AS Biology Notes – AQA Unit 2: The Variety of Living Organisms

Variation:

- Variation describes the differences in characteristics between organisms.
- Can be inter- or intraspecific:
  - Inter = between members of different species.
  - Intra = within the same species.
- Also continuous/discontinuous:
  - Continuous = infinite number of possible values, e.g. height, weight.
  - Discontinuous = finite number of possible values, e.g. eye colour, number of legs.
- Continuous numerical data can be analysed using the mean or standard deviation:
  - Mean gives the average value ($\bar{x} = \frac{\sum x}{n}$)
  - Standard deviation gives a measure of how the data is spread around the mean: low standard deviation means consistent data, high means inconsistent ($s = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}}$). N.B. calculation of standard deviation is not required according to AQA specification.
- When data is sampled and analysed, there is always a possibility of trends being due to chance; in biology a 95% confidence level is set: if the probability of something not being due to chance is above 95% it is accepted.
- Phenotype describes an organisms physical characteristics; genotype describes its genetic makeup.
- Variation can be caused by genetic or environmental factors. Often genetic factors cause discontinuous variation whilst environmental factors cause continuous variation, though this is not always true.

DNA structure:

- DNA is a long and complex molecule containing the genetic information of an organism; it codes for protein synthesis. DNA is a polymer made up of many single units called nucleotides.
- A nucleotide is made up of three parts:
  - A pentose – i.e. 5-carbon – sugar (ribose in RNA, deoxyribose in DNA).
  - A phosphate group.
  - A nitrogen-containing base: either Adenine, Guanine, Cytosine or Thymine (A,T,C or G)
- Nucleotides join together by phosphodiester bonds (condensation reactions) to form polynucleotide chains.
- In DNA, two polynucleotide chains line up so that the sugar and phosphate groups point outwards (the sugar-phosphate backbone). The bases point inwards and form hydrogen bonds, joining the two strands. Base pairing is specific and complementary: A will only bond with T; C will only bond with G. Complementary base pairing is essential to the function of DNA.
- The ratio of pyrimidine (i.e. T and C) to purine (i.e. A and G) bases in DNA is thus 1:1.

One gene, one polypeptide:

- A gene or cistron is a sequence of bases in DNA which codes for the synthesis of a specific polypeptide. Each triplet of bases codes for an amino acid; a sequence of amino acids forms a polypeptide.

- In the 20th century Beadle and Tatum proved that each gene codes for a single polypeptide. They cultured a fungus, and then caused a mutation in a single gene. The mutated fungus only grew when a specific amino acid was present, showing that the fungus lacked the enzyme (a polypeptide) for the synthesis of that amino acid.
- A gene for a particular characteristic or polypeptide occupies a specific position on a chromosome, known as a gene locus. Different versions of the same gene are known as alleles.
- Polypeptide synthesis also involves RNA, a molecule similar to DNA but with certain key differences:
  - Ribose sugar instead of deoxyribose.
  - Uracil present instead of thymine.
  - Single stranded.
- Polypeptide synthesis has two main stages:
  - Transcription – the DNA partially unravels, exposing a single gene and enzymes construct a strand of mRNA (messenger RNA) by complementary base pairing, which is the opposite base sequence to the original gene. This leaves the nucleus through the nuclear pores.
  - Translation – The mRNA attaches to a ribosome, where tRNA (transfer RNA) transports amino acids to their specific positions corresponding to the codons (base triplets). Enzymes link the amino acids to form a polypeptide.
- Genes contain not only coding bases, but also sequences of bases which do not code for polypeptide production. These are known as introns, and are removed from the mRNA during transcription.

DNA in prokaryotes and eukaryotes:

- Eukaryotic DNA is enclosed in a nucleus. It is mixed with proteins known as histones to form a complex known as chromatin. During cell division it forms chromosomes: tightly packed and folded packages, each containing a single DNA molecule. Chromosomes are formed of two chromatids joined at a point known as the centromere. At the ends of each chromosome are telomeres – these seal the chromosomes and prevent them from unravelling.
- Prokaryotic DNA is 'naked' i.e. unassociated with histones. It is free within the cytoplasm – there is no nucleus, and it is circular unlike eukaryotic DNA which is linear.
- Cells can be diploid or haploid:
  - Diploid: two of each chromosome; one from the father and one from the mother. Chromosomes containing the same genes are known as homologous chromosomes. They often contain different alleles at the same gene loci.
  - Haploid: only one of each chromosome, such as in gametes or simple organisms.

Genetic diversity:

- Variation in living organisms is caused by variation in the base sequences in the organisms' DNA. The entirety of an organism's inherited information is described by the genome. Variation is generally positive as it increases the chance of survival in the instance of, for example, a genetic disease.
- In populations, different alleles have different frequencies, e.g. in China black hair and brown eyes are very common whilst blonde hair and blue eyes are not. This can be caused by a founder effect:

    - A small group becomes separated from a larger population and is unable to interact with the original population (so cannot breed with it).
    - By chance, this small group contains an abnormally high frequency of certain alleles.
    - Breeding within the group causes the frequency of these alleles to rise further; the new population can have characteristics totally different from the original one. This can result in the formation of a new species.
- Random genetic drift is the chance fluctuation of the frequency of alleles between generations. In smaller populations this has a greater effect and can result in alleles becoming lost (0% frequency) or fixed (100% frequency)
- A genetic bottleneck can also affect variation. This is when a significant portion of a population is killed or prevented from reproducing. This reduces genetic diversity and also increases inbreeding, further decreasing variation as the gene pool is restricted.

Artificial selection:

- Artificial selection also affects genetic variation. There are two methods used in artificial selection:
    - Inbreeding – genetically similar individuals sharing characteristics are bred together in the hope that desirable characteristics are passed on to offspring. This results in well-suited individuals to the desired environments, but severely reduces diversity and can result in homozygosity: this is when the alleles are the same at each gene locus. This is devastating in the event of a disease to which the individuals have no resistance, and can lead to the presentation of harmful recessive characteristics such as deformities.
    - Outbreeding – genetically different individuals are bred together to increase diversity. This makes individuals less likely to succumb to diseases etc. and is often used to punctuate inbreeding.

Haemoglobins:

- These are conjugated globular proteins with quaternary structures – they consist of four polypeptide chains bonded together, each containing a prosthetic (non-protein) haem group to which oxygen binds reversibly.
- Haemoglobins are responsible for carrying oxygen from the gaseous exchange apparatus of an organism to its cells for respiration.
- The level of oxygenation of haemoglobin is governed by the partial pressure of oxygen (the $p(O_2)$). This is calculated by multiplying the air pressure by the proportion of oxygen in the air.
- At low $p(O_2)$ values it is difficult for oxygen to bind, but after a single O_2 molecule binds the shape of the haemoglobin opens out to allow more molecules to attach more easily. This means that the gradient of a graph of oxygen saturation against $p(O_2)$ will start off with a shallow gradient, but this will quickly become steeper. At high $p(O_2)$ values the haemoglobin becomes saturated and thus the gradient of the curve levels off.
- The loading $p(O_2)$ is the pressure of oxygen corresponding to 95% saturation. The unloading $p(O_2)$ corresponds to 50% saturation. Normally in the body the saturation of haemoglobin is between these two values.
- Different organisms adapted to different habitats have different orders of amino acids in their haemoglobin molecules, giving them different properties:

    - Individuals from low-oxygen habitats such as at high altitude usually have oxygen dissociation curves to the left of others, i.e. oxygen will bind more readily. This allows oxygen to bind even when there are low levels in the air. However, it makes it harder for oxygen to be released to the cells.
    - Individuals from high-oxygen habitats which require lots of movement (e.g. ducks) have oxygen dissociation curves to the right – oxygen binds less readily. This enables it to be easily released to the cells for respiration.
    - Foetuses have haemoglobin with oxygen dissociation curves to the left of the mother to absorb oxygen from the mother's blood.
- The carbon dioxide level in the blood affects the haemoglobin's affinity for oxygen. Carbon dioxide in the blood is absorbed into the red blood cells where it makes them more acidic. A lower pH decreases the affinity for oxygen – this means that when the red blood cells receive CO_2 from cells, the give up the oxygen that they are carrying.

Structural polysaccharides:

- There are two isomers (versions) of glucose molecules: alpha and beta. Alpha glucose polymerises to form starch or glycogen, used to store energy in plants and animals. Beta glucose polymerises to form cellulose, which is used as a structural material in many plants.
- Cellulose is insoluble in water and is a long chain molecule. Groups of cellulose molecules known as microfibrils are cemented together by another polysaccharide (hemicellulose) to form strong cell walls in plant cells. These are tough and protect the cell, though they are still permeable to water.
- The enzymes which digest starch in animals have active sites which do not fit the glycosidic bonds between beta glucose molecules; this is why many animals cannot digest cellulose. Herbivorous animals often have bacteria in their stomachs which digest the cellulose for them.
- Glycogen is a chain of alpha glucose molecules, and is used as an energy store in animals. It is an effective molecule for energy storage because it can be quickly broken down into glucose for use in respiration, and because it is insoluble, so does not exert an osmotic pressure.
- Some tissues in plants, such as the xylem vessels (which carry water) are lined with lignin, a substance which makes them impermeable to water. This makes them woody, and kills the cells so that they are protected against rot or decay.

Plant cells:

- Plant cells contain many of the same organelles as eukaryotic animal cells, but with some extra structures:
    - Cell walls: these are made of cellulose and have pores in them known as plasmodesmata for communication between cells.
    - Vacuoles: these are large cavities containing sap, a solution of water with salts, sugars and enzymes. They are used to maintain turgor pressure and store sugars, starch grains and waste products.
    - Chloroplasts: these are specialised organelles for carrying out photosynthesis. Chloroplasts are surrounded by a chloroplast envelope, and contain thylakoid membranes. These are specialised membranes for carrying out photosynthesis; they contain chlorophyll which harnesses the energy from sunlight. Chloroplasts also contain circular DNA, and may store the products

of photosynthesis in starch or lipid droplets. The matrix inside the chloroplast is known as the stroma, similar to the cytoplasm in a cell.

- A palisade cell in a plant contains all the organelles commonly found in plants, so can be used as a generic model of a cell. An intestinal epithelial cell in an animal can be used similarly.

DNA replication:

- In order for cells to divide, the DNA in them must first replicate itself. It does this by the following process:
  - Helicase enzymes break the hydrogen bonds holding the two strands of DNA together, 'unzipping' it. This occurs at many points along the molecule, known as replication forks, to speed up the process.
  - Nucleotides line up next to their corresponding bases by complementary base pairing, and are joined together to form polynucleotides by DNA polymerase enzymes.
  - Ligase enzymes join the polynucleotide chains to from two separate identical DNA molecules.
- This process is known as semiconservative replication, because each new molecule of DNA contains one strand from the parent DNA and one new one.
- Semiconservative replication was only one hypothesis for DNA replication: the others were conservative replication – this is where one DNA molecule contained both of the parent strands and another was totally new, and dispersive replication in which each strand is a random mixture of the two. Semiconservative replication was proved by Mendelsohn and Stahl as follows:
  - Bacteria were cultured in a medium of 'heavy' nitrogen (^{15}N). This meant that the DNA strands, which contain nitrogen, would be heavy. A sample of the bacterial DNA was taken.
  - The bacteria were transferred to a medium containing normal nitrogen (^{14}N) and allowed to divide once. A sample was taken, and the bacteria were allowed to divide again, after which a third sample was taken.
  - The three samples were analysed using centrifugation, a process which separates molecules by order of density:
    - The parent strands, as would be predicted, gave a single band in the lower region, because they contained only the heavy nitrogen.
    - The first generation had a band of intermediate density. This ruled out conservative replication as this would have produced two bands – one light and one heavy.
    - The second generation had two bands, one light and one intermediate. This ruled out dispersive replication as this would have still produced a single intermediate band.

The cell cycle:

- This is a sequence of events carried out by every dividing eukaryotic cell – after the cell cycle two genetically identical copies are formed, used either for growth or asexual reproduction.
- The first three stages of the cell cycle are known as interphase and are as follows:
  - G_1 (Gap 1) phase: the cell grows and carries out metabolic functions. Checks are performed to ensure normal function – if not the cell cycle may terminate.

    - S (DNA synthesis) phase: growth continues and the DNA is replicated, duplicating the chromosomes.
    - G_2 (Gap 2) phase: growth still continues. Organelles are replicated and the apparatus for mitosis forms.
- Following interphase is mitosis – the division of the cell to from two diploid daughter cells.

Mitosis:

- This is the process by which the cell divides. It is continuous, but is often arbitrarily divided into four phases for convenience:
    - Prophase: the DNA in the nucleus condenses into chromosomes so they can move apart without becoming entangled. They are visible as sister chromatids joined at the centromeres. The nuclear membrane disintegrates and spindle apparatus forms: this is a network of microtubules which help to carry out mitosis.
    - Metaphase: the centromeres of the chromosomes line up along the equator of the cell. The spindle fibres attach to the chromosomes and pull them apart at the centromeres; the sister chromatids become daughter chromosomes, one attached to each pole.
    - Anaphase: the spindle fibres attached to the chromosomes shorten, pulling the chromosomes to the poles. The pole-to-pole spindle fibres lengthen, elongating the cell.
    - Telophase: when the two sets of chromosomes reach opposite poles the nuclei reform around them; the spindle apparatus disappears.
- Mitosis is normally followed by cytokinesis. The cell membrane pinches and separates into two separate diploid cells.

Meiosis:

- Meiosis is cell division to form haploid gametes for sexual reproduction: a diploid cell divides twice to form four gametes.
- Meiosis begins with prophase 1 which is similar to mitotic prophase. However, when the chromosomes meet at the centre, the homologous chromosomes cross to form bivalents, where genetic information is exchanged between them in a process known as genetic recombination.
- The rest of the first division in meiosis is similar to mitosis, except the chromosomes do not divide. Instead, the homologous chromosomes separate into two nuclei so that each cell contains only one allele for each gene.
- The process then repeats itself; the nuclear envelopes disintegrate again and the cells divide once more. This time the chromosomes separate; four gametes are formed.
- Variation is ensured in the following ways:
    - Genetic recombination – the genes recombine randomly to so each chromosome in the gametes is different to those of the parent.
    - Independent assortment: when the homologous chromosomes line up during the first division they segregate randomly – there are millions of possible combinations of chromosomes in each nucleus.
    - Random fusion of gametes: a single organism produces millions of gametes, which could hypothetically fuse with the gametes of any member of the same species, giving billions of possible combinations.

Mitosis and cancer:

- Cells in multicellular organisms only divide when required; otherwise they enter the G_0 phase of the cell cycle where no division occurs.
- If a cell is no longer required or a mutation is detected, the cell may enter apoptosis – a process of controlled cell death in which the organelles break down and the cell disintegrates into membrane-bound packages.
- If a cell enters the cell cycle unnecessarily and is not terminated by apoptosis it can divide uncontrollably, forming a tumour. This is known as cancer.
- Cancer can be detected by searching for abnormal cells such as in a cervical smear test. If diagnosed early it can be treated. Cancer treatments aim to destroy the tumours without affecting the surrounding cells – examples include radiotherapy (which uses radiation) or chemotherapy (which uses drugs), both of which attempt to induce apoptosis in cancer cells.

Animal tissues and organs:

- Animals begin life as a single cell – a zygote. This divides by mitosis and eventually becomes a multicellular organism. Initially the cells are unspecialised but have the potential to divide and become new cells – these are known as embryonic stem cells. However, within a few weeks of foetal development the stem cells differentiate into specialised cells with specific purposes.
- Each cell in an organism contains the full genome of that organism. However, in specialised cells only the genes necessary for the cell's function are switched on. These normally are unable to produce other types of cell and are dependent upon other similar cells.
- Specialised cells join together to form tissues. Each tissue is specialised to carry out a particular function. There are four main types of animal tissue:
    - Connective tissue, which adds support or structure; e.g. bone, blood.
    - Epithelial tissue, which lines the body surfaces such as organs or vessels.
    - Muscle tissue, which is used for movement.
    - Nerve tissue, which is used for communication between cells.
- Tissues are organised into organs, which are comprised of two or more tissues which work towards a common purpose – examples include the brain, lungs or liver.
- Organs are organised into organ systems. These consist of two or more organs functioning for a common purpose.

Plant tissues:

- All cells of flowering plants are originally from meristematic tissues. These are groups of unspecialised cells which constantly divide – the plant equivalent of stem cells. The meristems of a plant are located at the apex of the shoot and the root tip.
- There are four types of plant tissue:
    - Protective tissues, such as the epidermis of leaves or the cork on the stems of trees and plants.
    - Packing tissues, such as the parenchyma which fills the space between other tissues and can be adapted for other functions such as photosynthesis or storage.
    - Mechanical tissues: the collenchyma, which is comprised of cells with extra cellulose for strength and flexibility, or the sclerenchyma, which is woody and gives structure and support.

    - Vascular tissues: the xylem, which transports water up the stem, and the phloem, which transports food substances.
- All plant cells are totipotent – i.e. with the correct stimulus any plant cell or cutting can be made into an entire plant. This is used to create genetically identical clones of plants such as crops for orchards etc.

Effects of size on animals:

- In general, an increase in the size of an organism decreases the surface area to volume ratio. This affects biological processes such as gaseous exchange and nutrition.
- The decrease in surface area to volume ratio means that less heat is lost, thus explains the large, round shapes of organisms from cold climates, and the fact that large organisms in warmer regions have adaptations to increase heat loss (e.g. the large ears of elephants).

Gaseous exchange:

- In small organisms, e.g. amoebae, respiratory gases have a short distance to travel and can be absorbed by diffusion alone. In larger multicellular organisms, gaseous exchange systems have developed.
- In insects:
    - Insects have an intricate network of tubes known as a tracheal system, through which they absorb oxygen and remove carbon dioxide.
    - The external surfaces of insects are lined with a cuticle to prevent water loss. This cuticle is also impermeable to respiratory gases, so there are holes in their exoskeletons known as spiracles, connecting to the tracheal system. Some insects have valves which open and close the spiracles in response to respiratory demand.
    - Air enters through the spiracles into large tubes known as tracheae, which are lined with chitin and are thus impermeable. These branch off into smaller tubes known as tracheoles, which are permeable; the gases diffuse through these into the cells. There are many tracheoles to increase the surface area, and their walls are thin for a minimal diffusion distance. In times of high respiratory demand, the fluid in the tracheoles retracts to further decrease the diffusion distance.
    - Some insects have air sacs, which are collapsible trachea; these can be used to pump air through the trachea when necessary.
- In bony fish:
    - Bony fish have gills which are adapted to removing oxygen from water, where it is at a much lower and more variable concentration than in air: rarely higher than 0.8%.
    - Fish have four pairs of gill arches, which support gill filaments. These are divided into stacks of lamellae (thin plate-like structures), giving them a massive surface area. The surface area is further increased by projecting gill plates.
    - The counter-current principle maintains a concentration gradient across the gill: water moves across the gills in the opposite direction to the flow of blood, so blood with the highest O_2 content lines up with water with the highest O_2 content and vice versa: there is always more oxygen in the water than in the blood directly beneath it.

  - Efficient circulation and ventilation also help maintain the concentration gradient – there is a constantly replenished blood supply, and the operculum, a bony flap, pumps water over the gills.
  - The gill plates of fish are very thin to decrease the diffusion distance.
- In plants:
  - Gaseous exchange occurs through stomata: microscopic pores on the surfaces of leaves. These lead into air spaces in the mesophyll layer of the cell.
  - The stomatal aperture (opening) can be controlled by the plant. Around the stomata are two guard cells; specially adapted epidermal cells which have outer walls which are thinner and more elastic than the inner walls. Thus, when the cells are turgid, they bend into a kidney-shape and create a wider opening. The turgidity can be controlled by the active transport of potassium ions. In sunlight the stomata open fully to allow CO_2 to diffuse in for photosynthesis.
  - Water leaves plants through the stomata by evaporation. Temperature, humidity and wind all affect the rate of water loss.

Plants in dry conditions:

- In all land organisms there is a constant balance that must be struck between efficient gas exchange and reduced water loss; the conditions for the best gas exchange also encourage the loss of water so organisms must compromise.
- Plants adapted to live in dry conditions are known as xerophytes. The features of xerophytes to suit dry conditions are known as xeromorphic features.
- Cacti have the following xeromorphic features:
  - Leaves are reduced to spines to protect the plant and reduce water loss.
  - A waxy impermeable cuticle coats the epidermis.
  - Carbon dioxide can be absorbed in the night and used in the day: this means the stomata do not have to be open in the heat of the day.
  - Extensive root networks allow massive amounts of water to be taken up.
- Plants in cold conditions often have xeromorphic features: coniferous plants also have spines and waxy cuticles. Deciduous plants lose their leaves in winter as low light intensities render the extra photosynthesis from them inefficient.

Mammalian blood transport:

- The circulatory system is used to transport nutrients and gases by mass flow: the bulk transport of substances from one area to another by pressure changes (initiated by the heart). It maintains concentration gradients and removes waste products.
- Mammals have closed circulatory systems with a network of blood vessels: arteries carry blood away from the heart, and lead to arterioles – small, narrow-walled vessels connecting arteries to capillaries. Capillaries are microscopic vessels forming networks in the body's tissues. They are connected via venules (narrow, vein-like vessels) to veins, which carry blood back to the heart.
- Mammals also have double circulatory systems: blood passes through the heart twice in a single circuit of the body. The pulmonary circulatory system transports between the heart and lungs; the systemic circulatory system between the heart and the rest of the body.
- Each organ has a major artery and vein connecting it to the heart:
  - Brain = jugular vein/carotid artery.

    - Upper limbs = subclavian vein/artery.
    - Liver = hepatic vein/artery.
    - Stomach and intestines = gastric and mesenteric arteries; deoxygenated blood from the stomach and intestines passes through the hepatic portal vein to the liver before returning to the heart.
    - Kidneys = renal vein/artery.
    - Genitals = genital vein/artery.
    - Lower limbs = iliac vein/artery.

Arteries, capillaries and veins:

- Arteries carry blood under high pressure away from the heart. The lumen (the space in the centre of the vessel) is relatively narrow to maintain a high pressure. It is lined with the endothelium (a layer of cells) and has a thick layer of smooth muscle and elastic tissue in the arterial wall.
- As arteries get closer to their target organs they decrease in size, eventually becoming arterioles which lead to capillaries. The junction between the two often has a sphincter muscle which controls blood supply to the tissue.
- Metabolic exchange occurs in capillaries, which are adapted in the following ways:
    - Very small in diameter, meaning a high surface area. Some are small enough to squeeze red blood cells out of shape, increasing their surface area also.
    - Thin walls for minimal diffusion distance. The endothelium (lining) of the capillaries is also smooth so as not to impede blood flow, and flexible to respond to pressure changes.
    - Numerous: there are very large numbers of capillaries throughout the body's tissues. This gives a massive combined surface area, but also a large combined volume: blood slows down as it passes through the capillaries to allow maximum time for diffusion.
- Veins carry blood under low pressure back to the heart. This means they do not need thick walls, instead they have wide lumen – the contraction of skeletal muscles squeezes the blood through the veins. Flaps of tissue act as valves to prevent backflow: blood can only flow in one direction.
- The smooth muscle in the walls of blood vessels can contract or relax, narrowing or widening the lumen. These occurrences are known as vasoconstriction and vasodilation respectively, and are used to control the flow of blood through vessels or for temperature regulation.
- The elastic tissue in arterial walls stretches when pressure rises and recoils when the pressure falls. This helps to maintain a relatively constant pressure in the arteries.

Tissue fluid and lymph:

- Tissue fluid forms the immediate environment of most mammalian cells. Water, oxygen and nutrients diffuse into cells from the tissue fluid; waste products diffuse out. Tissue fluid has specific chemical makeup and temperature etc. to provide optimum conditions of the cells.
- Tissue fluid is present because of the high pressure at the arterial end of capillaries. This squeezes water and small molecules out of the capillaries in a process known as ultrafiltration.
- Tissue fluid, because it comes from blood, has a similar composition to plasma, but without the globular proteins – these are too large to be squeezed out of the capillaries. These create an osmotic effect drawing water back in. At the venous end

the osmotic pressure is higher than the ultrafiltration pressure; water and solutes move back into the capillaries. Any excess drains into the lymphatic system.

- The lymphatic system is a second circulatory system made up of lymph vessels which are similar to veins. Lymph, the fluid in the lymph vessels, is similar to tissue fluid but contains more fatty substances and white blood cells. The major organs in the lymphatic system are the spleen (this also stores an emergency supply of blood and white blood cells), the adenoids, the tonsils and the appendix (also the thymus in infants). Lymph flows slowly through the lymphatic system by external pressures such as from breathing or contraction of skeletal muscles.
- The lymphatic system has several important functions:
    - It transports tissue fluid back to the blood, to maintain a constant environment for the body's cells.
    - It plays an important part in the immune system – along the lymph vessels are lymph nodes which produce and store white blood cells. Lymph nodes also filter out foreign particles, bacteria etc. before they can enter the bloodstream.

Roots and water transport:

- The roots of a plant extend underground in order to absorb vital water and nutrients.
- The structure of a typical root is as follows:
    - A thin walled outer layer known as the epidermis, which is permeable to water.
    - Between the epidermis and the vascular bundle is a layer of packing tissue (parenchyma) known as the cortex. This contains air spaces for efficient diffusion.
    - The inner part of the cortex is the endodermis, which is a single layer of cells around the vascular bundle. The walls of the endodermal cells contain suberin, an impermeable substance which affects water transport – this is called the Casparian strip.
    - Inside the endodermis is lignified (i.e. woody) sclerenchyma – this is a type of tissue which provides structural support.
    - The vascular tissues (xylem and phloem) are enclosed in a cylinder known as the stele.

Water transport mechanisms:

- Water is drawn up through plants in three different ways:
    - Cohesion tension: when water molecules evaporate from the stomata, the hydrogen bonds between water molecules pull water up the xylem. This pull is transmitted all the way down through the roots.
    - Root pressure: solutes are actively transported into the root hair cells and xylem. This lowers the water potential, causing water to be drawn into the root hair cells from outside, and travel through to the xylem where it moves up the plant.
    - Capillarity (also known as capillary action). This is the spontaneous movement of water up very fine tubes such as the thinner xylem vessels against gravity. It can be observed using an absorbent material such as paper – if one touches a piece of paper to a water source, water will be drawn up the paper.

- Water can take three possible routes from the root hair cells to the xylem:
  - The apoplast route: water moves only through the cellulose cell walls by cohesion tension. However, once the water reaches the impermeable Casparian strip it cannot pass and is forced to travel through the living part of the cells.
  - The symplast route: water passes through the cytoplasm from cell to cell along the water potential gradient maintained by root pressure. The cytoplasms of neighbouring cells are joined by fine tubes known as plasmodesmata which form an unbroken water transport pathway.
  - The vacuolar route: similar to the symplast route, but water also passes through the vacuoles.

Transpiration:

- The transpiration stream describes the continuous passage of water from the roots of a terrestrial plant upwards. The speed of the transpiration stream is governed by the rate of the evaporation of water through the plant's surfaces.
- Transpiration is not solely to provide water for photosynthesis; only 1% is used for this purpose. It is an unavoidable consequence of the gaseous exchange system: it replaces the water lost through it. In warmer climates it also cools the plant.
- The rate of transpiration can be measured using a potometer:
  - A cut shoot is placed in one end of a capillary tube.
  - A single air bubble in the capillary tube is formed.
  - As water is drawn up through the shoot, the air bubble moves. The speed at which the air bubble moves can be used to determine the rate of transpiration.

Classification:

- Classification is the grouping together of organisms on the basis of common features. Modern classification is based upon phylogenetic relationships, i.e. the historical evolutionary relationships between organsims.
- Evolution is the process by which the genetic composition of a population gradually changes over time. It is governed by natural selection: genetic variation causes a variety of different characteristics, some of which are more desirable than others. Organisms with characteristics which help them to survive are more likely to reproduce and pass on these characteristics; this results in adaptations for different environments.
- The identification and naming of species is known as taxonomy. Organisms are placed into groups known as taxa. There are seven taxa; in decreasing order of size:
  - Kingdom: e.g. animals, plants, fungi.
  - Phylum: e.g. vertebrates.
  - Class: e.g. mammals, reptiles.
  - Order: e.g. carnivore.
  - Family: e.g. primates.
  - Genus: e.g. Homo
  - Species: e.g. sapiens, erectus.
- Organisms are named by their genus and species in common scientific usage (this is known as the binomial system). The genus is given with a capital letter and the species with lowercase, e.g. *Homo sapiens*, *Canis lupus*, *Bufo bufo.*

- If two individuals are able to mate and produce fertile offspring, the two individuals are members of the same species. Thus, all hybrids are infertile.

Classification and DNA:

- Originally, organisms were classified by comparative anatomy. This is the observation of analogous body parts, such as the pentadactyl (five-digit) limb of mammals. This often gives strong evidence of a common ancestor, but can be mistaken: the wings of birds, bats and insects, for example, are totally unrelated.
- Comparative DNA analysis is now used to determine the genetic makeup of an organism: organisms with more similar DNA are more closely related, and thus share a more recent common ancestor.
- One method of comparing DNA is by sequencing the genome of an organism, as follows:
    - A strand of DNA to be sequenced is used as a template, and is added to a mixture of nucleotides, enzymes for synthesising DNA, and fluorescently labelled bases.
    - The enzymes synthesise strands of DNA of differing lengths – each one has the last base fluorescently labelled,
    - The synthesised DNA fragments are separated by order of size, and the last base is identified in each.
    - From the last base in each fragment, the entire genome can be derived, as each fragment is one nucleotide longer than the one before it.
    - This process gives a very accurate account of how related two organisms are, but, even with modern technology, takes a very long time and is expensive.
- A second method is DNA-DNA hybridisation:
    - DNA from two species to be compared is extracted and isolated.
    - It is heated so the hydrogen bonds break and the DNA unravels, giving single strands of DNA.
    - The DNA is cooled and allowed to reform into double helices. However, some of the new DNA formed will be hybrid DNA with one strand from each species. This hybrid DNA is isolated.
    - The hybrid DNA is heated again in small increments. The closer related the organisms, the more similar the base sequences in the DNA. The more similar the base sequences, the more hydrogen bonds will form in the hybrid DNA. These require more energy to break. Thus, the hybrid DNA of closely related species will unravel at higher temperatures than the hybrid DNA of distantly related species.
- A third method is the comparison of proteins:
    - Proteins are coded for by DNA base sequences. Organisms with different base sequences will often have different amino acids or orders of amino acids in their proteins; the closer related the organisms, the more similar the proteins.
    - Proteins which are found in a variety of organisms are often used, such as haemoglobins or cytochromes.
    - The proteins can be sequenced exactly like in DNA sequencing, but, like with DNA sequencing, this is costly and time-consuming. Instead, immunological comparisons are often used:

        - Proteins from one species are injected into another animal, commonly a rabbit.
        - The rabbit's immune system recognises the proteins as non-self and produces antibodies against them.
        - When a serum containing the rabbit's antibodies is mixed with a sample of the original protein, the antibody-antigen reaction causes a precipitation.
        - When the serum is mixed with a protein from a different species, precipitation still occurs, but at different levels: the closer related the species, the more similar the proteins; this means more precipitation.

Courtship behaviour:

- Courtship is the sequence of behavioural events which precedes the fertilisation of the female's eggs by the male's sperm.
- Courtship ensures that the two mating individuals have synchronised reproductive behaviours, thus increasing the chance of successful mating. It is also species-specific; it is used to recognise fertile individuals from the same species and ensure that mating only occurs within a species, again increasing the chance of successful fertilisation.
- Courtship behaviour is widely varied between animals. For example, stickleback males build a nest in which the female lays her eggs; fruit flies perform a synchronised dance and the male 'sings' to the female.
- Courtship often includes a display of desirable characteristics. Thus, organisms with more effective courtship techniques are more likely to successfully mate and reproduce: this is a form of natural selection known as sexual selection.

Antibiotics:

- An antibiotic is a substance produced by a micro-organism which damages or destroys another micro-organism; this is almost always against bacteria. They give micro-organisms a competitive advantage over others, and are used extensively in medicine. Some antibiotics are harvested directly from micro-organisms; others are synthetically altered or completely synthesised.
- Antibiotics destroy bacteria in one of four ways:
    - By inhibiting the synthesis of the protein links between the peptidoglycan molecules in bacterial cell walls. This weakens the cell walls and causes osmotic lysis. This only affects bacteria which are actively growing.
    - By interfering with protein synthesis and either preventing it or causing the synthesis of abnormal proteins; these antibiotics bind to prokaryotic ribosomes.
    - By inhibiting DNA replication.
    - By disrupting the cell membranes: fungal cell membranes contain ergosterol, which lubricates the plasma membrane. Antibiotics bind to the ergosterol and prevent it from functioning; the plasma membrane distorts and lyses.

Mutations:

- A mutation is a change in the chemical structure of DNA. If a mutation occurs in one of the sequences of DNA coding for a polypeptide, it can change an organism's characteristics. This makes mutations an important source of genetic variations, especially in asexually reproducing organisms.

- Mutations can happen as a result of errors in DNA replication, or by the interference of external factors such as radiation or chemicals – these are known as mutagens.
- There are four types of mutation:
    - Substitution: the replacement of one nucleotide with another containing a different base.
    - Insertion: the addition of an extra nucleotide.
    - Duplication: the repetition of a portion of a nucleotide sequence.
    - Inversion: the reversal of a portion of a nucleotide sequence.
- Some mutations may have no effect, if they occur within non-coding DNA or produce the same amino acid as previously. Mutations with an external effect are often damaging and can result in the organism being unable to function. However, some mutations can be beneficial, such as mutations in bacteria which lead to resistance to antibiotics.

Antibiotic resistance:

- There are two ways in which genes for antibiotic resistance can be passed between bacteria:
    - Vertical gene transmission: this occurs when a bacterium reproduces asexually by dividing into two, producing genetically identical clones. If the parent bacterium has a gene which codes for antibiotic resistance, this gene, and thus the resistance will be replicated and passed on to the next generation.
    - Horizontal gene transmission: this is when genetic information is transferred from one bacterium to another in a process known as conjugation. Two bacteria join by a cytoplasmic bridge; a plasmid containing the gene for antibiotic resistance replicates itself and is transferred from one bacterium to another. This enables the gene to be incorporated into the genome of the other bacterium, thus giving it antibiotic resistance. Horizontal gene transmission can occur between bacteria of different species.
- Antibiotic resistance often prevails due to a form of natural selection: if antibiotics are used, resistant bacteria will survive whilst non-resistant ones will be killed. This reduces the competition for the resistant bacteria; they reproduce and pass on their resistant genes. This can cause the development of highly dangerous resistant strains of bacteria such as MRSA or XDR-TB.

Species diversity:

- Biodiversity refers to the richness of an ecosystem, including its complexity, its genetic variation, and its species richness (i.e. the number of species present).
- Species diversity takes into account not just the number of species but the number of individual species. It can be calculated using the Simpson species diversity index – a numerical measure of biodiversity, from the formula $D = \frac{N(N-1)}{\sum[n(n-1)]}$, where N is the total number of individual organisms found, and n is the number of individuals found from each species.
- The biodiversity of the world's ecosystems is in decline. This is due in part to human actions such as deforestation: the removal of the world's natural forests for fuel, to make room for housing or for other purposes. This causes the number of individuals of each species to decline, and some species may become extinct.
- Ecological stability describes an ecosystem's ability to resist change or to return to its original state after change. Decreasing biodiversity often causes a decreased

ecological stability, as the ecosystem depends on certain species to remain in its state; removing or depleting these upsets the balance of the ecosystem.

- The declining biodiversity of the world's ecosystems results in problems such as the loss of possible natural drugs which could cure many diseases. For this reason, many groups and individuals campaign for conservation of wildlife and biodiversity, using techniques such as education or the offering of a monetary incentive to conserve wildlife (such as ecotourism).