amino acids are the monomers from which proteins are made. Amino acids contain an amino group, a carboxyl group, and a variable R group which is a carbon-containing chain. There are 20 different amino acids with different R groups. Amino acids are joined by peptide bonds formed in condensation reactions. A dipeptide contains two amino acids and polypeptides contain three or more amino acids.

The **structure of proteins** is determined by the order and number of amino acids as this determines the bonding present and the shape of the protein:

- **Primary structure** of a protein is the sequence of amino acids in a protein.
- The **secondary structure** is the 2D arrangement of the chain of amino acids– either **alpha helix** or **beta pleated sheet**.
- **Tertiary structure** of a protein is the 3D folding of the secondary structure into a complex shape. The shape is determined by the type of bonding present, namely: **hydrogen bonding** (forces of attraction between partially charged atoms in R groups), **ionic bonds** (salt bridges, form between oppositely charged groups on the R groups) and **disulphide bridges** (covalent bonds between sulphur atoms in cysteine).
- **Quaternary structure** of a protein is the 3D arrangement of more than one polypeptide. Not all proteins have all levels of structure.

Proteins can be **fibrous** or **globular**.

Fibrous Proteins:

- Long **parallel polypeptides**
- Very little tertiary/quaternary structure
- Occasional **cross-linkages** which form microfibres for tensile strength
- Insoluble
- Used for structural purposes - such as collagen.

Globular Proteins:

- **Complex tertiary/quaternary structures**
- Form colloids in water
- Many uses e.g. hormones, antibodies, carrier proteins, for example haemoglobin.

Collagen is an example of a **fibrous** protein. It has high tensile strength due to presence of both **hydrogen and covalent bonds** in the structure. Collagen molecules are made up of three polypeptides which form an alpha triple helix which forms fibrils and strong collagen fibres. Collagen forms the structure of **bones, cartilage and connective tissue** and is a main component of **tendons** which connect muscles to bones.

Haemoglobin is a **water soluble globular protein** which consists of **four beta polypeptide chains and a haem group**. It **carries oxygen** in the blood as oxygen can bind to the haem (Fe2+) group and oxygen is then released when required.

Enzymes

Enzymes are biological catalysts and increase the **rate of reaction** by lowering the **activation energy** of the reactions they catalyse, including both **anabolic and catabolic**, **intracellular and extracellular** reactions.
The **active site** is the area of the enzyme where the **substrate** binds. Enzymes are **specific to substrates** they bind to, as only one type of substrate fits into the active site of the enzyme. This was known as the lock and key model.
A more recent model of enzyme activity is the induced-fit theory:
When the enzyme and substrate form a **complex**, the structure of the enzyme is distorted so that the active site of the enzyme fits around the substrate. This is the **induced fit model**.

Initial rate of reaction can be measured by calculating the gradient of a concentration-time graph.

Factors affecting the rate of enzyme-controlled reactions:

- **Enzyme concentration** – the rate of reaction increases as enzyme concentration increases as there are more active sites for substrates to bind to. However, increasing the enzyme concentration beyond a certain point has no effect on the rate of reaction as there are more active sites than substrates so substrate concentration becomes the limiting factor.

- **Substrate concentration** – as concentration of substrate increases, rate of reaction increases as more enzyme-substrate complexes are formed. However, beyond a certain point the rate of reaction no longer increases as enzyme concentration becomes the limiting factor

- **Temperature** – rate of reaction increases up to the optimum temperature which is the temperature enzymes work best at. Rate of reaction decreases beyond the optimum temperature because enzymes denature.

- **pH** - enzymes work within a narrow range of a specific pH value, values above or below this alter the bonds within its structure, hence the shape of its active site.

DNA Replication

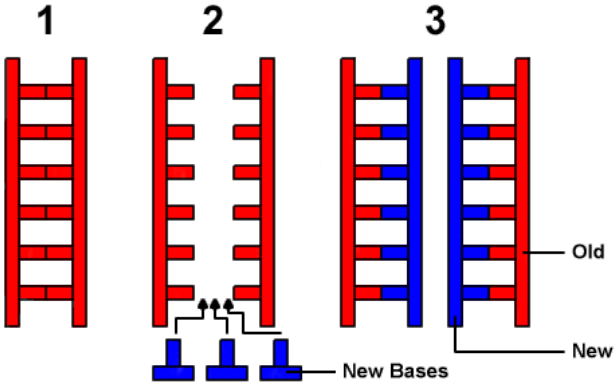
The **semi-conservative replication** of DNA ensures genetic continuity between generations of cells meaning that genetic information is passed on from one generation from the next.

Semi-conservative replication was proven by the **Meselson-Stahl** experiments (as opposed to **conservative replication**, which conserves both strands of parent DNA, or **dispersive replication**, where individual DNA strands are a mixture of old and new DNA).

Meselson and Stahl originally grew DNA in a culture containing N15 - (an **isotope of nitrogen**) for several generations, so all the bases contained this isotope. They then grew the DNA in a culture of N14 for one generation. After this generation, the DNA contained **one strand containing 15-N and one strand containing 14-N**. After another generation, half of the DNA molecules were the **same as in generation one**, and the other half contained **entirely 14-N** (where the 14-N strand from generation one had been used as a template). This provides evidence for the semi-conservative model.

The steps of semi conservative replication of DNA are as following:

1. The **double helix unwinds** and the **hydrogen bonds between the complementary bases break,** catalysed by **DNA helicase,** thus separating the two strands of DNA.



2. One of the strands is used as the **template** and **complementary base pairing occurs** between the template strand and **free nucleotides.**

3. Adjacent nucleotides are joined by **phosphodiester bonds** formed in condensation reactions, catalysed by **DNA polymerase.**

Cystic Fibrosis

Mutations are **permanent changes in the DNA** of an organism.

Gene mutations are changes in the arrangement of bases by:

- **Substitution** (change in one base)
- **Insertion** (adding another base in)
- **Deletion** (taking a base out)
- **Duplication** (adding the same base more than once)

- **Inversion** (swapping the order of bases around)

This change to the base sequence results in a change to the mRNA, tRNA and therefore to the primary structure of the protein. Mutations may also occur in the formation of mRNA and tRNA themselves.

For example, **cystic fibrosis** is a genetic disorder caused by a mutation of a single gene which codes for the **CFTR protein**. **CFTR** is a channel protein **which transports chloride ions out of cells of the respiratory tract and into the mucus**. This makes the mucus watery as it causes water to move into mucus by osmosis. Therefore, a **mutation in this gene makes the mucus very thick**, as a mutant **CFTR** protein is less efficient at transporting chloride ions. Sticky and thick mucus causes many problems in **gas exchange, reproduction and digestion**.

Respiratory system:

- Build-up of mucus in the **lungs traps bacteria, thus increasing the risk of infection.**
- Build-up of mucus in the airways decreases the surface area of **alveoli** involved exposed to fresh air, therefore **reducing the surface area for gas exchange.**

Reproductive system:

- Cervical mucus **prevents the sperm from reaching the egg.**
- In men, the **sperm duct is blocked** with mucus, meaning that **sperm produced cannot leave the testes.**

Digestive system:

- The **pancreatic duct** which connects the pancreas to the small intestine can become blocked with mucus, so the **digestive enzymes do not reach the small intestine.** As a result food is not properly digested, so **fewer nutrients are absorbed.**
- The **mucus lining in the duodenum is very thick,** thus reducing the absorption of nutrients.
- Mucus can cause **cysts** to form in the pancreas and damage the insulin producing cells, thus leading to **diabetes.**

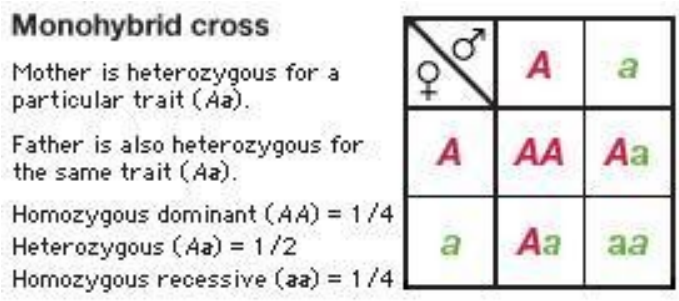
Genetics

Keywords:

- **Gene** - a piece of **DNA** which has a specific sequence of **bases**. Each gene codes for a specific **protein.**
- **Allele -** one of the **different forms** of a particular gene.
- **Genotype - all the alleles** of an organism.
- **Phenotype -** the set of **observable characteristics of an individual** resulting from the interaction of its genotype with the environment.

- **Recessive –** an allele that produces a feature only if **two copies** are present.
- **Dominant –** an allele that produces a feature even if only **one copy** of the allele is present.
- **Incomplete dominance -** a form of intermediate inheritance in which one allele for a **specific trait is not completely expressed** over its paired allele. This results in a third phenotype in which the expressed physical trait is **a combination of the dominant and recessive phenotypes.**
- **Homozygote -** an individual having **two identical alleles** of a particular gene.
- **Heterozygote -** an individual having **two different alleles** of a particular gene.

Monohybrid inheritance is the inheritance of just one characteristic. The image presents a test cross of monohybrid inheritance.



Genetic Screening

The purpose of gene c screening is to determine if the DNA of an individual contains alleles for **genetic disorders**. For instance, it can be used to **identify carriers and for preimplantation genetic diagnosis and prenatal testing** such as **chorionic villus sampling.**

Pre-implantation genetic diagnosis – embryos created through IVF are tested for genetic disorders before they are implanted into the woman's uterus.

Chorionic villus sampling – this test is carried out at **8 to 12 weeks** of pregnancy. A sample of **embryonic tissue** is taken from the placenta and the DNA is analysed. This form of testing is quicker than amniocentesis

Amniocentesis – carried out at **14-16 weeks.** A sample of **amniotic fluid,** which contains **foetal cells,** is obtained using a needle. The DNA is then analysed. Results are available after 2-3 weeks, as foetal cells need to be grown in culture first.

There are many social and ethical issues surrounding genetic testing. Some of the viewpoints are:

- There's a **risk of harm to foetus** or miscarriage.
- The outcome of testing might lead to an **abortion** - right to life.
- The **cost** of bringing up a baby with a genetic disorder.

- **Emotional and mental issues** surrounding caring for a baby with a genetic disorder.