Edexcel (A) Biology A-level

Topic 2: Genes and Health

Notes
Gas Exchange

The rate of gas exchange by diffusion becomes more rapid as:

- **Surface area** of the surface increases
- **Diffusion distance** decreases
- **Diffusion gradient** becomes more steep

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

\[
\text{Rate of Diffusion} \propto \frac{\text{Surface area} \times \text{concentration difference}}{\text{distance}}
\]

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 breathing
- 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 surface area increases, diffusion distance decreases and 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 from an area of low concentration to high concentration. 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

### DNA

- **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

**Mononucleotides**

**DNA**

- **Bases:**
  - Purine (two nitrogen-containing rings): adenine, guanine
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  - 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 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** which attach to mRNA 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:

- The **hydrogen bonds** between the complementary bases break and DNA uncoils, thus separating the two strands.
- 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.
mRNA then moves out of the nucleus through a pore and attaches to a ribosome in the cytoplasm which is the site of next stage of protein synthesis.

This is catalysed by RNA polymerase.

Translation:

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

- mRNA attaches to a ribosome. tRNA binds to a specific amino acids from the cytoplasm depending on its anti-codon. tRNA is a single stranded molecule with an amino acid binding site.
- Complementary anticodons of tRNA bind to mRNA and is held in place by a hydrogen bond.
- The amino acids attached to two tRNA molecules join 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 acids and is known as a codon. 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 acids.
- The genetic codes 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, 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 such as 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

Globular Proteins:

- Complex tertiary/quaternary structures
• Form colloids in water
• Many uses e.g. hormones, antibodies

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.

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 called 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.
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 to the next.

Semi-conservative replication (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) was proven by the Meselson-Stahl experiments.

Meselson and Stahl originally grew DNA in a culture containing 15-N (an isotope of nitrogen) for several generations, so all the bases contained this isotope. They then grew the DNA in a culture of 14-N 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).

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

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

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

- 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)
- **Addition** (adding another base in)
- **Deletion** (taking a base out)

This change to the base sequence results in a change to the mRNA, tRNA and therefore to the primary structure of the protein.
For example, cystic fibrosis is a genetic disorder caused by a mutation of a single gene which codes for the CTFR protein. CTFR is a channel protein which transports chloride ions out and into the mucus. This channel protein 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 CTFR 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 number 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 connect 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**

**Keyword:**
- **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 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 pedigree diagram of monohybrid cross.

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**Genetic Screening**

The purpose of genetic 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 chronic villus sampling.

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

**Chronic 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 the birth a baby with a disorder.