Higher Biology Learning Outcomes

Langholm Academy

Unit 1 - Cell Biology

Cell Ultrastructure

Cell Structure in Relation to Function

- ✓ Cells have a wide variation in their structure
- ✓ Some cells are complete organisms (single celled or unicellular organisms)
- ✓ The cell of a single celled organism must be able to perform every life function
- ✓ Cells in multicellular organisms are specialised for a single function – this is known as a "division of labour"
- ✓ The specialised structure of a cell in a multicellular organism depends on the particular function that it performs
- ✓ Examples of specialised cells include:
  - o sperm cells that are specialised for swimming - their structure includes a tail for propulsion and lots of mitochondria to supply energy
  - o palisade mesophyll in a leaf – they contain many chloroplasts to absorb maximum light energy for photosynthesis

Absorption and Secretion

Cell Membrane and Cell Wall Strucutre

- ✓ Cellulose cell walls are rigid and therefore help to maintain plant shape and prevent them from bursting when water enters the cell by osmosis
- ✓ Cell walls are freely permeable
- ✓ Cellulose is a large structural carbohydrate
- ✓ Cell walls are made of cellulose fibres
- ✓ The structure of the plasma membrane is described as a "fluid mosaic"
- ✓ The fluid mosaic model shows the membrane as a bi-layer of phospholipids with embedded protein molecules
- ✓ Some of these proteins form channels that can transport some substances rapidly through the membrane, but can prevent other substances from passing through
- ✓ This structure makes membranes both selectively permeable and very fluid (able to change shape very easily and quickly)

Diffusion

- ✓ The plasma membrane surrounding all cells is selectively permeable which means that molecules of different substances diffuse through at different rates – and many cannot diffuse through at all
- ✓ Chemicals passing through a membrane, by diffusion, move down a concentration gradient, and this requires no energy

Osmosis

- ✓ Water can diffuse through the plasma membrane
- ✓ "High water concentration" means a high proportion of water and very little solute (pure water has the highest water concentration possible)
- ✓ "Low water concentration" means a solution with lots of solute dissolved in it
- ✓ Osmosis is the movement of water molecules through a selectively permeable membrane from an region of high water concentration to an region of lower water concentration
- ✓ Hypotonic means "a solution with a higher water concentration than the one it is being compared with"
- ✓ Hypertonic means "a solution with a lower water concentration than the one it is being compared with"
- ✓ Isotonic means "having the same water concentration as the solution it is being compared with"
- ✓ Animal cells burst in hypotonic solutions and shrink in hypertonic solutions
- ✓ Plant cells become turgid in hypotonic solutions and plasmolysed in hypertonic solutions

Active Transport

- ✓ Active transport is the movement of molecules across the plasma membrane against a concentration gradient
- ✓ Active transport is selective as individual ions and molecules are accumulated or expelled
- ✓ Active transport depends on energy and so can be limited by any factor that reduces the supply of ATP – such as a shortage of food or oxygen, temperatures higher or lower than the optimum and chemicals that inhibit respiration

Photosynthesis

The role of light

- ✓ Light falling on a leaf is either transmitted, reflected or absorbed
- ✓ Transmitted light passes right through the leaf
- ✓ Reflected light bounces off the surface of the leaf
- ✓ Only some of the light which is absorbed can be used for photosynthesis
- ✓ "White" sunlight consists of a range of colours or wavelengths
- ✓ The range of colours is called a spectrum
- ✓ Light is absorbed by special molecules called photosynthetic pigments

Photosynthetic Pigments

- ✓ The main photosynthetic pigment is chlorophyll of which there are two forms; chlorophyll A & B
- ✓ They absorb mainly red and blue light, which is converted into chemical energy
- ✓ Carotene and xanthophylls are accessory pigments
- ✓ They absorb other wavelengths of light and pass on the absorbed energy to chlorophyll
- ✓ Each pigment absorbs some wavelengths of light more than others; this is called the absorption spectrum for that photosynthetic pigment

Separation of photosynthetic pigments by means of chromatography

- ✓ Leaf tissue is ground with acetone to dissolve the pigments
- ✓ Filtering separates the cell debris from a clear pigment solution
- ✓ A concentrated spot of pigment is built up near the bottom of the chromatography paper
- ✓ Pigments are separated as the chromatography solvent rise up through the paper
- ✓ The chromatography solvent is made from acetone and petroleum ether
- ✓ The pigment that dissolves best in the solvent rises highest
- ✓ Rf values for each pigment can be calculated by dividing the distance moved by the pigment by the distance moved by the solvent front

Chloroplasts

- ✓ Chloroplasts are disk shaped organelles enclosed in a double membrane
- ✓ The grana are stacks of disks, containing photosynthetic pigments, where photolysis takes place
- ✓ The stroma is the enzyme rich fluid surrounding the grana and is the site of the Calvin cycle
- ✓ The chloroplast may also contain starch grains which are a storage carbohydrate produced during photosynthesis

Photolysis (The light dependent stage)

- ✓ The light dependent stage takes place in the grana of the chloroplast
- ✓ Energy from light is absorbed by chlorophyll and converted to chemical energy
- ✓ This chemical energy is used for the photolysis of water and the synthesis of ATP from ADP + P_i
- ✓ Photolysis is the splitting of water into hydrogen and oxygen
- ✓ The hydrogen combines with NADP (a hydrogen carrier) to become $NADPH_2$ and is used in the Calvin cycle
- ✓ The oxygen is released into the atmosphere as a by-product
- ✓ The ATP which is synthesised is used to supply energy for carbon fixation in the Calvin cycle

Carbon fixation (the Calvin cycle)

- ✓ Carbon fixation takes place in Calvin cycle in the stroma of the chloroplast
- ✓ The Calvin cycle is a sequence of enzyme controlled reactions that produce glucose by the reduction of CO_2
- ✓ It requires ATP and hydrogen from the light dependent stage, and carbon dioxide from the atmosphere
- ✓ In the Calvin cycle, carbon dioxide combines with 5-carbon RuBP to form an unstable 6-carbon compound
- ✓ The unstable 6-carbon compound breaks down to give 2 molecules of the 3-carbon GP
- ✓ Some of the GP is converted to 6-carbon glucose, the rest is used to regenerate RuBP
- ✓ The conversion of GP to form glucose and RuBP requires both hydrogen and the energy from ATP
- ✓ Glucose may be converted to starch for storage or cellulose for cell wall formation

Respiration

The role and production of ATP

- ✓ ATP is adenosine tri-phosphate
- ✓ ATP is found in all living cells and is the immediate source of energy for most biological reactions – active transport, muscle contraction, nerve conduction and cell division
- ✓ The chemical energy which ATP contains is released when it is converted to ADP and inorganic phosphate (P_i)
- ✓ ATP can be regenerated from ADP + P_i when energy is supplied
- ✓ The process of respiration involves the synthesis of ATP using the energy from glucose
- ✓ There are three stages in aerobic respiration; glycolysis, Krebs cycle and the cytochrome system
- ✓ All the stages in respiration are controlled by enzymes

Glycolysis

- ✓ Glycolysis takes place in the cytoplasm of the cell
- ✓ Glucose is the most common substrate for glycolysis, but fats and proteins can also be used
- ✓ During glycolysis, 6-carbon glucose is split into 2 molecules of 3-carbon pyruvic acid
- ✓ 2 ATPs are used to activate the glycolysis reaction
- ✓ 4 ATPs are produced giving a net gain of 2 ATPs per glucose molecule
- ✓ Hydrogen is released during glycolysis which is accepted by NAD becoming $NADH_2$
- ✓ Oxygen is not required for glycolysis

Krebs cycle

- ✓ Takes place in the matrix of the mitochondrion
- ✓ Pyruvic acid is converted to a 2-carbon acetyl group and carbon dioxide is released
- ✓ The acetyl group combines with coenzyme A to give acetyl – Co A
- ✓ In the Krebs cycle, the 2-carbon acetyl from acetyl – Co A combines with a 4-carbon compound to form 6-carbon citric acid
- ✓ Citric acid is converted to a 5-carbon and then the original 4-carbon compound
- ✓ Each time carbon is lost it is released as carbon dioxide
- ✓ Hydrogen is also released at the same time
- ✓ The hydrogen is collected by NAD, to become $NADH_2$, a reduced carrier
- ✓ The final 4-carbon compound completes the cycle by reacting with the next acetyl – Co A

The cytochrome system

- ✓ The hydrogen from earlier stages is taken (as $NADH_2$) to the cytochrome system
- ✓ The cytochrome system takes place on the cristae of the mitochondrion
- ✓ In the cytochrome system the high energy hydrogen is passed through a series of carriers
- ✓ Oxygen is the final hydrogen acceptor and water is produced
- ✓ 36 ATPs are produced per glucose molecule

Mitochondrion structure

- ✓ A mitochondrion is a cell organelle bounded by two membranes
- ✓ The inner of these two membranes is folded to form a greatly increased surface area
- ✓ The folds of this membrane are called the cristae
- ✓ The cristae of the mitochondrion are the site of the cytochrome system
- ✓ The enzyme rich fluid filled central space inside this membrane is called the matrix
- ✓ The matrix of the mitochondrion is the site of the reactions involved in the Krebs cycle

Aerobic and anaerobic phases of respiration

- ✓ If oxygen is available the entire aerobic respiration process can take place
- ✓ Aerobic respiration produces 38 ATP per glucose molecule
- ✓ Anaerobic respiration occurs if oxygen is not available. In this circumstance only glycolysis takes place (no Krebs' cycle or cytochrome system), and so only 2ATP are produced from each glucose molecule
- ✓ When respiration is anaerobic, the pyruvic acid is converted to:
    - o Lactic acid in animals/bacteria
    - o Ethanol and carbon dioxide in plants/yeast

DNA, RNA and Proteins

DNA

- ✓ Chromosomes are made of DNA which is a double helix
- ✓ The basic units of DNA are called nucleotides
- ✓ Each nucleotide consists of a deoxyribose sugar, a phosphate and one of the four bases
- ✓ The bases are adenine (A), thymine (T), guanine (G) and cytosine (C)
- ✓ The base-pairing rule states that A only pairs with T and C only pairs with G
- ✓ The bases pair by joining with hydrogen bonds
- ✓ The steps in DNA replication are:
    - o DNA molecules replicate by unwinding and then unzipping to expose the bases
    - o Free DNA nucleotides join to the exposed bases of each strand using the base-pairing rule
    - o Adjacent nucleotides join to form a sugar-phosphate "backbone"
    - o The daughter molecules rewind
- ✓ Replication requires a supply of free nucleotides, enzymes and energy from ATP
- ✓ Replication produces two identical DNA molecules
- ✓ DNA replication is important since every new cell which is produced by an organism must receive a full set of instructions if it is to function properly
- ✓ DNA replication occurs before every cell division

RNA

- ✓ RNA is single stranded and contains ribose sugar instead of deoxyribose
- ✓ Thymine in DNA is replaced by Uracil in RNA
- ✓ A gene is a short length of DNA which codes for a particular protein
- ✓ Messenger RNA (mRNA) is formed in the nucleus using the DNA template for a particular gene
- ✓ This process is called transcription and involves the following steps
    - o DNA unwinds and unzips
    - o Free RNA nucleotides bond to exposed bases on one DNA strand by complementary base pairing

DNA	mRNA
A	U
T	A
G	C
C	G

    - o Adjacent RNA nucleotides join to form a sugar-phosphate "backbone"
    - o mRNA molecule peels off and the DNA zips-up again
    - o The mRNA molecule then moves out of the nucleus to attach to a ribosome for protein synthesis
- ✓ This requires enzymes and the energy from ATP

- ✓ Protein synthesis on the ribosome is also known as mRNA translation:
  - A triplet of bases on the mRNA molecule (called a codon) codes for only one specific amino acid
  - tRNA captures a specific amino acid and brings it to the ribosome
  - Each mRNA codon in a ribosome attracts a molecule of tRNA with a corresponding triplet of bases (called and anti-codon)
  - The amino acids are lined up in order and attach to their neighbours by a peptide bond

Cellular organelles

- ✓ Ribosomes are the site of protein synthesis where the sequence of mRNA triplet codes are translated into proteins
- ✓ Ribosomes are attached to the endoplasmic reticulum
- ✓ The endoplasmic reticulum is a continuous network of membranes throughout the cell
- ✓ The endoplasmic reticulum functions as a transport system for proteins
- ✓ Proteins are processed or "packaged" for secretion in the Golgi apparatus
- ✓ The Golgi apparatus attaches various carbohydrates to the protein molecules, making them glycoproteins
- ✓ Vesicles pinch off the ends of the Golgi body and carry the protein to the plasma membrane for secretion

The functional variety of proteins

- ✓ There is a huge variety of proteins in living things
- ✓ Proteins are constructed from chains of amino acids (of which there are 20)
- ✓ The structure and properties of each protein depends largely on the length of the amino acid chain, and the order of the amino acids which form the chain
- ✓ Proteins can be classified as either fibrous, globular or conjugated
- ✓ Fibrous proteins form structural elements of the body (e.g. collagen/keratin)
- ✓ Globular proteins can have a variety of functions, for example as enzymes, membrane proteins, some hormones and antibodies
- ✓ Conjugated proteins have a non-protein molecule attached (i.e. the haem group in haemoglobin)

Viruses and Cellular Defence Mechanisms

The nature of viruses and their invasion of cells

- ✓ Viruses consist of a strand of DNA/RNA surrounded by a protein coat
- ✓ They invade cells and take over their metabolism so cell replicates the DNA/RNA
- ✓ The cell is then made to synthesise the protein coats and assemble the new virus
- ✓ The host cell bursts (lysis) releasing the new viruses to invade further cells

Cellular defence mechanisms in animals

- ✓ The main mechanisms of cellular defence in animals are phagocytosis and antibody production
- ✓ Phagocytosis is where:
    - o Specialised white blood cells called phagocytes engulf invading viruses or bacteria
    - o The invaders are enclosed in a vacuole
    - o Lysosomes merge with the vacuole and release powerful digestive enzymes which destroy the invader
- ✓ Antibodies are specific Y-shaped protein molecules which attack invading organisms
- ✓ Antibodies are made by another type of white blood cell called lymphocytes
- ✓ Lymphocytes recognise invaders as foreign by the antigens which they carry on their surfaces
- ✓ The lymphocytes then produce the particular antibody required to combat that particular antigen
- ✓ Each antibody is specific to one antigen
- ✓ Antibodies attach themselves to the invader and attract phagocytes to dispose of them
- ✓ After each attack, a few of the lymphocytes remain as memory cells so that the response to that particular antigen will be both faster and stronger on a future occasion
- ✓ Transplanted organs, e.g. a kidney, also have antigens that are recognised as foreign by
- ✓ Antibodies attempt to destroy the "invader" – this is known as tissue rejection
- ✓ Doctors reduce the chance of tissue rejection by matching the antigens of donor and recipient as closely as possible and by using drugs to suppress the immune system

Cellular defence mechanisms in plants

- ✓ The two main means of cellular defence in plants are production of poisonous chemicals, and isolation of injured areas to prevent the spread of infection
- ✓ Plant cells can produce various toxic chemicals when attacked, including tannins, cyanide and nicotine
- ✓ Infections can be prevented from spreading by isolating the injured area by means of substances such as resin

Unit 2 – Genetics and Adaptation

Meiosis

Sexual reproduction as a means of enabling variation

- ✓ Sexual reproduction is vital in enabling the genetic variation of populations to be maintained
- ✓ Since natural selection acts upon this variation, sexual reproduction is very important for evolution
- ✓ Sexual reproduction involves the fusion of two haploid gametes during fertilisation

Meiosis

- ✓ The process by which gametes are formed is called meiosis
- ✓ Each gamete has a single set of chromosomes (that's what haploid means)
- ✓ Meiosis only takes place in organs which produce gametes: ovaries, testes or anthers
- ✓ Meiosis involves two cell divisions, producing 4 haploid gametes from a diploid cell called the gamete mother cell

First Meiotic Division

- ✓ The DNA of each chromosome replicates, forming two chromatids attached at a centromere
- ✓ The chromosomes shorten and thicken (become visible under the microscope)
- ✓ Homologous chromosomes pair up
- ✓ The homologous pairs line up at the equator of the cell
- ✓ Spindle fibres attach to the centromeres and pull the homologous pairs to opposite poles of the cell
- ✓ The cell divides to form two daughter cells (but each chromosome is still composed of two chromatids)

Second Meiotic Division

- ✓ Each chromosome lines up at the equator of the cell
- ✓ Spindle fibres attach to each centromere dragging the chromatids to opposite poles of the cell
- ✓ Each cell divides, so there are now 4 gametes, each with a single set of chromosomes
- ✓ The main source of variation in gametes results from the random lining up of the homologous chromosomes at the equator of the cell during the first meiotic division. This is called random/independent assortment
- ✓ The independent assortment of chromosomes ensures that each offspring has a unique phenotype

Genetic Crosses

The dihybrid cross

- ✓ A dihybrid cross is when we consider the inheritance of two genes at the same time
- ✓ Since each parent has two alleles for each of the two genes, a dihybrid cross can involve considering up to 4 possible gametes from each parent. (AaBb gives AB, Ab, aB and ab whilst aabb gives only ab)
- ✓ The following phenotype ratios may be produced
  - AaBb X AaBb → 9:3:3:1
  - AaBb X aabb → 1:1:1:1
  - Aabb X aaBb → 1:1:1:1

Linked genes

- ✓ Predictions for dihybrid crosses depend upon the assumption that during gamete formation each allele is selected independently of the other gene in the cross
- ✓ This assumption is not true if the two genes involved are on the same chromosome
- ✓ Genes on the same chromosome are called linked genes
- ✓ The result is that we get far more than the predicted number of the 2 parental types and none of the others
- ✓ The "non-parental" types are called recombinants
- ✓ The frequency of recombinants between any two linked genes increases the further apart the genes are on the chromosome

Crossing over

- ✓ Crossing over is when two chromatids from a homologous pair of chromosomes swap a number of alleles during the first stage of meiosis
- ✓ Crossing-over occurs at points called chiasmata
- ✓ The frequency of crossovers between any two linked genes increases the further apart the genes are on the chromosome
- ✓ We can "map;" chromosomes using recombinance percentages
- ✓ When a crossover happens, two genes which had previously been linked become independent of each other
- ✓ Crossing-over is a further source of variation, as it gives new combinations of alleles

Sex linkage

- X and Y chromosomes determine the sex of animals
- In mammals XX=female and XY=male
- Some genes occur on the X chromosome but not on the shorter Y chromosome. These are called sex linked genes
- Sex linkage problems in genetics are similar to monohybrid crosses except that you put the alleles as little superscripts only on the X. There is no allele on the Y
- The only possibilities are:
    - **Females** $X_A X_A$ (Normal) $X_A X_a$ (Carrier) $X_a X_a$ (Affected) **Males** $X_A Y$ (Normal) $X_a Y$ (Affected)
- Sex linked conditions are mostly found in males
- A male child inherits the recessive allele for a sex linked condition from his mother

Mutation

Mutant alleles

- Mutations are spontaneous changes in the genotype of a cell
- Mutations are completely random and relatively rare
- They give rise to new alleles and are therefore a source of variation
- The rate of mutation can be increased by chemical agents or irradiation (X-rays & UV light etc.)
- These are called mutagenic agents
- There are two main types of mutation, chromosome mutations and gene mutations
- Chromosome mutations are changes either in the number of chromosomes, or in the structure of an individual chromosome involving more than one gene

Non disjunction

- Changes in chromosome number are caused by non-disjunction during meiosis due to spindle failure
- If only one chromosome is affected then offspring may have an extra chromosome (Downs' syndrome is an example), or one chromosome missing

Polyploidy

- Polyploid plants have one or more sets of chromosomes in excess to the normal diploid number
- Plant polyploidy results in increased vigour which can give advantages in crop production
- These advantages include increased yield, hardiness and disease resistance

Change in the structure of one chromosome

- ✓ When parts of a chromosome become separated and re-attached chromosome mutations occur
- ✓ These are classified under the following types: deletion, duplication, translocation, inversion
- ✓ Deletion is where one or more genes have been lost from a chromosome
- ✓ Duplication is when a chromosome has two copies of a gene or genes
- ✓ Translocation is when a chromosome has two copies of a gene or genes – one copy coming from a non-homologous chromosome
- ✓ Inversion is when two or more genes come out, flip 180^o and are reinserted into the same chromosome

Alteration of base type or sequence

- ✓ Gene mutations are alterations in the sequence of bases in DNA
- ✓ Gene mutations are classified into the following types: substitution, insertion, deletion, inversion
- ✓ Changes in the DNA sequence cause corresponding changes in the sequence of amino acids in the protein being coded for and so its shape
- ✓ This may involve only a single amino acid in the case of a substitution or inversion
- ✓ Insertion and deletion change all the triplets after the mutation point and so all the amino acids too

Selection and Speciation

Natural Selection

- ✓ Natural selection is the survival of the fittest (those organisms best suited to their environment):
    - o Many more young are produced than can possible survive
    - o In a population there is variation caused by meiosis, sexual reproduction and mutation
    - o Organisms poorly adapted to their environment die from predation, disease or competition
    - o Organisms best suited to their environment survive passing on favourable combinations of alleles to the next generation
- ✓ The most favourable alleles increase in the population over time
- ✓ If the environment changes the frequency of certain alleles will change over many generations

The concept of the species

- ✓ A species is a group of organisms which are sufficiently closely related to breed with each other and produce fertile offspring
- ✓ Members of a species share a common gene pool

Isolating mechanisms

- ✓ Isolating mechanisms are barriers to gene exchange – this can lead to evolution of new species
- ✓ Isolating barriers can be geographic, ecological or reproductive
- ✓ When a species becomes divided into two populations by an isolation barrier there is no interbreeding or exchange of genes between the groups
- ✓ The environment for both groups may differ
- ✓ Both mutations and natural selection will differ for each group
- ✓ Each group will therefore evolve differently
- ✓ The gene pools of each population will gradually become different
- ✓ Over a very long period the two populations may become sufficiently different from each other to prevent interbreeding
- ✓ Once the two groups can no longer interbreed and produce fertile offspring, they have become two separate species

Adaptive radiation

- ✓ The evolution of several different species from a common ancestor is called adaptive radiation
- ✓ A feature e.g. beak shape, evolves into many forms to fill different niches

High speed evolution

- ✓ Evolution is almost always a very slow process
- ✓ Some examples of rapid evolution allow us to see it happening in a relatively short time. Examples of this include;
    - o The evolution of antibiotic resistant strains of bacteria
    - o Changes in gene frequency of the melanic form of the peppered moth

Conservation of species

- ✓ A variety of ways are adopted by a man to preserve a species and to maintain genetic diversity. These include:
    - o Wild life reserves
    - o Captive breeding
    - o Cell and seed banks
    - o Laws and quotas

Selective Breeding

- ✓ Humans have contributed to the evolution of both crop plants and domesticated animals by selective breeding
- ✓ The parents are selected for desirable characteristics such as high yield
- ✓ Offspring that reach a standard for the desired characteristic are in turn kept for breeding
- ✓ The rest are prevented from passing on their "inferior" genes
- ✓ The desirable characteristic becomes more common over a long period
- ✓ Hybridisation is another artificial technique for producing new types of plants and animals
- ✓ Hybridisation involves crossing two breeds or varieties of the same species
- ✓ The offspring are heterozygous for many alleles which gives hybrid vigour

Genetic engineering

- ✓ Techniques of genetic engineering have greatly increased the ability of humans to produce new varieties by allowing direct manipulation of genes
- ✓ It involves transferring a gene from one species to another:
    - o The location of the desired gene can be found using a gene probe, or by recognising characteristic banding patterns on chromosomes
    - o Endonuclease is used to cut out the target gene
    - o Plasmids are removed from bacteria and cut open with the same endonuclease enzyme
    - o Ligase enzymes seal the desired gene into the plasmid
    - o The plasmids are taken up by bacteria
    - o The bacteria are multiplied and make the desired product
- ✓ The manufacture of human insulin and human growth hormone using a bacterium called *Escherichia coli* are good examples

Somatic fusion

- ✓ Crosses can be achieved between two plant species which could not normally interbreed:
    - o The cell walls are removed using the enzyme cellulose, forming protoplasts
    - o The protoplasts from the two species are fused
    - o The resulting cells are grown into plants
- ✓ The new plants have characteristics from both species
- ✓ An example of an application of somatic fusion might be the introduction of disease resistance from a wild potato species into a high yielding crop plant

Maintaining a Water Balance

Osmoregulation in fresh and salt water bony fish

- ✓ All animals must take in the same volume of water as they lose
- ✓ Freshwater fish:
    - Are hypertonic to their environment
    - They gain large volumes of water by osmosis through their gills and lose salts by diffusion
    - To combat this they have large kidneys with many glomeruli
    - They have relatively short kidney tubules since there is little need for the reabsorption of water
    - These two adaptations allow freshwater fish to produce large volumes of very dilute urine
    - Chloride secretory cells in the gills take salts from the water into the blood by active transport
- ✓ Saltwater fish:
    - Are hypotonic to their environment
    - This means that they lose water by osmosis and gain salts by diffusion
    - They replace the water by drinking sea water
    - The chloride secretory cells in the gills of marine fish actively expel the salts
    - The kidneys of marine fish contain very few, small glomeruli (or none)
    - This means that they produce a very small volume of concentrated urine

Adaptations of salmon and eels

- ✓ Certain exceptional fish, including salmon and eels migrate over long distances
- ✓ They spend part of their lives in fresh water and the rest at sea
- ✓ This means that their osmoregulation mechanisms have to change as their habitats change
- ✓ In particular their kidney function changes from large volumes (freshwater) to small volumes of urine (sea water) – and back again – as necessary
- ✓ Their chloride secretory cells reverse the direction in which they transport ions
- ✓ In freshwater salts are pumped in and in sea water salts are pumped out

Desert mammals

- ✓ Desert mammals (the kangaroo or desert rat is a good example) have particular problems of water conservation
- ✓ They live in an environment where water is scarce and the days are extremely hot
- ✓ These problems are solved by a combination of physiological and behavioural adaptations
- ✓ Physiological adaptations can include:
  - No sweat glands
  - Very long kidney tubules to reabsorb water and produce very concentrated urine
  - Maximum reabsorption of water in large intestine to produce dry faeces
  - Narrow nostrils to reduce water loss in exhaled air
- ✓ Behavioural adaptations can include:
  - Nocturnal habit – feed during the cooler night
  - Remain in burrow (cooler, more humid) during the hot day

The transpiration stream

- ✓ Transpiration is the loss of water vapour from the leaves of plants
- ✓ The transpiration stream is the flow of water through a plant from root hairs, through the cortex of the root into the xylem, until it is lost as vapour from the stomata in the leaves
- ✓ As well as supplying water to all the cells of the plant, the transpiration stream allows the uptake of minerals
- ✓ The force of cohesion between water molecules is very strong and allows narrow "threads of water" to be pulled from the soil water surrounding the root tips up the plant via the xylem vessels
- ✓ This is known as transpiration pull
- ✓ The adhesion of water to the walls of the xylem vessels aids the transpiration pull as it helps resist the effects of gravity
- ✓ Root pressure pushes water upwards through the xylem vessels contributing to the transpiration stream
- ✓ Root hairs have a large surface area and are hypertonic, so soil water enters by osmosis
- ✓ Water moves inwards through the root cortex cells by osmosis
- ✓ The combination of transpiration pull and root pressures moves large volumes of water up through the xylem to the leaves
- ✓ Factors which influence the rate of transpiration include temperature, humidity, wind speed, leaf surface area and the degree of stomatal opening

Stomatal mechanism

- ✓ Open stomata are needed for gas exchange to allow photosynthesis
- ✓ Transpiration through open stomata involves a hugh water loss, so it helps survival for the stomata to remain closed when photosynthesis is not taking place
- ✓ The guard cells which surround stomata have thickened inner walls which makes them more curved when they are turgid and straighter when flaccid
- ✓ Therefore turgid guard cells open the stomata and flaccid cells close the stomata

Adaptations in xerophytes and hydrophytes

- ✓ Xerophytes are plants which are adapted to survive in very dry habitats
- ✓ Adaptations of xerophytes include:
    - o Reduced leaf surface area of cacti spines or pine needles gives fewer stomata for water loss
    - o Small, thick leaves reduces the surface area relative to leaf volume
    - o Rolled leaves, hairy leaves and stomata in pits all allow a build-up of humid air outside the stomata and so decrease the water vapour concentration gradient
    - o Thick waxy cuticles prevent water evaporating through the cuticle
    - o Deep roots to seek water deep underground
    - o Wide spreading surface roots to maximise water collection after rare rain showers
    - o Succulent tissues store water that is used sparingly until the next rain
    - o Reversed stomatal rhythm where stomata are open during the cool night and closed during the hot daytime when transpiration would be greater
- ✓ Hydrophytes are plants which are adapted to live in fresh water
- ✓ Adaptations of hydrophytes include:
    - o Air spaces in stems and leaves to give buoyancy
    - o Reduced central xylem gives flexible leaf stalks that can adjust to changes in water levels and prevent damage by currents
    - o Floating leaves with stomata on top surface for gas exchange, but none on lower surface to prevent leaf filling with water

Obtaining Food

Foraging behaviour and search patterns

- ✓ Foraging is the name given to food searching behaviour in animals. Animals adopt a variety of search patterns depending on habitat and quality of food
- ✓ Examples of foraging behaviours and search patterns:
    - o Ants leave a scent trail for others to follow to the food
    - o Bees show the direction of a good food source with a waggle dance
- ✓ To maximize the quantity of food obtained animals may remain where food is plentiful, hunt weakest or best size of prey

Economics of foraging behaviour

- ✓ Foraging uses large amounts of energy
- ✓ It is essential for survival that the energy gained in food exceeds the loss involved in foraging
- ✓ Survival depends on economical foraging in terms of optimum search patterns and selection of the best food

Competition

- ✓ All organisms are in competition with other organisms for scarce resources
- ✓ Competition with other species is called inter-specific competition
- ✓ Competition with other members of the same species is called intra-specific competition
- ✓ Intra-specific competition is particularly fierce since the animals of the same species have exactly the same needs and are competing for the same resources in terms of food, mates and shelter

Dominance hierarchy and co-operative hunting within the social group

- ✓ Dominance hierarchies and co-operative hunting may benefit the subordinate animals as well as the dominant
- ✓ Dominance hierarchy means that every animal "knows" its place, or rank, in the group based on the threat of aggression
- ✓ Dominance hierarchies result in :
    - Reduced fighting over food or females
    - Dominant animals gain the most food or mates
    - Subordinate animals gain a share of food when plentiful
    - Group share sentry duty and warn others of danger
    - Large group can defend females and young
    - Large group can confuse or attack predator
- ✓ Co-operative hunting means that animals hunt in groups
- ✓ Co-operative hunting results in
    - An individual gaining more food than by foraging alone
    - Group will be able to take larger prey items than a single individual
    - Group will have more chance of success of catching prey
    - Group can defend kill or territory together
- ✓ Group behaviour and food sharing will only occur as long as the reward for sharing exceeds that for individual foraging

Territorial behaviour

- ✓ Territorial behaviour is an alternative to dominance hierarchies and co-operative hunting
- ✓ An individual or breeding pair will defend and utilise a food supply, and will preserve it for their own use
- ✓ It is only efficient in energy terms to defend just enough for their needs, so that in times of plenty the territory will be smaller than when there is a shortage
- ✓ Only individuals or pairs fit enough to defend a territory will survive and breed

Plants

- ✓ Plants are sessile (they don't move around)
- ✓ Plants compete for water, light and soil nutrients
- ✓ Grazing tends to reduce species diversity
- ✓ Grasses tolerate grazing because they have low meristems
- ✓ The compensation point is the light intensity at which a particular plant is respiring at exactly the same rate as it is photosynthesising – it is making food at exactly the same rate as it is using it up
- ✓ Sun plants have relatively high compensation points – they need high light intensities
- ✓ Shade plants have relatively low compensation points – they can produce food efficiently at lower light intensities

Coping with Dangers

Avoidance behaviour and habituation

- ✓ Many animals have instinctive (genetic) responses which help them to avoid danger
- ✓ Examples of avoidance behaviour include; withdrawing into a shell or burrow, running away or rolling up into a ball
- ✓ If a particular stimulus turns out to be harmless, the avoidance response stops temporarily
- ✓ This short term modification of response to a repeated harmless stimulus is called habituation
- ✓ Habituation allows the animal to continue feeding and reduces the energy expenditure on unnecessary avoidance behaviours
- ✓ Habituation is specific to one stimulus as a different stimulus may be harmful
- ✓ After a short time the habituation disappears and the response returns to normal, since it is essential for the protection and survival of the organism in normal circumstances

Learning as a long term modification of response

- ✓ Although instinctive responses can offer excellent protection they are not very adaptable
- ✓ Animals can make long term changes in their behaviour patterns as a result of experience – this is called learning

Individual and social mechanisms for defence

- ✓ Individual animals have a great variety of defence mechanisms: teeth, claws, size, protective shells or skin, horns and other "weapons", poisons, camouflage, warning coloration, etc.
- ✓ Social animals also have extra methods of defence: extra lookouts, alarm calls, mobbing of predators, defensive formations, etc.

Plants

- ✓ Plants must employ different defence mechanisms from animals since they are sessile
- ✓ Defence mechanisms include stings, thorns and spines and toxic chemicals
- ✓ Some plants are able to tolerate grazing by having low meristems, deep root systems or underground stems

Unit 3 – Control and Regulation

Growth and Development

Meristems

- ✓ Meristems are areas of plants where active cell division is taking place
- ✓ Plants have apical meristems, which are the growing areas at the tips of roots and shoots
- ✓ Plants also have lateral meristems, which are the areas of cell division which are responsible for secondary thickening
- ✓ Lateral meristems are made of a tissue called cambium
- ✓ Animals do not have meristems; growth tends to be spread over the whole organism

Formation of annual rings

- ✓ Annual rings in the trunks of trees are made of xylem vessels
- ✓ Xylem vessels are formed when newly formed cells in the cambium differentiate

Regeneration in angiosperms and animals

- ✓ Angiosperm is the fancy name for flowering plants
- ✓ Regeneration is the process by which an organism replaces lost or damaged parts
- ✓ Flowering plants (angiosperms) have extensive powers of regeneration
- ✓ Mammals have very limited powers of regeneration (such as wound healing, recovery of broken bones, and regrowth of damaged liver)

Growth patterns in plants and animals

- ✓ Growth is defined as an irreversible increase in the dry mass of an organism
- ✓ Growth is not uniform throughout the life of an organism
- ✓ A graph showing the changes in dry mass (or other measure of growth) against time is called growth curve
- ✓ The shape of growth curves differs according to the organism:
    - Annual plant; initial decrease during germination, increase due to photosynthesis then decrease due to ageing and seed dispersal
    - Perennial plant; series of annual cycles of fast spring growth, slower summer and little or no winter growth
    - Human; infant spurt and adolescent spurt with slower growth between and very little growth after age 20 or so
    - Locust; a series of sudden increases as old exoskeleton is cast off, with little growth between moults

Genetic Control

Jacob-Monod hypothesis

- ✓ Each gene in the nucleus of a cell codes for a protein
- ✓ Every cell in an organism contains every gene which that organism uses
- ✓ As cells specialise, many of the genes in the cell are not required and are "switched off"
- ✓ In the specific case of producing the enzyme which digests lactose in the bacterium *E. coli* we know how the mechanism works – thanks to Jacob and Monod
- ✓ The enzyme is called β-galactosidase, and it digests lactose to glucose and galactose
- ✓ The control of β-galactosidase production depends on a regulator gene, operator and a structural gene
- ✓ When lactose is absent:
    - The regulator gene produces a repressor protein
    - The repressor protein binds to the operator
    - This prevents the operator switching on the structural gene and the enzyme is not made
    - This prevents energy being wasted producing an enzyme when it is not needed
- ✓ When lactose is present:
    - The regulator gene produces a repressor protein
    - Lactose and the repressor protein join together to form a complex
    - The lactose-repressor complex cannot bind to the operator
    - The operator is free to switch on the structural gene and the enzyme β-galactosidase is made
    - The enzyme continues to be produced until it has digested all the lactose
    - When the lactose is all digested, the repressor returns to the operator which then switches off the structural gene stopping it from producing the enzyme until the next time that lactose is present
- ✓ A group of genes operating together in this way is called an operon

PKU

- ✓ PKU (phenylketonuria) is an inherited condition which resulted from a gene mutation many generations ago
- ✓ This prevents a whole series of metabolic reactions from taking place
- ✓ Normally the amino acid phenylalanine is converted to another amino acid, tyrosine by an enzyme. Tyrosine is then converted into various substances including the hormone thyroxine and the skin pigment melanin
- ✓ People with PKU can't make the enzyme which converts phenylalanine to tyrosine
- ✓ The phenylalanine from their diet builds up to high concentrations
- ✓ The phenylalanine is converted into a toxic substance instead, which affects brain function and severely limits mental development

Effect of Hormones on Growth and Development

Pituitary hormones

- ✓ Hormones are chemical messengers which are produced by endocrine glands in one part of the body and transported in the blood to a target organ where they have their effect
- ✓ The pituitary gland, which protrudes below the brain is one of the most important endocrine glands
- ✓ The pituitary gland produces many hormones; the two which control growth and development are growth hormone (GH) and thyroid stimulating hormone (TSH)
- ✓ Growth hormone is produced throughout childhood and controls growth
- ✓ GH encourages the uptake of glucose and amino acids by bone and muscle cells and therefore stimulates protein synthesis and cell division
- ✓ TSH stimulates the thyroid gland in the throat to produce the hormone thyroxine
- ✓ Thyroxine acts on the cytochrome system in mitochondria to control the rate ATP synthesis
- ✓ Thus, thyroxine controls the metabolic rate and therefore growth
- ✓ High blood thyroxine suppresses TSH secretion by the pituitary – an example of negative feedback that maintains a constant blood thyroxine concentration

Plant growth substances

- ✓ IAA is a plant growth hormone produced in meristems at tips of roots and shoots, and in terminal buds. IAA then diffuses to other parts of the plant
- ✓ The following are some of the effects of IAA
  - Causes cell elongation
  - Causes phototropism – growth of shoot towards light – by stimulating more growth on the shaded side
  - Increases cell division
  - Stimulates fruit formation
  - Reduced IAA concentration in leaf/fruit stems causes abscission – leaf or fruit fall
  - IAA from the terminal bud inhibits the growth of side branches – this is called apical dominance
- ✓ GA is another plant hormone
- ✓ GA ends dormancy in buds
- ✓ GA ends dormancy in seeds by diffusing into the aleurone layer and inducing the production of α-amylase. α-amylase then converts the store of starch in the seed into sugars, providing energy for germination
- ✓ Both IAA and GA are manufactured and used by man to control plants in various ways
  - IAA is used as a selective herbicide
  - IAA stimulates root production in cuttings
  - IAA can produce fruits by flowers which have not been fertilised
  - IAA can prevent fruit drop

Effect of Chemicals on Growth and Development

Plants

- ✓ Nitrogen is needed for making nucleic acids, amino acids, proteins and membranes; deficiency symptoms include chlorosis (yellowing) and greatly reduced growth
- ✓ Phosphorus is needed for making DNA, ATP, membranes; deficiency symptoms include reduced growth
- ✓ Potassium is important in membrane transport; deficiency symptoms include reduced growth
- ✓ Magnesium is an essential part of chlorophyll; deficiency symptoms include severe chlorosis and reduced growth

Humans

- ✓ Iron and calcium are important in the diet of animals
- ✓ Iron is a component of haemoglobin, many enzymes and hydrogen carrying systems
- ✓ Calcium is a component of shells, bones and teeth and is needed for blood clotting
- ✓ Lead is a powerful inhibitor of enzyme activity
- ✓ Deficiency in vitamin D leads to rickets as vitamin D is required for calcium absorption from the intestine
- ✓ Many drugs can have severe effects on foetal development
    - Thalidomide causes severe limb deformation
    - Nicotine retards growth and mental development and lowers average birth weight
    - Alcohol retards growth and mental development and lowers average birth weight

Effect of Light on Growth and Development

Plants

- ✓ Light helps stems to grow short and sturdy – stems growing in the dark become very long, thin and weak – a condition known as etiolation
- ✓ Plant stems grow towards light; this is because the lighted side grows slower than the shaded side of the stem. This is called phototropism
- ✓ The time of year for flowering is often controlled by the length of the day – photoperiod
- ✓ Plants which flower when the day length exceeds a critical value are called long day plants - long day plants flower in the late spring or early summer
- ✓ Plants which flower when the day length goes below a critical value are called short day plants - short day plants flower in the late summer, autumn or winter

Animals

- ✓ Light also affects the timing of the breeding season in many species of birds and mammals
- ✓ Shortening day length in autumn stimulates breeding behaviour in deer and sheep
- ✓ Lengthening day length in spring stimulates breeding behaviour in birds
- ✓ This ensures that the young are born in the spring when food is plentiful

Physiological Homeostasis

The need to maintain conditions within tolerable limits

- ✓ Homeostasis is the maintenance of a constant internal environment
- ✓ Negative feedback is the way in which homeostasis is achieved
- ✓ Negative feedback describes a process in which any deviation from the normal value switches on a mechanism to return the situation to normal
- ✓ This involves receptors constantly monitoring the level and sending out messages to effectors
- ✓ The messages are either nerve impulses or hormones
- ✓ The effectors then act to counteract the change from normal

Water content of the blood

- ✓ A decrease of blood water concentration:
    - Is detected by the hypothalamus which stimulates the release of more anti-diuretic hormone (ADH) by the pituitary
    - ADH travels in the blood to the kidney tubules and collecting duct
    - ADH increases the permeability of the tubules to water and so more is reabsorbed
    - A smaller volume of urine is produced
- ✓ ADH also makes us thirsty and drinking brings the blood water concentration back up to the norm
- ✓ An increase in the water concentration of the blood:
    - Is detected by the hypothalamus
    - The pituitary releases less ADH
    - The kidney tubules and collecting duct reabsorb less water
    - The kidney produces a larger volume of urine

Glucose

- ✓ Glucose can be rapidly converted into glycogen for storage and then back to glucose when required
- ✓ The liver acts as a reservoir or store of the carbohydrate glycogen
- ✓ The conversion of glucose to glycogen is stimulated by the hormone insulin
- ✓ The conversion of glycogen to glucose is stimulated by the hormone glucagon
- ✓ The pancreas monitors the blood glucose concentration
- ✓ When the blood glucose concentration falls:
    - The decrease is detected by the pancreas
    - The pancreas releases more glucagon (hint: glucose-has-gone) and less insulin
    - This stimulates the conversion of glycogen to glucose
    - Which increases the blood sugar concentration back to normal
- ✓ When the blood glucose concentration rises:
    - The increase is detected by the pancreas
    - The pancreas releases more insulin and less glucagon
    - This stimulates the liver to convert glucose to glycogen
    - Which decreases the blood sugar concentration back to normal
- ✓ In cases of stress or danger the body needs extra glucose in the blood to provide the extra energy required for the "fight or flight" response:
    - The adrenal glands release the hormone adrenaline
    - Adrenaline produces a higher than normal blood sugar concentrations by stimulating the rapid conversion of glycogen to glucose in the liver and muscles
    - Once the stress or danger is over, adrenaline release is reduced and the normal action of insulin returns the blood glucose concentration to normal

Temperature

- ✓ Temperature is monitored by the hypothalamus
- ✓ The skin is the major organ in regulating the temperature of the body
- ✓ If the blood temperature falls below normal, the hypothalamus sends out nervous impulses to the skin which trigger a variety of temperature increasing measures:
    - o Sweating does not occur
    - o Vasoconstriction – the arterioles become narrower (constricted) thus reducing the blood flow and the loss of heat to the surroundings
    - o Erection of hairs
    - o Shivering – generating metabolic heat
- ✓ If the blood temperature rises above normal, the hypothalamus sends our nervous impulses to the skin which trigger a variety of temperature decreasing measures:
    - o Sweat production increases
    - o Vasodilation – the arterioles taking blood to the surface of the skin become wider (dilated) thus increasing the blood flow and the loss of heat to the surroundings
    - o Hair erector muscles relax

Population Dynamics

Population fluctuations

- ✓ Established populations are relatively stable
- ✓ Numbers remain reasonably constant in the long term, despite short term rises and falls

Factors influencing population change

- ✓ Density independent factors affect populations in the same way whatever the population density
- ✓ Examples of density independent factors are temperature, forest fires, droughts or floods
- ✓ Density dependent factors have an increasing effect as populations become denser, and less effect on small numbers
- ✓ Examples of density dependent factors include disease, food supply, predation and competition
- ✓ Density dependent factors are the most important influence on maintaining the stability of populations

Monitoring populations

- ✓ There is a need for accurate monitoring of many wild populations
- ✓ Reasons to monitor wild populations include:
    - o To monitor species which are used by man for food or raw materials
    - o Monitoring populations of pest species (such as locusts, mosquitoes, virus epidemics, bacteria and plant diseases) allowing control measures to be targeted accurately and economically
    - o Indicator species are species which are particularly sensitive to particular aspects of the environment; monitoring populations of these allows us to find out about environmental conditions in a reliable and easy way
    - o Monitoring populations may allow for conservation action to be started promptly to protect endangered species

Succession

Succession and climax in plant communities

- ✓ Plant succession is the gradual change in the types of plants present in a particular area
- ✓ These changes are unidirectional and cause considerable habitat modification
- ✓ Succession may be the development of communities in a previously uncolonised habitat or may occur in previously colonised land which had been cleared (e.g. by forest fire or agriculture)
- ✓ Succession always begins with a pioneer community
- ✓ Examples of pioneers are lichens on bare rocks, marram grass on sand dunes and annual weeds on abandoned farming land
- ✓ Pioneer communities consist of very few species and very simple food chains
- ✓ Pioneer communities are often very productive but contain relatively little biomass
- ✓ Often pioneer communities are composed of plants adapted to survive extreme conditions with very few nutrients
- ✓ The plants present at each stage of the succession will change the environment, making it less suitable for themselves and allowing the next stage to take over
- ✓ Eventually a relatively stable community becomes established which does not change – called the climax community
- ✓ Climax communities consist of many species and complex food webs
- ✓ Climax communities usually contain most biomass, but are less productive than earlier stages in the succession
- ✓ High species diversity and complex food webs of a climax community give the best ecological stability and the ability to adapt to environmental fluctuations