IB Biology Revision Notes

Based on 2016 syllabus

Core & Option D

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Topic 1: Cells

1.1 Cell theory, cell specialization, and cell replacement

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U2	Organisms consisting of only one cell carry out all functions of life in that cell
U3	Surface area to volume ratio is important in the limitation of cell size.
U4	Multicellular organisms have properties that emerge from the interaction of their cellular components.
U5	Specialized tissues can develop by cell differentiation in multicellular organisms.
U6	Differentiation involves the expression of some genes and not others in a cell's genome.
U7	The capacity of stem cells to divide and differentiate along different pathways is necessary in embryonic development and also makes stem cells suitable for therapeutic uses.
A1	Questioning the cell theory using atypical examples, including striated muscle, giant algae and aseptate fungal hyphae.
A2	Investigation of functions of life in Paramecium and one named photosynthetic unicellular organism.
A3	Use of stem cells to treat Stargardt's disease and one other named condition.
A4	Ethics of the therapeutic use of stem cells from specially created embryos, from the umbilical cord blood of a new-born baby and from an adult's own tissues.
S1	Use of a light microscope to investigate the structure of cells and tissues, with drawing of cells. Calculation of the magnification of drawings and the actual size of structures and ultrastructures shown in drawings or micrographs. (Practical 1)

Cell Theory

- **Cells are the basic unit of structure in all living things (smallest unit of life)**

Specialized structures within cells (organelles) carry out different functions. Organelles cannot survive alone.

- **All living organisms are composed of cells.**
- **New cells are formed from pre-existing cells.**

Cells multiply through division

All life evolved from simpler ancestors

Mitosis results in genetically identical diploid daughter cells

Meiosis generates haploid gametes (sex cells)

Functions of life (Mrs.H.Gren)

- **M**etabolism: All the chemical reactions that occur within an organism
- **R**eproduction: Hereditary molecules that can be passed to offspring
- **S**ensitivity:
- **H**omeostasis: the maintenance and regulation of internal cell condition e.g. temperature
- **G**rowth: limited but always evident in one way or another
- **R**esponse: imperative for the survival of an organism
- **E**xcretion: Enable those chemical compounds that an organism cannot use or that may be toxic or harmful to it to be released from the organism's system
- **N**utrition: Providing a source of compounds with many chemical bonds that can then be broken down to provide an organism with the energy necessary to maintain life

Cells and sizes

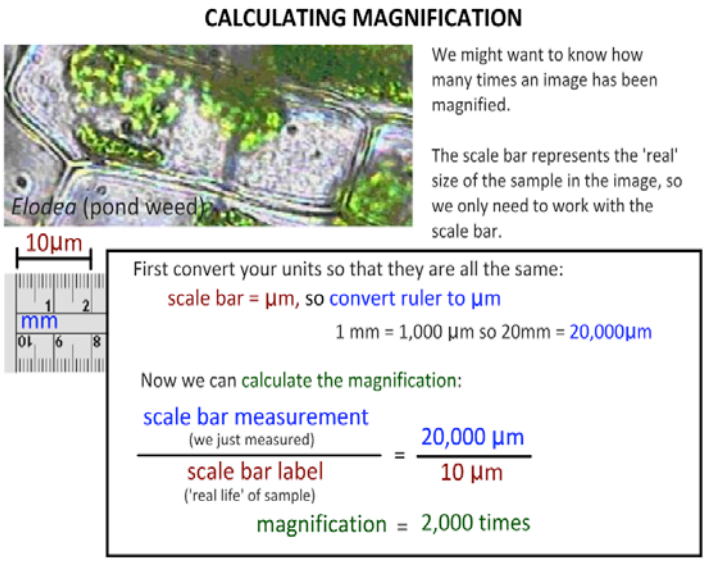
➢ Why are cells small?

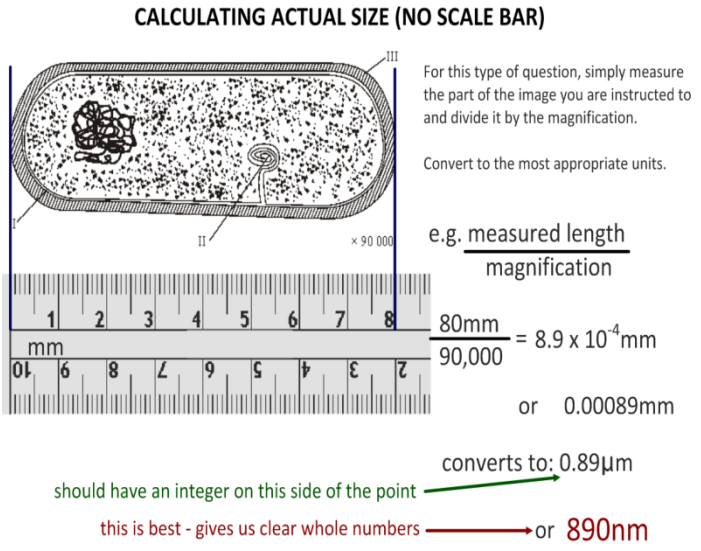
- ✓ Diffusion pathway is smaller when cell is smaller, takes less time and energy to move.
- ✓ Surface area to volume ratio is larger
- Larger **SA: VOL Ratio**, more efficient diffusion.
- (However, loses heat and water more quickly)

- Cells need to exchange substances with their surroundings, such as food, waste, heat, and gases.
- In the cytoplasm, chemical reactions take place which are known as metabolic reactions. These reactions produce heat, wastes, and also consume resources. The rate of these reactions is proportional to the **volume of the cell**, while the exchange of these materials and heat energy is a function of the cell's surface area.
- **A cell increases in size, its surface area to volume ratio (SA/V) will decrease.**
- As the SA to volume ratio decreases, the rate or the cell's ability to exchange materials through diffusion or radiation decreases.
- If metabolism is to continue at an optimum rate, substances such as oxygen must be absorbed and waste products such as carbon-dioxide need to be removed.
- Also if too much heat is produced during metabolism in comparison to the amount the cell is able to remove, the cell might overheat.

- **Therefore, the greater the SA/volume ratio is, the faster the cell can remove waste and heat, and absorb oxygen and nutrients essential for the cell to function properly.**
- **Exception:** small, warm-blooded mammals lose heat very quickly due to their large SA:Vol ratio e.g shrew; desert plants would lose water quickly with fat leaves, so they minimizetheir SA:Vol ratio in order to conserve more water e.g. cactus

Calculate magnification

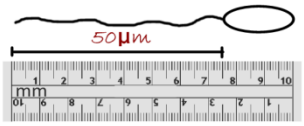




Example

2.A sperm cell has a tail 50µm long. A student draws it 75mm long. What is the magnification?

If you're stuck, draw it out...



1. Convert mm to µm:

75mm = 75,000um

2. drawing length / scale bar label

= 75000/50

= 1500x magnification

Stem cells

- Stem cells are characterized by the ability to divide through mitotic cell division and differentiate along different pathways to become a diverse range of specialized cell types.
- At early embryonic stages, the stem cells can still divide have ability to become any type of cell, until they express certain genes and differentiate into a specific type of cell.
- Two **main** types of stem cells are adult stem cells which are found in adult tissues such as the **bone marrow** and **embryonic stem cells** that are found in the inner cell mass of blastocysts.
- Another source of stem cells is from the umbilical **cord** of newly born fetuses (cord blood stem cells)
- Stem cells can be categorized into totipotent, pluripotent, multipotent and unipotent according to their ability to differentiate

The use of stem cells in some disease

- **Stargardt's Macular Dystrophy** – Is a genetic disease that develops in children that can cause blindness
- The disease affects a membrane protein in the **retina** causing the photoreceptor cells in the retina to become degenerative
- The treatment involves injecting embryonic stem cells that can develop into retina cells in to the back of the eyeball
- The cells attach to the retina and begin to grow, improving an individual's vision, with limited side effects

- **Leukemia** (same from above) – is caused by a mutation in the genes that control cell division, which will create an abnormal amount of white blood cells. These white blood cells are produced in the bone marrow
- One of the greatest therapeutic successes for the use of stem cells has been for the treatment of leukemia or lymphomas through bone marrow transplants.
- This involves using hematopoietic stem (HS) cells (blood stem cells) derived from bone marrow tissue.

- These cells will divide continually to form new red and white blood cells.
- Using a large needle, stem cells are removed from the bone marrow of the patient or from a donor person, such as a brother or a sister.
- The patient undergoes **chemotherapy and radiation therapy to kill the cancer cells** in the bone marrow. However, normal dividing cells in the blood will also be killed.
- After chemotherapy and radiation therapy the HS cells will be transplanted directly in to the bloodstream through a tube called a central venous catheter.
- The stem cells find their way into the bone marrow, where they will begin reproducing and making healthy new blood cells.

Ethical concern of using stem cells

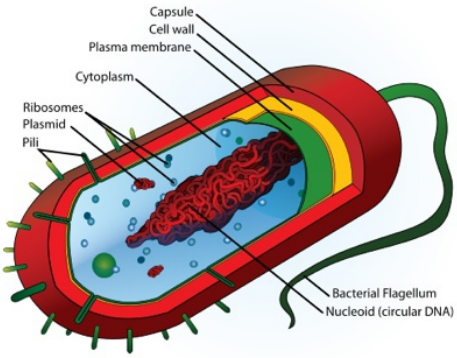
- The therapeutic use of stem cells involves the creation and the death of an embryo that that has not yet differentiated in order to supply embryonic stem cell lines for stem cell research and stem cell therapies.
- The biggest ethical concern involves the creation of a new human embryo. Is it ethically acceptable to create a human embryo for biomedical research even if the research and therapies developed from the research could save human lives? Different people have a views of when human life begins.

1.2 Ultrastructure of cells

U1	Prokaryotes have a simple cell structure without compartmentalization.
U2	Eukaryotes have a compartmentalized cell structure.
U3	Electron microscopes have a much higher resolution than light microscopes.
A1	Structure and function of organelles within exocrine gland cellsof the pancreas and within palisade mesophyll cells of the leaf.
A2	Prokaryotes divide by binary fission.
S1	Drawing of the ultrastructure of prokaryotic cells based on electron micrographs.
S2	Drawing of the ultrastructure of eukaryotic cells based on electron micrographs.
S3	Interpretation of electron micrographs to identify organelles and deduce the function of specialized cells

Prokaryotic cell structure

- All prokaryotes have a cell membrane and a cell wall surrounding the outside membrane. The cell wall is made from peptidoglycan. The entire interior of the cell is filled with cytoplasm (not compartmentalized) as no membrane-bound nucleus is present. (**bacteria cells**)
- The cell wall
- The plasma membrane
- Flagella
- Pili
- Ribosomes
- The nucleoid (a region containing free DNA)



The cell wall and plasma membrane

✓ The prokaryotic cell wall protects and maintains the shape of the cell

✓ To large extent the plasma membrane controls the movement of materials into and out of the cell, and it plays a role in binary fission of the prokaryotic cell. All cellular processes within prokaryotic cells occur within the cytoplasm.

✓ Cell wall is made from peptidoglycan not from celluose

Pili and flagella

✓ Hair-like growths on the outside of the cell wall; Used for attachment, joining bacteria cells in preparation for the transfer of DNA (sexual reproduction)

*Ribosomes**(70s)***

✓ Occur in all prokaryotic cells (granular appearance in an electron micrograph of prokaryotic cell)

✓ Sites of protein synthesis

The nucleoid region

✓ Non-compartmentalized

✓ Contains a single, long, continuous, circular thread of DNA, the bacterial chromosome

✓ Involves cell control and reproduction

Binary fission

✓ Replicated semi-conservatively

✓ Two DNA loops attached to membrane

✓ Form two separate cells

✓ Genetically identical

Summary

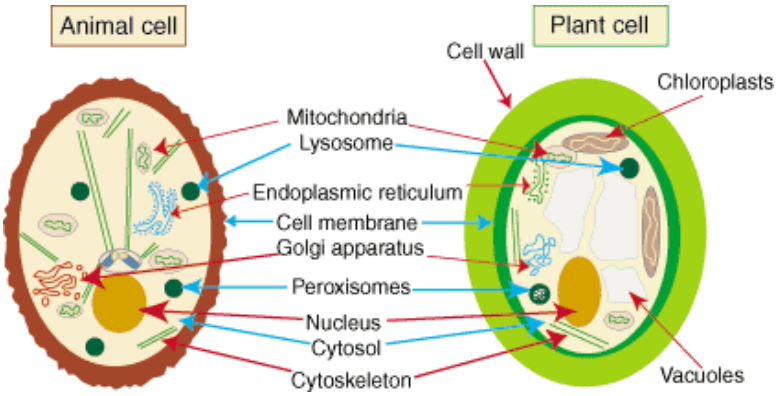
- DNA is not enclosed within a membrane and forms one circular chromosome
- DNA is free; not attached to proteins
- Lack membrane-bound organelles
- Cell wall is made up of peptidoglycan
- Divide by binary fission
- Characteristically mall in size

Eukaryotic cell structure

Eukaryotes have a much more complicated cellular structure. The inside of the cell also contains cytoplasm but it is separated by compartments that allow for specialization. The compartments are membrane bond organelles such as the nucleus and the mitochondria. Compartmentalization enables different chemical reactions to be separated and chemicals to be isolated (increase efficiency.)

Organelles of eukaryotic cells

- Rough/ Smooth Endoplasmic reticulum
- Ribosomes
- Lysosomes
- Golgi apparatus
- Mitochondria
- Nucleus
- Chloroplasts
- Vacuoles

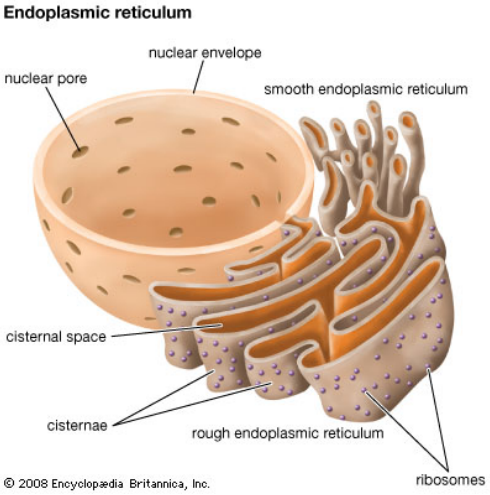


Cytoplasm

- Occurs inside the plasma membrane or the outer boundary of the cell, where organelles are found
- The fluid portion of the cytoplasm around the organelles is called the cytosol

Endoplasmic reticulum

- Extends from the nucleus to the plasma membrane
- Transports materials throughout the internal region of the cell
- Smooth ER (no ribosomes on its exterior) and Rough ER (with ribosomes on its exterior)
  - Rough endoplasmic reticulum
- Consist flattened membrane sacs, called **cisternae**
- Contains ribosome for secreted protein (transportation)

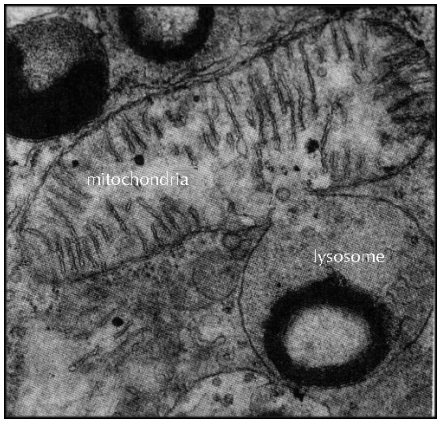


*Ribosomes(**80s**)*

- Composed of RNA and protein
- Proteins Synthesis

Lysomsomes

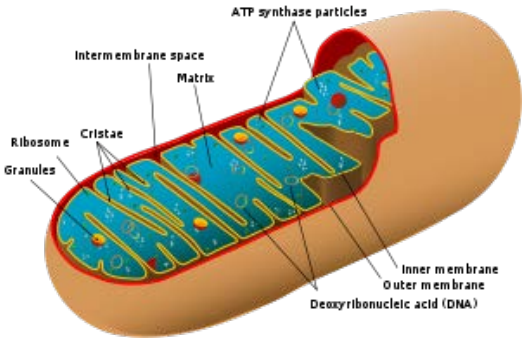
- Spherical with a single membrane
- Formed from Golgi Vesicles
- Contain digestive enzymes for breakdown of
  1. Ingested food in vesicles
  2. Damaged/unwanted organelles
  3. The cell itself
- Stain heavily – appear dark on micrographs



Golgi apparatus

- Flattened membrane sacs, called cisternae
- No attached ribosmes
- Sited close to the plasma membrane
- Shorter and more curved cisternae
- Processes proteins from the rER. The proteins are then repackaged in vesicles for secretion outside the cell.

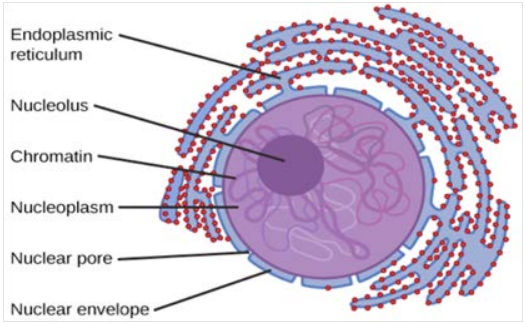
Mitochondria



- Double membrane
- Smooth outside, folded inside
- Folds----**cristae**
- Variable in shape
- Site of ATP production by aerobic respiration

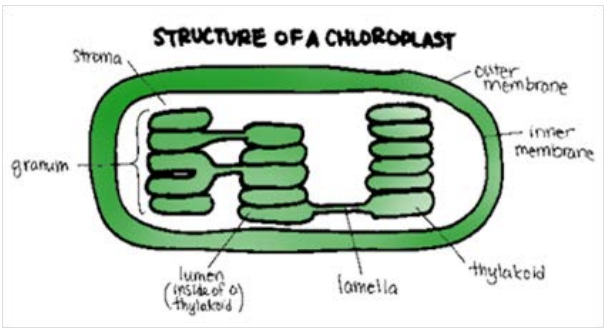
Endosymbiotic theory: mitochondria and chloroplast, long before, are individual bacteria who decide to join larger eukaryotic cells

Nucleus



- Generally spherical with a double membrane
- Pores (holes) are present in the membrane
- Contains genetic information in the form of chromosomes (DNA and associated histone proteins)
- Uncoiled chromosomes are referred to as chromatin – they stain a dark colour and are concentrated at the edges of the nucleus
- mRNA is transcribed in the nucleus (prior to use in protein synthesis in the cytoplasm)
- mRNA leaves the nucleus via the pores (DNA is too large to move through the pores)

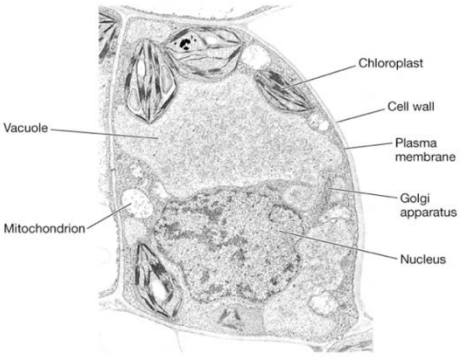
*Chloroplasts**(plants only)***



- **Many, but not all, plant cells** contain chloroplasts
- A double membrane surrounds the chloroplast
- Inside are stacks of thylakoids
- Each thylakoid is a disc composed of a flattened membrane
- The shape of chloroplasts is variable but is usually ovoid
- The site of photosynthesis and hence where glucose is produced.
- Starch grains maybe present if photosynthesis is happening quickly

*Cell wall**(plants only)***

- An extracellular component not an organelle.
- Secreted by **all plant cells** (fungi and some protists also secrete cell walls).
- Plant cell walls consist mainly of **cellulose** which is:
    1. Permeable - does not affect transport in and out of the cell
    2. Strong – gives support to the cell and prevent the plasma membrane bursting when under pressure
    3. Hard to digest –resistant to being broken down, therefore lasts a long time without the need for replacement/maintenance



Vacuoles

- Single membrane with fluid inside
- In Plant cells vacuoles are large and permanent, often occupying the majority of the cell volume
- In animal cells vacuoles are smaller, temporary, and used for various reasons.
  e.g. to absorb food and digest it

A comparison of prokaryotic and eukaryotic cells

Prokaryotic	Eukaryotic
DNA in a ring without protein	DNA with proteins as chromosomes
DNA free in the cytoplasm	DNA enclosed within nucleus
No mitochondria	Mitochondria present
70s ribosomes	80s ribosomes
No internal compartmentalization	internal compartmentalization present to form many organelles
Size less than 10μm	Size mo re than 10μm

A comparison of plant and animal cells and their extracellular components

Plant	Animal
The exterior of the cell only includes a cell wall with a plasma membrane inside	The exterior of the cell only includes a plasma membrane; no cell wall
Chloroplasts present	No chloroplasts
Vacuoles present	No vacuoles
70s ribosomes	80s ribosomes
No internal compartmentalization	internal compartmentalization present to form many organelles
Size less than 10μm	Size more than 10μm

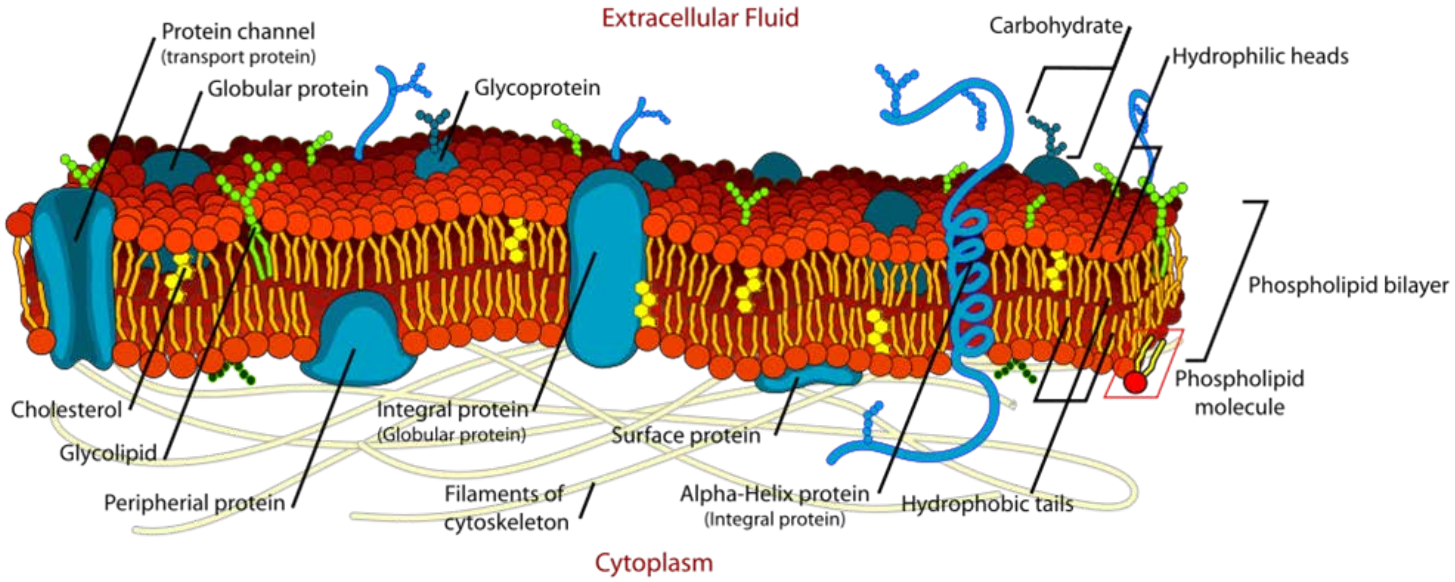
Electron microscope

- The limit of resolution is the minimum distance that can be observed before two objects merge together to form one object. The smaller the limit of resolution the higher the resolving power.
- Electron microscopes have a greater resolution (about .001 μm) when compared to a light microscope (about 0.2 μm)
- The resolution of light microscopes is limited by the wavelength of light (400-700 nm). If the magnification becomes too great the image becomes blurry
- Electrons have a much shorter wavelength so they have much greater resolution (about 200x greater than a light microscope)

1.3 Membrane structure

U1	Phospholipids form bilayers in water due to the amphipathic properties of phospholipid molecules.
U2	Membrane proteins are diverse in terms of structure, position in the membrane and function. Cholesterol is
U3	a component of animal cell membranes.
A1	Cholesterol in mammalian membranes reduces membrane fluidity and permeability to some solutes.
S1	Drawing of the fluid mosaic model.
S2	Analysis of evidence from electron microscopy that led to the proposal of the Davson-Danielli model.
S3	Analysis of the falsification of the Davson-Danielli model that led to the Singer-Nicolson model.

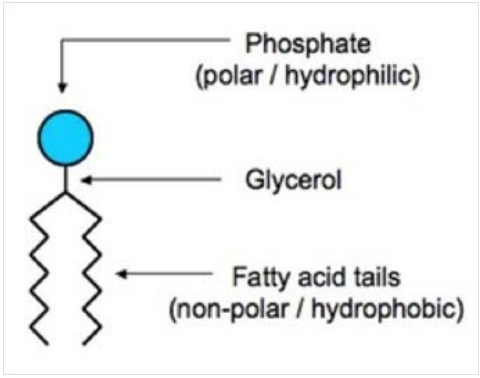
Membrane Structure



Properties of cell membrane

- Cell membranes are composed of phospholipids that consist of a **hydrophilic** (attracted to water) head and a **hydrophobic** (repelled by water) tail
- The phospholipid head contains a negatively charged phosphate group which because of its charge is attracted water because of its polarity
- The fatty acid hydrocarbon tail has no charge and is therefore repelled by water
- When placed in water, the phospholipids naturally form a double layer with the heads facing outwards towards the water and the tails facing each other inwards (micelle or liposome)
- This forms a very stable structure that surrounds the cell because of the attractions and bonds that are formed between the heads to the water and to each other, and the hydrophobic interactions between the tails
- Even though it is a very stable structure, it is still **fluid**, as the phospholipids can move along the horizontal plane
- To increase stability, many cells have **cholesterol** embedded between the phospholipids

Phospholipids



- A bilayer produced from huge numbers of molecules
- Composed of a three-carbon compound called glycerol
- Two of the **glycerol** carbons have fatty acids
- The third carbon is attached to a highly polar organic alcohol that includes a bond to a phosphate group

Cholesterol

- Allow membrane to function effectively at a wider range of temperatures
- **Plant cells do not have cholesterol molecules**
- Cholesterol is a lipid that belongs in the steroid group and is also a component of the cell membrane
- Most of the cholesterol molecule is hydrophobic and therefore embeds within the tails of the bilayer. A small portion (hydroxyl –OH group) is hydrophilic and is attracted to the phospholipid head
- Cholesterol embedded in the membrane will reduce the fluidity making the membrane more stable by the hydrophilic interactions with the phospholipid heads
- While cholesterol adds firmness and integrity to the plasma membrane and prevents it from becoming overly fluid, it also helps maintain its fluidity by disrupting the regular packing of the hydrocarbon tails.
- Therefore, cholesterol helps prevent extremes-- whether too fluid, or too firm-- in the consistency of the cell membrane

Proteins

- Embedded in the fluid matrix of the phospholipids bilayer

Integral protein	Permanently embedded, go all the way through,
Peripheral protein	Temporary association, bounded to the surface of the membrane
Glycoprotein	Protein attached with a sugar chain

Membrane protein functions

- ✓ Transport: Protein channels (facilitated) and protein pumps (active)
- ✓ Receptors: Peptide-based hormones (insulin, glucagon, etc.) binding------relay the message
- ✓ Anchorage: permanent or temporary junctions
- ✓ Cell recognition: MHC proteins and antigens
- ✓ Intercellular (between cells) joinings: Tight junctions, an identification label
- ✓ Enzymatic activity: Metabolic pathways (e.g. electron transport chain)

1.4 Membrane transport

U1	Particles move across membranes by simple diffusion, facilitated diffusion, osmosis and active transport.
U2	The fluidity of membranes allows materials to be taken into cells by endocytosis or released by exocytosis. Vesicles move materials within cells.
A1	Structure and function of sodium–potassium pumps for active transport and potassium channels for facilitated diffusion in axons.
A2	Tissues or organs to be used in medical procedures must be bathed in a solution with the same osmolarity as the cytoplasm to prevent osmosis.
S1	Estimation of osmolarity in tissues by bathing samples in hypotonic and hypertonic solutions.

Passive and active transport

- Passive transport (no energy required) -- Movement occurs along a concentration gradient
- Active transport (energy required) -- The substance is moved against a concentration gradient

Passive transport: diffusion and osmosis

➢ **Diffusion** is the passive net movement of particles from a region of high concentration to a region of low concentration. All living things need to take in nutrients to live and to get rid of waste

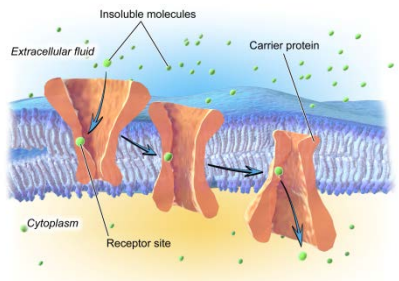
- Take in to the cells: Oxygen, Nutrients (food), Water etc.
- Remove from the cells:Carbon dioxide, Urea etc.

➢ **Facilitated Diffusion (passive)** - Specific ions and other particles that cannot move through the phospholipid bilayer sometimes move across protein channels.

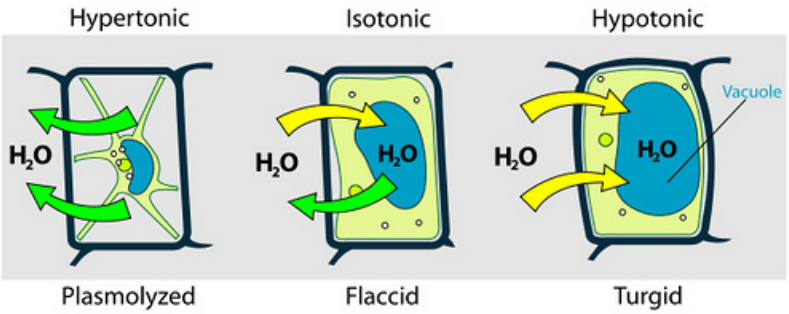
- A particular type of diffusion involving a membrane with specific carrier proteins that is capable of combining with the substance to aid its movement.
- Molecules cannot pass the membrane due to its size or charge
- Each protein channel structure allows only one specific molecule to pass through the channel. For example, magnesium ions pass through a channel protein specific to magnesium ions.

➢ **Example of facilitated diffusion: Osmosis**: The movement of water molecules from an area of high **water potential** to an area of low **water potential** through a **partially permeable membrane**.

- **Hypertonic solution** – Is a solution with a higher osmolarity (higher solute concentration) then the other solution. If cells are placed into a hypertonic solution, water will **leave the cell** causing the cytoplasm's volume to **shrink** and thereby forming indentations in the cell membrane, leading to weak structure. The cell in this case is **plasmolysed**
- **Hypotonic solution** – Is a solution with a lower osmolarity (lower solute concentration) then the other solution. If cells are placed in a hypotonic solution, the **water will rush into** the cell causing them to **swell** and possibly burst, leading to strong structure. The cell in this case is **turgid**.
- Both of the above solutions would damage cells, therefore isotonic solutions are used (same osmolarity as inside the cell)
- **Isotonic solution**: A solution that has the same salt concentration as cells and blood. The cell in this case is **flaccid**.

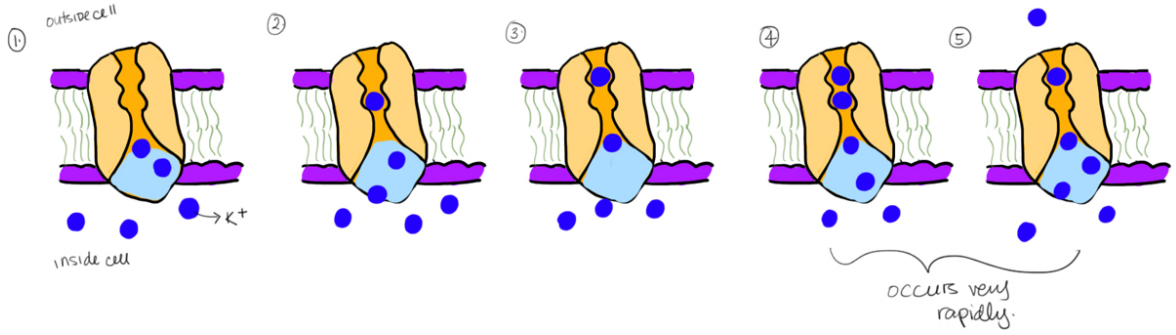


Facilitated Diffusion



- In **medical procedures**, isotonic solutions are commonly used as: eye drops; packing donating organs, fluid introduction to blood system

Potassium channels



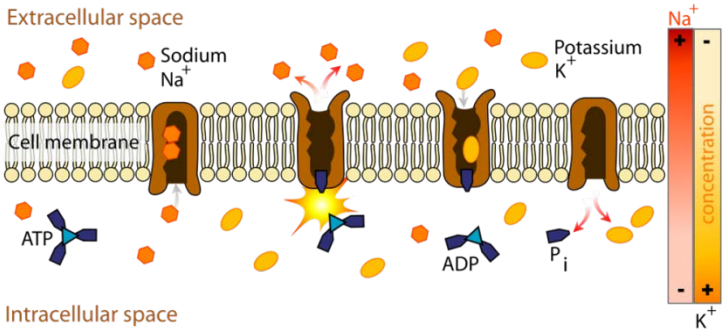
Potassium channel is an example of facilitated diffusion. They are voltaged gated, which means it uses voltage to control the open and close of the gate. If there is more positive charges inside the cell, voltage will change and lead to the open of the gate; then, potassium ions will rush out until the charge is neutral.

Type of passive transport	Description of membrane
Simple diffusion	passive net movementof particles from a region of high concentration to a region of low concentration
Facilitated diffusion	Specific ions and other particles that cannot move through the phospholipid bilayer sometimes move across protein channels
Osmosis	Only water moves through the membrane using aquaporins, which are proteins with specialized channels for water movement

Active transport

- **Active transport** is movement of molecules through a cell membrane from a region of low concentration to a region of high concentration against the concentration gradient using ATP (energy)
- Many different protein pumps are used for active transport. Each pump only transports a particular substance; therefore cells can control what is absorbed and what is expelled.
- Pumps work in a specific direction; substances enter only on one side and exit through the other side.
- Substances enter the pump from the side with a lower concentration.
- Energy from ATP is used to change the conformational shape of the pump.
- The specific particle is released on the side with a higher concentration and the pump returns to its original shape.

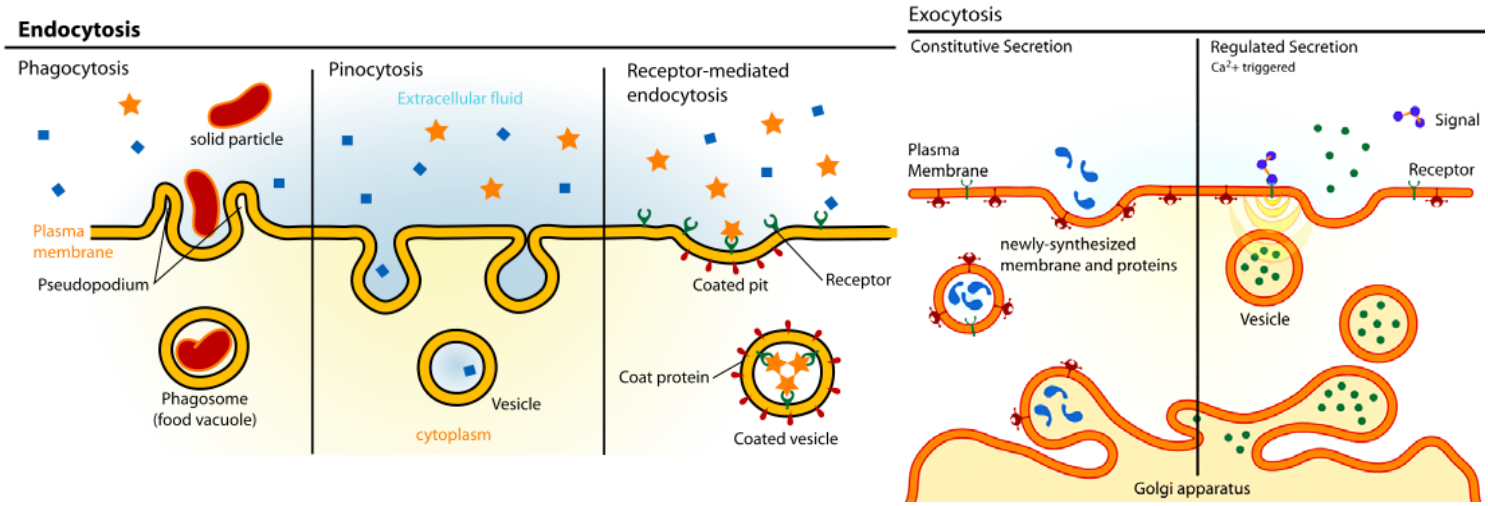
The sodium-potassium pump



- **The sodium–potassium pump** follows a repeating cycle of steps that result in three sodium ions being pumped out of the **axon (of neurons)** and two potassium ions being pumped in. Each time the pump goes round this cycle it uses one ATP.

Endocytosis and exocytosis

- They are all thanks to the fluidity of the plasma membrane
- **Endocytosis**: The taking in of external substances by an inward pouching of the plasma membrane, forming a vesicle
- Plasma membrane is pinched as a result of the membrane changing shape.
- External material (i.e. Fluid droplets) are engulfed and enclosed by the membrane.
- A vesicle is formed that contains the enclosed particles or fluid droplets, now moves into the cytoplasm.
- The plasma membrane easily reattaches at the ends that were pinched because of the fluidity of the membrane.
- Vesicles that move through the cytoplasm are broken down and dissolve into the cytoplasm.
- Endocytosis is future categorized into **phagocytosis** (solid excretion); **pinocytosis** (liquid excretion); **receptor-mediated endocytosis** (using receptors)
- **Exocytosis**: The release of substances from a cell (secretion) when a vesicle joins with the cell plasma membrane.
- After a vesicle created by the rough ER enters the Golgi apparatus, it is again modified, and another vesicle is budded from the end of the Golgi apparatus, which moves towards the cell membrane.
- This vesicle migrates to the plasma membrane and fuses with the membrane, releasing the protein outside the cell through a process called exocytosis.
- The fluidity of the hydrophilic and hydrophobic properties of the phospholipids and the fluidity of the membrane allows the phospholipids from the vesicle to combine to the plasma membrane to form a new membrane that includes the phospholipids from the vesicle.
- Exocytosis can happen continuously (**constitutive secretion** e.g. saliva) or response to a signal (**regulated secretion** e.g. insulin)



1.5 The origin of cells

U1	Cells can only be formed by division of pre-existing cells.
U2	The first cells must have arisen from non-living material.
U3	The origin of eukaryotic cells can be explained by the endosymbiotic theory.
A1	Evidence from Pasteur's experiments that spontaneous generation of cells and organisms does not now occur on Earth.

Cell division

- Prokaryotic cells are formed during a process called **binary fission**.
- Eukaryotic cells form new identical cells by the process called **mitosis** (genetically identical) and form sex cells through **meiosis** (haploid cells which not genetically identical to the parent cell and contain half the genetic material).
- All cells are formed by the division of pre-existing cells.

Origin of the cell

- If we go back to how the very first living cells were created, we have to conclude they either originated from non-living material, came from somewhere else in the universe or were created by some other unknown entity

Endosymbotic theory

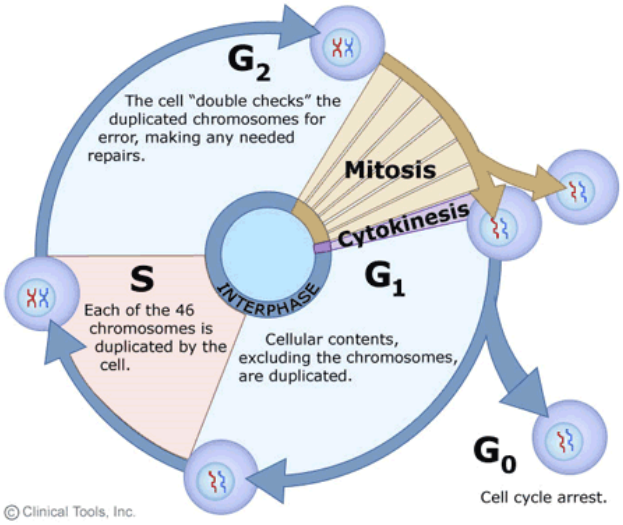
- There is compelling evidence that **mitochondria and chloroplasts** were once primitive free-living bacterial cells.
- Symbiosis occurs when two different species benefit from living and working together. When one organism actually lives inside the other it's called endosymbiosis.
- The endosymbiotic theory describes how a large host cell and the bacteria ingested through endocytosis, could easily become dependent on one another for survival, resulting in a permanent relationship.
- As long as the smaller mitochondria living inside the cytoplasm of the larger cell divided at the same rate, they could persist indefinitely inside those cells
- The smaller cell was provided food and protection by the larger cell and the smaller mitochondria would supply energy through aerobic respiration for the larger cell
- Over millions of years of evolution, mitochondria and chloroplasts have become more specialized and today they cannot live outside the cell.

1.6 Cell division

U1	Mitosis is division of the nucleus into two genetically identical daughter nuclei.
U2	Chromosomes condense by supercoiling during mitosis.
U3	Cytokinesis occurs after mitosis and is different in plant and animal cells.
U4	Interphase is a very active phase of the cell cycle with many processes occurring in the nucleus and cytoplasm.
U5	Cyclins are involved in the control of the cell cycle.
U6	Mutagens, oncogenes and metastasis are involved in the development of primary and secondary tumours.
A1	The correlation between smoking and incidence of cancers.
S1	Identification of phases of mitosis in cells viewed with a microscope or in a micrograph.
S2	Determination of a mitotic index from a micrograph.

Cell cycle

- **G1 phase**: increase cytoplasm volume, organelle production and protein synthesis (normal growth)
- **S phase**: DNA replication
- **G2 phase**: increase cytoplasm volume, double the amount of organelle and protein synthesis (prepare for cell division)
- **M phase**: Mitosis
- **Interphase**: consists of the parts of the cell cycle that don't involve cell division (G1,S and G2 phase)
- **G0 phase**: resting phase where the cell leaves the cell cycle and has stopped dividing. Cell carries out all normal functions without the need of dividing. e.g. brain cell



Prophase:

- **DNA supercoil**: chromatin condenses and becomes sister chromatids, which are visible under the light microscope.
- **Nuclear membrane** is broken down and disappeared.
- **Centrosomes** move to the opposite poles of the cell and **spindle fibers** begin to form.

Metaphase:

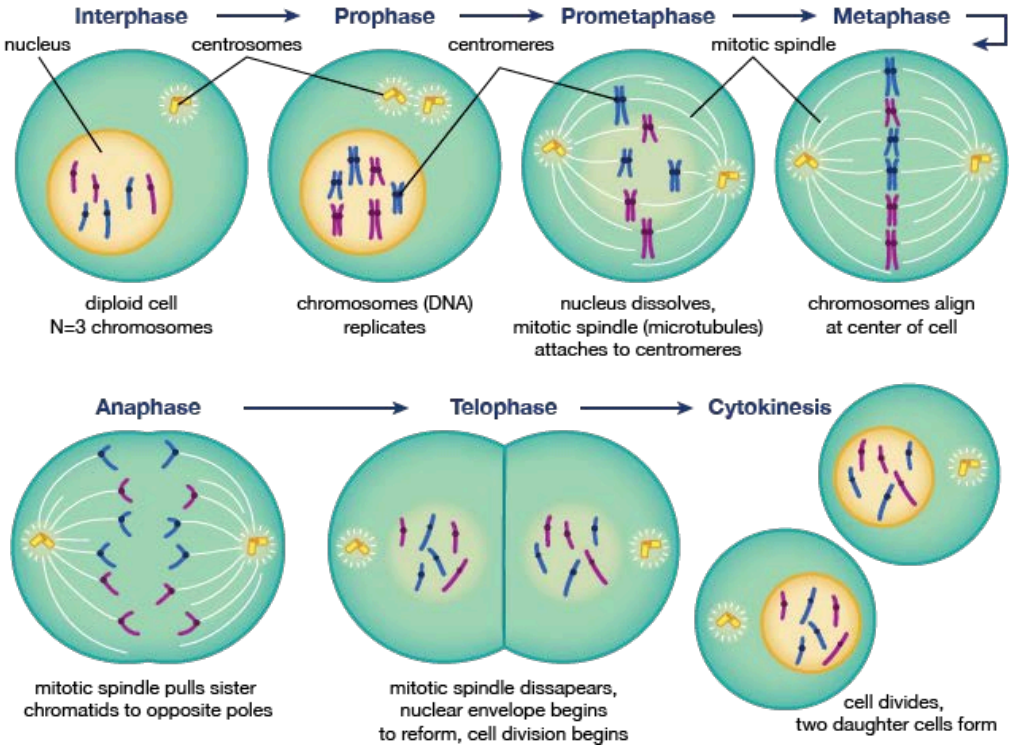
- Spindle fibers (**microtubules**) from each of the centrosomes attach to the centromere of sister chromatids.
- Chromatids line up in the equator.

Anaphase:

- Contraction of the spindle fibers cause the separation of the sister chromatids.
- The chromatids are now considered as chromosomes.
- Chromosomes move to opposite poles of the cell.

Telophase:

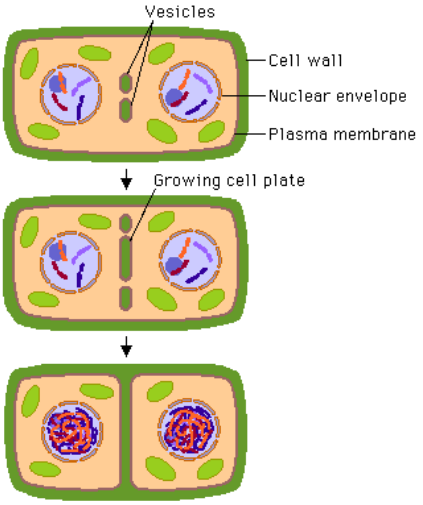
- Chromosomes uncoil to become chromatin.
- Spindle fibers break down and new nuclear membrane reform at opposite pole.



Cytokinesis in animal cells:

- a cleavage furrow forms when the plasma membrane is pulled inwards around the equator by the contractile proteins actin and myosin
- Once the invagination reaches the centre the membrane pinches off and to new cells are formed

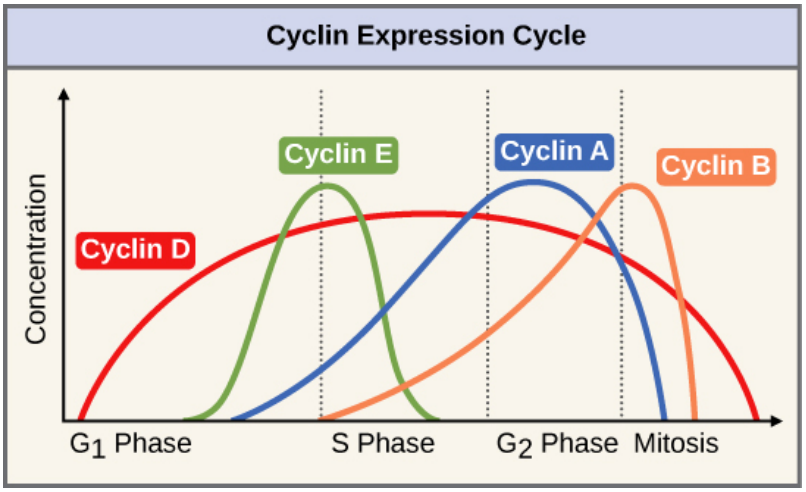
Cytokinesis in plant cells:



- In plant cells tubular structures are formed by vesicles along the equator of the cell
- This continues until two layers of membrane exist across the equator, which develop into the plasma membrane of the two new cells
- Vesicles bring pectin and other substances and deposit these between the two membranes through exocytosis forming the **cell plate**
- Cellulose is then brought and deposited by exocytosis between the membranes as well, forming the new cell walls

Cyclins:

- Cyclins are a family of proteins that control the **progression** of cells through the cell cycle.
- It is used to mark the checkpoints between two stages
- Cells cannot progress to the next stage of the cell cycle unless the specific cyclin reaches its threshold
- Cyclin binds to enzyme called cyclin-dependent kinases
- This enzyme then trigger the signal to move on to the next stage.



Mutagens and oncogenes:

- Tumors (cancer) are the result of **uncontrolled cell division**, which can occur in any organ or tissue.
- These abnormal growths can either be localized (**primary tumours**), meaning they do not move to other part of your body. These tumours are benign.
- If the cancer cells detach and move elsewhere into the body (**secondary tumours**), they are called malignant and are more life-threatening
- Diseases due to malignant tumours are known as cancer
- **Metastasis** is the movement from a primary tumour to set up secondary tumours in other parts of the body
- Cancer is usually caused by genetic abnormalities due to a variety of different sources called carcinogens or due to inheritance or errors in DNA replication.
- Carcinogens are agents that can cause cancer, such as viruses, X-Rays, UV Radiation and many chemical agents
- **Mutagens are agents that can cause mutations** in one's DNA which can lead to cancer
- In cancer two types of genes are usually affected, **oncogenes** and **tumor suppressor genes**.
- Oncogenes are genes that control cell cycle and cell division.
- Tumor suppressor genes usually control replication and the cell cycle. In cancer cells these genes are generally inactivated causing a loss of normal function.

Topic 2: Molecular Biology

2.1 Molecules to metabolism

U1	Molecular biology explains living processes in terms of the chemicalsubstances involved.
U2	Carbon atoms can form four covalent bonds allowing a diversity of stablecompounds to exist.
U3	Life is based on carbon compounds including carbohydrates, lipids, proteinsand nucleic acids.
U4	Metabolism is the web of all the enzyme-catalysed reactions in a cell ororganism.
U5	Anabolism is the synthesis of complex molecules from simpler moleculesincluding the formation of macromolecules from monomers by condensationreactions.
U6	Catabolism is the breakdown of complex molecules into simpler moleculesincluding the hydrolysis of macromolecules into monomers.
A1	Urea as an example of a compound that is produced by livingorganisms but can also be artificially synthesized.
S1	Drawing molecular diagrams of glucose, ribose, a saturated fatty acidand a generalized amino acid.
S2	Identification of biochemicals such as sugars, lipids or amino acids frommolecular diagrams.

Molecular biology is the chemistry of living organisms

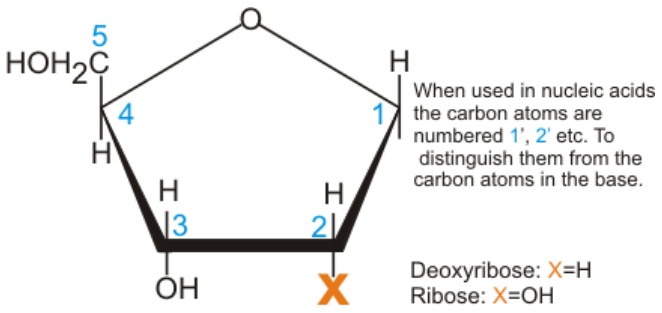
- "DNA makes RNA makes protein".
- The information in this flow cannot be reversed and the protein generated cannot change the RNA or DNA
- There are many molecules important to living organisms including water, carbohydrates, lipids, proteins and nucleic acids
- Proteins are one of the most varied macromolecules, performing many cellular functions, including catalyzing metabolic reactions (enzymes).

Carbon-based life

- Covalent bonds are the **strongest** type of bond between atoms. **Stable** molecules can be formed.
- Carbon atoms contain **four electrons** in their outer shell allowing them to form four covalent bonds with potential four other different atoms.
- Carbon has a few unique bonding properties - the most important of which is its ability to form long chains of carbon. No other element can bond like carbon does.
- Since carbon-carbon bonds are strong and stable, carbon can form an almost infinite number of compounds
- Covalent Bonds are chemical bonds formed by the sharing of a pair of electrons between atoms. The nuclei of two different atoms are attracting the same electrons.
- Carbon compounds including **carbohydrates, lipids, proteins and nucleic acids**.

Carbohydrates

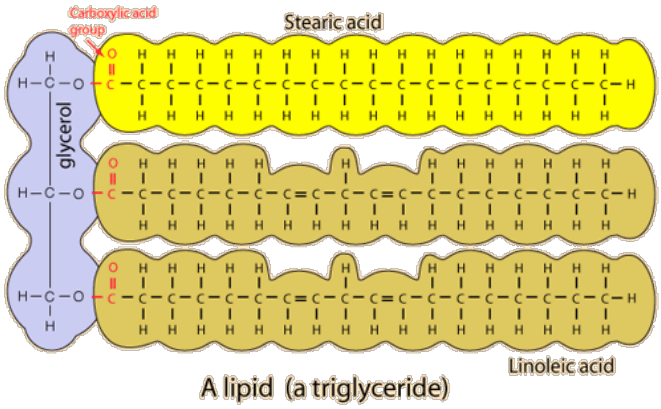
- Contain **carbon, hydrogen and oxygen**
- Organic compounds consisting of **one or more simple sugars**
- Monomers follow the general basic formula of $\mathbf{(CH_2O)_n}$
- Monomers are commonly **ring shaped** molecules
- Many carbohydrates are used for energy or structural purposes
- Carbohydrates contain starch, glycogen and cellulose



Deoxyribose & Ribose Sugars

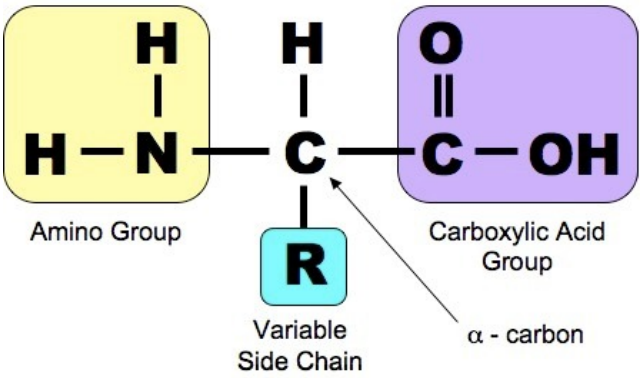
Lipids

- Lipids are a **group of organic molecules** that are **insoluble** in **water** but **soluble** in **non-polar** organic solvents
- Common lipids include triglycerides (fats – solid at room temperature and oils – liquid at room temperature), phospholipids and steroids
- Some lipids function in long-term energy storage. Animal fat is a lipid that has six times more energy per gram than carbohydrates.
- Some examples of lipids are triglycerides, steroids, waxes and phospholipids
- Animal fats (saturated) are solid at room temperature and plant fats (unsaturated) are liquid at room temperature
- Is made by **glycerol + fatty acid**



Protein

- Contain **carbon, hydrogen, oxygen and nitrogen**
- Proteins are **large organic compounds** made of **amino acids** arranged into one or more linear chains
- Proteins are distinguished by their "R" groups. Some of these also contain sulphur



Nucleic acid

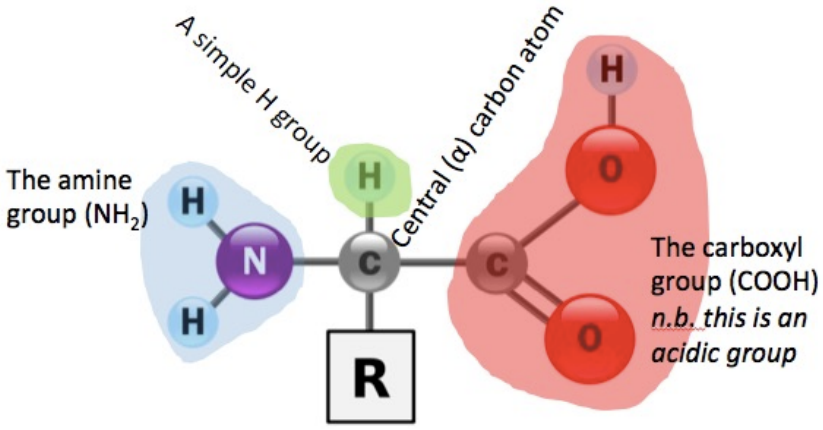
- Contain **carbon, hydrogen, oxygen, nitrogen and phosphorus**
- Chains of sub-units called **nucleotides**
- Nucleotides consist of **base, sugar and phosphate groups** covalently bonded together
- The bases of DNA are **A**denine, **T**hymine, **C**ytosine, and **G**uanine; In RNA, **U**racil substitutes for Thymine
- If the sugar is **ribose** then the nucleic acid formed is **RNA** if the sugar is **deoxyribose** then **DNA** is formed

Category	Subcomponents	Containing elements
Carbohydrates	Monosaccharaides	Hydrogen, carbon, oxygen
Lipids	Glycerol, fatty acids, phosphate groups	Hydrogen, carbon, oxygen
Proteins(polypeptides)	Amino acids	Hydrogen, carbon, oxygen, nitrogen, other elements in R group (sulphur, selenium, etc.)
Nucleic acid	nucleotides	Hydrogen, carbon, hydrogen, oxygen, nitrogen, phosphorus

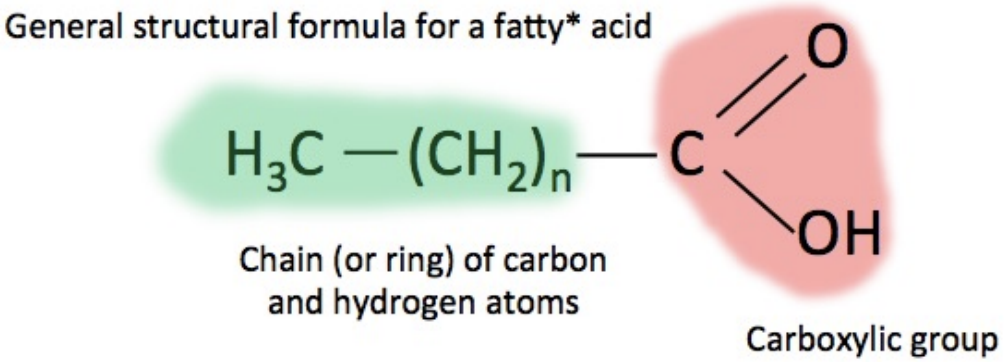
Identification of biochemical

- The generalized formula for carbohydrates is CH_2O. All carbohydrate contain C, H and O
- Proteins also contain C,H, O but they all have N. Some proteins also contain S in their R-groups
- Lipids contain C, H and O as well, but in different ratios and much less O then carbohydrates.

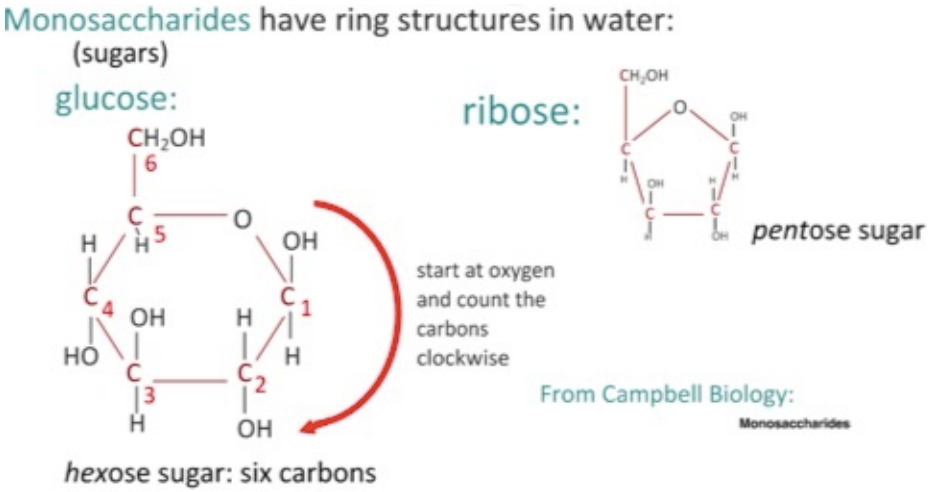
- **Amino acids**



- **Fatty acid**



- **Glucose**



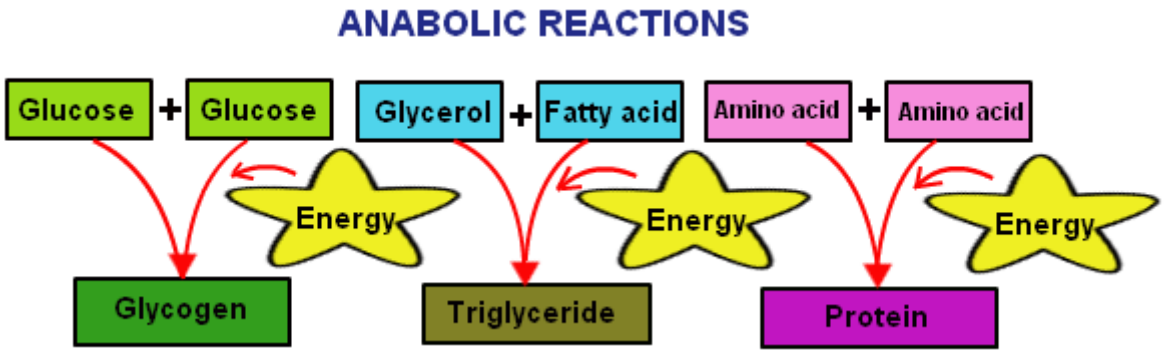
Metabolism

- Metabolism is the set of life-sustaining chemical reactions within the cells of living organisms.
- These reactions are catalyzed by enzymes and allow organisms to grow and reproduce, maintain their structures, and respond to their environments.
- Many of these reactions occur in the cytoplasm, but some are extracellular including digestion and the transport of substances into and between different cells
- The word metabolism can refer to the sum of all chemical reactions that occur in living organisms

- Anabolic reactions **require energy** as you are **building large molecules** from small ones (takes energy to build things)
- Some anabolic processes are protein synthesis, DNA synthesis and replication, photosynthesis, and building complex carbohydrates, such as cellulose, starch and glycogen

Definition of anabolism

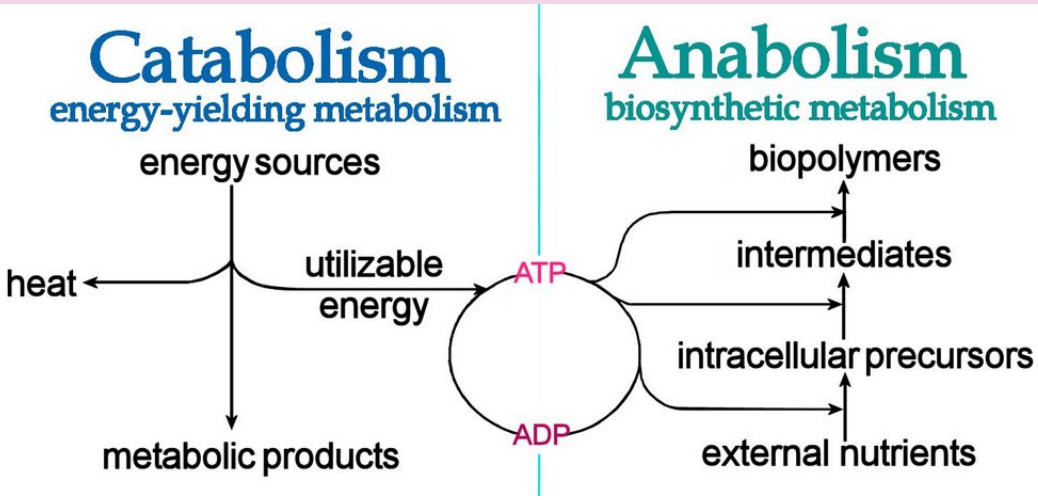
Anabolism is the synthesis of complex molecules from simpler molecules including the formation of macromolecules from monomers by condensation reactions.



- Catabolism are reactions that **break down larger molecules** into smaller ones or their component parts
- Catabolic reactions **release energy** (sometimes captured in the form of ATP)
- Some examples of catabolic reactions are digestion of food, cellular respiration, and break down of carbon compounds by decomposers

Definition of catabolism

Catabolism is the breakdown of complex molecules into simpler molecules including the hydrolysis of macromolecules into monomers.



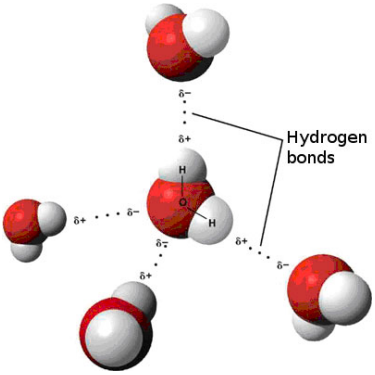
- **Condensation** makes bond, release water, take in heat, as an anabolism reaction, which is **endothermic**
- **Hydrolysis** breaks bond, give out heat, as a catabolism reaction, which is **exothermic**

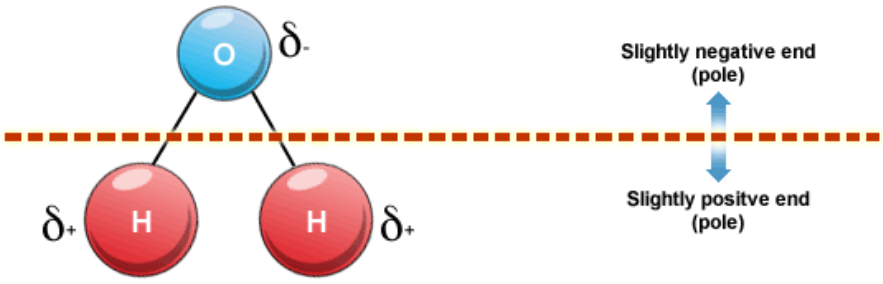
2.2 Water

U1	Water molecules are polar and hydrogen bonds form between them.
U2	Hydrogen bonding and dipolarity explain the cohesive, adhesive, thermaland solvent properties of water.
U3	Substances can be hydrophilic or hydrophobic.
A1	Comparison of the thermal properties of water with those ofmethane.
A2	Use of water as a coolant in sweat.
A3	Modes of transport of glucose, amino acids, cholesterol, fats,oxygen and sodium chloride in blood in relation to their solubility in water.

The structure of water molecules

- A water molecule consists of an oxygen atom covalently bound to two hydrogen atoms
- Since O is more electronegative than H, an unequal sharing of electrons occurs
- This creates a **polar covalent bond**, with H having a partial positive charge and O having a partial negative charge
- Water is also bent so the positive charge exists more or less on one side and the negative charge from the O exists on the opposite side
- The partial +ve charge is attracted to the partial –ve charge creating an intermolecular attraction between the water molecules called a **"Hydrogen bond."**
- H-bonds are the strongest of the intermolecular bonding, but is still considered a weak bond; however since there are so many H_2O molecules they give water its unique properties and make it essential to life on this planet
- The covalent bonds between the oxygen atom and the two hydrogen atoms of a single water molecule are categorized as polar bonds





Cohesive properties

- Water is a polar molecule, with a negative oxygen end and a positive hydrogen end.
- **Hydrogen bonds** that exist between water molecules create a high level of attraction linking water molecules together. This attraction between two of the same molecules is called cohesion.
- These cohesive forces allow water to move up **vascular tissue** in plants against gravity. It also creates surface tension on water that allows **some organisms to walk on water**.

Definition of cohesion

Cohesion is when molecules of the same type are attracted to each other.

Adhesive properties

- Not only does water bind strongly to itself, it also forms **H-bonds with other polar molecules**. This is called adhesion.
- This is an important property in transpiration as well, as water adheres to the **cellulose in the walls of the xylem vessels**
- As water is evaporated from the stomata, the adhesion can help the water move up through the xylem

Definition of adhesion

Any attraction between two unlike molecules is called adhesion.

Thermal properties

- Water has a **high specific heat capacity** (amount of energy needed to raise temperature of a substance by a certain temperature level). Basically, water can absorb a lot of heat and give off a lot of heat without drastically changing the temperature of water.
- Water's high specific heat capacity results from the extensive hydrogen bonding between the water molecules.
- Water also has a high latent heat of vaporization which means it takes a lot of heat to evaporate water from a liquid to a vapor. This is very important as a **cooling mechanism** for humans. As we sweat, the water droplets absorb heat from our skin causing the water to evaporate and our bodies to cool down.
- Water has thermal properties, one of which is high specific heat. This means water can absorb or give off a great deal of heat without changing temperature very much.

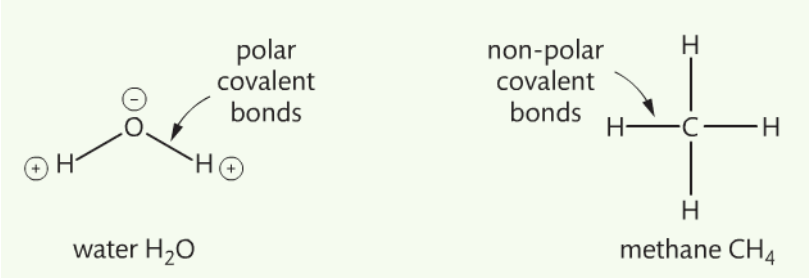
Solvent properties

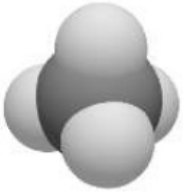
- Water is known as the "universal solvent" because of its ability to dissolve many substances because of its polarity.
- Water is able to dissolve other **polar molecules** such as many carbohydrates, proteins and DNA; and positively and negatively charged ions such as Na^+.
- This is essential because it allows water to act as a **transport medium** (blood and cytoplasm) of important molecules in biological organisms.
- Water is also the medium in which most of the biochemistry of a cell occurs. A cell contains a wide variety of fluids, all of which most of the biochemistry.

Hydrophilic & hydrophobic

- Essentially hydrophilic means "water loving"
- Any substances that dissolves in water including charged ions such as Na^+ or polar molecules such as glucose and fructose are hydrophilic. Molecules that are attracted to water like phospholipid heads are also hydrophilic
- Hydrophobic molecules are kind of "water fearing" but basically, these are non-polar, insoluble in water or non-charged substances, such as lipids
- Molecules such as water, that are polar substances are said to be **hydrophilic**, or water-loving
- Molecules that are classified as non-polar are said to be **hydrophobic**, or water-fearing

Comparison of the thermal properties of water with those of methane



	Methane	Water
		
Formula	CH_4	H_2O
Molecular mass	16	18
Bonding	Single covalent	
Polarity	nonpolar	polar
Density (g cm^{-3})	0.46	1
Specific Heat Capacity (J g^{-1} $^oc^{-1}$)	2.2	4.2
Latent heat of vapourisation (J g^{-1})	760	2257
Melting point (^oC)	-182	0
Boiling point (^oC)	-160	100

Methane
- waste product of anaerobic respiration in certain prokaryotes living in anaerobic conditions
- Methane can be used as a fuel
- If present in the atmosphere it contributes to the greenhouse effect.

Key chemical property that causes the major differences seen in the physical properties.

Methanogenic prokaryotes
- can be found in swamps, wetlands, the guts of animals (including cattle and sheep)
- can also be found in waste dumps

Polarity of different molecules

Substance	High or low relative solubility in water	Mode of transport in an aqueous environment (no specific mode means the substance dissolves directly and easily into water)
Glucose	Polar molecule/high solubility	No specific mode of transport needed/dissolves directly in **aqueous plasma**
Amino acids	Varying polarity but all are reasonably soluble	No specific mode of transport needed/dissolves directly in **aqueous plasma**
Cholesterol	Largely non-polar/very low solubility	Transported by blood proteins that have polar amino acids on the outer portion to give water solubility, and non-polar amino acids internally to bind the non-polar fatty acid molecules (cipoprotein)
Fats	Non-polar/low solubility	Transported by blood proteins that have polar amino acids on the outer portion to give water solubility, and non-polar amino acids internally to bind the non-polar fatty acid molecules (cipoprotein)
Oxygen	Travel as diatomic O2/low solubility	Relatively low solubility in water is exacerbated by the relatively high T of warm-blooded animals
Sodium chloride	Ionizes/high solubility	No specific mode of transport needed/sodium chloride is an ionic compound, it ionizes into separately charged Na+ and Cl- ions in **aqueous plasma**

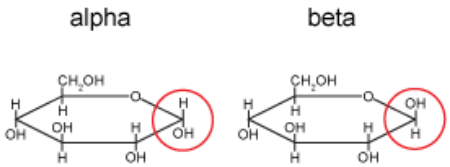
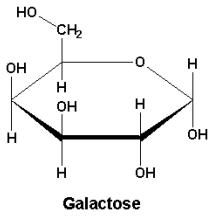
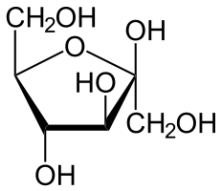
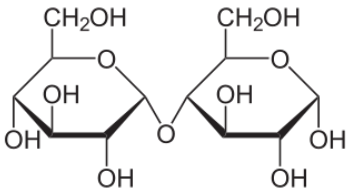
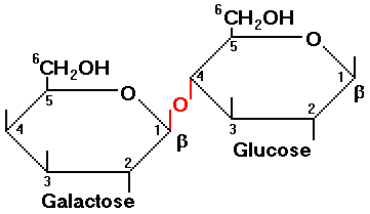
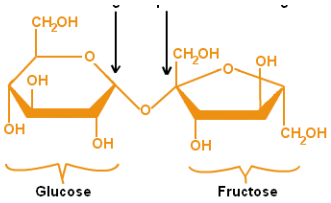
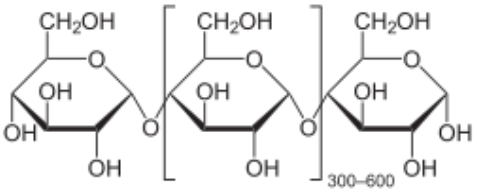
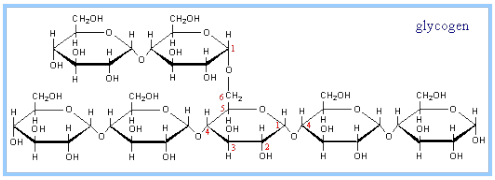
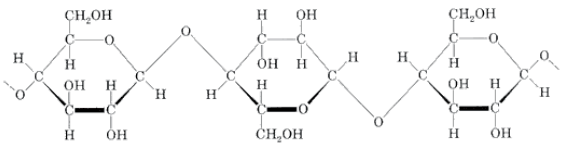
Water used as a coolant

- Water is essential to living organisms.
- Water has a high latent heat of vaporization which means it takes a lot of heat to evaporate water from a liquid to a vapor.
- This is very important as a cooling mechanism for living organisms. As humans sweat, the water droplets absorb heat from the blood flowing under our skin causing the water to evaporate and our blood to cool down. This will in turn cool our whole body down.
- This cooling is controlled by negative feedback through receptors in the hypothalamus
- If the body is overheated, receptors in the hypothalamus sense this and stimulate the sweat glands to secrete sweat
- Some reptiles such as crocodiles cool by opening their mouths (gaping).

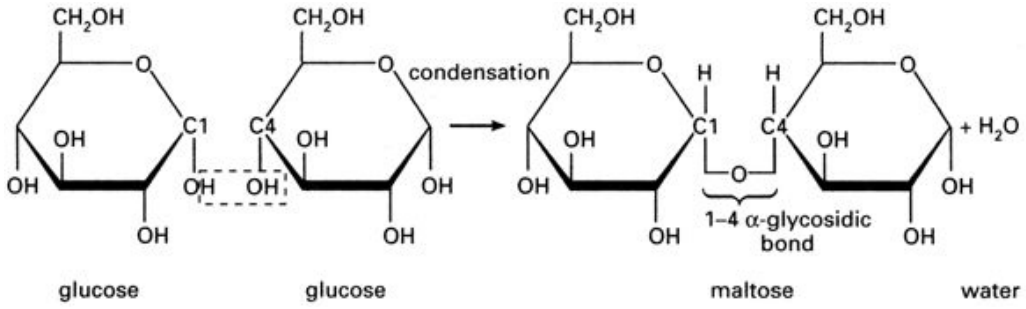
2.3 Carbohydrates and lipids

U1	Monosaccharide monomers are linked together by condensation reactions to form disaccharides and polysaccharide polymers. Fatty acids
U2	can be saturated, monounsaturated or polyunsaturated.
U3	Unsaturated fatty acids can be cis or trans isomers.
U4	Triglycerides are formed by condensation from three fatty acids and one glycerol.
A1	Structure and function of cellulose and starch in plants and glycogen in humans.
A2	Scientific evidence for health risks of trans fats and saturated fatty acids.
A3	Lipids are more suitable for long-term energy storage in humans than carbohydrates.
A4	Evaluation of evidence and the methods used to obtain the evidence for health claims made about lipids.
S1	Use of molecular visualization software to compare cellulose, starch and glycogen.
S2	Determination of body mass index by calculation or use of a nomogram.

Monosaccharide: the building blocks of polysaccharides

Type	Name	Formation	Sturcture	Functions
Monosaccharides	Glucose	N/A		Energy molecules used in cell respiration
	Galactose	N/A		Nutritive sweetener in foods, less sweet than glucose
	Fructose	N/A		Fruit sugar
Disaccharides	Maltose	Glucose+ Glucose		Malt sugar found in barley, consists of 2 glucose molecules
	Lactose	Glucose+ Galactose		Sugar found in milk
	Susrose	Glucose+ Fructose		Transport sugar found in plants because of its solubility, known as the table sugar
Polysaccharides	Starch	Linking alpha glucose together		Storage carbohydrate in plants
	Glycogen	Linking alpha glucose together		Storage carbohydrate in animals
	Cellulose	Linking beta glucose together		Main component in plant cell walls, used for structure

- When two monomers combine together they form a dimer. When many monomers combine together they form a polymer.
- Condensation Reactions: The building of large macromolecules (polymers) by the removal of water molecules when monomers combine. Each time two monomers combine, one water is removed.
- For example: Glucose is a monosaccharide that is used to build up large storage molecules (polysaccharides) in plants and animals. In plants, many glucose molecules combine through condensation reactions to form the polysaccharide starch. In animals, glucose molecules are combined to form the polysaccharide glycogen through condensation reactions.
- Bonds between two sugar are called **glucosidic bond**

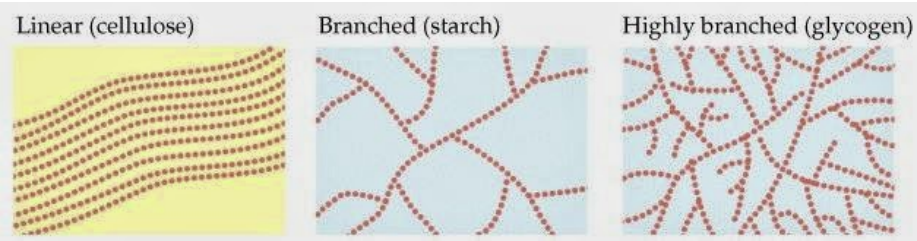


- When a plant or an animal needs to use energy stored in polysaccharide molecules, the opposite reaction to condensation takes place. This break down of larger polysaccharides into smaller monosaccharides through the addition of water is called hydrolysis (water split or separate).
- Starch and glycogen are broken down by the addition of water into glucose molecules (the energy molecule used in aerobic respiration).
- Remember: **anabolism is endothermic and catabolism is exothermic**

Structure of cellulose, starch and glycogen

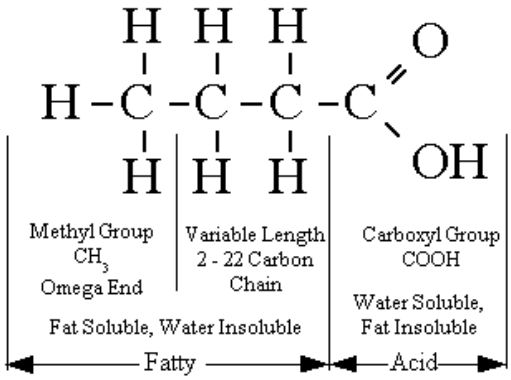
- Polysaccharides are long chains of monosaccharides held together with glycosidic linkages made by condensation reactions
- Starch, cellulose and glycogen are all polysaccharides that are made from long chains of glucose; however, they differ in their structure and the type of glucose, which leads to different functions
- Starch consists of two types of molecules, **amylose which helix and amylopectin which is branched**
- Since the bonds in starch are **α-glucose**, the –OH groups from the glucose molecules are always pointed down, causing **starch to have a curved appearance**. This makes starch a good molecule for storing glucose in plants.
- Even though glucose is hydrophilic, starch is too large to be soluble in water at room temperature
- Cellulose are unbranched straight chains of **β (beta) glucose molecules**, held together with glycosidic bonds
- Since the –OH groups point out in opposite directions and every other β glucose is flipped 180 degrees, **cellulose forms a nice straight chain**
- These straight chains also allow cellulose to form bundles linked by H-bonds
- This is essential for cellulose's function, which is to provide strength for cell walls in plant cells (high tensile strength)
- Notice the up and down alternating glycosidic bonds between the glucose molecules
- Glycogen – Is a multi-branched energy storage polysaccharide for animals
- Glycogen consists of many **α (alpha) glucose** molecules linked by glycosidic bonds
- It is **highly branched**, making the molecule more compact and a perfect molecule for energy storage
- It is **stored in the liver and some muscles of humans**

Substance	Monomer	Function	Structure
Starch	Alpha glucose	Plants energy storage	Amylose: helix structure Amylopectin: branched
Cellulose	Beta glucose (can't digest)	Cell membrane and cell structure	Straight chain
Glycogen	Alpha glucose	Animal short-term energy storage	branched



Fatty acid

- Main component of **triglycerides(lipids) and phospholipids**
- Fatty acids are non-polar and therefore hydrophobic
- Chains consist of covalently bonded carbon with hydrogen
- Saturated FA's are **all single bonds** and are therefore saturated with hydrogen.
- Unsaturated FA's contain a **double bond or double bonds**.



Saturated fatty acid

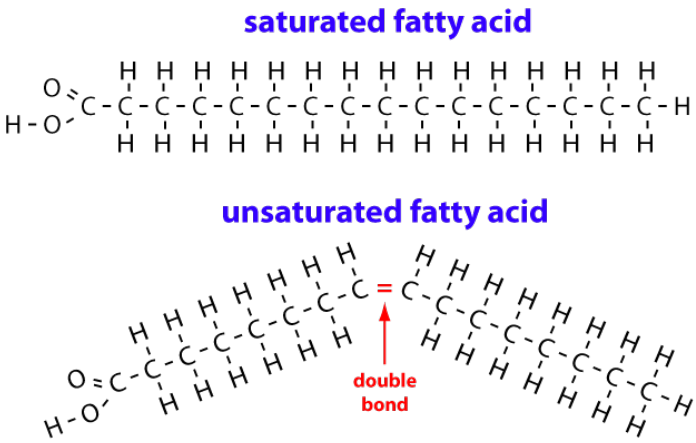
- Saturated fatty acid are called that because the carbons are carrying as many hydrogen atoms as they can, in other words they are saturated with hydrogen atoms.
- Found in animals products like butter, bacon and red meat
- Solid at room T
- No double bonds between the carbon atoms

Monounsaturated fatty acid

- If one double bond exists in the chain of hydrocarbons, the fatty acid is not saturated. This is monounsaturated.

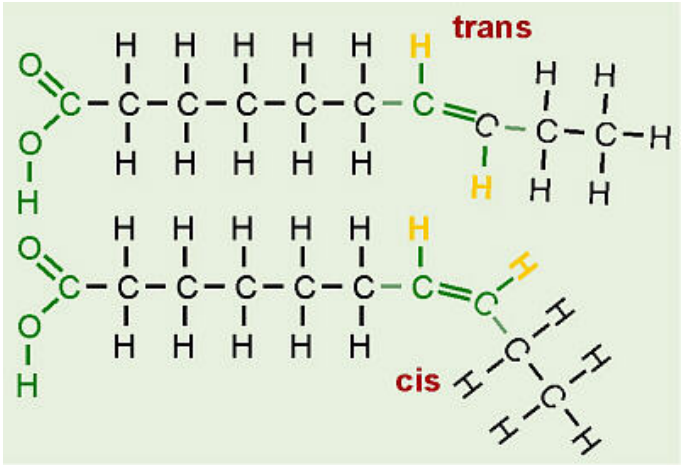
Polyunsaturated fatty acids

- Have at least two double bonds in the carbon chain
- Come from plants (e.g. olive oil)



Hydrogenation: cis and trans fatty acids

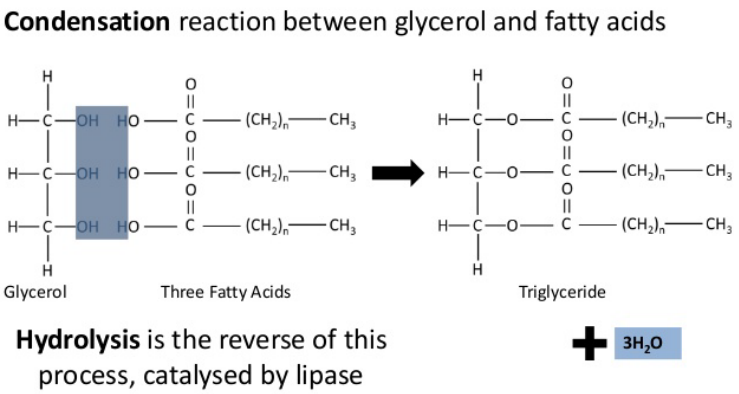
- If the **hydrogen atoms are on the same side of the double bond** then the isomer is "cis" and if the hydrogens are on opposite side of the double bond then the isomer is "trans"
- "cis" fatty acids have a **bent** at the double bonds, causing the fatty acids to pack more loosely, lowering the melting point and making them liquid at room temperature
- "trans" fatty acids do not have the **bent** at the double bond, can pack more tightly, have a higher melting point and are solid at room temperature.
- Trans fats are partial hydrogenated oils found in some **processed foods** like margarine. They can cause health risks for humans.



Properties	Cis Fatty acids	Trans Fatty acids
Health implications	Good	Detrimental; lowers good cholesterol and increases the level of bad cholesterol in the body.
Natural occurrence	Yes	Very less, hence produced artificially by partial hydrogenation of polyunsaturated fatty acids.
Orientation at double bonded carbon atoms	Hydrogen atoms at double bonded carbon atoms on same side	Hydrogen atoms at double bonded carbon atoms on opposite side
Recommended consumption	Can consume as per requirment	No more than 1% of total calories per day
Commonly found in	Natural fatty acids	Processed food, fast foods, butter and milky products.
Melting point	Lower	Higher

Condensation reactions result in the formation of triglyceride lipids

- Fatty acids have a long hydrocarbon (carbon and hydrogen) chain with a carboxyl (acid) group. The chains usually contain 16 to 18 carbons.
- Glycerol contains 3 carbons and 3 hydroxyl groups. It reacts with **3 fatty acids** to form a triglyceride or fat molecule through a condensation reaction, which gives off 3 water molecules and forms and **ester bond**



Energy storage

- One's body requires energy to function, more specifically each cell relies on a source of energy to drive the chemical reactions involved in metabolism, growth and other physiological functions
- **Both carbohydrates and lipids (triglycerides) are a major source of energy in animals.**
- Fats contain about twice as much energy as carbohydrates. Each gram of carbohydrates stores about 4 calories of energy, whereas each gram of lipid stores about 9 calories.

- Therefore, lipids serve as a more compact way to store energy, since it contains more energy per gram than carbohydrates. As a result, your body tends to use fat to store energy over long periods of time and uses carbohydrates to store energy short-term.
- Glycogen can be quickly into glucose for energy.
- Triglycerides (fats) contain a glycerol and 3 fatty acids and is stored mainly in the body's adipose tissue
- Fats also provide thermal insulation, protection for organs (shock absorber) and hormones
- Lipids are stored in the **adipose cells**

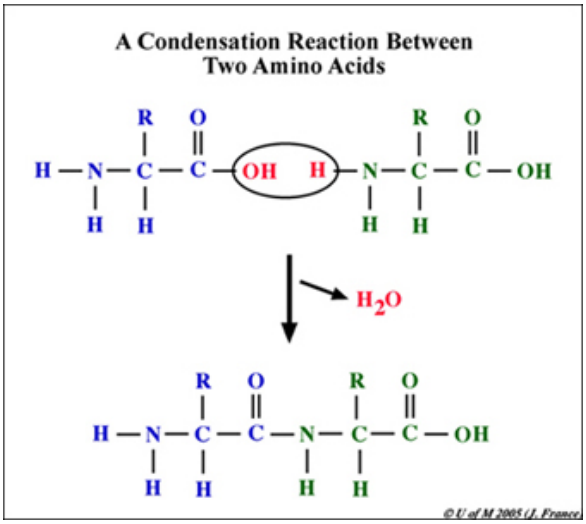
Glycogen	Lipids
Storage in liver	Storage in adipose cell
Can be transport by blood	Cannot be transported by blood
Easy to break down	More difficult to break down
Used in both anaerobic and aerobic respiration	Used only in aerobic respiration
Store less energy	Store 2 times more energy
High energy to mass ratio	One sixth of energy to mass ratio
Short-term storage	Long-term storage

2.4 Proteins

U1	Amino acids are linked together by condensation to form polypeptides.
U2	There are 20 different amino acids in polypeptides synthesized on ribosomes.
U3	Amino acids can be linked together in any sequence giving a huge range of possible polypeptides.
U4	The amino acid sequence of polypeptides is coded for by genes.
U5	A protein may consist of a single polypeptide or more than one polypeptide linked together.
U6	The amino acid sequence determines the three-dimensional conformation of a protein.
U7	Living organisms synthesize many different proteins with a wide range off unctions.
U8	Every individual has a unique proteome.
A1	Rubisco, insulin, immunoglobulins, rhodopsin, collagen andspider silk as examples of the range of protein functions.
A2	Denaturation of proteins by heat or by deviation of pH from the optimum.
S1	Drawing molecular diagrams to show the formation of a peptide bond.

Formation of polypeptides

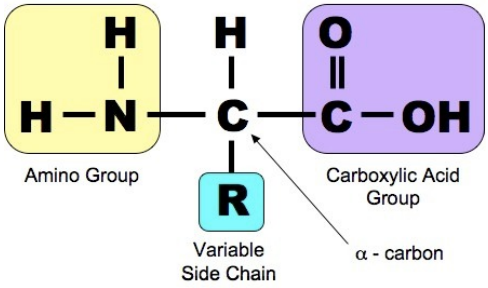
- Cells use the naturally occurring **20** amino acids to synthesize polypeptides.
- When polypeptides are **synthesized at ribosomes** under the control of genes, the reaction is a **condensation reaction**



- As there are 20 amino acids, there is a large choice for the sequence of the amino acids as well as total number of amino acids to use within a polypeptide.
- Each polypeptide has **own amino acid sequence, own three-dimensional shape**
- Polypeptides can contain up to 30,000 amino acids (e.g. Titin) the different possible combinations of polypeptides are effectively infinite.

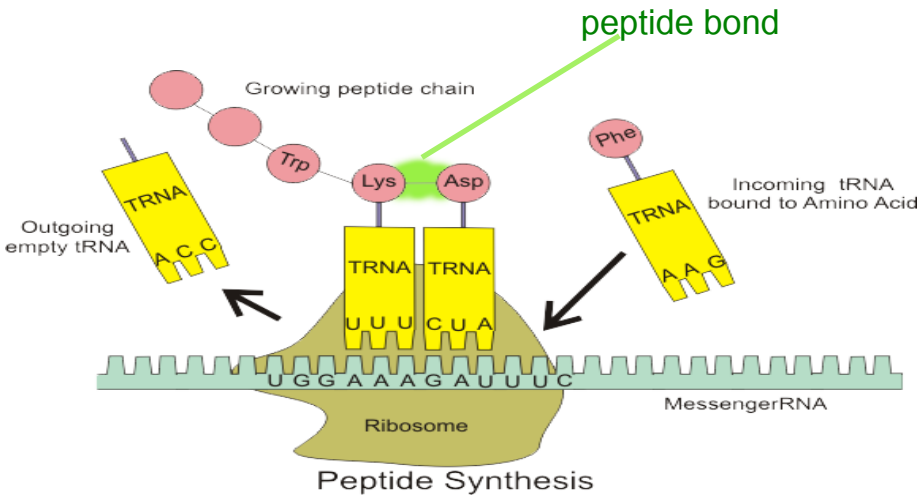
Amino acids

- Twenty different amino acids are used by the ribosomes to create polypeptides in our body
- They all contain an **amine (NH_2) group, a carboxyl (-COOH) group** which combine to form the peptide bond and a "R" group
- The different "R" groups are what makes the amino acids different and allow the proteins to form a wide array of structures and functions
- Some are charged or **polar**, hence they are hydrophilic
- Some are not charged and are non-polar, hence they are **hydrophobic**
- In some special cases, R group contains **sulfur and selenium**



The amino acid sequence of polypeptides is coded for by genes

- Ribosomes need a template – the **messenger RNA (mRNA)**, which is translated by transfer RNA molecules, which **carry specific amino acids**.



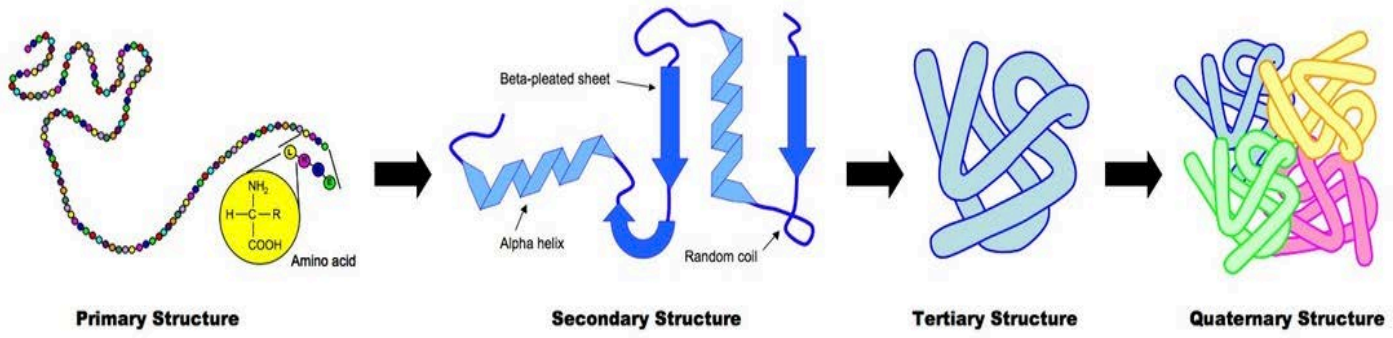
- Genes are simply **codes for making polypeptides**
- **Messenger RNA** is a message from the nucleus to the ribosome-instructions for how to put the polypeptide together.
- The **genetic code** is the **sequence of bases on mRNA**-this tells the ribosome which **amino acids** to use
- The sequence of amino acid in polypeptides is coded by the base sequence in an organism's genes
- Each 3 bases codes for 1 amino acid in a polypeptide**(a codon)**
- So if a polypeptide is 300 amino acids in length, 900 bases actually code for that polypeptide (not including the 3 base pairs that code for the stop codon). Also, the genes are actually longer as they contain non-coding regions that don't code for the polypeptide.
- The actual coding region is called the reading frame

Three-dimensional conformation of a protein

- Proteins are commonly described as either being fibrous or globular in nature.
- Fibrous proteins have structural roles whereas globular proteins are functional (active in a cell's metabolism).
- Some proteins consist of a single polypeptide, while some contain more than one polypeptide
- Hemoglobin for example has 4 linked polypeptides, which are folded into a globular protein to carry oxygen in the blood

Properties	Fibrous Protein	Globular Protein
Shape	Long and narrow	Rounded / spherical
Role	Structural (strength and support)	Functional (catalytic, transport, etc.)
Solubility	(Generally) insoluble in water	(Generally) soluble in water
Sequence	Repetitive amino acid sequence	Irregular amino acid sequence
Stability	Less sensitive to changes in heat, pH, etc.	More sensitive to changes in heat, pH, etc.
Examples	Collagen, myosin, fibrin, actin, keratin, elastin	Catalase, haemoglobin, insulin, immunoglobulin

Four levels of protein structure



- **Primary** structure: **basic amino acid chain**
- **Secondary** structure: Held together by **hydrogen bonds** between (non-adjacent) amine (N-H) and carboxylic (C-O) groups, H-bonds provide a level of structural stability. (**alpha helix shape & beta pleated sheet**)
- **Tertiary** structure:The polypeptide folds and coils to form a complex **3D shape.** Caused by **interactions between R group**s including **ionic bonds, sulfur bridge, hydrophobic and hydrophilic interaction**
- **Quaternary** structure: 2 or more polypeptide chains and/or an inorganic compound (**prosthetic group**) (e.g.: hemoglobin)

Functions of proteins

- **Enzyme catalysis**
- Muscle contraction
- Cytoskeletons
- Tensile strengthen
- Blood clotting (stop bleeding)
- Transport of nutrients and gases
- Cell adhesion
- **Membrane transport**
- Hormones
- Receptors
- **Packing of DNA**
- **Immunity**

Protein example

Protein	Functions
Insulin	**Hormone**: signals cells (liver) to absorb glucose and reduce the glucose concentration of the blood, turning glucose into glycogen; insulin binds reversibly to receptors in the cell membrane to promote uptake Is produced by beta cells in pancreas and transported by blood
Rubisco	**Enzyme catalysis**: Catalyzes the reaction in the **Calvin cycle that fixes CO_2 into organic carbon** to be used by living organisms to produce the carbon compounds need for life.Full name is ribulose bisphosphate carboxylase. It is one of the most abundant and important enzyme in the world

Immunoglobulins	**Immunity**: also known as antibodies. They are Y shaped proteinscells to identify and neutralize foreign pathogens like bacteria and viruses. They send signals to immune systems to come and destroy
Rhodopsin	**Receptors**: rhodopsin is a biological pigment in the photoreceptor cells of the retina. When the retinal absorbs light through the eye, it changes its shape and the shape of the opsin. This sends a nerve impulse through the optic nerve to the brain
Collagen	**Tensile strengthen**: main structure molecule in various connective tissues such as skin, blood vessels and ligaments. Forms bones and teeth, to prevent crack
Spider silk	**Tensile strengthen:** spider silk consists of many different types with different functions and areused in the spokes of a web and when a spider suspends itself. It is very extensible and resistant to breaking

Versatility of proteins

- Biotechnologically has allowed us to use proteins in **industry** examples are:

1. Enzymes for **removing stains in clothing detergent**
2. Monoclonal antibodies for **pregnancy tests**
3. Insulin for **treating diabetics**
4. **Disease treatments**

Every individual has a unique proteome

- A proteome is all of the different kinds of proteins produced by a genome, cell, tissue or organism at a certain time.
- This is completed by extracting mixtures of proteins and using gel electrophoresis with antibodies specific to those proteins with florescent markers
- Proteomes vary in different cells (different cells make different proteins) and at different times within the same cell (cell activity varies)
- Proteomes vary between different individuals because of not only cell activity but slight variations in amino acid sequences
- Within species there are strong similarities between proteomes

Definition of Genome

All of the genes of a cell, a tissue or an organism

- The genome determines what proteins an organism can possibly produce. A genome is unique to most individuals (identical twins and clones share a genome)

Definition of proteome

All of the proteins produced by a cell, a tissue or an organism.

- Being a function of **both the genome and the environment** to which the organism is exposed the proteome is both **variable** (over time) and **unique** to every individual (including identical twins and clones).
- **Environmental factors:**influences what proteins an organism needs to produce and in what quantity. (e.g.: nutrition, temperature, activity levels)
- Proteome **larger** than genome

Denaturation of proteins

- **Heat** can cause denaturation: vibrations within the molecule break intermolecular bonds or interactions.
- **Extremes of pH** can cause denaturation: charges on R groups are changed, breaking ionic bonds within the protein or causing new ionic bonds to form.

2.5 Enzymes

U1	Enzymes have an active site to which specific substrates bind.
U2	Enzyme catalysis involves molecular motion and the collision of substrateswith the active site.
U3	Temperature, pH and substrate concentration affect the rate of activity ofenzymes.
U4	Enzymes can be denatured
U5	Immobilized enzymes are widely used in industry.
A1	Application: Methods of production of lactose-free milk and its advantages.
A2	Skill: Design of experiments to test the effect of temperature, pH andsubstrate concentration on the activity of enzymes.
A3	Skill: Experimental investigation of a factor affecting enzyme activity.(Practical 3)

Definitions

Enzyme: A biological catalyst which speeds up the rate of a chemical reaction bylowering the activation energy.

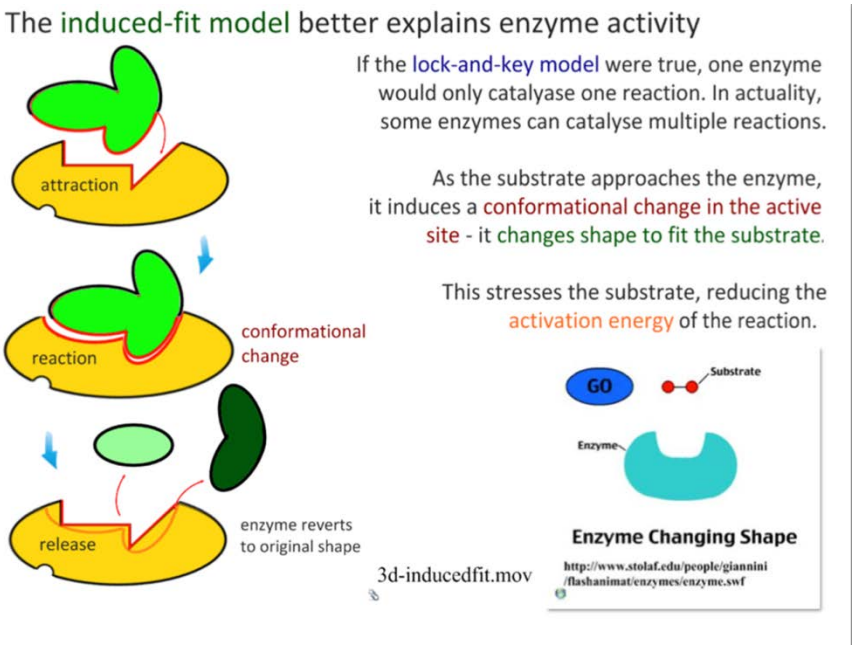
Active Site: The region on an enzyme's surface to which the substrate binds and which catalyses the reaction.

Substrate: Reactant in a biochemical reaction.

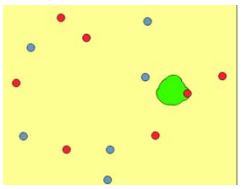
Denaturation: A structural change in a protein that results in a loss of biological properties.

Active site

- Active site: The area or the pocket on the enzyme where the substrate binds.
- Enzyme: Proteins that catalyze chemical reactions (increase the rate by lowering the activation energy)
- Each enzyme catalyzes a specific reaction for a specific substrate
- Enzymes are not used up during the chemical reactions
- **Enzymes are very specific, because both the enzyme and the substrate possess specific complementary shapes that fit into one another**. (lock-and-key)
- The binding of the substrate to the enzyme causes the chemical bonds of the substrate to weaken.
- This eventually causes the reactions that take place that form the products.
- After the products are released, the enzyme can bind to another substrate, because enzymes are not used up in these chemical reactions.
- The substrate and active site match each other in two ways: **structurally and chemically**.
- Structurally: The 3D structured of the active site is specific to the substrate. Substrates that don't fix won't react.
- Chemically: Substrates that are not chemically attracted to the active site won't be able to react.



Enzyme catalysis involves molecular motion and the collision of substrates with the active site



- The coming together of a substrate molecule and an active site is known as a **collision**.
- Most enzyme reactions occur when the substrates are dissolved in water.
- All molecules dissolved in water are in random motion, with each molecule moving separately.
- If not immobilized the enzyme can move too, however enzymes tend be larger than the substrate(s) and therefore move more slowly.
- Collisions are the result of the random movements of both substrate and enzyme.
- The substrate may be at any angle to the active site when the collision occurs.
- Successful collisions are ones in which the substrate and active site happen to be correctly aligned to allow binding to take place.
- Successful reactions only occur if the substrate and the active site of the enzyme are correctly aligned and the collide with sufficient KE

Denaturation of proteins

- The three-dimensional conformation of proteins is stabilized by bonds or interactions between R groups of amino acids within the molecule. Most of these bonds and interactions are relatively weak and they can be disrupted or broken. This results in a change to the conformation of the protein, which is called denaturation and is permanent.
- Enzymes are proteins and denaturation is a key to how enzyme activity is affected by **temperature and pH**.
- Heat can cause denaturation: vibrations within the molecule break intermolecular bonds or interactions.
- Extremes of pH can cause denaturation: charges on R groups are changed, breaking ionic bonds within the protein or causing new ionic bonds to form.

Explain the effect of certain factors on enzyme activity

Temperature:

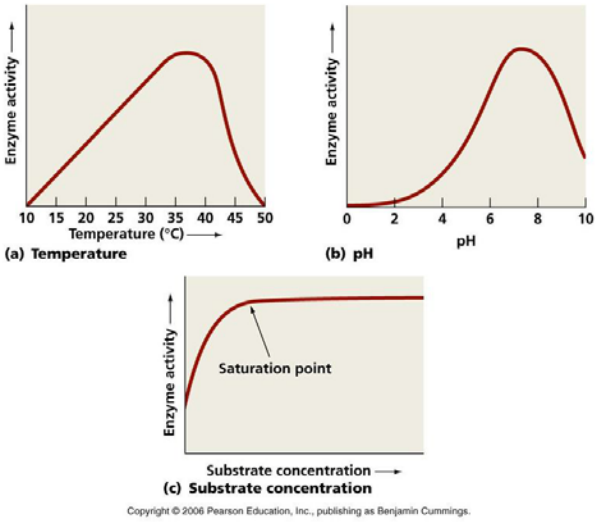
- Increasing temperature increases the kinetic energy of enzyme and substrate, leading to more frequent collisions and a higher rate of activity.
- At a certain temperature an optimum rate of reaction is achieved.
- Above this temperature the enzyme starts to denature and the rate of activity decreases.

pH:

- Enzymes have an optimal pH for activity
- At a higher or lower pH enzyme activity will decrease
- This is because changing pH can alter the charge, shape and solubility of the protein molecule.

Substrate Concentration:

- Increasing substrate concentration increases the frequency of enzyme-substrate collisions, resulting in a higher rate of enzyme activity
- When all enzymes in solution are reacting (i.e. substrate saturation), energy activity increases.
- Substrate concentration will have no further effect and rate of reaction will reach **plateau**.



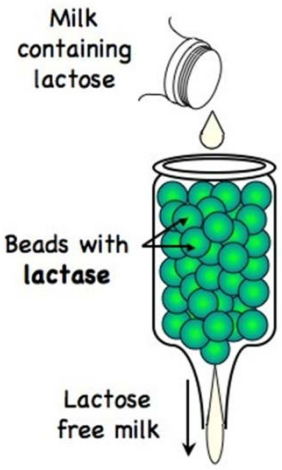
Immobilized enzymes are widely used in industry.

- **Detergents** contain proteases and lipases to help breakdown protein and fat stains.
- Enzymes are used to breakdown the starch in grains into **biofuels** that can be combusted.
- In the textiles industry enzymes help in the processing of **fibres**, e.g. polishing cloth to make it appear shinier.
- In the brewing industry enzymes help a number of processes including the **clarification of the beer**.
- Paper production uses enzymes to helping in the **pulping of wood**.
- Enzymes are widely used in the food industry, e.g. fruit juice, pectin to increase the juice yield from fruit; fructose is used as a sweetener, it is converted from glucose by isomerise; rennin is used to help in cheese production.

Reasons for using enzymes:

1. Convenience – only small amounts of proteins dissolve in the reactions leaving only solvent and the products. This means the enzymes and products can be easily separated
2. Economics – The immobilized enzymes can be easily removed and recycled from the solution, saving money. Eg. Particular useful in the removal of lactase in the production of Lactose Free Milk.
3. Stability – Immobilized enzymes generally have a greater thermal and chemical stability than the soluble form of the enzyme
4. Reaction rate is faster because substrates can be exposed to a higher concentration of enzymes

Explain the use of lactase in the production of lactose-free milk

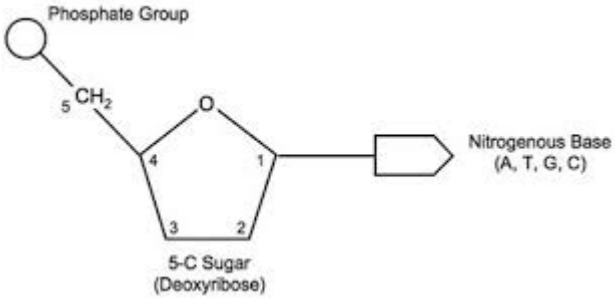


- Lactose is a disaccharide sugar present in milk composed of monosaccharides glucose and galactose.
- Lactase is the enzyme that breaks down lactose into its two monosaccharides.
- Humans are born with the ability to digest milk (lactase produced) but as we grow older, most humans lose the ability to produce lactase in significant amounts.
- If the lactose is broken down in milk before it is consumed, people that are **lactose intolerant** can drink the milk.
- Some types of yeasts produce lactase.
- Biotechnology companies can culture these yeasts and remove the lactase.
- Milk is treated with lactase before distribution, allowing lactose intolerant people to consume milk and milk products.
- Milk is passed (repeatedly) over the beads
- The lactose is broken down into glucose and galactose
- The immobilized enzyme remains to be used again and does not affect the quality of the lactose free milk
- Lactose-free products are useful for lactose-intolerant individuals and limit the need for artificial sweeteners

2.6 Structure of DNA and RNA

U1	The nucleic acids DNA and RNA are polymers of nucleotides
U2	DNA differs from RNA in the number of strands present, the base composition, and the type of pentose
U3	DNA is a double helix made of two antiparallel strands linked by hydrogen bonding between complementary base pairs
A1	Crick and Watson's elucidation of the structure of DNA using model making
A2	Drawing simple diagrams of the structure of single nucleotides of DNA and RNA, using circles, pentagons, and rectangles to represent phosphates, pentoses, and bases.

Nucleotides are the building blocks of nucleic acids

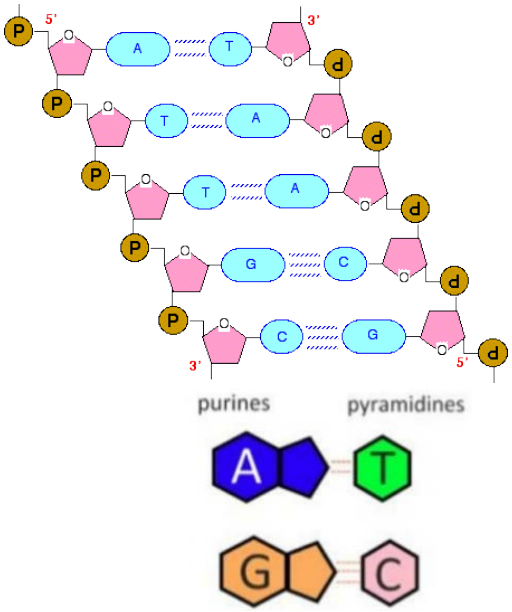


- Nucleic acids are one of the major carbon-based groups. There are three major examples of nucleic acids in nature: ATP, DNA and RNA.
- Both DNA and RNA are polymers of nucleotides. Individual nucleotides are referred to as monomers and always consist of three major parts: one phosphate group, one 5-carbon monosaccharide, and a single nitrogenous base.
- All the bonds within the nucleotide involve the sharing of electrons, and are therefore referred to as covalent bonds. The phosphate group is the same in DNA and RNA. However, there are five possible nitrogenous bases.
- DNA nucleotides are made up of 3 components; a phosphate group (PO_4^{3-}), a pentose sugar, and a nitrogenous base.
- The phosphate, sugar and base are linked by covalent bonds
- In DNA and RNA each nucleotide is linked to the next nucleotide between the phosphate of one and the pentose sugar of the other nucleotide

Difference between RNA and DNA

RNA	DNA
Sugar is **ribose** (carbon 2 has an –OH attached)	Sugar is **deoxyribose** (carbon 2 - no oxygen attached)
Nitrogenous bases are guanine, adenine, cytosine and ***uracil***	Nitrogenous bases are guanine, adenine, cytosine and ***thymine***
Single-stranded molecule	**Double-stranded** molecule

Explain how DNA nucleotides form a double helix



- Nucleotides joined by a condensation reaction (between 5'-phosphate & 3'-sugar)
- This forms a sugar-phosphate backbone linked covalently (phosphodiester bonds)
- Two strands run anti-parallel with bases facing inwards (5'→ 3' versus 3'→ 5')
- Bases complementarily pair with hydrogen bonds (A pairs with T ; G pairs with C)
  There are 3 H bonds between G and C; 2 H bonds between T and A.
- This creates a double stranded structure that then twists to form a double helix.
- **Guanine and cytosine are held together by 3 hydrogen bonds.**
- **Adenine and thymine are held together by 2 hydrogen bonds.**
- **Adenine and Guanine are purines**
- **Thymine and Cytosine are pyramidines**

Crick and Watson's elucidation of the structure of DNA using model making

- Whist others worked using an experimental basis Crick and Watson used stick-and-ball models to test their ideas on the possible structure of DNA. Building models allowed them to visualize the molecule and see how well it fitted available evidence.
- Their first model, a triple helix, was rejected for several reasons:
  The ratio of Adenine to Thymine was not 1:1
  It required too much magnesium.
- From their setbacks they realize:
  DNA must be a double helix;
  The relationship between the bases and base pairing;
  The strands must be anti-parallel to allow base pairing to happen.

2.7 DNA replication, transcription, and translation

U1	The replication of DNA is semi-conservative and depends on complementary base pairing.
U2	Helicase unwinds the double helix and separates the two strands by breaking hydrogen bonds.
U3	DNA polymerase links nucleotides together to form a new strand, using the pre-existing strand as a template.
U4	Transcription is the synthesis of mRNA copied from the DNA base sequences by RNA polymerase.
U5	Translation is the synthesis of polypeptides on ribosomes.
U6	The amino acid sequence of polypeptides is determined by mRNA according to the genetic code.
U7	Codons of three bases on mRNA correspond to one amino acid in a polypeptide.
U8	Translation depends on complementary base pairing between codons on mRNA and anticodons on tRNA.
A1	Use of Taq DNA polymerase to produce multiple copies of DNA rapidly by the polymerase chain reaction (PCR).
A2	Production of human insulin in bacteria as an example of the universality of the genetic code allowing gene transfer between species.

Replication of DNA

- Complementary base pairing ensures two identical DNA strands are formed after replication is complete.
- In replication, the original strands are used as templates, allowing complementary bases to be added according to base pairing rules.
- DNA replication is semi-conservative, meaning the new DNA that is created consists of one old strand (template) and one new strand (synthesized strand).
- The significance of complimentary base pairing means that the two daughter cells have the exact same DNA genome as the parent cell.
- Gene sequences (if no mutations occur) are therefore successfully passed on from generation to generation.
- Adenine is always matched with thymine with two hydrogen bonds and guanine is always matched with cytosine with three hydrogen bonds.

Helicase unwinds the double helix and separates the two strands by breaking hydrogen bonds.

- Unwind DNA helix
- Separate two strands by breaking the hydrogen bonds between base pairs
- ATP is require for helicase move along the DNA molecule and for breaking H bonds
- Two separate strands become template / parent strands for replication

DNA polymerase links nucleotides together to form a new strand, using the pre-existing strand as a template.

- Free nucleotides found in the nucleus are added to the strands of DNA by an enzyme called **DNA polymerase**.
- DNA polymerase brings the nucleotide into position so a hydrogen bond can form between the base pairs
- A covalent bond is formed between the phosphate on the free nucleotide and the sugar on the existing chain
- Nucleotides are added to complimentary bases on the DNA template strands according base-pairing rules (adenine pairs with thymine and guanine pairs with cytosine).
- Bases are added in one direction on one strand and are added in the opposite direction on the other strand.
- Very few mistakes occur
- The newly formed DNA strands rewind to form a double-helix spiral staircase shape once again.
- DNA polymerase is an enzyme. This protein family consists of multiple polypeptides sub-units. The polymerisation reaction is a condensation reaction.
- DNA polymerase always moves in a **5' to 3' direction**. DNA polymerase moves in opposite directions on each strands.
- DNA polymerases catalyse the covalent bonds between sugar and phosphate groups.
- Free nucleotides are collected by DNA polymerase and attached to the new strand by complementary base pairing.

Use of Taq DNA polymerase to produce multiple copies of DNA rapidly by the polymerase chain reaction (PCR).

PCR is a way of producing large quantities of a specific target sequence of DNA. It is useful when only a small amount of DNA is available for testing. E.g. crime scene samples of blood, semen, tissue, hair,etc.

- PCR needs a thermal cycler, primer (where DNA polymerase binds to), free nucleotides and DNA polymerase (Taq polymerase in this case)

PCR occurs in a thermal cycler and involves a repeat procedure of 3 steps:

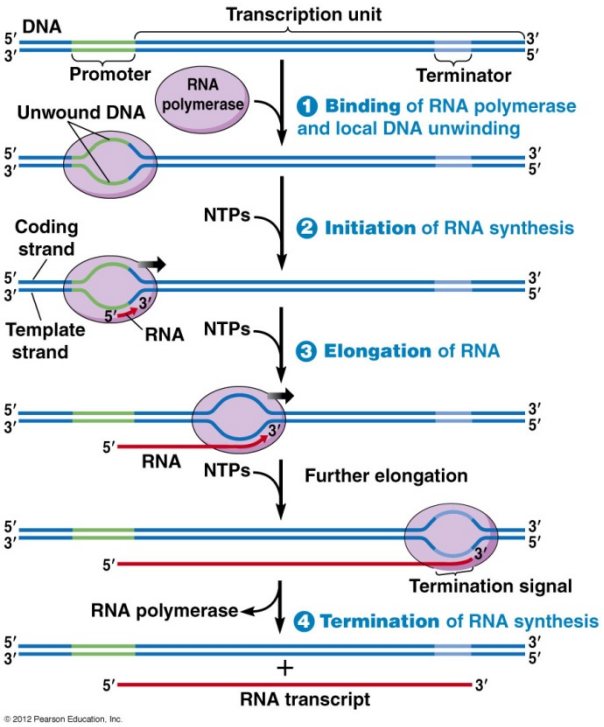
- Denaturation: DNA sample is heated to separate it into tow strands.
- Annealing: DNA primers attach to opposite ends of the target sequence.
- Elongation: A heat-tolerant DNA polymerase (Taq) copies the strands.
- One PCR cycle yields two strand of new DNA

Transcription

Definitions

Transcription: the process by which an RNA sequence is produced from a DNA template.

- In the nucleus, the cell's machinery copies the gene sequence into messenger RNA, a molecule that is similar to DNA. Like DNA, mRNA has four nucleotide bases- but in mRNA, the base **U replaces T**.
- Transcription begins when the area of DNA that contains the gene is unwound by RNA polymerase
- RNA nucleotides found in the nucleus are added to the template strand of the DNA by the enzyme RNA polymerase according to base-pairing rules.
- RNA polymerase also creates covalent bonds between the nucleotides of the mRNA strand.
- Once the RNA sequence has been synthesised:
  -RNA polymerase will detach from the DNA molecule
  -RNA detaches from the DNA
  - the double helix reforms
- Transcription occurs in the nucleus (where the DNA is) and, once made, the mRNA moves to the cytoplasm (where translation can occur)



Three main types of RNA are predominantly synthesised:

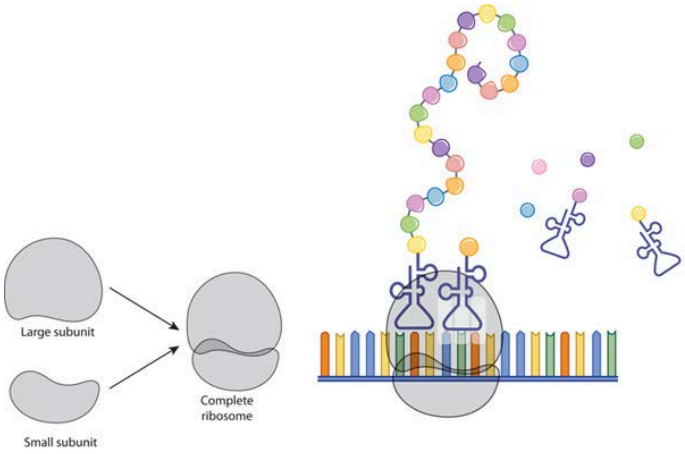
- Messenger RNA (mRNA): A transcript copy of a gene used to encode a polypeptide
- Transfer RNA (tRNA): A clover leaf shaped sequence that carries an amino acid
- Ribosomal RNA (rRNA): A primary component of ribosomes

Translation is the synthesis of polypeptides on ribosomes.

Definitions

Translation: the process of protein synthesis in which the genetic information encoded in mRNA is translated into a sequence of amino acids in a polypeptide chain

- Translation is the synthesis of polypeptides with a specific amino acid sequence that is determined by the base sequence on the mRNA molecule
- That base sequence is determined by the specific gene
- Translation takes place at the ribosomes in the cytoplasm or on the rough ER
- A ribosome is composed of two halves, a **large and a small subunit**. During translation, ribosomal subunits assemble together like a sandwich on the strand of mRNA:
- Each subunit is composed of RNA molecules and proteins
- The small subunit binds to the mRNA
- The large subunit has binding sites for tRNAs and also catalyzes peptide bonds between amino acids

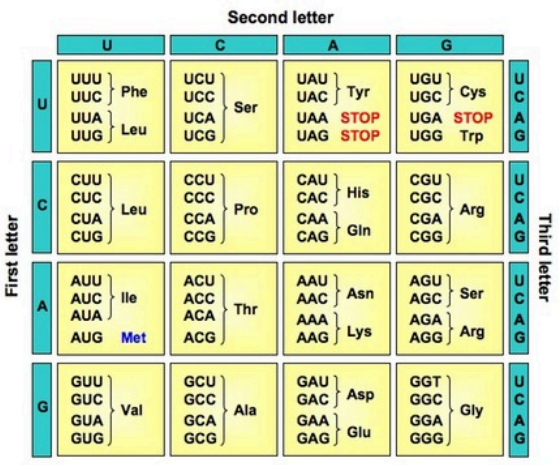


The amino acid sequence of polypeptides is determined by mRNA according to the genetic code.

- The length of mRNA molecules varies
- Only certain genes in a genome need to be expressed
- Therefore not all genes (are transcribed) and translated
- If a cell needs to produce a lot of a certain protein then many copies of the required mRNA are created.

Codons of three bases on mRNA correspond to one amino acid in a polypeptide.

- Codons are a triplet of bases which encodes a particular amino acid
- The codons can translate for 20 amino acids
- The order of the codons determines the amino acid sequence for a protein
- The coding region always starts with a START codon (**AUG**) therefore the first amino acid in all polypeptides is **Methionine**
- The coding region of mRNA terminates with a STOP codon (UAA, UAG, and UGA) - the STOP codon does not add an amino acid – instead it causes the release of the polypeptide
- Amino acids are carried by **transfer RNA (tRNA)**
- The anti-codons on tRNA are complementary to the codons on mRNA



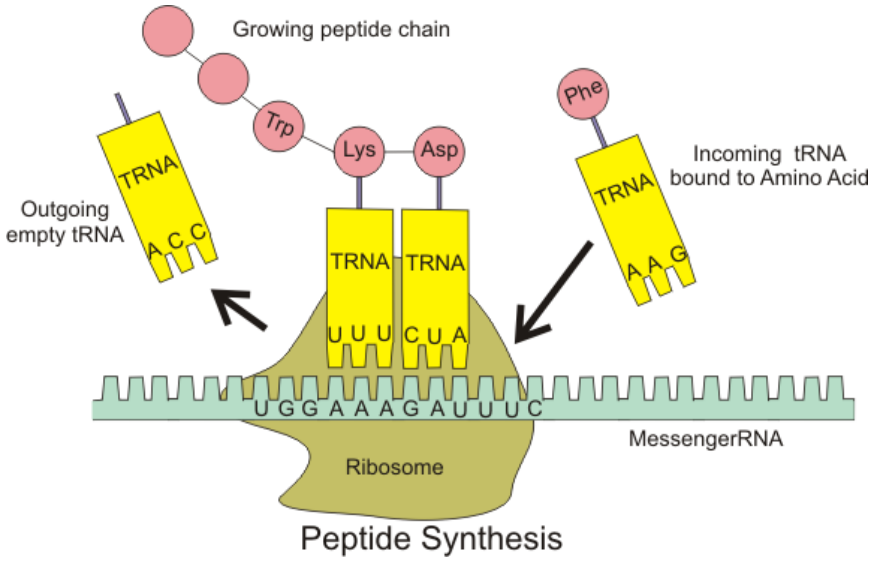
Key:

Ala = Alanine (**A**)
Arg = Arginine (**R**)
Asn = Asparagine (**N**)
Asp = Aspartate (**D**)
Cys = Cysteine (**C**)
Gln = Glutamine (**Q**)
Glu = Glutamate (**E**)
Gly = Glycine (**G**)
His = Histidine (**H**)
Ile = Isoleucine (**I**)
Leu = Leucine (**L**)
Lys = Lysine (**K**)
Met = Methionine (**M**)
Phe = Phenylalanine (**F**)
Pro = Proline (**P**)
Ser = Serine (**S**)
Thr = Threonine (**T**)
Trp = Tryptophan (**W**)
Tyr = Tyrosine (**Y**)
Val = Valine (**V**)

Translation depends on complementary base pairing between codons on mRNA and anticodons on tRNA

- Process where amino acids are combined to form proteins (polypeptides).
- mRNA has a sequence of codons (3 base pairs) that specifies the AA sequence of the polypeptide
- tRNA have an **anticodon** that matches and binds to their complementary codon carrying the AA corresponding to that codon
- After transcription occurs the transcribed mRNA moves out from the nucleus through the nuclear pore into the cytoplasm and binds to the ribosome unit either in the cytoplasm or attached to the rough ER

- mRNA binds to the small subunit of the ribosome with its first two codons contained within the binding sites of the ribosome.
- The first codon is called the **start codon (AUG)** which codes for **methionine**.
- The corresponding tRNA attaches to the mRNA bringing the amino acid methionine to the ribosome to start the polypeptide chain.
- While still attached, a second tRNA attaches to the mRNA at the second binding site on the ribosome, carrying the amino acid that corresponds to the mRNA codon.
- The two amino acids are combined by a condensation reaction, forming a covalent dipeptide bond.
- The bond between the first amino acid and the tRNA that carried it to the ribosome is broken by an enzyme.
- The ribosome slides along the mRNA, moving down one codon releasing the tRNA back into the cytoplasm so it can go pick up another amino acid (in this case methionine).
- Another tRNA moves into the empty site bringing the next amino acid that corresponds to the mRNA codon.
- Again, the amino acid is attached to the polypeptide and the previous tRNA is released back into the cytoplasm as the ribosome moves along the mRNA.
- This process continues until 1 of the 3 stop codons (**UAA, UGA, and UAG**) is reached. These tRNA have no attached amino acid.
- Finally, when the ribosome moves along the mRNA, the polypeptide will fall off and be released into the cytoplasm.



Production of human insulin in bacteria as an example of the universality of the genetic code allowing gene transfer between species.

- All living things use the same bases and the same genetic code.
- Each codon produces the same amino acid in transcription and translation, regardless of the species.
- So the sequence of amino acids in a polypeptide remains unchanged.
- Therefore, we can take genes from one species and insert them into the genome of another species.
- An example of this is human insulin production.

2.8 Cell respiration

U1	Cell respiration is the controlled release of energy from organic compoundsto produce ATP.
U2	ATP from cell respiration is immediately available as a source of energy in thecell.
U3	Anaerobic cell respiration gives a small yield of ATP from glucose.
U4	Aerobic cell respiration requires oxygen and gives a large yield of ATP fromglucose.
A1	Use of anaerobic cell respiration in yeasts to produce ethanoland carbon dioxide in baking.
A2	Lactate production in humans when anaerobic respiration isused to maximize the power of muscle contractions.
S1	Analysis of results from experiments involving measurement ofrespiration rates in germinating seeds or invertebrates using a respirometer.

Reasons for cell respiration

- Organic compounds from the food we eat such as glucose contain stored energy within their covalent bonds.
- All living organisms carry out cell respiration in order to convert stored energy into a form that can be used by the cell.
- When organic molecules are broken down, the energy formed is eventually stored in a high energy molecule called **ATP**.
- **Cell respiration is the controlled release of energy from organic compounds in cells to produce ATP.**

Anaerobic respiration

- Alcohol fermentation (for yeasts and plants): $\text{pyruvate} \xrightarrow{\text{irreversible}} \text{ethanol} + CO_2$
- Application: make breads, make alcohol, make biofuel (using yeast to break sugar cane to make ethanol; cellulose and starch is broken into sugar by enzymes)

- Lactic acid fermentation (for human and some bacteria): $\text{pyruvate} \xrightarrow{\text{reversible}} \text{lactic acid}$
- Application: lactic acid bacteria make yogurts

- Glucose (6C) is broken down into 2 pyruvate (3C) in the cytoplasm by the process of glycolysis.
- There is a net gain of 2 ATP molecules.
- Glycolysis does not require oxygen.
- Anaerobic respiration (without oxygen) occurs in the cytoplasm.
- During glycolysis, glucose is converted into pyruvate with a net gain of 2 ATP.
- After glucose is converted to pyruvate, if no oxygen is available, pyruvate is further converted in tolactate or ethanol depending on the organism.
- When no oxygen is available, humans convert pyruvate into lactate (lactic acid) with no further gain of ATP.
- No CO_2 is produced, because like pyruvate, lactate is also a 3 carbon molecule.
- In yeast and plants, pyruvate is converted into ethanol (2C) and carbon dioxide with no further yield of ATP.
- Ethanol and CO2 are excreted as waste products.

Aerobic respiration

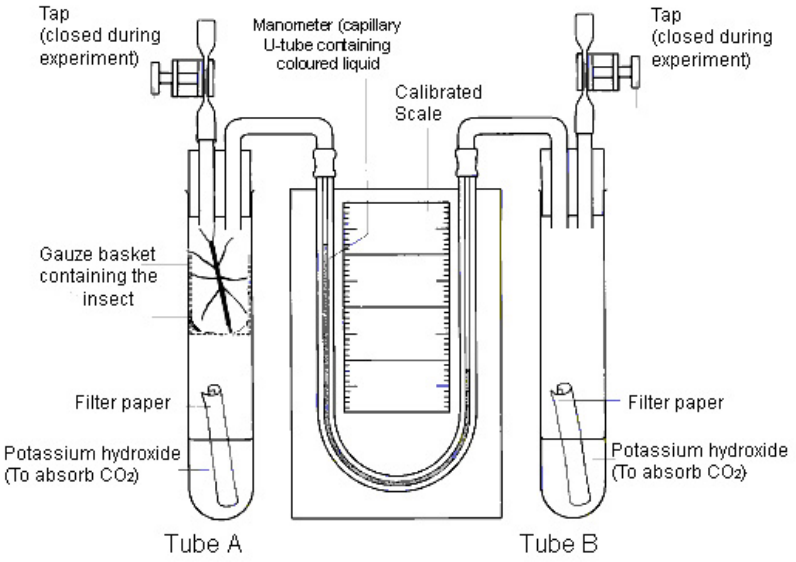
- Aerobic respiration also begins with glycolysis which produces 2 pyruvate molecules per glucose.
- Aerobic respiration occurs in the mitochondria.
- Aerobic respiration is much more efficient than anaerobic respiration as the glucose molecule is fully oxidized.
- The products created in the redox reactions of the Kreb's cycle, plus oxygen (terminal electron acceptor) will produce large quantities of ATP though oxidative phosphorylation (phosphate added to ADP to form ATP) in the ETC, with water being released.
- Overall in aerobic respiration glucose + oxygen will produce carbon dioxide + water with a large yield of ATP
- About 32-34 molecules of ATP are produced by aerobic respiration, while in anaerobic respiration, only 2 ATP molecules are produced

Summary

Net ATP Gain for anaerobic respiration: 2

Net ATP Gain for anaerobic respiration: 36

The Respirometer



2.9 Photosynthesis

U1	Photosynthesis is the production of carbon compounds in cells using lightenergy.
U2	Visible light has a range of wavelengths with violet the shortest wavelengthand red the longest.
U3	Chlorophyll absorbs red and blue light most effectively and reflects greenlight more than other colours.
U4	Oxygen is produced in photosynthesis from the photolysis of water.
U5	Energy is needed to produce carbohydrates and other carbon compoundsfrom carbon dioxide.
U6	Temperature, light intensity and carbon dioxide concentration are possiblelimiting factors on the rate of photosynthesis.
A1	Changes to the Earth's atmosphere, oceans and rock depositiondue to photosynthesis.
S1	Drawing an absorption spectrum for chlorophyll and an actionspectrum for photosynthesis.
S2	Design of experiments to investigate the effect of limiting factors onphotosynthesis.
S3	Separation of photosynthetic pigments by chromatograph.

Production of carbon compounds

- Living organisms require complex carbon compounds to carry out life processes and build the structures in their cells
- Photosynthesis involves the conversion of light energy into chemical energy (carbohydrates, lipids, protein and nucleic acids).
- Chloroplasts absorb light energy from the sun and convert this energy into chemical energy (glucose) to be used by the organisms for energy.

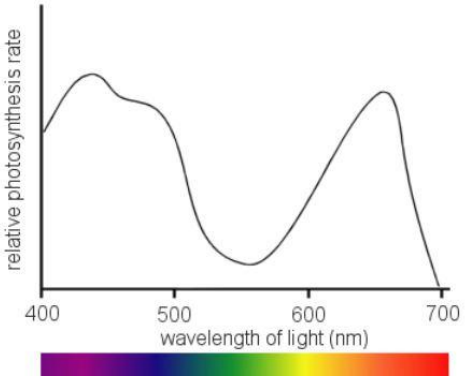
Light frequency

- Light from the sun is composed of a range of wavelengths.
- The visible spectrum is the portion of the electromagnetic spectrum that is visible to or can be detected by the human eye.
- Electromagnetic radiation in this range of wavelengths (400 to 700 nm) is called visible light.
- All these wavelengths together form white light, with violet/blue colours having shorter wavelengths (more energy) and red colours having longer wavelengths (less energy).
- The two main colors of light that are absorbed by chlorophyll are **blue and red** light.
- The main color that is reflected is green light, which is why most leaves look green.

Action spectrum

- The electromagnetic spectrum consists of the entire range of electromagnetic radiation.
- The part of the spectrum that is involved in photosynthesis is called the visible light spectrum.
- An action spectrum is the rate of a photosynthesis plotted against wavelength of light. It shows which wavelength of light is most effectively used during photosynthesis.
- The highest rates of photosynthesis occur at red and blue wavelengths.
- The absorption spectrum shows the % of light absorbed by the photosynthetic pigments in chloroplasts at each different wavelength.
- The graphs are very similar because photosynthesis occurs when light is absorbed by the chlorophyll pigments; therefore the wavelengths that have greatest rates of absorption will also have high rates of photosynthesis.

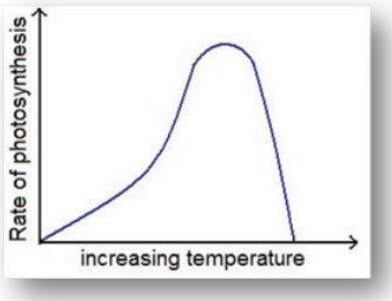
- Green wavelength of light is reflected and therefore has a very low % absorption level on the absorption spectra (this is why most leaves are green).
- Peak approximately at **450nm**
- Peak approximately at **670nm**
- First peak is higher than second peak

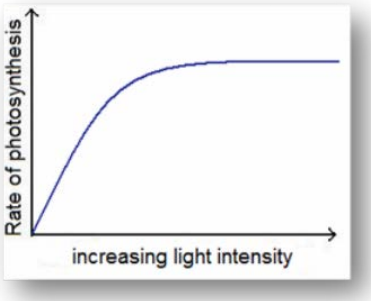


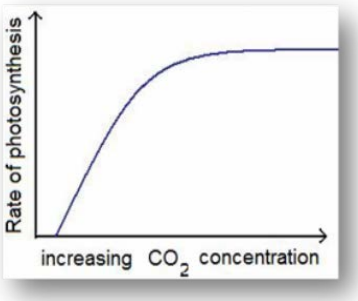
Limiting factor of photosynthesis

- Light intensity, CO_2 concentration and temperature can all be limiting factors for the rate of photosynthesis
- If any of these factors is below their optimal level, they can be limiting; however, only one of these factors can be limiting at one time
- This is usually the factor that is the furthest away from its optimal level
- This is the only factor that can increase the rate of photosynthesis
- As this factor gets closer to its optimal level, the limiting factor can change to one of the other factors

Temperature	Light intensity	CO_2 concentration
• At low temperatures the rate of photosynthesis is very low. • Because photosynthesis requires enzymes, as the temperature increases the amount of kinetic energy in the reactants increases, thereby increasing the rate of photosynthesis. • This rate increases until an optimum temperature is reached. In plants this optimum temperature is usually between 25º and 35º C. • After the optimum temperature is reached, the rate of photosynthesis drops dramatically, because the temperature can cause the enzymes to denature (lose their shape and active site)	• Light is used to produce ATP and split water by photolysis to form H^+ ions and oxygen. • As light intensity increases the rate of photosynthesis also increases. • At low light intensities, an increase in light causes a drastic increase in the rate of photosynthesis. • As light intensity increases the rate of photosynthesis begins to level off and becomes constant. • As light intensity increases further there is no change in the rate of photosynthesis as enzymes are working at their maximum rate.	• CO_2 is the essential molecule in the formation of organic molecules. • At low CO_2 concentrations, an increase in the amount of CO_2 will increase the rate of photosynthesis. At very low levels, no photosynthesis will take place • As the CO_2 concentration increases, the rate of photosynthesis begins to plateau. • At high levels of CO_2 concentration, the rate of photosynthesis remains constant unless light intensity is increased to create more ATP or temperature is increased to provide more kinetic energy.







Topic 3: Genetics

3.1 Genes

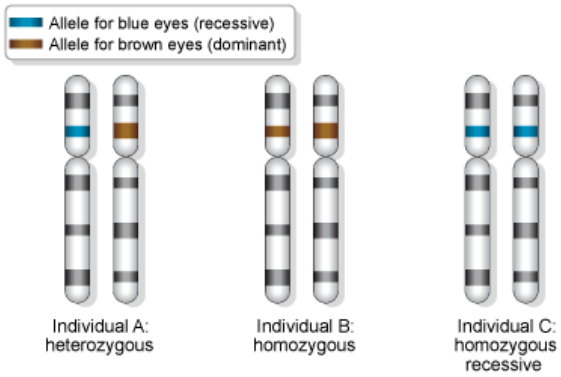
U1	A gene is a heritable factor that consists of a length of DNA and influences a specific characteristic.
U2	A gene occupies a specific position on a chromosome.
U3	The various specific forms of a gene are alleles.
U4	Alleles differ from each other by one or only a few bases.
U5	New alleles are formed by mutation.
U6	The genome is the whole of the genetic information of an organism.
U7	The entire base sequence of human genes was sequenced in the Human Genome Project.
A1	The causes of sickle cell anemia, including a base substitution mutation, a change to the base sequence of mRNA transcribed from it and a change to the sequence of a polypeptide in hemoglobin.
A2	Comparison of the number of genes in humans with other species.

Genes: is a **heritable** factor that controls or influences a specific character consisting of a length of DNA occupying a particular position on chromosome

- Humans have between 21,000-23,000 protein coding genes
- The number of genes in an organism's genome does not indicate how complicated an organism is, for example dogs have larger genome than human
- Each gene occupies a specific location or position on a chromosome called a **locus**.
- Since there are only46 chromosomes in a human diploid cell (23 pairs in females including two X chromosomes and 22 pairs plus and X and a Y chromosome in males). Each chromosome contains many different genes often linked in groups.

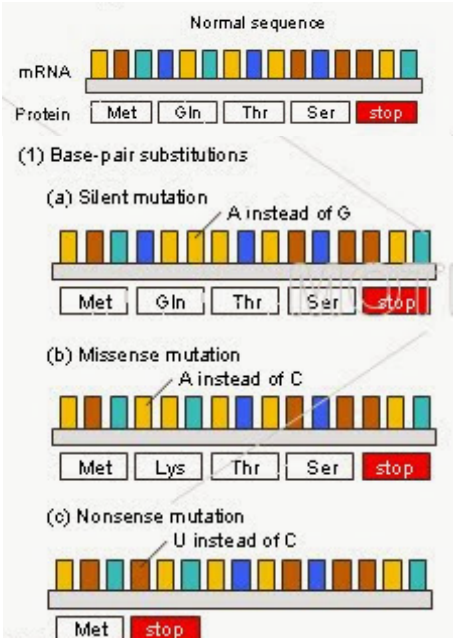
Alleles: one specific form of a gene, differing from other alleles by one or a few bases only and occupying the **same gene locus** as other alleles of the same gene.

- There can be two or more alleles of a specific gene depending on the gene.
- The gene that influences human blood type has three different alleles that code for blood types A, B and O. When there are more than two alleles, this is called multiple alleles.
- Since each human cell consists of **2 copies of each chromosome** (except X and Y), there are two copies of each gene. Sometimes a person can have two of the **same allele (homozygous)** or **two different alleles (heterozygous)**



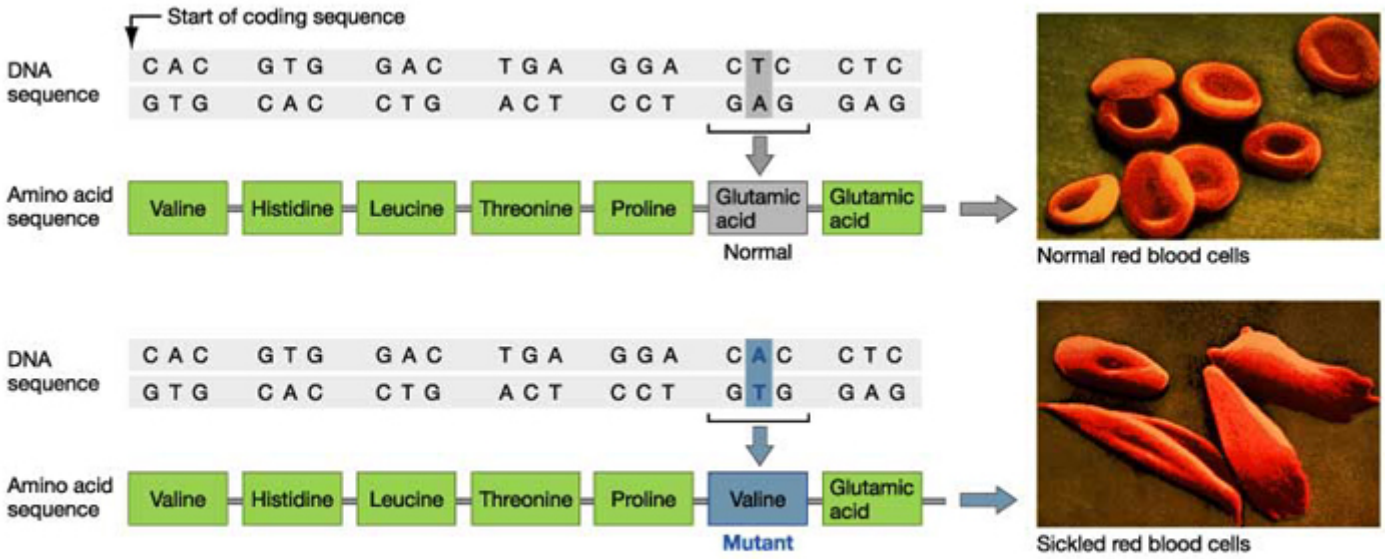
Gene mutation: is a **permanent change** in the base sequence of DNA. Not all mutation causes disease.

- When one of the bases is changed, this will cause a change in the mRNA sequence when the DNA is copied during **transcription** of the gene.
  - **Silence mutation**: a mutation in DNA sequence will not change in protein structure. (multiple codons coded for one amino acid)
  - **Missense mutation**: a mutation in DNA sequence leads to a change in protein structure.(change in amino acid sequence)
  - **Nonsense mutation**: a mutation in DNA shortens the polypeptide chain.(codons mutate to become a STOP signal.)



Sickle-cell anaemia:

- is a disease that causes red blood cells to form a **sickle shape** (half-moon). These sickled blood cells cannot carry as much oxygen as normal red blood cells. They can cause **clots in blood vessels (capillaries)** because of their abnormal shape and inflexibility caused by crystallization of the abnormal hemoglobin.
- Sickle cell anaemia occurs on chromosome 11, happens ob gene **HBB**
- Sickle cell is caused by a base-substitution when the adenine base in GAG is replaced by a thymine base, changing the triplet to GTG.
- **Glutamic acid** then changed to **valine**, a negative charged amino acid changed to neutral one.
- Amino acid sequence change will then lead to a change in protein structure.



The change in amino acid sequence causes hemoglobin molecules to crystallize when oxygen levels in the blood are low. As a result, red blood cells sickle and get stuck in small blood vessels.

- Sickle-cell anaemia gives immune to **malaria**, which is a parasite disease carried by mosquitoes.
- Malaria cannot infect sickle cells. So people with sickle cell trait are resistance to the disease.

Genome: the whole of the genetic information of an organism

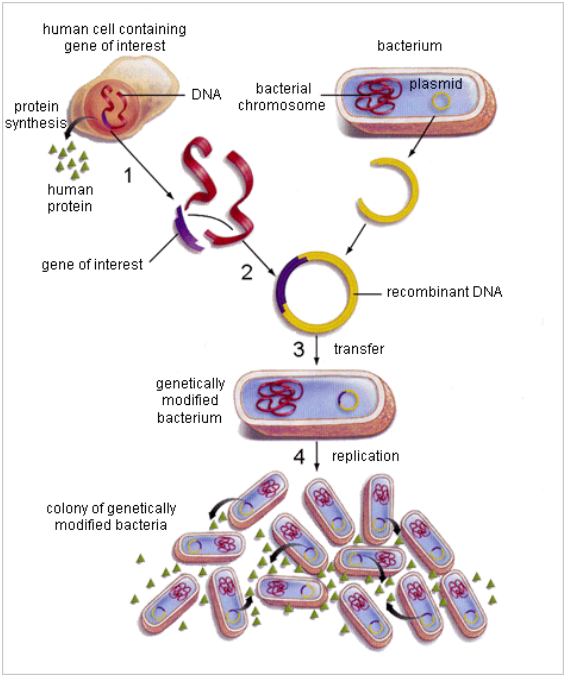
- In humans, the genome consists of 46 chromosomes plus the mitochondrial DNA
- In plants, the genome also consists of chloroplast DNA on top of their chromosomes and mitochondrial DNA
- Prokaryotes have a circular chromosome and plasmids in their genome
- Human Genome Project: **entire base sequence of human genes** was sequenced: Most of the genome does not code for proteins (originally labeled "junk DNA"). Some of these regions consist of areas that can **affect gene expression** or are highly repetitive sequences called satellite DNA. Scientists can now also predict which sequences do code for protein (approximately 21000-23000 sequences)

3.2 Chromosomes

U1	Prokaryotes have one chromosome consisting of a circular DNA molecule.
U2	Some prokaryotes also have plasmids but eukaryotes do not.
U3	Eukaryote chromosomes are linear DNA molecules associated with histoneproteins.
U4	In a eukaryote species there are different chromosomes that carry differentgenes.
U5	Homologous chromosomes carry the same sequence of genes but notnecessarily the same alleles of those genes.
U6	Diploid nuclei have pairs of homologous chromosomes.
U7	Haploid nuclei have one chromosome of each pair.
U8	The number of chromosomes is a characteristic feature of members of aspecies.
U9	A karyogram shows the chromosomes of an organism in homologous pairs ofdecreasing length.
U10	Sex is determined by sex chromosomes and autosomes are chromosomesthat do not determine sex.
A1	Cairns' technique for measuring the length of DNA molecules byautoradiography
A2	Comparison of genome size in T2 phage, *Escherichia coli*,*Drosophila melanogaster*, *Homo sapiens* and *Paris japonica.*
A3	Comparison of diploid chromosome numbers of *Homo sapiens*,*Pan troglodytes*, *Canis familiaris*, *Oryza sativa*, *Parascaris equorum.*
A4	Use of karyograms to deduce sex and diagnose Down syndromein humans.

Prokaryotes:

- Prokaryotes have **circular DNA** without association of protein.
- There is one copy of each gene except when the cell and its DNA are replicating
- Plasmids are small separate (usually circular) DNA molecules located in some prokaryotic cells
- Plasmids are also naked (not associated with proteins) and are not needed for daily life processes in the cell.
- The genes in plasmids are often associated with **antibiotic resistant** and can be **transferred from one bacterial cell to another**.
- Plasmids are readily used by scientists to artificially transfer genes from one species to another (ie. Gene for human insulin)



Insulinproduction in bacteria.

Using DNA ligase and the **same** restriction enzymes.

Plasmid features:

- Naked DNA without association of protein such as histone
- Small circular ring of DNA
- Not responsible for normal life process
- Contain survival characteristics, e.g. antibiotic resistence
- Can be passed on between bacteria
- Can be incorporated into nucleoid chromosomes (save permanently)

Eukaryotes:

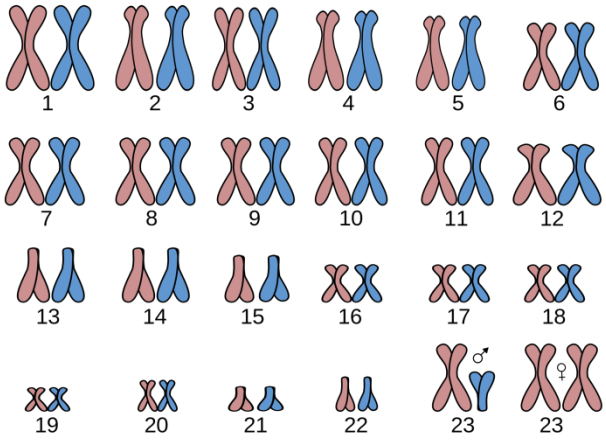
- Eukaryotic chromosomes are linear and are made up of DNA and **histone** proteins.
- Histones are globular shaped protein in which the DNA is wrapped around.
- Linear chromosomes vary in **length**, **centromere** location and **genes** containing
- In humans there are **23** types of chromosomes. There are 22 pairs of **autosomes**. The 23rd pair are the **sex chromosomes**. Males have an X and a Y chromosome and females have two X chromosomes
- Each chromosome carries a specific sequence of genes along the linear DNA molecule. The position where the gene is located is called the **locus**
- The number of chromosomes is known as **N** number.
- Normal cell contains **diploid nucleus – 2N**(two pairs of homologous chromosomes)
- Sex cell contains **haploid nucleus – N**(one pairs of homologous chromosomes)
- The **chromosome number** is an important characteristics of the species

Homologous chromosome:

- Homologous chromosomes are chromosomes within each cell that carry the same genes at the same loci
- One chromosome came from an individual's mother and one from the father
- They have the same **structure and size**
- These chromosomes pair up during meiosis
- Even though these chromosomes carry the same genes, they could have **different alleles**

Sex chromosome:

- The X and Y chromosome determine the sex of an individual
- The X chromosome is quite large in comparison to the Y chromosome and has a centromere that is located near the centre or middle of the chromosome
- The Y chromosome is relatively small with its centromere located near the end of the chromosome
- If an individual has two X chromosomes they will be a female and if they have an X and a Y chromosome they will be a male
- All other chromosomes are called **autosomes** and do not affect the sex of an individual
- **SRY** genes on Y chromosomes lead to male development
- Using a **karyogram**, we distinguish sex, it shows the chromosomes of an organism in homologous pairs of decreasing length.



3.3 Meiosis

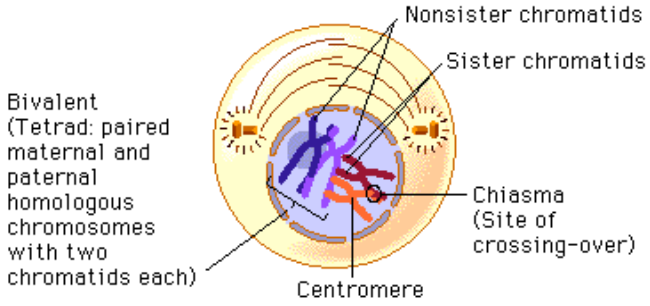
U1	One diploid nucleus divides by meiosis to produce four haploid nuclei.
U2	The halving of the chromosome number allows a sexual life cycle with fusionof gametes.
U3	DNA is replicated before meiosis so that all chromosomes consist of two sister chromatids.
U4	The early stages of meiosis involve pairing of homologous chromosomes and crossing over followed by condensation.
U5	Orientation of pairs of homologous chromosomes prior to separation is random.
U6	Separation of pairs of homologous chromosomes in the first division ofmeiosis halves the chromosome number.
U7	Crossing over and random orientation promotes genetic variation.
U8	Fusion of gametes from different parents promotes genetic variation.
A1	Non-disjunction can cause Down syndrome and other chromosome abnormalities.
A2	Studies showing age of parents influences chances of non disjunction.
A3	Description of methods used to obtain cells for karyotype analysis e.g. chorionic villus sampling and amniocentesis and the associated risks.

Interphase:

- **G1 phase**: increase cytoplasm volume, organelle production and protein synthesis (normal growth)
- **S phase**: DNA replication
- **G2 phase**: increase cytoplasm volume, double the amount of organelle and protein synthesis (prepare for cell division)

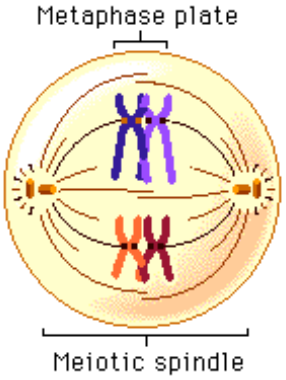
Prophase I:

- DNA supercoils and condenses. Chromosomes are visible under light microscope.
- Nuclear membrane begins to break down and disintegrate.
- The **homologous chromosomes** associate with each other to form **bivalent or tetrads**.
- **Crossing over** occurs: non-sister chromatids exchange genetic information. The crossing over point is called **chaisma** (pl. chaismata)
- **Spindle fiber** begins to form



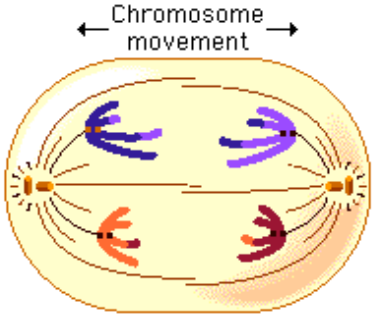
Metaphase I:

- Bivalents line up at the equator
- **Random Orientation** occurs: bivalents (homologous pairs) that come from the mother or the father line up randomly on either side of the cell equator, independently of the other homologous pairs. Hence the daught nuclei get a different mix of chromosomes.
- Spindle fibers (**microtubules**) from each of the centrosomes attach to the centromere of bivalents.



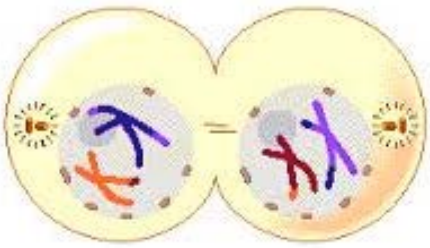
Anaphase I:

- Contraction of the spindle fibers pulls homologous chromosome pair apart.
- Chaismata breaks apart and separate.
- One chromosome of each pair move to opposite poles of the cell.



Telophase I:

- Chromosome begins to uncoil and nuclear envelop reforms.
- Chromosome number reduces from 2n (diploid) to n (haploid); however each chromatid still has the replicated sister chromatid still attached (not **homologous pairs** anymore).
- Cytokinesis occurs and the cell splits into two separate cells.



Prophase II:

- Chromosomes condense again and become visible.
- Spindle fibers again form.
- Nuclear membrane disintegrates again.

Metaphase II

- Chromosomes line up along the equator.
- Spindle fibre attaches to the centromere of the chromosome.

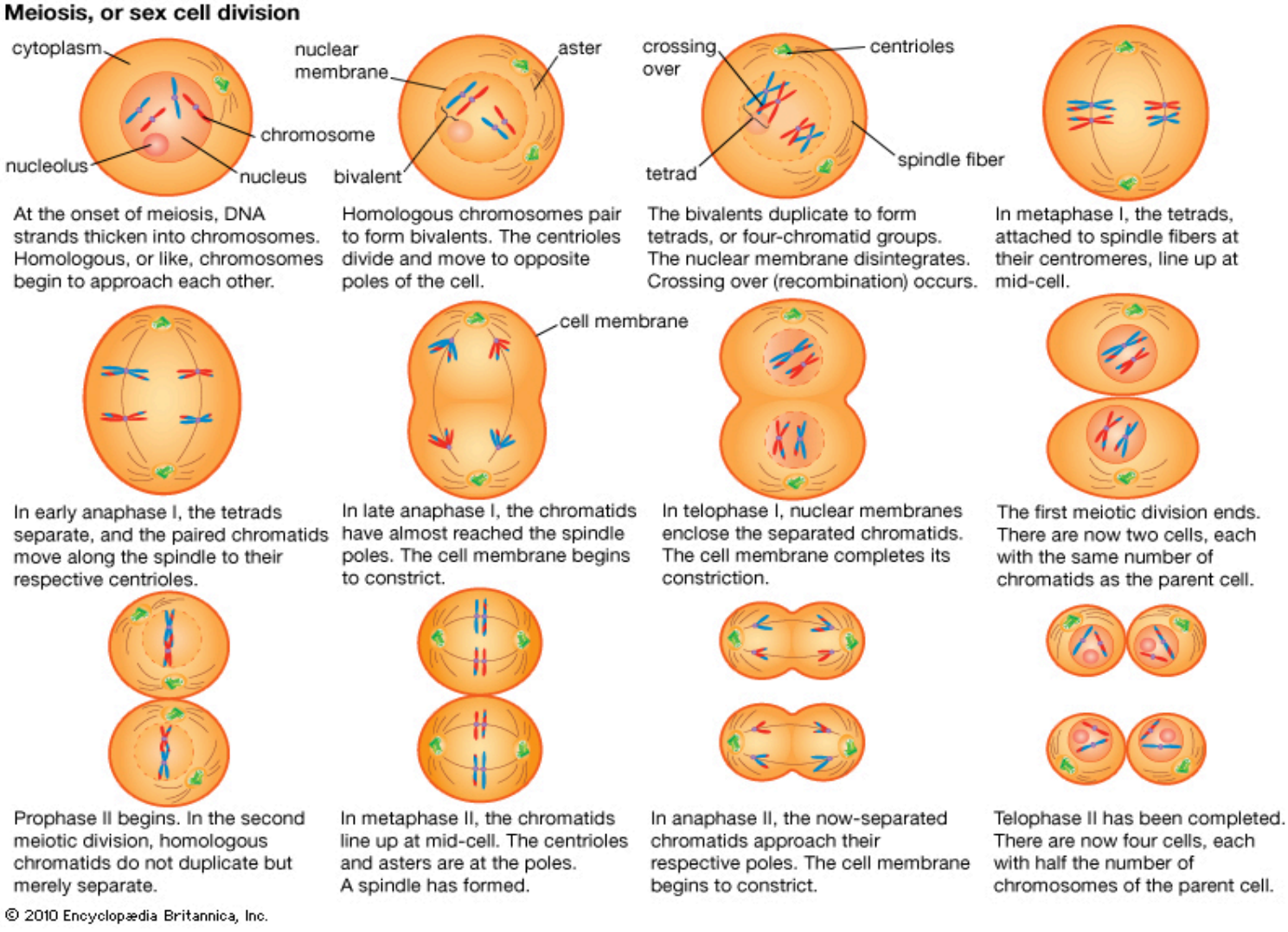
Anaphase II:

- Spindle fibers pull apart the centromeres and sister chromatids are pulled towards the opposite poles.

Telophase II:

- Chromosomes arrive at opposite poles.
- Nuclear envelope begins to develop around each of the four haploid cells.
- Chromosomes begin to unwind to form chromatin.
- Cytokinesis occurs and cells are split apart.

Meiosis, or sex cell division



At the onset of meiosis, DNA strands thicken into chromosomes. Homologous, or like, chromosomes begin to approach each other.

Homologous chromosomes pair to form bivalents. The centrioles divide and move to opposite poles of the cell.

The bivalents duplicate to form tetrads, or four-chromatid groups. The nuclear membrane disintegrates. Crossing over (recombination) occurs.

In metaphase I, the tetrads, attached to spindle fibers at their centromeres, line up at mid-cell.

In early anaphase I, the tetrads separate, and the paired chromatids move along the spindle to their respective centrioles.

In late anaphase I, the chromatids have almost reached the spindle poles. The cell membrane begins to constrict.

In telophase I, nuclear membranes enclose the separated chromatids. The cell membrane completes its constriction.

The first meiotic division ends. There are now two cells, each with the same number of chromatids as the parent cell.

Prophase II begins. In the second meiotic division, homologous chromatids do not duplicate but merely separate.

In metaphase II, the chromatids line up at mid-cell. The centrioles and asters are at the poles. A spindle has formed.

In anaphase II, the now-separated chromatids approach their respective poles. The cell membrane begins to constrict.

Telophase II has been completed. There are now four cells, each with half the number of chromosomes of the parent cell.

Genetic variation:

Crossing over:

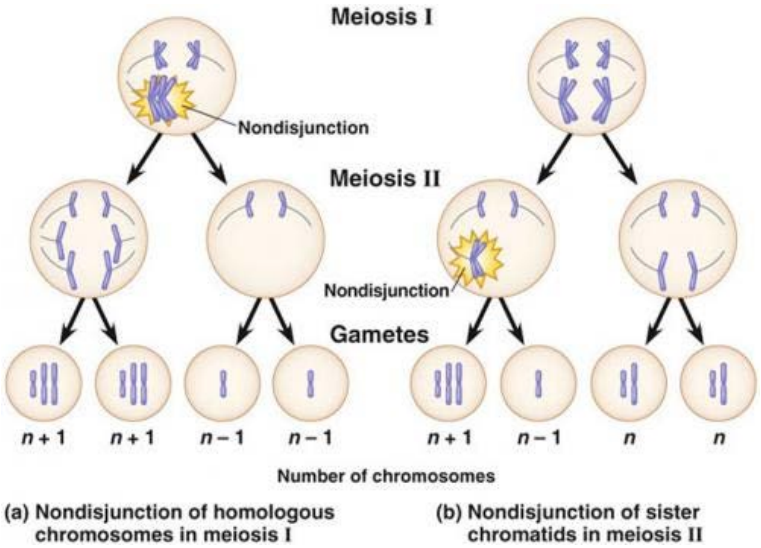
- Occurs in **prophase I** of meiosis.
- Crossing over occurs between non-sister chromatids of a particular chromosome.
- Chiasmata are points where two homologous non-sister chromatids exchange genetic material during crossing over in meiosis.
- Chromosomes intertwine and break at the exact same positions in non-sister chromatids.
- Segments of the adjacent homologues are exchanged during crossing over, therefore the two sister chromatids are no longer identical.
- Crossing over creates new **combinations of linked genes** (genes on the same chromosome) from the mother and the father.
- When the chromatids are separated into different gametes after anaphase II, the gametes produced will not contain the same combination of alleles as the parental chromosomes.
- This creates variation in the offspring regardless of random orientation.

Random Orientation:

- Occurs in metaphase I of meiosis.
- When homologues line up along the equatorial plate in metaphase I, the **orientation of each pair is random**; meaning the maternal or paternal homologue can orient toward either pole.
- This means the number of combinations that can occur in the gamete is $\mathbf{2^n}$(n=number of chromosome pairs).
- Therefore, in a female or male gamete there can be 2^{23} or 8,388,608 different possible combinations.
- Now when you consider there is the same number of possible combinations in the other gamete that it will combine with to form a zygote (random fertilization); the genetic possibilities are staggering.
- If one takes into consideration crossing over, which was explained above, the genetic variation possibilities in the offspring is immeasurable.

Non-disjunction:

- A non-disjunction is an error in meiosis, where the chromosome pairs **fail to split** during cell division.
- Non-disjunction can occur in **anaphase I** where the homologous pairs fail to split, or it can occur in **anaphase II**, where the sister chromatids fail to split.
- The result of this error is too many chromosomes in a gamete cell or too few chromosomes in the final gamete cell.
- One of the gamete cells could have 22 chromosomes and one could have 24 chromosomes. The resulting zygote will therefore have 47 or 45 chromosomes.
- An example of a non-disjunction is **Down's syndrome**.
- Down syndrome occurs when **chromosome 21** fails to separate, and one of the gametes ends up with an extra chromosome 21. Therefore, a child that receives that gamete with an extra chromosome 21 will have 47 chromosomes in every cell.



- Down syndrome is also called **Trisomy 21**.
- Some Down syndrome symptoms include impairment in cognitive ability and physical growth, hearing loss, oversized tongue, shorter limbs and social difficulties.

Karyogram:

- A diagram or photograph of the chromosomes present in a nucleus arranged in homologous pairs of descending length.
- It can be used to make diagnosis of non-disjunction genetic disorder, such as Down's Syndrome.
- **Amniocentesis**: a sample of the amniotic fluid surrounding the baby is removed using a syringe.
- The sample contains skin cell from the baby, so we can use that to make a karyogram, in order to check for genetic disorder.

3.4 Inheritance

U1	Mendel discovered the principles of inheritance with experiments in whichlarge numbers of pea plants were crossed.
U2	Gametes are haploid so contain only one allele of each gene.
U3	The two alleles of each gene separate into different haploid daughter nucleiduring meiosis.
U4	Fusion of gametes results in diploid zygotes with two alleles of each genethat may be the same allele or different alleles.
U5	Dominant alleles mask the effects of recessive alleles but co-dominant alleleshave joint effects.
U6	Many genetic diseases in humans are due to recessive alleles of autosomal genes, although some genetic diseases are due to dominant or co-dominant alleles.
U7	Some genetic diseases are sex-linked. The pattern of inheritance is differentwith sex-linked genes due to their location on sex chromosomes.
U8	Many genetic diseases have been identified in humans but most are veryrare.
U9	Radiation and mutagenic chemicals increase the mutation rate and can causegenetic diseases and cancer.
A1	Inheritance of ABO blood groups.
A2	Red-green colour blindness and hemophilia as examples of sexlinkedinheritance.
A3	Inheritance of cystic fibrosis and Huntington's disease.
A4	Consequences of radiation after nuclear bombing of Hiroshimaand accident at Chernobyl.

Definitions

Genotype:the **combination** of alleles of a gene carried by an organism

Phenotype:the **expression** of alleles of a gene carried by an organism

Homozygous dominant: two copies of the same dominant gene (capital letter AA)

Homozygous recessive: two copies of the same recessive gene (lowercase aa)

Heterozyous: two different alleles (one dominant, one recessive) (Aa)

Codominant: pairs of alleles which are both expressed when present

Carrier: an individual that has one copy of a recessive allele that causes a genetic disease in individuals that are homozygous for this allele.

Test cross: testing a suspected heterozygote by crossing it with a known **homozygous recessive**.

Mendel's pea plants:

- Mendel was known as the father of genetics
- Mendel performed experiments on a variety of different **pea plants**, crossing these varieties by using the male pollen from one variety and transferring it to the female part of another variety
- He collected the seeds and grew them to determine their characteristics
- He then crossed these offspring with each other and also grew their seeds to determine their characteristics
- He continued performing many crosses and recorded his results.

Gametes

- Gametes which are sex cells such as sperm and eggs
- Gametes contain **one set of chromosomes** or one chromosome of each type and are therefore haploid **(n)**
- Since they have only one chromosome of each type, gametes also only contain one allele of each gene
- Together the two gametes form a **zygote**
- When the gametes (n) fuse to form a zygote (2n), **two copies of each gene** exist in the diploid zygote
- The zygote may contain two of the same allele AA or aa or two different alleles such as Aa

mono-hybrid

Aa x Aa

	A	a
A	AA	Aa
a	aA	aa

Phenotype - 3:1
(normal : albino)

Genotype - 1:2:1
(normal : het for albino : albino)

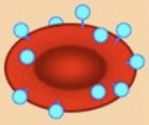
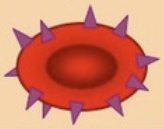
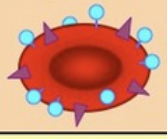
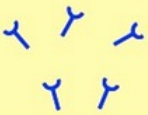
Monohybrid crossing:

- Cross using a **Punnett square**
- F1 generation genotype ratio is 1:2:1 and phenotype ratio is 3:1

ABO Blood Group:

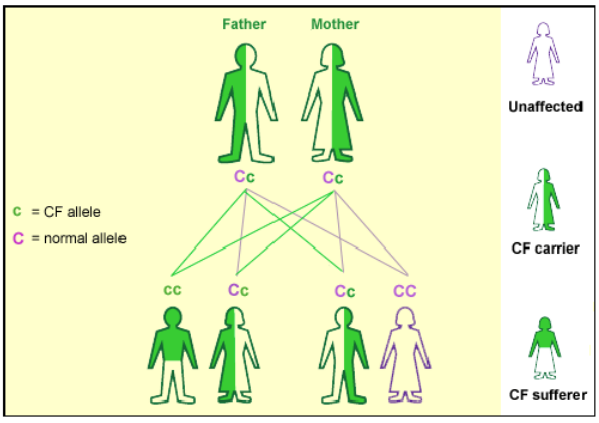
- Human blood types are an example of both multiple alleles (A, B, O) and co-dominance (A and B are co-dominant).
- Co-dominant alleles such as A and B are written as a superscript **(I^A and I^B)**. Blood type O is represented by **(i).**
- Both I^A and I^B are dominant over the allele (i).
- A, B and O alleles all produce a basic **antigen** (glycoprotein) on the surface of the red blood cells
- People with **A** blood group will possess **anti-B antibodies** and **antigen A**, which are able to kill B and AB type blood. A blood group people can accept **A and O** type blood but not the **AB and B** type.
- People with **B** blood group will possess **anti-A antibodies** and **antigen B**, which are able to kill A and AB type blood. B blood group people can accept **B and O** type blood but not the **AB and A** type.
- People with **AB** blood group will possess **NO antibodies** and **antigen A&B**. AB blood group people can accept **ALL type of blood.**
- People with **O** blood group will possess **anti-A & anti-B antibodies** and **NO antigens**, which are able to kill A, B and AB type blood. O blood group people can accept **O** type blood but not the **A, AB and B** type.
- AB blood group is universal receiver; O blood group is universal donor.

ABO Blood Groups

Antigen (on RBC)	Antigen A 	Antigen B 	Antigens A + B 	Neither A or B 
Antibody (in plasma)	Anti-B Antibody 	Anti-A Antibody 	Neither Antibody	Both Antibodies 
Blood Type	**Type A** Cannot have B or AB blood. Can have A or O blood	**Type B** Cannot have A or AB blood. Can have B or O blood	**Type AB** Can have any type of blood. Is the universal recipient	**Type O** Can only have O blood. Is the universal donor

Cystic fibrosis:

- Cystic fibrosis is a **autosomal recessive disease** caused by an allele of the **CFTR gene** on **chromosome 7**
- Mutation in the CFTR gene causes secretion of **mucus** to become very thick. Thick mucus **blocks the airway** tubes especially in lungs
- Cystic fibrosis patient dies young, around the age of 35-50



Huntington's disease:

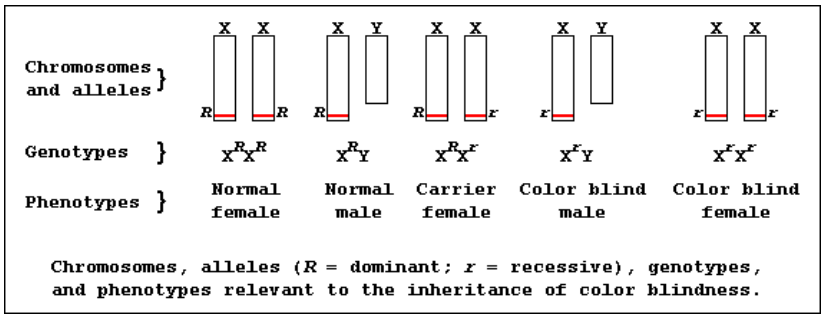
- Humans have two copies of the Huntingtin gene (HTT) on **chromosome 4**, which codes for the protein Huntingtin (Htt)
- Huntington's disease is **dominantly inherited**. Meaning only one bad copy of the gene from either the mother or father will result in Huntington's disease.
- Huntington's disease is a **neurodegenerative genetic disorder** that affects muscle coordination and leads to mental decline and behavioral symptoms
- **Neuron degeneration** will lead to brain disorder, affecting the ability to think, talk and move.

Sex linkage:

- These are patterns of inheritance where the ratios are different in males and females because the **gene is located on the sex chromosomes**
- Generally, sex-linked diseases are on the **X chromosome**
- Sex-linked trait are those which carried on the X chromosomes **non-homologous region**.
- Normal genes are expressed in $\mathbf{X^N}$(dominant)
- Abnormal genes are expressed in $\mathbf{X^n}$ (recessive)
- X-linked recessive diseases such as color blindness and hemophilia are more common in males because males only carry one X chromosome, therefore if they inherit the X chromosome with the disease, they will have the disease.
- Males that have the disease can only pass the colorblind or hemophilia allele onto **their daughters**. Their sons will receive the Y chromosome.

Red-green colour blindness:

- Red-green blindness genes are **recessive** on the non-homologous region of X chromosome Xq28. So it is a **sex-linked disease**.
- Patient's retinal pigment will lose certain frequency so the cannot distinguish between red and green.



Chromosomes, alleles (*R* = dominant; *r* = recessive), genotypes, and phenotypes relevant to the inheritance of color blindness.

Hemophilia:

- Globular protein called **clotting factor** is needed to clot the blood. A mutation will cause clotting factor not to work.
- Clotting response to injury does not work: patient may bleed to death.
- Hemophilia is a **recessive sex-linked disease**.

Genetic disease summary table

Genetic Disease	Allele nature	Location of mutation	Sex-linked	Symptom
Sickle-cell anaemia	**Co-dominant**	HBB genes on chromosome 11 GAG mutate to GUG	Not	clots in blood vessels (capillaries) because of their abnormal shape Immune to malaria
Cystic fibrosis	recessive	CFTR gene on chromosome 7	Not	Thick secretion of mucus causes block of airway in lungs, leading to premature death
Huntington's disease	**dominant**	HTT gene on chromosome 4	Not	Neuron degeneration will lead to brain disorder, affecting the ability to think, talk and move
Red-green colour blindness	recessive	Xq28 gene on X chromosome	Yes	Failure to distinguish between red and blue. Lose certain frequceies of light
Hemophilia	recessive	X chromosome	Yes	Clotting response to injury does not work. Patient may bleed to death

Radiation effects:

- A mutation is a random change to the base sequence of a gene
- Both radiation and certain chemicals can cause **genetic diseases and cancer**
- Radiation can cause mutations if it has enough energy to chemical change one's DNA. Gamma rays and alpha particles from **radioactive** decay, UV radiation and x-rays are all considered to be mutagenic
- Nuclear bombing of Hiroshima and accident at Chernobyl leads to high cancer rate

Mutagens and oncogenes:

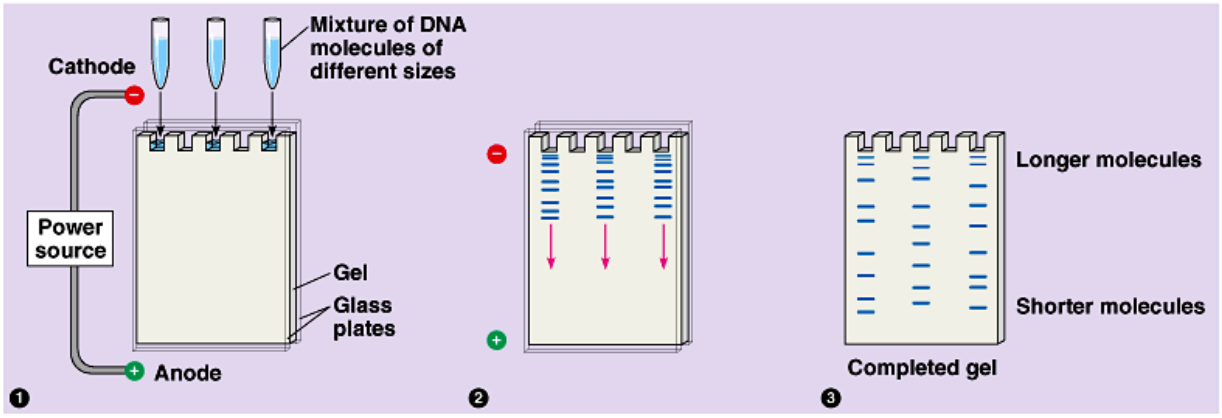
- **Mutagens**: are agents that cause gene mutation such as chemicals, high energy radiation, ultraviolet light and some virus
- **Oncogenes**: genes that control the cell cycle and **cell division**
- If a mutation occurs on oncogenes, it may lead to cancer.
- **Mutation in oncogenes** will lead to malfunction in control of the cell cycle, leading to uncontrolled cell division and cancer.
- Mutation occurs in somatic cells will remain in the organism, but if it occurs in gametes, it will be passed on for generations

3.5 Genetic modification and biotechnology

U1	Gel electrophoresis is used to separate proteins or fragments of DNA according to size.
U2	PCR can be used to amplify small amounts of DNA.
U3	DNA profiling involves comparison of DNA.
U4	Genetic modification is carried out by gene transfer between species.
U5	Clones are groups of genetically identical organisms, derived from a single original parent cell.
U6	Many plant species and some animal species have natural methods ofcloning.
U7	Animals can be cloned at the embryo stage by breaking up the embryo into more than one group of cells.
U8	Methods have been developed for cloning adult animals using differentiated cells.
A1	Use of DNA profiling in paternity and forensic investigations.
A2	Gene transfer to bacteria using plasmids makes use of restriction endonucleases and DNA ligase.
A3	Assessment of the potential risks and benefits associated with genetic modification of crops.
A4	Production of cloned embryos produced by somatic-cell nuclear transfer.

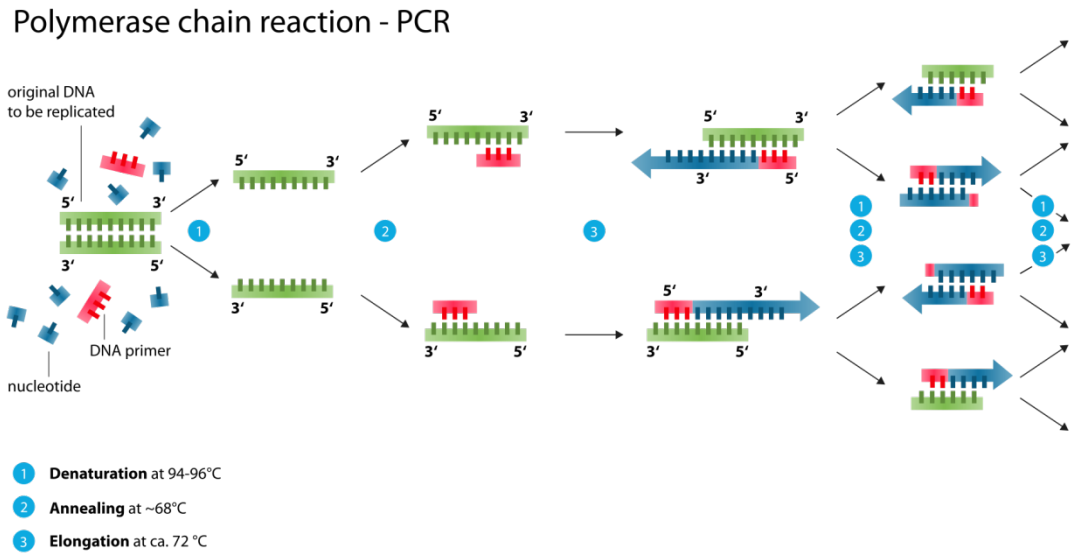
Gel electrophoresis:

- Before gel electrophoresis takes place, **restriction enzymes** are used to cut DNA into fragments of various lengths and different charges.
- **Restriction enzyme**: cut DNA into fragments at specific base sequences in each sample.
- These fragments are placed into small depression or wells at one end of the gel.
- An electrical current is applied to the gel (positive on one side and negative on the other).
- The fragments of DNA will fall out and embed in the gel based on **their size and charge**.
- The smallest particles that are charged go the farthest in the gel, while the large non-charged particles fall out and embed in the gel the quickest.



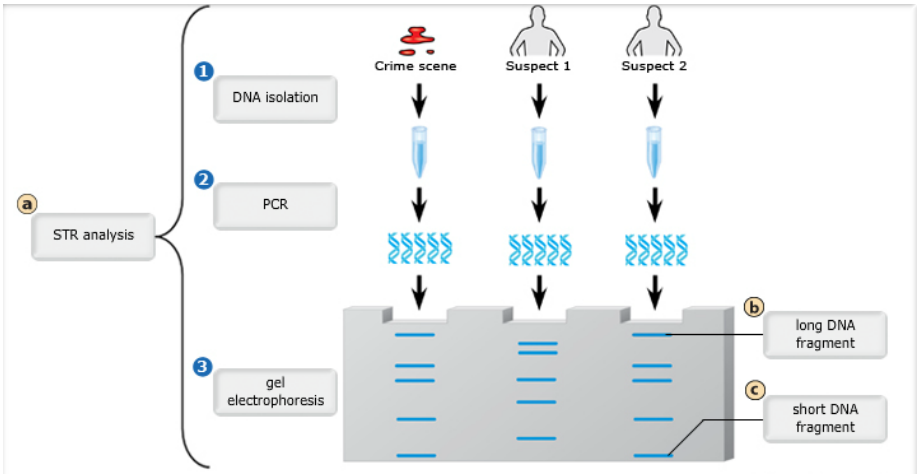
PCR (polymerase chain reaction):

- **PCR (polymerase chain reaction)** is a laboratory technique that takes a single or few copies of DNA and **amplifies** them to generate millions or more copies of a particular DNA sequence.
- When you collect DNA from different sources such as sperm samples or small drops of blood, there are usually very little usable cells to collect DNA.
- Therefore, PCR is used to create enough DNA to be analyzed for investigations such as forensics or custody cases.
- Once large quantities of the DNA have been created, other methods such as gel electrophoresis are used to analyze the DNA.
- **Denaturation**: DNA sample is heated to separate it into two strands
- **Annealing:** DNA primers attach to the opposite ends of the **target gene sequence**
- **Elongation:** A heat-tolerant DNA polymerase (**Taq polymerase**) copies the strand



DNA profiling:

- DNA profiling is a method or technique used to **identify individuals on the basis of their DNA profiles** in comparison to an unknown sample of DNA.
- DNA profiling can be used in **paternity test** to identify the biological father of a child. Scientists can take a blood sample which contains a father's DNA and a blood sample from a child which contains the child's DNA. They can then run a gel electrophoresis to compare the banding patterns between the father and the child.
- DNA profiling can also be used in **criminal investigations** where a small sample of blood, semen, hair or other cells where DNA is present is collected.
- **PCR** can be applied to these small samples of DNA to amplify the DNA into millions of copies to create enough DNA to be analyzed for the investigation.
- Using **restriction enzyme** to cut the DNA into fragments that are separated through **gel electrophoresis** and DNA profiling, the DNA sample can be compared to a suspect's DNA to prove if they are innocent or guilty.
- DNA profiling can also be used to support **ancestral relationships** between organisms for evolutionary studies.
- **Fluorescent marker** may be added to show the colour.



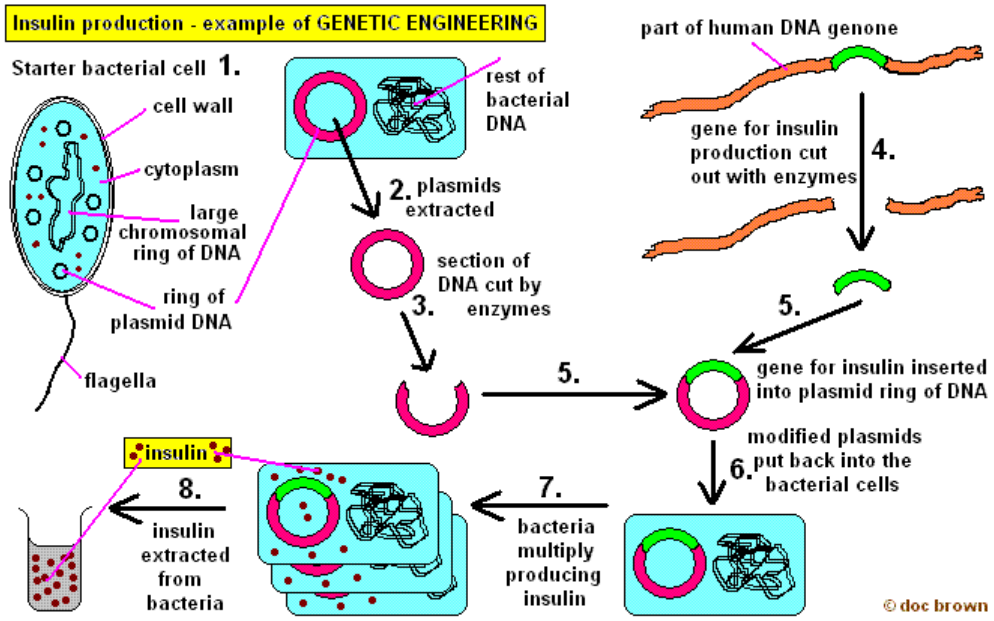
Genetic modification:

- A gene produces a certain polypeptide in an organism.
- Since the genetic code is **universal**, when a gene is removed from one species and transferred to another the sequence of amino acids in the polypeptide produced remains unchanged.

Gene transfer:

- Gene transfer is taking one gene from an organism and inserting it into another organism.
- An example of gene transfer is for the production of **human insulin** produced by the pancreatic cells.
- First, insulin production genes are cut off using **restriction enzyme**.
- Use the **same restriction enzyme** to cut the bacteria plasmid open

- Place the gene into the plasmid using **DNA ligase**. (antibiotic resistance may also be put in to make the plasmid attractive)
- Put the plasmid back in the bacteria.
- Bacteria go through replication and production of human insulin.
- Harvest and purify the insulin.



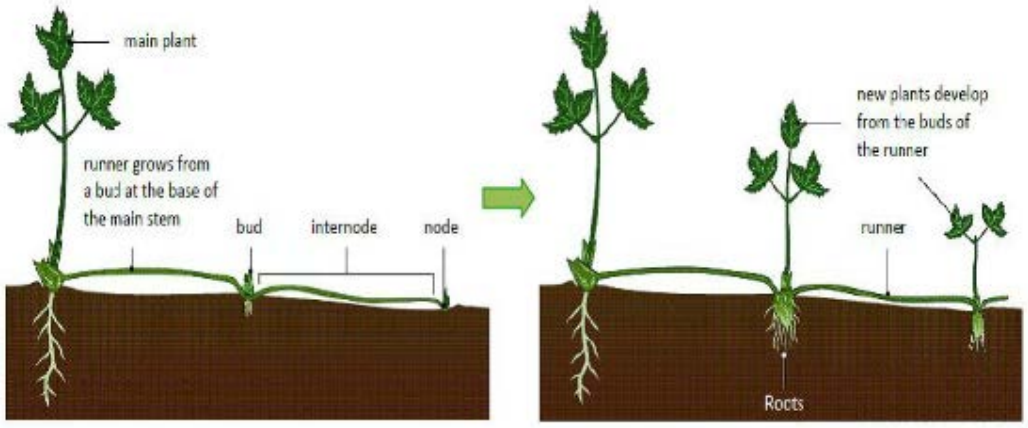
Potential risks and benefits of genetic modified crops:

- **Bt corn**: combine with soil bacterium that produces insecticidal toxin – give resistance to insects

Potential Benefits	Potential Risks
Higher crop **yield** (more production = more money) - crop yield is a debatable benefit	Long term effects on humans are unknown
Less or **no pesticides** used because already resistant to harmful pests	Non-targeted organism will be affected by the toxin
Can use pest resistant crops or modified crops in areas where water availability is limited	Transfer gene could **mutate**
Could add genes for certain proteins, vitamins or possible vaccines (less cost than producing in a lab)	Increased resistance to toxin **eolves** in pest
Crops last longer or don't spoil during storage	Accidental release may result in competition with native species
Increased disease resistance	Biodiversity reduced
Increased hardiness: grow in more locations/seasons	Super weed may appear

Clone:

- Clone: **a group of genetically identical organisms** or a group of cells derived from a single parent cell.
- Organisms that reproduce asexually, produce genetically identical offspring
- Identical twins in humans are also clones (monozygotic twin)
- Bacteria uses binary fission to clone itself
- Underground stems called **tubers** in potatoes can form new potato plants which are clones of the original parent potato plant
- **Runner**: growing stems used to reproduce asexually



Other natural methods of vegetative propagation include specialised underground stems forming **tubers** – stems which become swollen full of nutrient molecules – from which new plants can grow. Potatoes grow in this way.

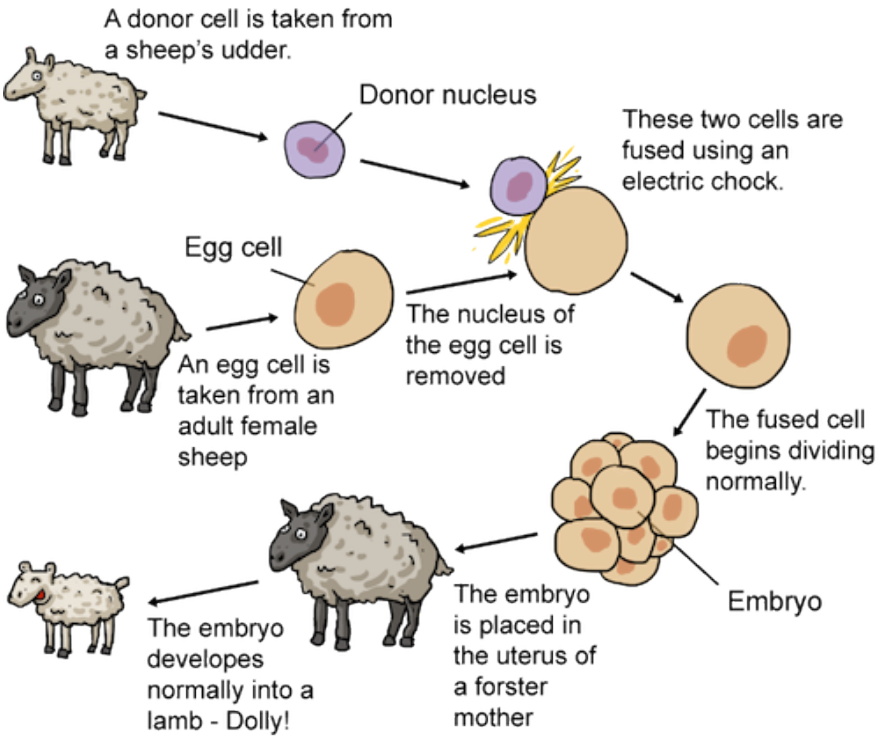
Embryonic stage cloning:

- At the very early embryo stage, cells are still **pluripotent** (meaning they can become any type of tissue)
- These cells can be separated artificially in a laboratory in order to create **more than one of the same organism**
- The separated pluripotent cells can then be inserted into the uterus of a surrogate mother or mothers in order to produce genetically identical offspring
- The separation of cells has to happen early in development, preferably the 8 cell stage

Cloning differentiated cells:

- Once cells start to differentiate and embryos develop into a fetus and eventually an adult cloning becomes much more difficult
- Therapeutic cloning is an example of cloning using differentiated cells
- This type of cloning can be used to **create a specific tissue or organ**
- Cloning using differentiated cells can also be used to reproduce organisms like dolly the sheep. This is done through **somatic-cell nuclear transfer.**

1. Remove a differentiated cell **nucleus**
2. **Enucleate** a donor egg cell
3. Insert nucleus into the cell
4. Treat with electricity and put in back to the womb
5. Produce genetically indentical organism



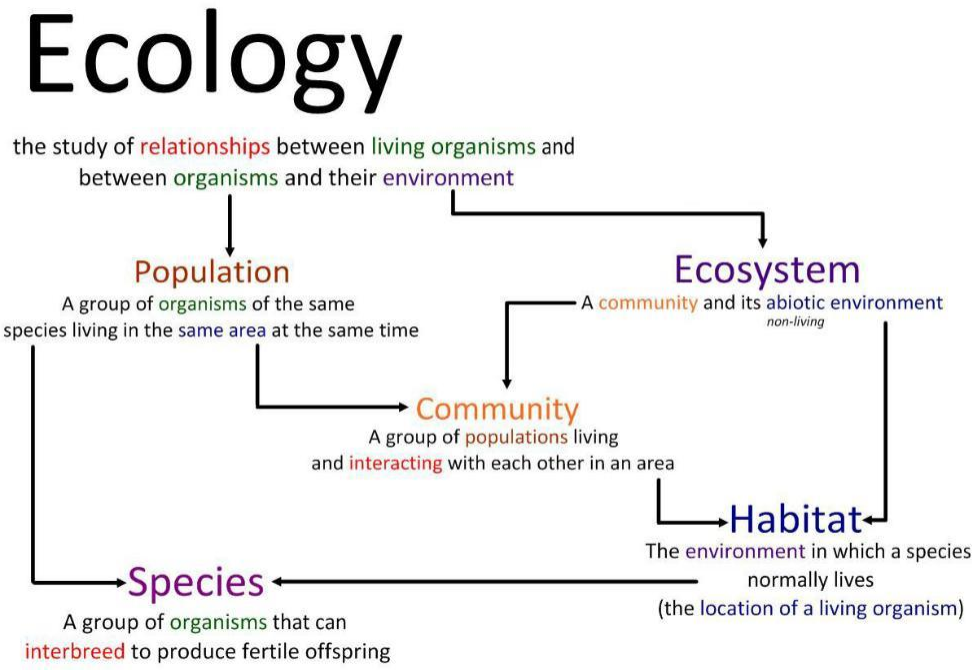
Topic 4: Ecology

4.1 Species, communities and ecosystems

U1	Species are groups of organisms that can potentially interbreed to produce fertile offspring.
U2	Members of a species may be reproductively isolated in separate populations.
U3	Species have either an autotrophic or heterotrophic method of nutrition (a few species have both methods).
U4	Consumers are heterotrophs that feed on living organisms by ingestion.
U5	Detritivores are heterotrophs that obtain organic nutrients from detritus by internal digestion.
U6	Saprotrophs are heterotrophs that obtain organic nutrients from dead organisms by external digestion.
U7	A community is formed by populations of different species living together and interacting with each other.
U8	A community forms an ecosystem by its interactions with the abiotic environment.
U9	Autotrophs obtain inorganic nutrients from the abiotic environment.
U10	The supply of inorganic nutrients is maintained by nutrient cycling.
U11	Ecosystems have the potential to be sustainable over long periods of time.
S1	Classifying species as autotrophs, consumers, detritivores or saprotrophs from a knowledge of their mode of nutrition.
S2	Setting up sealed mesocosms to try to establish sustainability. (Practical 5)
S3	Testing for association between two species using the chi-squared test with data obtained by quadrat sampling.
S4	Recognizing and interpreting statistical significance.

Definitions of ecology:

- **Species**: a group of organisms that can interbreed and produce fertile offsprings
- **Population**: a grooup of organisms of the same species in the same area at the same time
- **Community**: a group of populations living and iteracting with each other in an area
- **Habitat**: the environment in which a species normaly lives
- **Ecosystem**: a community and its abiotic factors



Autotrophs:

- An organism that synthesizes its own organic molecules (makes their own food) from simple inorganic substances.
- Usually autotrophs convert light energy to chemical energy through photosynthesis (**producers**)
- Chemoautotrophs obtain their energy through the oxidation of inorganic molecules in their environments.

Mixotrophs:

- Some unicellular organisms use both methods of nutrition such as *Euglena gracilis* which have chloroplasts to carry out photosynthesis when there is enough sunlight; however, they can also feed on detritus (dead or decaying material) or other smaller organisms. It has a combination of different modes of nutrition.

Heterotrophs:

- An organism that obtains organic molecules from other living organisms or their dead remains. (consumer)
- Heterotrophs consume other organisms because they cannot make their own food.
- Consist of:
    - **Detritivore**: an organism that obtains food by ingesting non-living organic matter such as detritus (decaying organic matter) and humus (decaying plant material) i.e. Vultures and earthworms.
    - **Saprotroph**: an organism that lives on or within nonliving organic matter, secreting digestive enzymes (external digestion) into it and absorbing the nutrients produced by digestion. Saprotrophs help with the decaying or break down of dead organic materials.
    - **Herbivore**: feed on producers (autotrophs)
    - **Omnivore**: feed on a combination of producers and consumers
    - **Carnivore**: feed on consumers
        - **Scavenger**: specialized carnivore that feed mostly on dead and decaying animals.

Quadrant Sampling:

- Estimate population density/size
- Measure the distribution of species
- Place systematically – finding the change of distribution
- Place randomly – finding the population density/size
- Limited to large mobile animals
- Suitable to plants and small, slow-moving animals.

- If the presence or absence of more than one species is recorded in every quadrat during the sampling of a habitat, one can test for an association between the species
- If two different species are found in the same habitat and within the same quadrat, they are **positively associated**. This basically means that one species is more likely to be found, when the other species is also present
- A **negative association** is when two species tend not to occur together
- If there is no association between the two species, negative or positive, the species are said to be **independent**. Basically this means that the location of species A has no effect on species B and vice versa.
- One can test these associations using a **chi-squared test** (called Chi Square Test for Independence)

Chi-square test:

- A chi-square test is a statistical test that can be used to determine whether **observed frequencies are significantly different from expected frequencies**
- These statistical tests enable us to compare observed and expected frequencies empirically and to decide if the results we see are statistically significant. Statistical significance in this case implies that the differences are not due to chance alone, but instead may be caused by other factors at work.
- This is the formula for a chi-squared test: $\chi^2 = \Sigma \frac{(o_i - e_i)^2}{e_i}$, where o means observed group and e means expected groups
- What it basically means is the sum of the (observed minus the expected) squared, divided by the expected.
- We can have two hypothesis out of Chi-square test
- **Null hypothesis**: data is due to chance and is random. There is no association between those two species.
- **Alternative hypothesis**: data is **not** due to chance and is not random, something influence the data
- Check the value with **degree of freedom** (0.05 column) corresponding the value of (number of set of data – 1) e.g. 2 species -1 = 1

Table 1. Critical chi-square values for a p-value of 0.05. Reject the null hypothesis if $\chi^2_{calc} > \chi^2_{crit}$.

df	χ^2_{crit}
1	3.84
2	5.99
3	7.81
4	9.49
5	11.07
6	12.59
7	14.07
8	15.51
9	16.92
10	18.3

- If the result is **less** than the critical value, accept null hypothesis
- If the result is **more** than the critical value, reject the null hypothesis

4.2 Energy flow

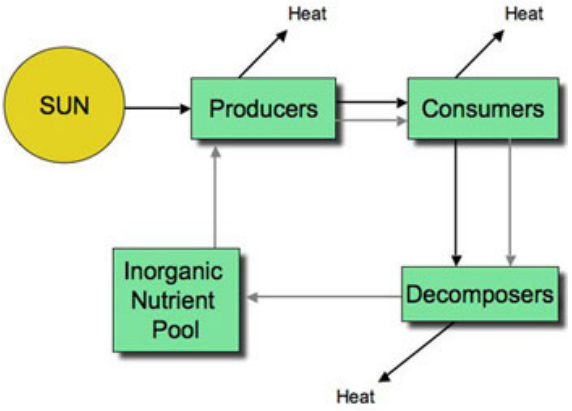
U1	Most ecosystems rely on a supply of energy from sunlight.
U2	Light energy is converted to chemical energy in carbon compounds by photosynthesis.
U3	Chemical energy in carbon compounds flows through food chains by means of feeding.
U4	Energy released from carbon compounds by respiration is used in living organisms and converted to heat.
U5	Living organisms cannot convert heat to other forms of energy.
U6	Heat is lost from ecosystems.
U7	Energy losses between trophic levels restrict the length of food chains and the biomass of higher trophic levels.
S1	Quantitative representations of energy flow using pyramids of energy.

Energy Cycle

- In food webs and communities all interactions between the organisms requires energy.
- **Sunlight** provides the initial energy source for almost all communities.
- Sunlight energy is converted to useable chemical energy through **photosynthesis.**
- **Autotrophs** that harvest the light energy and produce chemical energy through photosynthesis are called producers. These include plants, eukaryotic algae, and cyanobacteria.
- Heterotrophs feed on other organisms in order to obtain their energy
- Producers release energy using **cellular respiration** and use it for cellular activities; some energy lost as heat. The energy remaining in the cells and tissues is available for consumers

Energy Flow

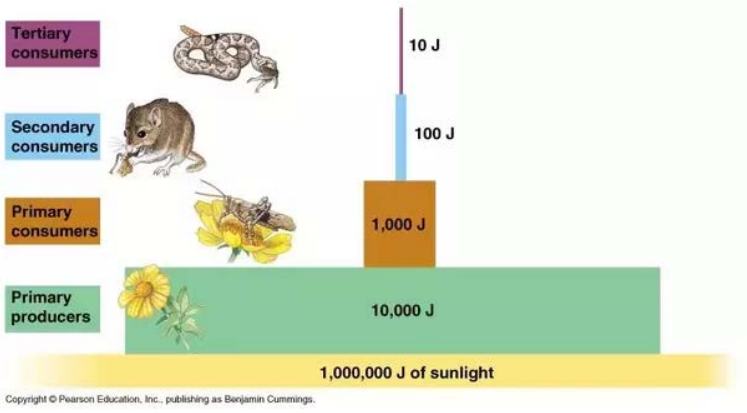
- **1º consumers** feed on **the producers**. Only around **10%** of the energy from the producer is passed on to the 1º consumers. The rest of the energy is **lost as heat** through **cell respiration, death and waste**.
- **2º consumers** feed on the **1º consumers**. Again only 10% of the energy is passed on to the next level, with the rest lost as **heat through respiration, death, and waste.**
- **3º consumers** feed on **2º consumers**. 10% is passed on to the tertiary consumer and the rest is lost as heat, death and waste.
- Most ecosystem rely on a supply of energy from sunlight and the energy flows through the food chain, bing lost at each stage due to respiration (heat).



- Organisms can perform a variety of energy conversions, such as light to chemical energy during photosynthesis, chemical energy to KE during muscle contractions, chemical energy to electrical energy in nerve impulses and chemical energy to heat energy in heat-generating adipose tissue
- **Organisms cannot turn heat energy into any other forms of energy**
- Eventually though, since heat passes from warmer to colder bodies (thermodynamics), all heat is lost from the ecosystem

Pyramid of energy

- Only 10% of energy can be passed on to the next trophic level due to energy loss as heat.
    - Energy is lost because:
- At each level, when an organism is consumed some parts might not be eaten or consumed
- Not all food is digested or absorbed fully. Indigestible food is egested in feces.
- Some energy can be trapped as fossil fuels or peat.
- Energy is also lost due to respiration (heat)



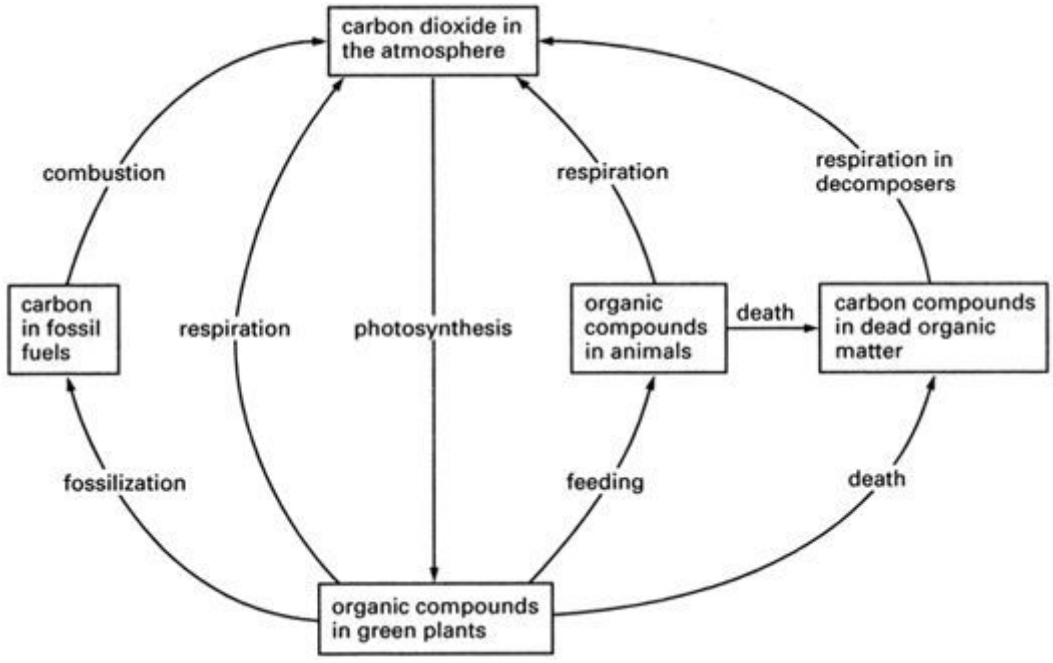
The length of food chain

- **Biomass** is the total dry mass of a group of organisms, consisting of the cells and tissues of the organisms and the carbohydrates and other carbon compounds they contain
- Since carbon compounds have chemical energy, scientists can measure the amount of energy added per year by groups of organisms to their biomass. Results are calculated per square metre of the ecosystem and the trophic levels can be compared. The energy added to the biomass by each successive trophic level is always less
- **Food chain length is limited by the amount of energy available as we move up the different trophic levels.**
- Most energy in food that is consumed, digested and absorbed by organisms for a certain trophic level is released by them during cellular respiration used in cellular activities and is therefore lost as heat
- As we go up the food chain, less energy will be available; thus, the limitation of energy will reduce the length of food chain.
- The unit of energy in biology is **$KJm^{-2}y^{-1}$** (energy per square meter per year)

4.3 Carbon cycling

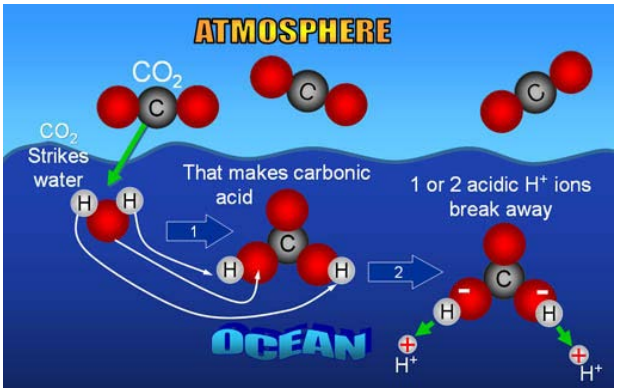
U1	Autotrophs convert carbon dioxide into carbohydrates and other carbon compounds.
U2	In aquatic ecosystems carbon is present as dissolved carbon dioxide and hydrogen carbonate ions.
U3	Carbon dioxide diffuses from the atmosphere or water into autotrophs.
U4	Carbon dioxide is produced by respiration and diffuses out of organisms into water or the atmosphere.
U5	Methane is produced from organic matter in anaerobic conditions by methanogenic archaeans and some diffuses into the atmosphere or accumulates in the ground.
U6	Methane is oxidized to carbon dioxide and water in the atmosphere.
U7	Peat forms when organic matter is not fully decomposed because of acidic and/or anaerobic conditions in waterlogged soils.
U8	Partially decomposed organic matter from past geological eras was converted either into coal or into oil and gas that accumulate in porous rocks.
U9	Carbon dioxide is produced by the combustion of biomass and fossilized organic matter.
U10	Animals such as reef-building corals and mollusca have hard parts that are composed of calcium carbonate and can become fossilized in limestone.
A1	Estimation of carbon fluxes due to processes in the carbon cycle.
A2	Analysis of data from air monitoring stations to explain annual fluctuations.
S1	Construct a diagram of the carbon cycle.

Carbon Cycle



- Autotrophs such as plants and algae, convert inorganic carbon dioxide into organic carbohydrates, lipids and all other carbon based compounds through photosynthesis.
- This reduces the carbon dioxide concentration in the atmosphere.

Carbon in water



- Carbon dioxide dissolves in water and some of it will remain as a **dissolved gas**
- Some of the carbon dioxide will combine with water to form carbonic acid

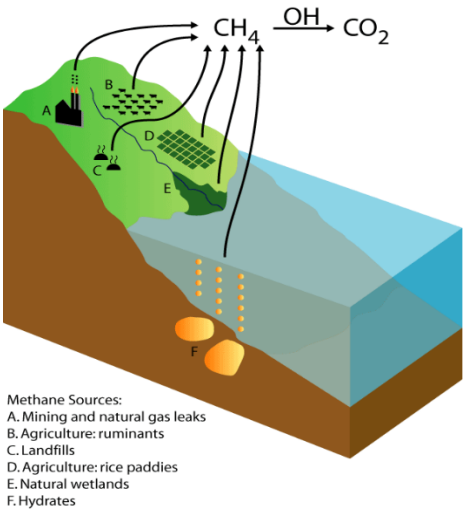
  $CO_2 + H_2O <--> H_2CO_3$.
- Carbonic acid can then disassociate to form H^+ and HCO_3^-

  ($H_2CO_3 <--> HCO_3^- + H^+$)
- This is why the pH of water decreases
- Autotrophs in water absorb both CO_2 and hydrogen carbonate ions, and use them to produce organic compounds
- Since autotrophs use carbon dioxide for photosynthesis, as the CO_2 is depleted by the autotroph, the concentration of CO_2 in the surrounding atmosphere or water is greater than inside the autotroph; therefore a concentration gradient is created. Carbon dioxide will **diffuse** from water and air to autotrophs.

Methanogen

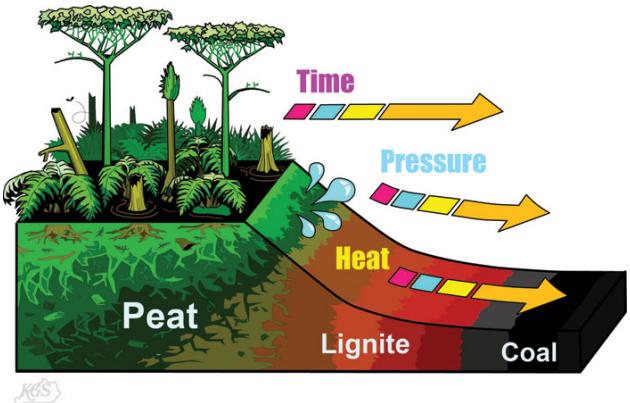
- Archaen microrganisms that produces **methane as a metabolic byproduct** in anaerobic conditions such as wetlands, swamps, landfill.
- Some bacteria use organic acids and alcohol to produce acetate, carbon dioxide and hydrogen

  $CO_2 + 4\ H_2 \rightarrow CH_4 + 2H_2O$ and $CH_3COO^- + H^+ \rightarrow CH_4 + CO_2$
- Methane is the main ingredient in natural gas. When you burn methane the reaction involves oxygen gas from the atmosphere to produce carbon dioxide and water
- When methane is actually released into the atmosphere through the anaerobic reactions, it can persist in the atmosphere for about 12 years, as it is **naturally oxidized by monatomic oxygen (O) and hydroxyl radicals (OH^-)**
- This is why methane concentrations are not very great in the atmosphere, even though large amounts are produced



Peat

- Partially decomposed organic matter can be **compressed** to form brown soil-like **peat** due to inhibition of decomposers by acidic and anaerobic condition.
- In many soils, saprotrophic bacteria and fungi, digest organic material from dead leaves and plants; however, oxygen (air spaces in the soil) is needed for cellular respiration.
- In muddy, **water-logged** environments, these air spaces might not be present and therefore **anaerobic conditions** exist
- Acidic conditions develop, further **inhibiting the decomposers**
- Since this organic material is not fully decomposed, energy rich molecules that would have been fed upon by saprotrophs and methanogens are left behind and energy rich peat is formed



- Partially decomposed peat when put under extreme weight, **pressure and heat** from above sediments can be transformed into **coal**
- This transformation takes place over millions of years
- The dead remains of marine organisms only partial decomposed when they settled at the bottom of the ancient oceans and seas in anaerobic conditions
- As more dead remains and sediment accumulated, intense pressure and heat caused this sludge to undergo a chemical transformation into a mixture of carbon compounds or gases.
- Oil and gas formation occurred in ancient ocean

Formation of limestone

- Animals such as coral and mollusca (clams etc.) contain body parts made out of **calcium carbonate (CaCO3)**
- Hard corals produce their exoskeletons by secreting calcium carbonate and molluscs have shells that contain calcium carbonate
- The calcium carbonate in alkaline or neutral conditions from a variety of these organisms, **settle onto the seafloor when they die**
- Through lithification, these sediments form limestone. The hard parts of many of these animals are visible as **fossils** in the **limestone rock**

4.4 Climate change

U1	Carbon dioxide and water vapour are the most significant greenhouse gases.
U2	Other gases including methane and nitrogen oxides have less impact.
U3	The impact of a gas depends on its ability to absorb long wave radiation as well as on its concentration in the atmosphere.
U4	The warmed Earth emits longer wavelength radiation (heat).
U5	Longer wave radiation is absorbed by greenhouse gases that retain the heat in the atmosphere.
U6	Global temperatures and climate patterns are influenced by concentrations of greenhouse gases.
U7	There is a correlation between rising atmospheric concentrations of carbon dioxide since the start of the industrial revolution 200 years ago and average global temperatures.
U8	Recent increases in atmospheric carbon dioxide are largely due to increases in the combustion of fossilized organic matter.
A1	Threats to coral reefs from increasing concentrations of dissolved carbon dioxide.
A2	Correlations between global temperatures and carbon dioxide concentrations on Earth.
A3	Evaluating claims that human activities are not causing climate change.

Greenhouse Gas

- Greenhouse Gas: gases in atmosphere that retain heat e.g. carbon dioxide, water vapor, methane, nitogen dioxide
- The gases that have the **greatest impact** on the warming effect on earth are CO_2 and water vapour
- **Carbon dioxide** is released into the atmosphere by cellular respiration by organisms and combustion of organic materials and burning of fossil fuels. It is removed by photosynthesis and absorption by the oceans
- **Water vapour** is created by evaporation of the water in oceans, seas and lakes and transpiration by plants. It is removed through precipitation.
- **Methane** has the third greatest impact on the greenhouse effect
- It is emitted from marches, other water-logged habitats and from landfill sites containing organic wastes
- **Nitrogen dioxide**, which is another significant greenhouse gas is released naturally by bacteria in some habitats and also by agriculture and vehicle exhaust
- All the greenhouse gases together make up less than 1% of the earth's atmosphere
- The greenhouse effect is a natural phenomenon that keeps the surface of the earth warm due to the presence of an atmosphere containing these gases that absorb and radiate heat.

Impact of greenhouse gas

- The two factors that determine how much of an influence a gas will have on the greenhouse effect are
  1) The ability of the gas to absorb **long-wave radiation (heat)**
  2) The **concentration of the gas in the atmosphere**
  - Methane actually has the ability to cause much more warming per molecule than carbon dioxide; however, there is a much lower concentration of methane in the atmosphere

- When light (shorter wavelengths) enters the earth's atmosphere, some of the light reflects off the earth's surface back towards outer space.
- Some of the light is converted into heat, which in turn warms the surface of the earth (the air, mountains and water).
- This **heat (longer wavelengths)** radiates off the earth back towards the atmosphere.
- Greenhouse gases such CO2 and water vapour absorb this heat (infrared radiation) trapping it within the atmosphere, further warming the earth.
- As the infrared radiation is reflected back off the earth, a large percentage of this heat is captured by the greenhouse gases in the atmosphere. This energy is re-emitted, thus heating up the earth's atmosphere. This effect is called global warming.

- There is a correlation between **rising atmospheric concentrations of carbon dioxide** since the start of the industrial revolution 200 years ago and **average global temperatures**.
- There is also strong correlation between human emissions and atmospheric carbon dioxide level
- This does not mean that the amount of greenhouse gas is the only reason for the earth warming and cooling
- Other factors such as the cycles in the Earth's orbit around the sun, variations in the amount of solar radiation due to sunspot activity, past volcanic activity, and changes or oscillations in ocean currents

Increase in greenhouse gas level

- The number one source of carbon emissions due to human activities is through **combustion of fossil fuels** in automobiles, buses and planes.
- Another source of carbon dioxide is the **deforestation** through burning large tracks of land and heating homes with fossil fuels, such as natural gas
- Humans **demand for meat** has led to large numbers of cattle, which is responsible for releasing methane into the atmosphere, which is changed into carbon dioxide
- As the human population increases and countries become more industrialized, human production of greenhouse gas, shows no sign of slowing down

- The increase in greenhouse gas will likely lead to:
    - Higher global average temperature
    - More frequent and intense heat wave
    - Some areas become prone to drought
    - Some areas become prone to rainfall and flooding
    - Ocean Acidification – more carbon dioxide dissolved in water

Coral reef

- **Ocean acidification** is the ongoing decrease in the **pH** of the Earth's oceans, caused by the uptake of carbon dioxide from the earth's atmosphere.
- Reef-building corals that use **calcium carbonate** in their exoskeletons need to absorb carbonate ions from seawater.
- The concentration of carbonate ions is low in seawater because they are not very soluble.
- Dissolved CO_2 makes the carbonate concentration even lower as a result of some interrelated chemical reactions:

$$CO_2 + H_2O \text{ <--> } H_2CO_3 \text{ <--> } H^+ + HCO_3^- \text{ <--> } H^+ + CO_3^{2-}$$

- If the carbonate ions concentrations drop it is more difficult for reef-building corals to **absorb these ions to make their exoskeletons**
- Also, if seawater ceases to be a saturated solution of carbonate ions, existing calcium carbonate **tends to dissolve**, so existing exoskeletons of reef-building corals are threatened.
- Global warming will cause the water temperature to increase, this will also affect the growth of coral reef.

Topic 5: Evolution and biodiversity

5.1 Evolution and biodiversity

U1	Evolution occurs when heritable characteristics of a species change.
U2	The fossil record provides evidence for evolution.
U3	Selective breeding of domesticated animals shows that artificial selection can cause evolution.
U4	Evolution of homologous structures by adaptive radiation explains similarities in structure when there are differences in function.
U5	Populations of a species can gradually diverge into separate species by evolution.
U6	Continuous variation across the geographical range of related populations matches the concept of gradual divergence.
A1	Development of melanistic insects in polluted areas.
A2	Comparison of the pentadactyl limb of mammals, birds, amphibians and reptiles with different methods of locomotion.

Evolution: cumulative change in the heritable characteristics of a population

- Cumulative change: small change over many generations
- Heritable characteristics: gene-controlled factors
- These traits cannot be acquired over a lifetime, they are heritable traits or alleles in an organism's DNA

Evidence of evolution:

- Fossil records – sedimentary rocks
- Homologous structure
- Vestigial structure e.g. appendix
- Selective breeding
- Comparative DNA
- Observable change

Fossil records:

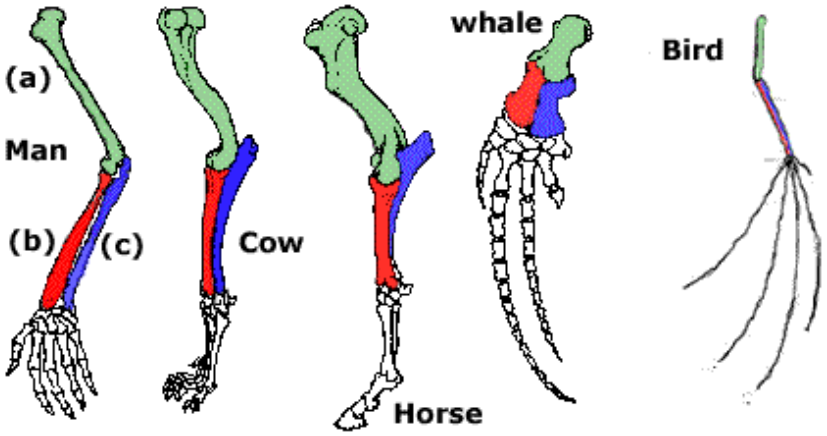
- Fossils are the preserved remains of animals, plants, and other organisms from the past.
- The fossil record shows the **gradual change** of species over time.
- The timeline in which fossils appear are what scientists would expect, with bacteria and algae being the oldest in the fossil record. Followed later by shelled animals and trilobites, then dinosaurs and early reptiles, birds and mammals later still.

Selective breeding:

- Breeding plants and animals for specific genetic traits.
- Shows a good record of recent changes in genetic characteristics over a few dozens of generations that man has selected to breed.
- For example, chickens that produce more eggs or cows that produce more milk are selected to breed, hopefully passing these traits onto next generations.
- Plants can be bred in a similar manner based on useful or beneficial characteristics breeders would like to see in the next generation of plants.
- The evolution of **domesticated dogs** has produced many different breeds through artificial selection

Homologous structure:

- Common **internal structures** that are similar in seemingly dissimilar animals that have evolved from a common ancestor.
- The standard example of homologous structures is the "**Pentadactyl limb**" which is the five digit limb found in animals such as humans, dolphins, bats, and dogs.
- Even though the shape, size and function of this structure vary between species, the general structure and position of the bones in these limbs are the same.



Gradual diverge:

- Within a population there is genetic variation
- If two populations of the same species become separated so that they do not reproduce or interbreed because they become separated by geographical boundaries; for example one group migrates to an island or they became separated by a mountain range, then natural selection will act differently on those two separate populations
- Over time, these populations change so that they are recognizably different and can or do not interbreed if they were to merge together again
- This process is called **speciation**

5.2 Natural selection

U1	Natural selection can only occur if there is variation among members of the same species.
U2	Mutation, meiosis and sexual reproduction cause variation between individuals in a species.
U3	Adaptations are characteristics that make an individual suited to its environment and way of life.
U4	Species tend to produce more offspring than the environment can support.
U5	Individuals that are better adapted tend to survive and produce more offspring while the less well adapted tend to die or produce fewer offspring.
U6	Individuals that reproduce pass on characteristics to their offspring.
U7	Natural selection increases the frequency of characteristics that make individuals better adapted and decreases the frequency of other characteristics leading to changes within the species.
A1	Changes in beaks of finches on Daphne Major.
A2	Evolution of antibiotic resistance in bacteria.

Occurrence of natural selection:

- Within a species, different individuals of that species show genetic variation.
- Individuals that are best suited for their environment will survive and reproduce.
- If there was no variation within a species, then all individuals would be the same and no individual would be favoured over the other and natural selection would not take place

Genetic variation:

- Sexual reproduction can produce variation in a species through fertilization and meiosis.
- Sexual reproduction occurs when two different members of a species create offspring that have a combination of genetic material contributed from both parents.
- During **meiosis** 50% of the females chromosomes will end up in the egg(haploid gamete) and 50% of the male's chromosomes will end up in the sperm (haploid gamete).
- **During meiosis chromosomes *will line up or assort independently*** of each other creating (2^n) possible variations of chromosomes in the sex cells.
- During meiosis, specifically prophase I, crossing over might occur in homologous chromosomes where parts of each chromosome are exchanged.
- **Random fertilization** through sexual reproduction gives millions of sperms a chance at fertilizing the egg. This allows mutations that have occurred in different individuals to come together in their offspring.
- Lastly, **genetic mutations** might occur where new alleles are produced. Genetic mutations are the original source of variation within a species.
- Mutations that give an advantage are selected for.
- Mutations that give a disadvantage are selected against.

Struggle for survival:

- Populations tend to produce more offspring than the environment can support or that could survive in a particular community or ecosystem.
- For example, fish produce thousands of eggs but only few make it to adulthood.
- Plants also can produce hundreds or thousands of seeds to be released into the environment.
- When parents don't spend a lot or even any time caring for their young, they produce many offspring. This is a reproductive method used to make sure **some offspring make it to the next generation**.
- Parents that put a lot of time and energy protecting and raising their young tend to have far smaller litters, i.e. most mammals.
- If there are too many organisms, the demand for resources increases.
- However, there is a limited supply of resources in an ecosystem.
- Overpopulation and a limited amount of resources creates competition within a population.
- They have to compete for mates, food, space, predation, and disease.

- Within a population, there is genetic variation between the individuals in the population.
- The organisms with the **beneficial characteristics** will be able to out-compete the other individuals with the less beneficial or harmful genetic traits for limited resources and mates.
- Therefore, these individuals will survive and reproduce and pass these genetic traits onto the next generation of offspring.
- Organisms with less desirable traits will die or produce less offspring
- Over many generations the **accumulation of these beneficial genetic** traits may result in a change in the population known as evolution.
- For another species to develop, these genetically different individuals eventually have to become reproductively isolated (separated from the general population) where they will only reproduce with individuals with similar genetic traits.
- Acquired characteristics of an individual such as large muscles are not passed on to an organism's offspring

Antibiotic resistance:

- Antibiotics kill bacteria directly or weaken the bacteria so your immune system can fight and destroy the invading pathogen.
- If a patient has a bacterial infection, when antibiotics are given to fight the infection the majority of the original population of bacteria will be destroyed.
- However, some of these bacteria might not die because of changes within their DNA. These changes could be caused by mutations within their genome or the transfer of an **antibiotic resistant** gene from another bacterium.
- Resistance is more likely to occur if the proper amounts of antibiotics aren't taken or if a patient doesn't finish the prescription.
- These resistant bacteria will survive and reproduce, creating more identical resistant bacteria.
- These resistant bacteria will make the person sick again in the future.
- However if given the same antibiotic, these bacteria will no longer be destroyed.
- Another antibiotic can be prescribed to kill these new resistant bacteria.
- Resistance can be passed onto other pathogenic bacteria, creating more species of resistant bacteria.

Finches on Daphne Major:

- Beak shape changes according to the food – environmental change causes change in available food.

5.3 Classification of biodiversity

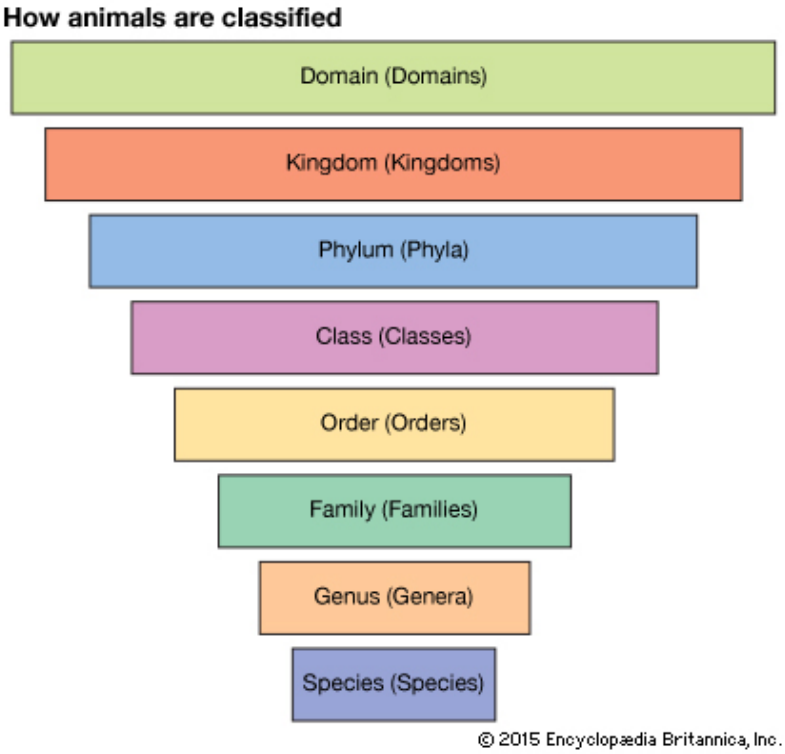
U1	The binomial system of names for species is universal among biologists and has been agreed and developed at a series of congresses.
U2	When species are discovered they are given scientific names using the binomial system.
U3	Taxonomists classify species using a hierarchy of taxa.
U4	All organisms are classified into three domains.
U5	The principal taxa for classifying eukaryotes are kingdom, phylum, class, order, family, genus and species.
U6	In a natural classification, the genus and accompanying higher taxa consist of all the species that have evolved from one common ancestral species.
U7	Taxonomists sometimes reclassify groups of species when new evidence shows that a previous taxon contains species that have evolved from different ancestral species.
U8	Natural classifications help in identification of species and allow the prediction of characteristics shared by species within a group.
A1	Classification of one plant and one animal species from domain to species level.
A2	Recognition features of bryophyta, filicinophyta, coniferophyta and angiospermophyta.
A3	Recognition features of porifera, cnidaria, platylhelmintha, annelida, mollusca, arthropoda and chordata.
A4	Recognition of features of birds, mammals, amphibians, reptiles and fish.
S1	Construction of dichotomous keys for use in identifying specimens.

Binomial Nomenclature:

- The first name in the binomial naming system is called the **genus** and is always capitalized.
- The second name starts with a small letter and is called the **species**.
- The name must be written in italic. (in handwriting, underline the name), for example: *Escherichia coli*
- Genus name abbreviation can be used if the full name is already used, for example *E.coli*
- Species: is a group of organisms which can **interbreed** and produce **fertile** offspring.
- Sub-species: species might potentially interbreed if a barrier (e.g. geographical) or other challenge was removed.

Taxonomy:

- A taxon means a group of something
- Scientists arrange or organize species in to a hierarchical set of groups in order to organize organisms into specific similar groups based on similar characteristics
- As one goes higher up on a classification chart, the greater the number of species are included into the group



- All organisms are classified into three domains: eukaryota, bacteria, archaea
- The Archaea and Bacteria domains are **prokaryotes**. These are organisms that do not have a membrane bound nucleus and their DNA is not associated with proteins.
- The Eukarya domain includes eukaryotes, or organisms that have a membrane bound nucleus.
- Groups organisms primarily based on differences in ribosomal RNA structure. Ribosomal RNA is a molecular building block for ribosomes.

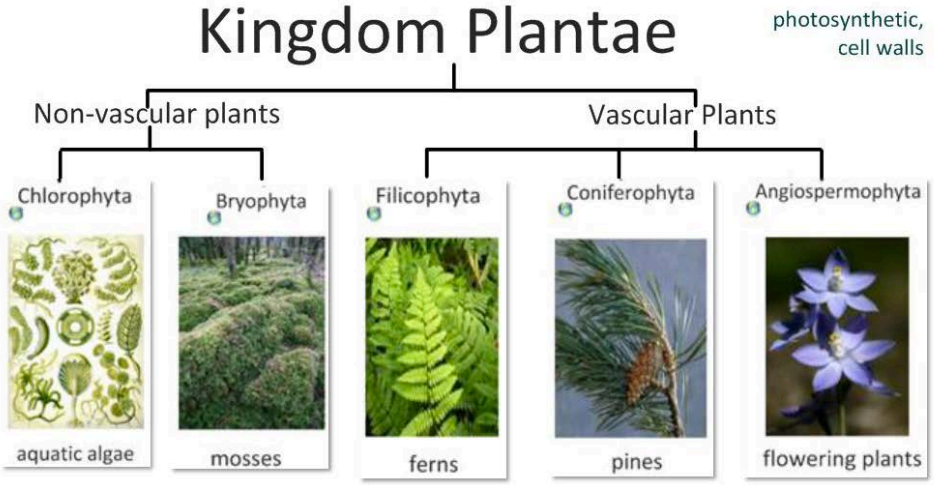
Identification of species:

- Natural classification is very useful for research into biodiversity
- Easier identification for new species that do not obviously fit into a specific
- A **dichotomous key** could be used to put an organism into a classification that fits that organism the best
- This would not work as well for artificial classification (e.g. Colour of flower petals)
- Since organism evolved from a common ancestor, new species would share similar characteristics (likely internal), allowing for easier identification and classification. For example the pentadactyl limb, or mammary glands in mammals

Plantae Classification:

- **Bryophytes**: no vascular tissue, very small, use spore to reproduce e.g. moss
- **Filicinophytes**: has vascular tissue, use spore to reproduce e.g. fern
- **Coniferophytes**: has vascular tissue, use naked seeds to reproduce, woody
- **Angiospermophytes**: has vascular tissue, produce flowers

Phylum name	Vascular tissue	Means of reprodcution	Roots and stems	Examples
Bryophytes	None	Spores	No roots, simple leaves and stems	Mosses
Filicinophytes	Yes	Spores	Has root, short non-woody stems	Ferns
Coniferophytes	Yes	Naked seeds	Has roots, woody stmes	Pines
Angiospermophytes	Yes	Flowering	Has roots, variable leaves and stems	Peach tree



Animalia classification:

- **Porifera**: sponges, no mouth or anus, filter food from current, attached to rocky surface
- **Cnidaria**: jellies, radical symmetry, has mouth but no anus, many has stinging cells
- **Platyhelminthes**: flatworms, bilaternal symmetry, mouth but no anus, no segmentation
- **Annelida**: segmented worms, bilaternal symmetry, has mouth and anus
- **Mollusca**: squid, bilaternal symmetry, has mouth and anus, usually has a shell
- **Arthropoda**: inserts, bilaternal symmetry, has mouth and anus, jointed, has exoskeleton and joints

Phylum name	Anus	Mouths	Symmetry	Segmentation	Other features	Examples
Porifera	None	None	None	None	Attach to rocks	Sponges
Cnidaria	None	Yes	Radical	None	Stinging cells	Jellies
Platyhelminthes	None	Yes	Bilaternal	None	Flatten body	Flatworms
Annelida	Yes	Yes	Bilaternal	Yes	Bristles	Earthworms
Mollusca	Yes	Yes	Bilaternal	None	Have shells	Squids
Athropoda	Yes	Yes	Bilaternal	Yes	Exoskeleton and joints	Insects

Use this dichotomous key to identify the 6 main phyla of invertebrates

Give the common name and latin name of one example of each

1. Is it symmetrical?	Yes	go to Q2
	No	Phylum Porifera e.g.
2. Symmetry is	Radial	Phylum Cnidaria e.g.
	Bilateral	go to Q3
3. Gastric tube	Mouth & anus	go to Q4
	Mouth, no anus	Phylum Platyhelminthes e.g.
4. Segmentation	Yes	Go to Q5
	No, or not visible	Phylum Mollusca e.g.

Classification of vertebrate class

	Limbs	Gas Exchange	Reproduction	Other features
Mammals	4 Pentadactyl limbs	Lungs with alveoli	• Internal fertilization • Give birth to live young • Mammary glands secrete milk	• Hairs growing from the skin • Teeth including living tissue
birds	4 Pentadactyl limbs, 2 limbs modified as wings	Lungs with parabronchial tubes	• Internal fertilization • Hard shells around the eggs	• Feathers growing from skin • Beak but no teeth
reptiles	4 Pentadactyl limbs	Lungs with extensive folding	• Internal fertilization • Soft shells around eggs	• Dry scaly impermeable skin • Simple teeth – no living tissue
amphibians	4 Pentadactyl limbs	Simple lungs with small internal folds and moist surfaces	• External fertilization in water • Protective jelly around eggs • Larval stage lives in water	• Soft moist permeable skin
fish	Fins	Gills	• External fertilization in most species	• Scales grow from the skin • with a single gill slit • Swim bladder for buoyancy

Dichotomous key:

- A dichotomous key is a key constructed from a series of statements arranged into pairs.
- The two descriptions should represent separate choices or characteristics that determine the difference between two organisms.
- Both choices are read and compared with the organism to be identified.
- If the first characteristic is present in the organism to be identified follow the instructions at the end of the statement. If the characteristic is not present go to the second statement as this should be true.
- Once a choice is made, that selection directs you to another pair of descriptive statements.
- One statement might identify the organism or lead you further on in the key.
- This process is repeated until a successful identification is obtained.

1. a. Organism has a backbone.....go to 2
1. b. Organism does not have a backbone.....go to 5

2. a. Organism has wings.....go to 6
2. b. Organism does not have wings.....go to 3

3. a. Organism has legs.....go to 4
3. b. Organism does not have legs.....Snake

4. a. Organism has a shell.....Turtle
4. b. Organism does not have a shell.....Frog

5. a. Organism has antenna.....Insect
5. b. Organism does not have antenna.....Spider

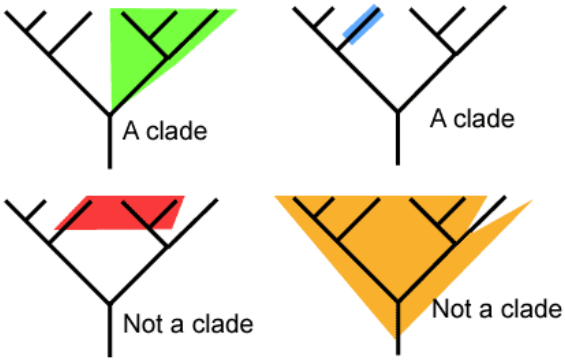
6. a. Organism has feathers.....Bird
6. b. Organism has hair.....Bat

5.4 Cladistics

U1	A clade is a group of organisms that have evolved from a common ancestor.
U2	Evidence for which species are part of a clade can be obtained from the base sequences of a gene or the corresponding amino acid sequence of a protein.
U3	Sequence differences accumulate gradually so there is a positive correlation between the number of differences between two species and the time since they diverged from a common ancestor.
U4	Traits can be analogous or homologous.
U5	Cladograms are tree diagrams that show the most probable sequence of divergence in clades.
U6	Evidence from cladistics has shown that classifications of some groups based on structure did not correspond with the evolutionary origins of a group or species.
A1	Cladograms including humans and other primates.
A2	Reclassification of the figwort family using evidence from cladistics.
S1	Analysis of cladograms to deduce evolutionary relationships.

Cladogram:

- Cladogram is a tree diagram showing the similarities and differences between different species
- Branching points on the cladgram is called **nodes**
- Nodes denote a speciation event when a common ancestor splits into two or more species
- These groups of species evolved from a common ancestor, that have shared characteristics is called a **clade**
- Sometimes determining which species are part of a certain clade is difficult
- The most accurate evidence is derived from amino acid sequences of certain proteins, such as *Hemoglobin and Cytochrome C* and from base sequences of genes



Time correlation:

- Differences in the base sequence of DNA are caused by mutations. These gradually accumulate over time.
- Rate at which mutations occur can be used as a **molecule clock** to calculate how long ago specie diverge.
- By sequencing nuclear DNA and mitochondrial DNA, we can establish a biochemical phylogeny between species to show common ancestry
- The difference in the sequences can be used to deduce when a certain species split from a common ancestor

Analogous structure:

- Some animals belonging to different groups live in the same or similar habitat
- This can lead to development of similar superficial structures for organisms that live in a similar manner
- The structures look comparable anatomically from the outside; however, are not alike on the inside (do not share a common ancestor)
- They are similar traits but not from a common ancestor

Homologous structure:

- Common internal structures that are similar in seemingly dissimilar animals that have evolved from a common ancestor.
- The standard example of homologous structures is the “pentadactyl limb” which is the five digit limb found in animals such as humans, dolphins, bats, and dogs.
- Even though the shape, size and function of this structure vary between species, the general structure and position of the bones in these limbs are the same.

Reclassification:

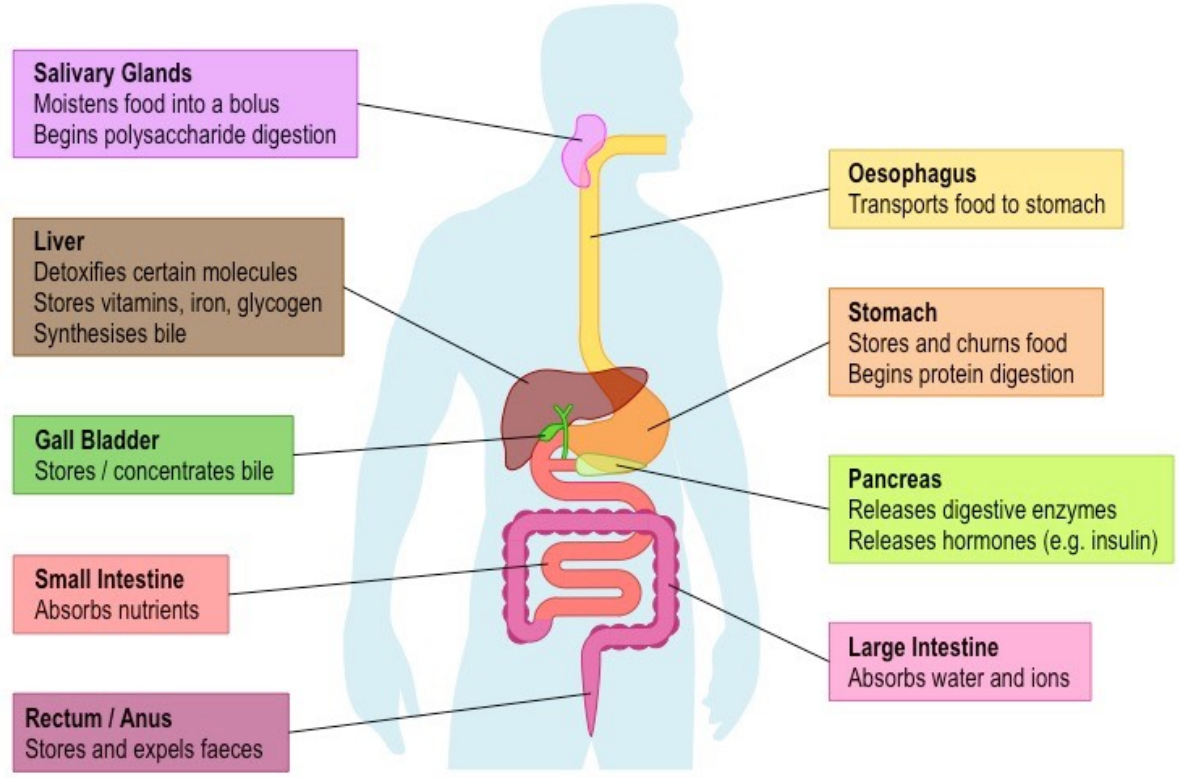
- Since evidence from base and amino acid sequences only became possible in the mid to late 1900’s, some changes have occurred in traditional classifications of certain plants and animals based solely on morphology
- Cladistics has provided evidence that shows some morphologies do not match the evolutionary origins of the groups of organisms they were put in to
- As a result some groups have been reclassified, some groups have merged or divided, and in some cases, some species have been moved to another group
- This process is time consuming; however, the new classifications based on cladistics, give a clear and more concise view of an organism’s true natural classification
- An example of the reclassification of an organism is the Family Scrophlahulariaceae
- At one point this family consisted of over 275 genera and 5000 species
- Scientists recently used cladistics to reclassify the Figworts family
- They focused on the base sequences of three **chloroplast genes** and discovered that the species in the Figwort family were not one clade but five clades and had been incorrectly grouped together into one family

Topic 6: Human physiology

6.1 Digestion and absorption

U1	The contraction of circular and longitudinal muscle of the small intestine mixes the food with enzymes and moves it along the gut.
U2	The pancreas secretes enzymes into the lumen of the small intestine.
U3	Enzymes digest most macromolecules in food into monomers in the small intestine.
U4	Villi increase the surface area of epithelium over which absorption is carried out.
U5	Villi absorb monomers formed by digestion as well as mineral ions and vitamins.
U6	Different methods of membrane transport are required to absorb different nutrients.
A1	Processes occurring in the small intestine that result in the digestion of starch and transport of the products of digestion to the liver.
A2	Use of dialysis tubing to model absorption of digested food in the intestine.
S1	Production of an annotated diagram of the digestive system.
S2	Identification of tissue layers in transverse sections of the small intestine viewed with a microscope or in a micrograph.

Digestive track



Mouth

- Chewing, physical digestion of the food
- Saliva moistens the food, produce a ball of food called **bolus**
- **Saliva amylase** begins chemical digestion of **starch** to maltose

Oesophagus

- A wave of muscle contraction to push the bolus to stomach; such movement of muscle called **peristalsis**
- Peristalsis also occurs in small intestine

Stomach

- Muscle contraction continues mechanical digestion
- Produce **hydrochloric acid** to kill bacteria and aid digestion
- Produce **pepsin** to break down protein
- Have thick layers of mucus to stop HCl from breaking down itself
- The end product is called **chyme**, which flows into duodenum.

Duodenum

- Beginning part of small intestine
- **Bile** from liver and gallbladder neutralize acid and emulsifies fat
- **Pancreatic amylase** to digest carbohydrates
- **Lipase** to digest fat
- **Trypsin** to digest protein

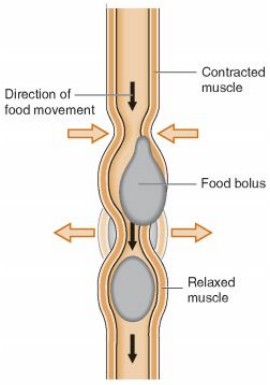
ileun:

- Lower half of small intestine
- Absorb nutrients into the blood via villi

Large intestine

- Water re-absorption
- Leaving semi-solid feces and store in the rectum

Peristalsis



- The contraction of **circular** and **longitudinal** muscle of the small intestine helps mix (mechanical digestion) the food with enzymes and moves the semi-digested food (bolus) along the gut in a process called **peristalsis**
- These muscles are made up of smooth muscle
- Contraction of longitude muscle expands the lumen in front of the food, giving it space to move into.
- Contraction of circular muscle behind the food propels it forward.
- Food is transported slowly through the small intestine to allow for maximum digestion and absorption of nutrients

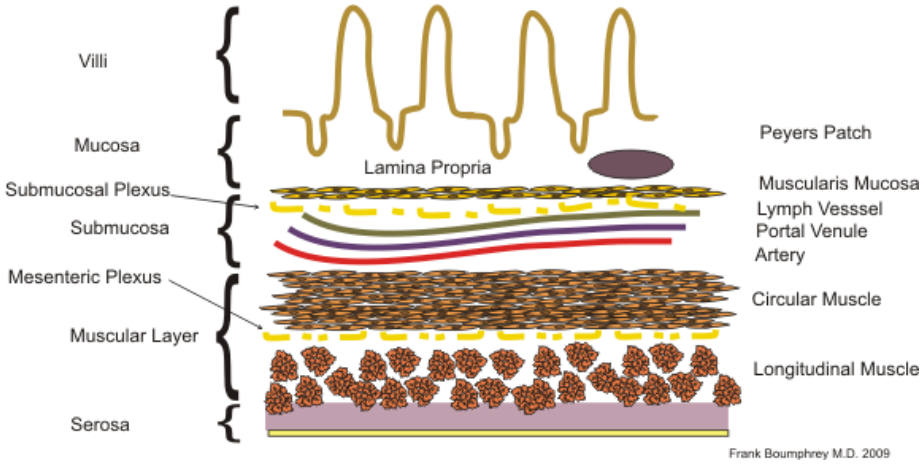
Enzymes in digestion

- Enzymes are biological catalysts that speed up the rate of reaction in chemical digestion.
- Enzymes in digestion catalyze **hydrolysis reactions**.
- Pancreatic juice secreted into small intestine contains enzymes such as:
- **Peptidases** – example **trypsin** (breaks apart the peptide bond between amino acids in polypeptides)
- Trypsin works in duodenum and pepsin works in stomach due to their different range.
- **Lipases** – catalyzes the hydrolysis of lipids (triglycerides and phospholipids)
- **Amylases** - digestion of starch.
- Pancreatic juice is **alkaline** (basic) to allow enzymes to work at an optimal pH (around 7-8 in the small intestine).
- **Bile** is produced in liver and stored in gallbladder, which is used to neutralize the stomach acid and emulsify the fat (breaking down fat into smaller droplets.).
- Please note that some carbohydrates such as **cellulose** cannot be digested by humans as we lack the enzymes needed to break down cellulose

Enzyme name	Site of production	Location of effects	Substrates and product	pH level
Saliva amylase	Salivary gland	Mouth	Starch to maltose	Neutral
Pepsin	Gastic gland	Stomach	Protein to smaller polypeptides	Acidic
Trypsin	Pancreas	Duodenum	Protein to smaller polypeptides	Basic
Lipase	Pancreas	Duodenum	Fat droplets to fatty acid and glycerol	Basic
Bile	Liver (Stored in gallbladder)	Duodenum	Fat emulsifies to fat droplets	Basic
Pancreatic amylase	Pancreas	Duodenum	Disaccharide	Basic

Small intestine structure

- **Serosa layer** – protective outer layer
- **Muscular layer** – inner circular and outer longitudinal muscle (smooth muscle) which performs peristalsis
- **Submucosa layer** – connective tissue between mucosa and muscular layer
- **Mucosa** – inner lining, includes villi for absorption



Villi

- Villi are finger-like projections that make the surface of the small intestine look highly folded. These projections increase the **surface area** (by about 10X) available for absorption (the process of taking substances into the cells and blood).
- The outermost layer of the villi is thin **epithelial cells** to allow nutrients to easily move across a short distance into the blood.
- **Microvilli** on the surface of each epithelial cells are small hair-like projections attached to the villi to further **increase surface area**.
- A dense network of **blood capillaries close** to the epithelium allows a shorter diffusion pathway.
- **Lacteals**, which are a part of the lymphatic system, run up the middle of the villi. The lacteal allows for the absorption of the products of **lipid digestion** which are not easily absorbed by the capillaries.
- **Rich blood supply** maintains a concentration gradient between lumen and blood

Absorption of villi

- **Digestion** – process which breaks down larger food molecules to smaller molecules.
- **Absorption** – process where small molecules and nutrients **pass into the blood vessels** (capillary beds) in the wall of the intestine.
- **Assimilation** – products of digestion that are absorbed into the blood are transported to the various tissues. These molecules are **used** to build up larger molecules that become part of the structure of the tissue or body.
- These products include the following monomers:
- **Monosaccharides**
- **Amino acids** from the breakdown of proteins
- **Nitrogenous bases** from the breakdown of nucleotides
- **Glycerol and fatty acids,** which are the products of lipids are absorbed by the lacteal inside the villi.
- **Mineral ions** such as sodium, potassium and calcium, and **vitamins** such as vitamin C, are also absorbed by the villi in the small intestine

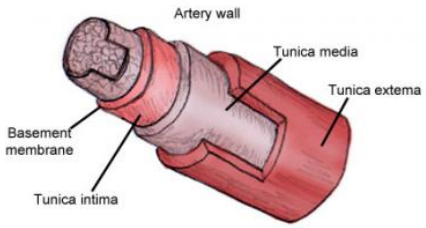
Ways to transport	Nutrients
Simple diffusion	Lipids
Facilitated diffusion	Frutose/vitamin
Active transport	Glucose/amino acid/mineral ions
Endocytosis	Antibodies(from breast milk)
Co-transport	Glucose/amino acid

6.2 The blood system

U1	Arteries convey blood at high pressure from the ventricles to the tissues of the body.
U2	Arteries have muscle cells and elastic fibres in their walls.
U3	The muscle and elastic fibres assist in maintaining blood pressure between pump cycles.
U4	Blood flows through tissues in capillaries. Capillaries have permeable walls that allow exchange of materials between cells in the tissue and the blood in the capillary.
U5	Veins collect blood at low pressure from the tissues of the body and return it to the atria of the heart.
U6	Valves in veins and the heart ensure circulation of blood by preventing backflow.
U7	There is a separate circulation for the lungs.
U8	The heart beat is initiated by a group of specialized muscle cells in the right atrium called the sinoatrial node.
U9	The sinoatrial node acts as a pacemaker.
U10	The sinoatrial node sends out an electrical signal that stimulates contraction as it is propagated through the walls of the atria and then the walls of the ventricles.
U11	The heart rate can be increased or decreased by impulses brought to the heart through two nerves from the medulla of the brain.
U12	Epinephrine increases the heart rate to prepare for vigorous physical activity.
A1	William Harvey's discovery of the circulation of the blood with the heart acting as the pump.
A2	Pressure changes in the left atrium, left ventricle and aorta during the cardiac cycle.
A3	Causes and consequences of occlusion of the coronary arteries.
S1	Identification of blood vessels as arteries, capillaries or veins from the structure of their walls.
S2	Recognition of the chambers and valves of the heart and the blood vessels connected to it in dissected hearts or in diagrams of heart structure.

Blood Vessel

- **Arteries:**
  - Take blood away from the heart to tissues around the body
  - Because large volumes of blood are flowing directly out of the heart, arteries must be able to withstand the **high pressure** and high blood volume created when the ventricles contract.
  - **Very thick wall of smooth muscle** tissue surrounding arteries makes them strong and elastic in nature with a **narrow lumen** (area where the blood flows).
  - Elastic fibres store energy when they are stretched by the flow of blood. As they recoil the blood is further propelled through the artery.
  - The thick smooth muscle layer in the arteries can be used to help regulate blood pressure by changing the diameter of the arteries.

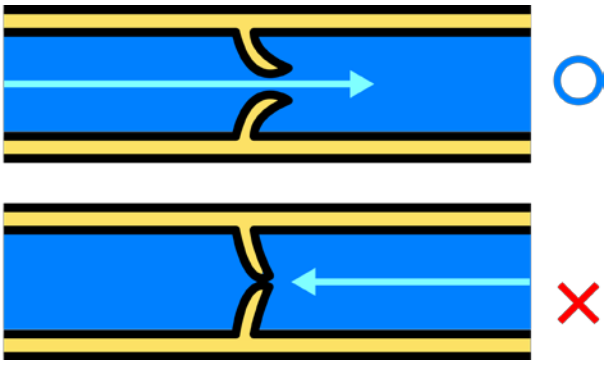


  - **Tunica externa** – outer layer made from connective tissue and **elastic fibre**
  - **Tunica media** – thick layer containing **smooth muscle**
  - **Tunica intima** – endothelium layer that lines the inside of the artery
  - When the ventricles of the heart contract (systole), the blood leaves the heart through the arteries at a very high pressure
  - The blood pushes the walls of the arteries outwards, thus increasing the diameter of the lumen and creating potential energy within the elastic walls of the artery
  - As the blood passes after the heart has contracted, the pressure drops and the stretched elastic walls snap back, squeezing the blood in the lumen to conserve energy and preventing the pressure from becoming too low inside the arteries
  - However, since this pressure still relatively high, blood flow in the arteries is fairly consistent and steady, even though the heart pumps in pulsating manner

- **Capillaries:**
  - Capillaries have a very **narrow diameter** (**one cell thick** 10 μm) with thin surrounding endothelium cells to allow the shortest distance for O_2 to diffuse into the blood from the alveoli in the lungs and from the blood into the body tissues. CO_2 also can easily diffuse out of the blood into the alveoli in the lungs and from the tissue into the blood after respiration.
  - The walls have pores, making them very **permeable** allowing plasma to leak out and form tissue fluid, which contains oxygen, glucose and all other substances contained in the blood plasma, except proteins (too large to fit through the pores in the capillary wall)

- Highly branched networks of capillaries increase the **surface area**, maximizing the amount of nutrients and gases that can move in and out of the capillaries.
- Because they are highly branched, the blood slows down to allow efficient transfer of O_2 and CO_2 into and out of the capillaries.
- Capillaries have **small lumen and low pressured** blood

- **Veins:**
  - Transport blood **back** to the heart from the capillary beds in tissues.
  - Very **low blood pressure** and therefore the walls can be **thin**. Blood is pushed back to the heart through the contraction of skeletal muscles. As the muscles contract, the veins are squeezed, pushing the blood back towards the heart
  - Large lumen allows large amounts of blood to slowly return to the heart because the blood has to slow down as it passes through the capillary beds.
  - Since the blood pressure in the veins is quite low because the blood slows down considerably when it reaches the capillary bed and there is not another pump like the heart to speed up the flow and increase the pressure, veins have a series of **valves to prevent backflow**.



Comparison table between different types of blood vessels

Blood Vessel	Wall	Lumen	Pressure	Valves
Arteries	Thick	Small	High	No
Vein	Thin	Large	Low	Yes
Capillaries	One-cell thick	Small	Low	No

Blood Circulation

- Humans and other mammals have a two different circulations of blood (blood is pumped twice).
- One circulation (systemic circulation) goes from the **left ventricle** to the rest of the body and back to the right atrium.
- The second circulation (pulmonary circulation) goes from the **right ventricle** to the lungs and returns to the left atrium of the heart.

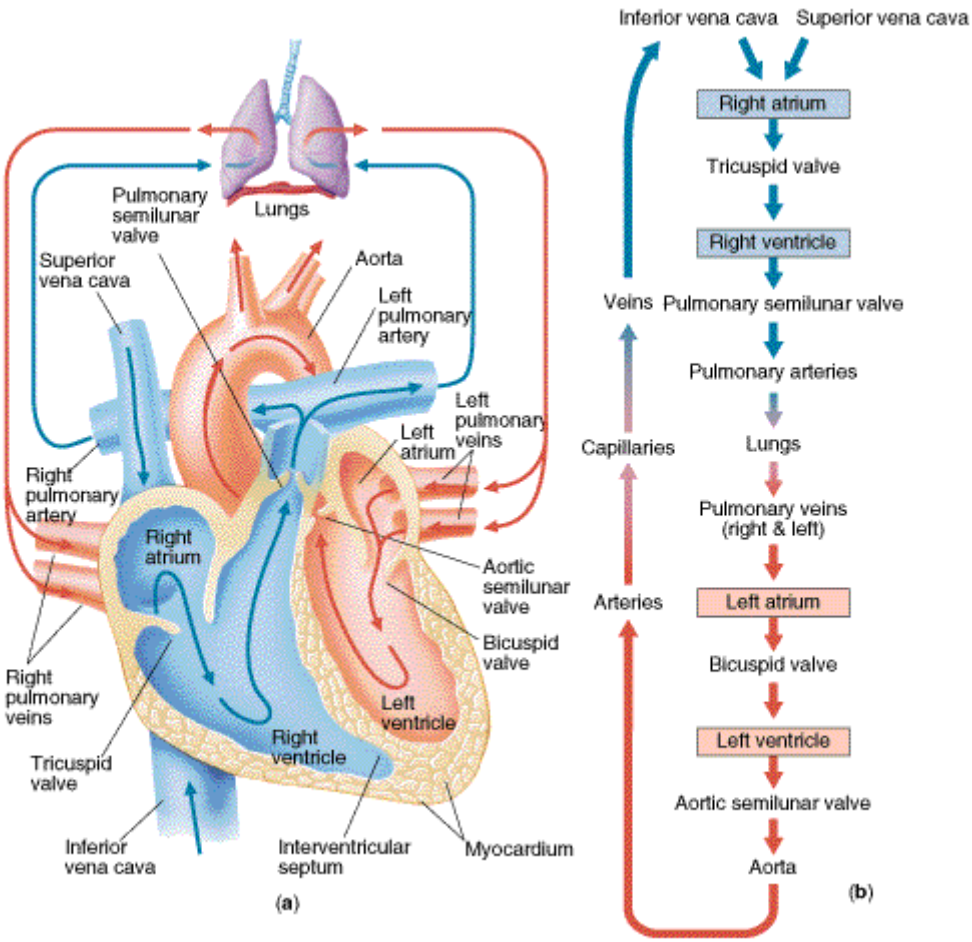
Pulmonary Circulation

- Blood flows from the **vena cava** the **right atrium** into the **right ventricle** through the **tricuspid valve**. The right atrium contracts right when the ventricle is almost full in order to push the rest of the blood into the ventricle.
- The right ventricle contracts sending the blood out of the ventricle past **pulmonary valve**, through the **pulmonary arteries** to the **lungs**..
- The blood flows through capillaries obtaining oxygen from the lungs and returning to the heart by the **pulmonary veins**; which empty into the **left atrium**.
- This blood is actually returning to the heart from the lungs at the same time as the blood that returns to the right atrium from the rest of the body.

Systemic Circulation

- The blood then flows into the **left ventricle** through **bicuspid valve**.
- The **left ventricle** contracts, sending the blood through **aortic valve** and out through the biggest artery in the body called the **aorta**.
- The oxygenated blood flows to all the tissues and organs in the body to be used in aerobic respiration.
- Blood then flows from the capillaries to the numerous venules and then through the different veins in the body
- These will all eventually dump the blood into the inferior and superior **vena cava**
- Blood returns to the **right atrium** of the heart flowing from **vena cava**
- Note: Both ventricles contract at the same time sending blood to the lungs and the other parts of the body.

Heart structure



Control of heart beat

- The heart beat is initiated by a group of specialized muscle cells in the right atrium called the **sino-atrial(SA) node**.
- The sino-atrial node acts as a **pacemaker**, sending a wave of excitations, leading to contractions of muscles.
- **Atrial-ventricle (AV) node**: excitation of SA node is conducted by AV node, then sending to the ventricle muscles.
- **Myocardium** is the muscle cells in the heart, and is thicker in left ventricle (need more pressure)
- Heart muscles have 30%-40% of mitochondria

- The rate of the pacemaker can be affected by nerves connected to the **medulla** region of the brain.
- Low blood pressure, high levels of CO_2 (low pH) and low levels of oxygen, stimulate the heart to increase its rate and therefore deliver more oxygen to the tissues and remove more carbon dioxide
- Cardiac nerves which are part of the sympathetic nervous system that signal heart rate to increase.
- The medulla of the brain controls most of the autonomic functions of the body such as breathing, heart rate and blood pressure.
- Cardiac nerves also cause the release of **epinephrine (adrenalin)** from the adrenal glands during strenuous physical activity or times of high levels of stress. This is also known as the fight or flight response

See more at **D.4 The heart**

6.3 Defense against infectious disease

U1	The skin and mucous membranes form a primary defense against pathogens that cause infectious disease.
U2	Cuts in the skin are sealed by blood clotting.
U3	Clotting factors are released from platelets.
U4	The cascade results in the rapid conversion of fibrinogen to fibrin by thrombin.
U5	Ingestion of pathogens by phagocytic white blood cells gives non-specific immunity to diseases.
U6	Production of antibodies by lymphocytes in response to particular pathogens gives specific immunity.
U7	Antibiotics block processes that occur in prokaryotic cells but not in eukaryotic cells.
U8	Viruses lack a metabolism and cannot therefore be treated with antibiotics. Some strains of bacteria have evolved with genes that confer resistance to antibiotics and some strains of bacteria have multiple resistance.
A1	Causes and consequences of blood clot formation in coronary arteries.
A2	Florey and Chain's experiments to test penicillin on bacterial infections in mice.
A3	Effects of HIV on the immune system and methods of transmission.

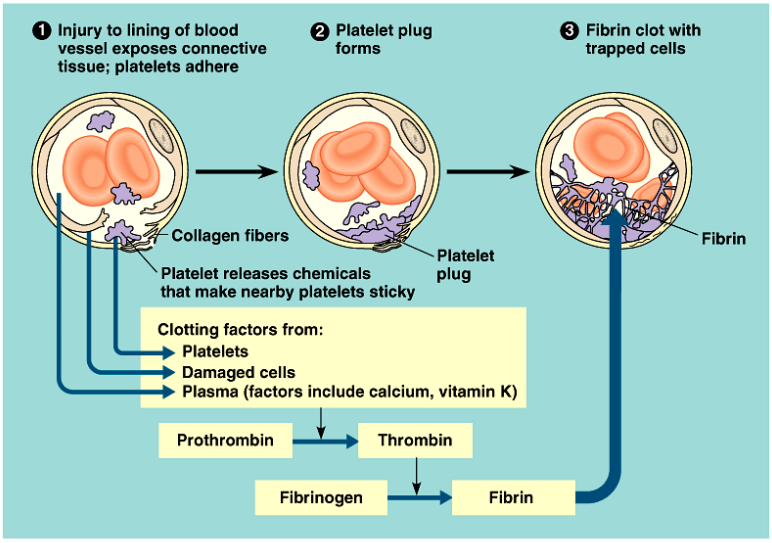
First line defence – physical barrier

- Skin and mucous membranes are physical barriers against infection from **pathogens**, including bacteria, virus, fungi and parasite
- Skin is **continuous**, so it is very hard to find an opening for pathogen to invade.
- Skin is constantly **replacing** its outermost epidermal layer of skin. These dead cells provide effective protection against foreign pathogens.
- Skin has about a **pH about 5**, which is not favorable to pathogens.
- There are **lysozyme** on the skin, which can break down pathogens
- **Natural organism** presents on the skin will compete living environment with pathogens.

- Mucous is **sticky** and traps foreign particles and pathogens contained in the air before they reach the lungs.
- Mucous contains **lysozymes** (enzymes) that can damage and kill pathogens.
- Trapped pathogens can also be expelled through the mouth or nose, or swallowed and destroyed by the high acidity of the stomach.
- There is also unfavorable pH and natural organisms in mucous

Blood Clotting

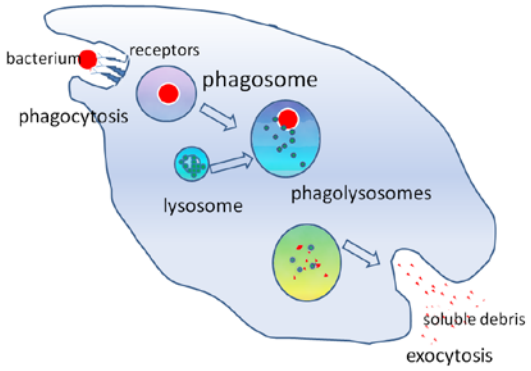
- **Blood clotting** is the process in which cuts or broken blood vessels are repaired and sealed to prevent excessive blood loss.
- When a blood vessel is broken or cut, **blood platelets** collect at the site of the damaged blood vessel forming a **platelet plug**.
- The platelets and the damaged tissue release chemical factors called **clotting factors**.
- The clotting factors convert the clotting protein prothrombin to its active form thrombin (enzyme).
- The enzyme **thrombin** converts clotting protein **fibrinogen** (which is soluble) into the **insoluble** fibrous protein **fibrin**.
- Fibrin forms a mesh at the point of the broken vessel further t**rapping other blood cells** sealing up the damaged vessel and forming a stable clot.
- Once the damaged vessel has fully healed, the blood clot dissolves in the blood.



Atherosclerosis

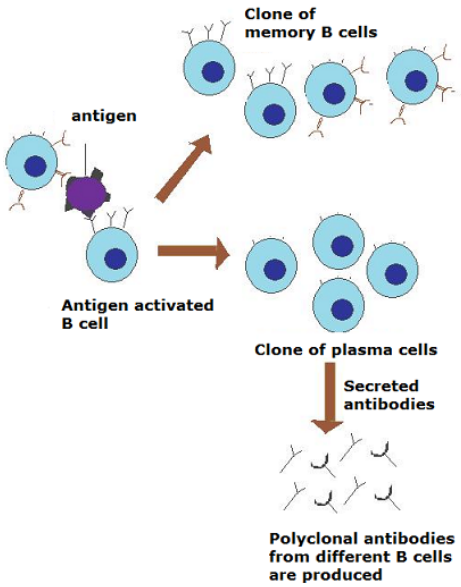
- Atherosclerosis is a disease of the arteries characterized by the deposition of plaques of fatty material on their inner walls. (blood clots in artery)
- Damaged coronary arteries wall leads to a growth of fibrous tissue, which will trap cholesterol.
- Plague of cholesterol will form on the artery
- High pressure of blood opens up the artery.
- Red blood cells bind to the plague.
- It will reduce blood flow, causing death of heart cells.
- **Myocardial infarction** (heart attack) occurs if a coronary artery becomes completely blocked.
- Coronary muscle tissue dies as a result of lack of oxygen**.**
- Risk factors: genetics/age/smoking/diet/exercise/obesity/stress
- **Bypass surgery** can avoid the block and supply blood to the heart.

Phagocytes



- Phagocytes use **chemotaxis** to find pathogens.
- Chemotaxis: movement in response to chemicals
- **Protein** produced by pathogen and **phospholipids** released by damaged cells will attract phagocytes to come
- Phagocytes attach to the pathogen's **cell surface protein** and then engulf it.
- Once the pathogen is engulfed, **lysosomes** within the phagocyte contain **hydrolytic enzymes** that will digest and destroy the foreign pathogens.
- Using **endocytosis** to engulf pathogens to form **phagosome**.
- **Lysosome** attaches to phagosome to form **phagolysosome**, which destroy the pathogens inside
- The corpse is expelled by **exocytosis**

Lymphocytes



- When a pathogen enters the blood, the specific **antigen** on the surface of the membrane is identified as being foreign or **non-self**
- This stimulates a specific immune response in which **antibodies** are produced that are specific for that particular antigen
- **Antibodies**: globular protein that recognizes a specific antigen and binds to it as a part of an immune system
- **Antigen**: substances found on a cell or virus causes antibody formation.
- B-lymphocytes are white blood cells that produce antibodies that bind to the antigen on the invading pathogen
- Once an antigen has been encountered the B-lymphocytes are stimulated to **divide to produce a large amounts of clones of themselves (clonal replication)**
- The active B-lymphocytes that are produced are called **plasma cells** which will begin to produce antibodies.
- The plasma cells created, produce and release mass amounts of antibodies into the bloodstream.
- Plasma cells fire antibodies to antigens and signal **phagocytes** to destroy them
- Some of these divisions also produce B-cells called **memory cells**, which stay in the blood in case of a second infection to provide a quick response to the new infection.
- The primary response is the production of antibodies to the initial challenge by the invading antigen.
- The secondary response which is much quicker because memory cells are still in the blood occurs after a subsequent challenge by the same antigen.
- Memory cells create **immunity**.

Antibiotics

- Antibiotics are a type of drug or chemical that inhibits the **growth of microorganisms**; mainly bacteria
- Antibiotics block **cellular processes** such as DNA replication, transcription, translation, and cell wall formation
- The first antibiotic discovered by Alexander Fleming was identified as penicillin
- Later on, two scientists named **Florey and Chain** were able to develop a method of growing the Penicillin in liquid cultures and purifying the Penicillin in these cultures.
- Since viruses **lack their own metabolism**, they have to use the chemical processes of a cell from a host that they infect
- They are unable to reproduce on their own and cannot perform protein synthesis, transcription and other metabolic functions

- Antibiotics work by blocking these vital processes in bacteria, killing the bacteria, or stopping them from multiplying
- **Virus lacks metabolic pathways so antibiotics won't work on them**
- **Antibiotic resistance** may develop due to evolution by natural selection, mutation, fast division.

Vaccination

- Active immunity can be acquired through vaccination.
- A vaccine is a **weakened version** of a pathogen.
- It is introduced to the body through an injection, which causes a primary immune response to the pathogen.
- This will create the plasma B-cells necessary to fight off the initial infection from the vaccine and the **memory B-cells** necessary for a secondary immune response if the person is exposed to the real pathogen.
- This secondary response is much quicker and more intense producing more antibodies in less time
- Sometimes "booster shots" are given which is a second round of vaccination that causes a secondary immune response.

HIV

- HIV (human immunodeficiency virus) is a retrovirus that causes AIDS, which is a condition in humans where the **immune system fails** and is susceptible to life-threatening opportunistic infections.
- HIV targets **helper-T cells**
- Helper-T cells play an important role in the production of clonal B lymphocyte cells, which produce antibodies for immune response.
- Therefore the reduction of T cells will **reduce the amount of antibodies** produced needed to fight off infection from invading pathogens.
- This inability to fight off disease is what eventually causes the person to die.
- HIV is a retrovirus, which means it inserts its own DNA into the host cells and use their cellular machine to reproduce.

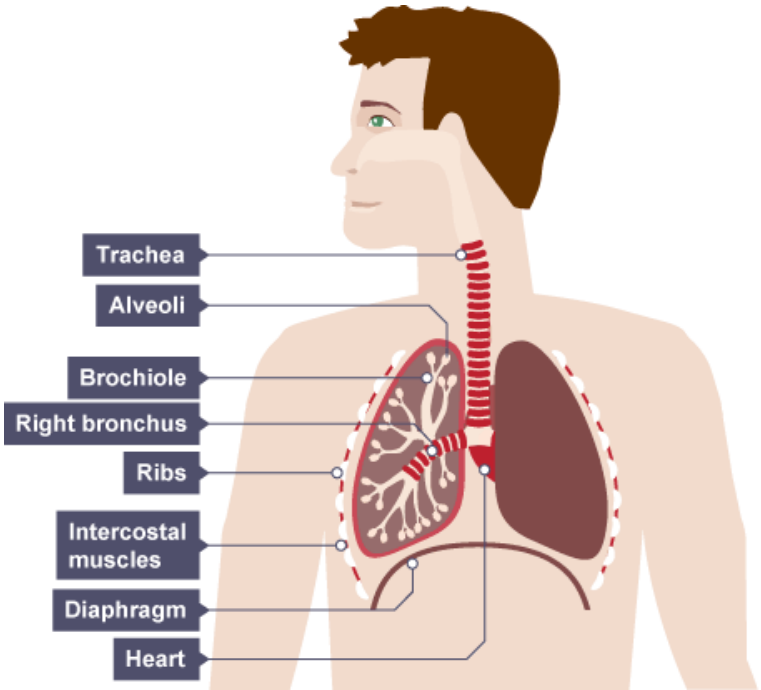
6.4 Gas exchange

U1	Ventilation maintains concentration gradients of oxygen and carbon dioxide between air in alveoli and blood flowing in adjacent capillaries.
U2	Type I pneumocytes are extremely thin alveolar cells that are adapted to carry out gas exchange.
U3	Type II pneumocytes secrete a solution containing surfactant that creates a moist surface inside the alveoli to prevent the sides of the alveolus adhering to each other by reducing surface tension.
U4	Air is carried to the lungs in the trachea and bronchi and then to the alveoli in bronchioles.
U5	Muscle contractions cause the pressure changes inside the thorax that force air in and out of the lungs to ventilate them.
U6	Different muscles are required for inspiration and expiration because muscles only do work when they contract.
A1	Causes and consequences of lung cancer.
A2	Causes and consequences of emphysema.
A3	External and internal intercostal muscles, and diaphragm and abdominal muscles as examples of antagonistic muscle action.
S1	Monitoring of ventilation in humans at rest and after mild and vigorous exercise.

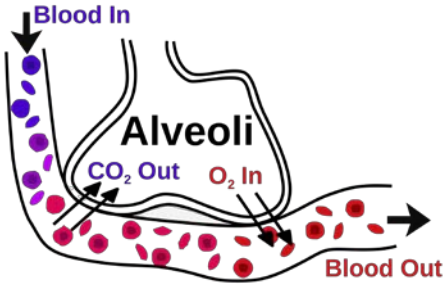
Ventilation :

- Small single celled organisms can easily diffuse gas in and out of the cell as long as they are in an environment where concentration gradients exist for passive diffusion.
- On the other hand human bodies are surrounded and protected by layers of **skin**. The cells in the tissue that need oxygen for respiration are too far away, too protected, and too numerous to **allow direct diffusion** with their environment.
- Therefore, humans need a system to keep a fresh supply of O_2 and to get rid of excess CO_2.
- The ventilation system provides a fresh supply of O_2 in the **alveoli**, allowing the oxygen to diffuse into the blood capillaries surrounding them
- The oxygen is then transported to all the tissues in the body.
- The CO_2 in the tissues is transported by the blood to the lungs, where it diffuses into the alveoli and is exhaled into the surrounding atmosphere.
- **Inspiration**: breathing in
- **Expiration**: breathing out

Gas exchange system



- Gas → Trachea → Bronchi (single bronchus) → Bronchioles → Alveoli
- The trachea divides into two bronchi (left and right)
- Inside each lung the bronchi divide into many smaller tubes called bronchioles
- These numerous bronchioles form a tree root-like structure that spreads throughout the lungs
- Each bronchiole ends in a cluster of air sacs called alveoli



Alveoli

- **Increase surface area** for gas exchange

- **Moist surface** – gas can **dissolve** and diffuse easily
- **Thin membrane** (single cell thick) – **short diffusion pathway**
- Have **networks of capillaries**
- Consisted of two type of cells: ***Type I pneumocytes*** and ***Type II pneumocytes***

- **Type I pneumocytes**
  - The **walls of the alveoli** are predominately made from a **single layer** of epithelial cells called **Type I pneumocytes**
  - These are **extremely thin** – **short diffusion pathway**
  - Since the alveoli are surrounded by capillaries that are also only one cell thick, oxygen and carbon dioxide have a very short distance to diffuse into the blood from the alveoli and out of the blood into the alveoli respectively
  - The cells are **permeable**, which will aid diffusion

- **Type II pneumocytes**
  - About 5% of the inner surface of the alveoli consists of Type II pneumocytes
  - These cells secrete a liquid made of proteins and lipids called **surfactant** in order to **moisten** the inner surface of alveoli
  - This liquid allows oxygen to dissolve into the surfactant and then diffuse into the blood
  - It will aid the gas to diffuse faster
  - The surfactant also prevents alveoli from **sticking** up with each other
  - They are also able to divide and become **Type I pneumocytes**, which means they can repair the damage

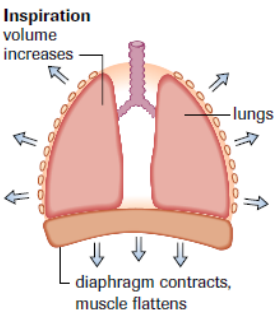
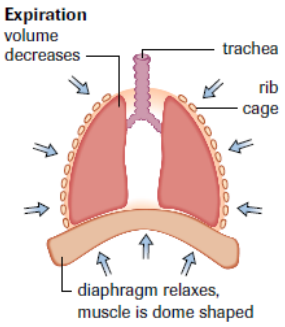
Muscle contraction in gas exchange

- External intercostal muscle and internal intercostal muscle works **antagonistically**; when one muscle contracts the other will relax

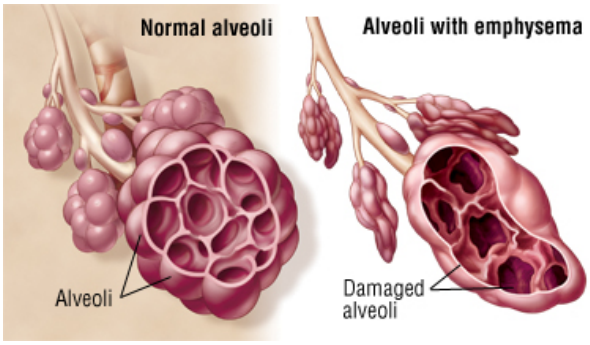
- **Inspiration**
  - **External intercostal muscles contract** pulling the ribs upwards and outwards.
  - The **diaphragm** which is a flat sheet of muscle extending across the bottom of the rib cage **contracts** and flattens out.
  - These two actions enlarge the volume in the lungs
  - When the volume of the lungs increases, the **pressure** inside the lungs **decreases** and becomes lower than the pressure in the surrounding atmosphere.
  - Since gas moves from higher pressure to lower pressure, air rushes into the lungs from the surrounding atmosphere to equalize the pressure.

- **Expiration:**
  - The **external intercostal muscles relax** and the **diaphragm relax** to its original shape (domed shape).
  - This moves the ribs back down and inwards and decreases the volume of the thoracic cavity and the lungs.
  - This decrease in volume increases the pressure inside the lungs.
  - Since the pressure inside the lungs is now greater than the atmospheric pressure, and gas moves from high pressure to low pressure, air rushes out of the lungs into the surrounding environment.

	Inspiration	Expiration
External intercostal muscle	Contract	Relax
Internal intercostal muscle	Relax	Contract
Diaphragm	Contract	Relax
Pressure in the lungs	Decrease	Increase
Volume of the lungs	Increase	Decrease
Rib cage movement	Up and outward	Down and inward

Graphical Presentation		

Emphysema



- Emphysema is respiratory disease that is often linked to smoking
- Emphysema is characterized by the loss of **elasticity of the alveoli** in the lungs, resulting in the destruction of lung tissue over time
- **Smokers** lungs generally contain a high number of phagocytes/macrophages in their blood
- This will cause **inflammatory response**, releasing **protease** to break down connective tissue and capillaries
- This results in the destruction of elastic fibres of the alveolar walls
- The alveoli can become over-inflated and fail to recoil properly
- Small holes can also develop in the walls of the alveoli
- The alveoli can merge forming huge air spaces and a **lower surface area**.
- This destruction cannot be reversed
- It will cause **insufficient gas exchange** and **low blood oxygen level**
- Symptoms are difficult to breathe, coughing, loss of appetite and weight loss.

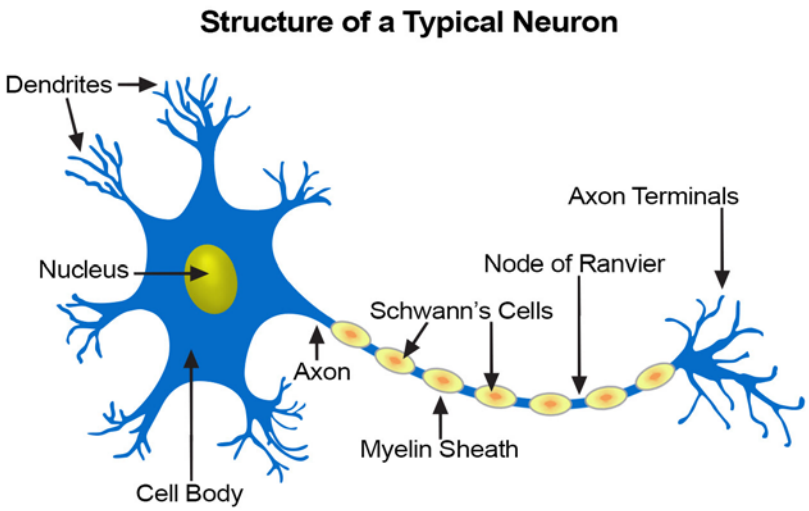
Lungs cancer

- **Smoking**
  - is the number one cause of lung cancer
  - there is an extremely high correlation with the number of cigarettes an individual smokes in a day and the incidence of lung cancer
  - Cigarettes contain a high number of **carcinogens**, such as polycyclic aromatic hydrocarbons and nitrosamines
  - Second-hand smoke can also be considered a cause of cancer in non-smokers
- **Air Pollution**
  - Air pollution from exhaust fumes containing nitrogen oxides, fumes from diesel engines and smoke from burning carbon compounds such as coal are a minor cause of lung cancer. This depends on where in the world you live and the air quality.
- **Radon Gas**
  - In some parts of the world, this **radioactive gas** can leak out of certain rocks such as granite, accumulating in poorly ventilated buildings
- Lung cancer is a very serious disease and the consequences can be severe, especially if the cancer is not recognized early on.

6.5 Neurons and synapses

U1	Neurons transmit electrical impulses.
U2	The myelination of nerve fibres allows for saltatory conduction.
U3	Neurons pump sodium and potassium ions across their membranes to generate a resting potential.
U4	An action potential consists of depolarization and repolarization of the neuron.
U5	Nerve impulses are action potentials propagated along the axons of neurons.
U6	Propagation of nerve impulses is the result of local currents that cause each successive part of the axon to reach the threshold potential.
U7	Synapses are junctions between neurons and between neurons and receptor or effector cells.
U8	When presynaptic neurons are depolarized they release a neurotransmitter into the synapse.
U9	A nerve impulse is only initiated if the threshold potential is reached.
A1	Secretion and reabsorption of acetylcholine by neurons at synapses.
A2	Blocking of synaptic transmission at cholinergic synapses in insects by binding of neonicotinoid pesticides to acetylcholine receptors.
S1	Analysis of oscilloscope traces showing resting potentials and action potentials.

Neuron

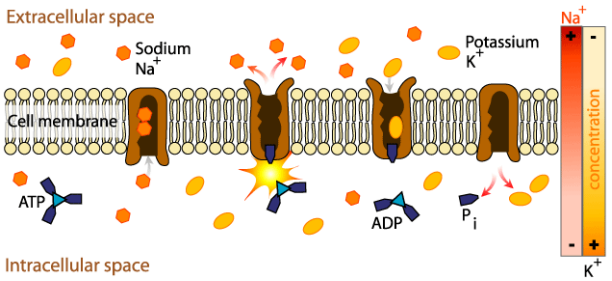


Saltatory conduction

- Nerve fibres conduct electrical impulses along the length of their axons. Some of these axons such as interneurons are unmyelinated, and therefore the impulse travels much slower
- The greater the diameter, the greater the speed of the nerve impulse
- Some axons are surrounded by a mixture of protein and phospholipids called **myelin** that collectively form a myelin sheath
- Many layers of myelin are deposited around the axon by special cells called **Schwann cells**
- The myelin sheath insulates the axon and greatly increases the speed of the nerve impulse
- In between the myelin are gaps called the **nodes of Ranvier**
- In myelinated neurons, the impulse can **jump from one node** to the next. This is called **saltatory conduction**
- This allows myelinated neurons to conduct impulses up to 100x faster than unmyelinated axons

Resting potential

- The time period when a neuron that is not conducting a nerve impulse, but is ready to conduct one, is called the **resting potential**.
- This membrane potential is due to an imbalance of positive and negative charges across the membrane
- Sodium-potassium pumps **pump Na^+ out of the axon and K^+ into the axon**
- Three Na^+ are pumped out of the neuron and two K^+ are pumped into the neuron
- This creates a **concentration gradient** of Na^+ (outside to in) and of K^+ (inside to out)
- The membrane is also much **more permeable to K^+** as Na^+, so K^+ **diffuses** back out of the neuron through leak channels
- This means the Na^+ concentration is much greater outside the neuron
- There are also negatively charged ions permanently located in the cytoplasm of the neuron
- These conditions create a resting membrane potential of **-70 mV** inside the neuron

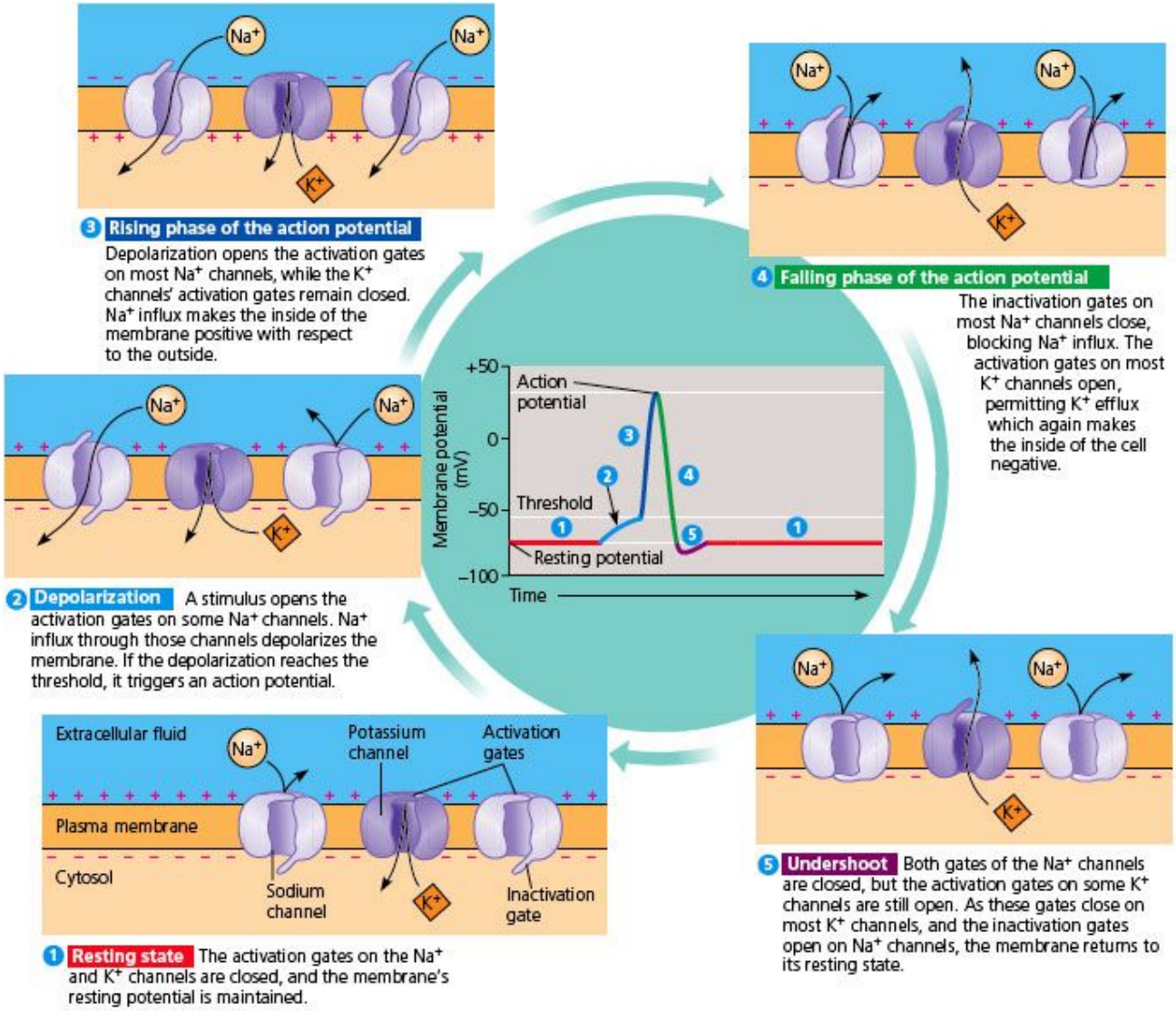


Depolarisation

- The arrival of an action potential caused by a stimulus causes a depolarization of the membrane as **Na$^+$ channels begin to open**.
- If the membrane potential reaches a threshold level of -55mV. Many more **voltage-gated Na$^+$ channels** open and Na$^+$ rapidly diffuses into the neuron
- The inside of the neuron becomes more positively charged than the outside of the neuron (depolarization)
- The voltage can rush up to +40mV

Repolarisation

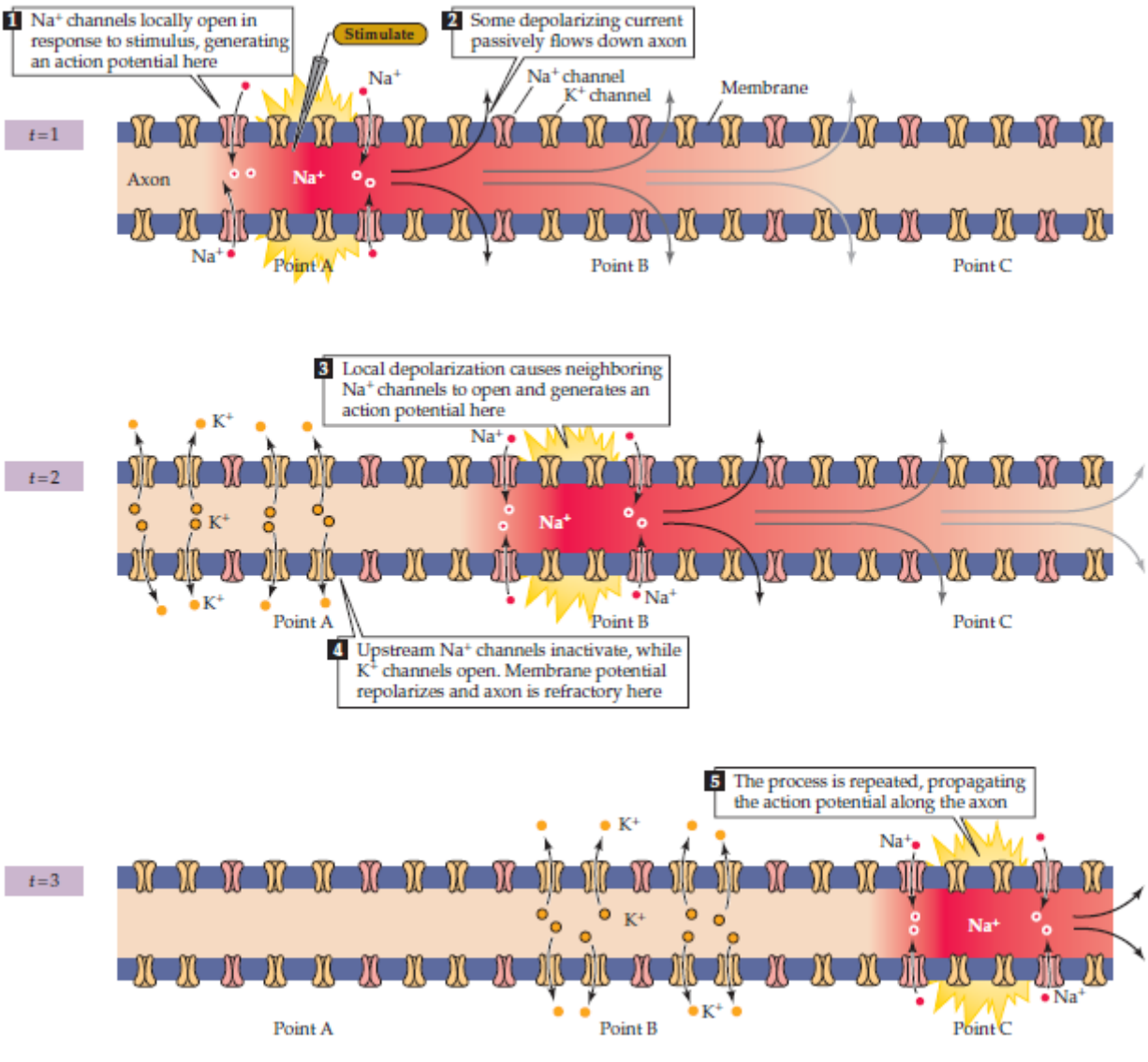
- K$^+$ channels open and **K$^+$ ions diffuse out of the neuron** making the inside negative again (repolarization)
- After the action potential, there is a **refractory period** where the impulse cannot go back in the same direction. This ensures a **one-way nerve impulse**



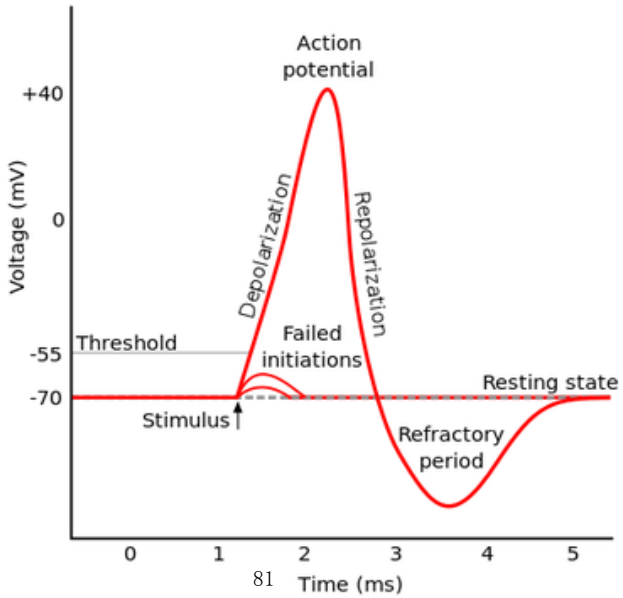
Step	Voltage-gated ion channels	Ion permeability	Action potential curve
Resting state	all channels closed	no ion movement	flat
Depolarization	Na$^+$ channels open (activation gates)	Na$^+$ flows into cell	sharp upward spike
Repolarization	Na$^+$ channels inactivating (inactivation gates) K$^+$ channels open	K$^+$ flows out of cell	downward curve
Hyperpolarization	some K$^+$ channels remain open Na$^+$ channels reset (activation gates close & inactivation gates open)	some K$^+$ continues to flow out of cell	slight dip below resting membrane potential

Propagation of action potential

- As a depolarization occurs in one part of the neuron, the **positive charge** triggers the Na^+ channels to open in the nearby regions causing an action potential to occur.
- This action potential will cause a depolarization in the next region.
- The propagation of action potentials will continue along the axon of the neuron.
- Nerve impulses move in one direction along the neuron from one end of the neuron to the other end
- A **refractory period** occurs after depolarization which prevent the electrical impulse from traveling backwards along the axon



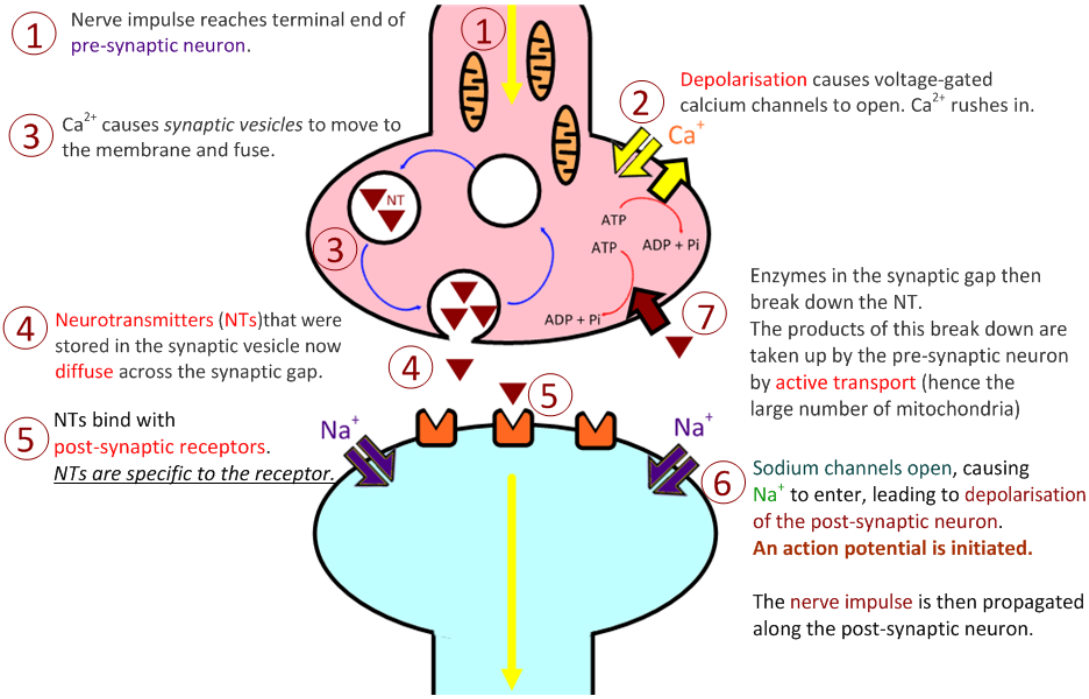
Oscilloscope traces of action potential



Synapse

- Synapses are junctions or structures between the **pre-synaptic and post-synaptic** membrane of two cells in the nervous system
- The junction can be between a neuron and an **effector** such as a muscle or a gland
- It can be between two different neurons.
- A junction also exists between the sense receptor cells and the sensory neurons
- **Neurotransmitters** are chemicals diffuse across a synapse from pre-synaptic membrane to post-synaptic membrane to send a signal to the next cell

- As the **nerve impulse** reaches the axon terminal of the pre-synaptic neuron, the positive charge from the depolarization causes voltage-gated channels permeable to **Ca^{2+}** to open.
- Ca^{2+} flows into the pre-synaptic neuron increasing the amount of Ca^{2+} in the pre-synaptic neuron.
- This Ca^{2+} causes **vesicles containing neurotransmitters** to bind to the membrane and release their neurotransmitters into the **synaptic cleft** (space between pre and post synaptic neuron).
- These neurotransmitters diffuse across the synaptic cleft and **bind to receptor sites** on the membrane of the post synaptic neuron.
- The binding of these neurotransmitters **open ion channels** allowing ions such as Na^+ to diffuse into the post synaptic neuron.
- This influx of positive charge possibly leads to an action potential and a depolarization in the post synaptic neuron.
- The neurotransmitter is **reabsorbed** by the pre-synaptic neuron or broken down in the synapse by enzymes.



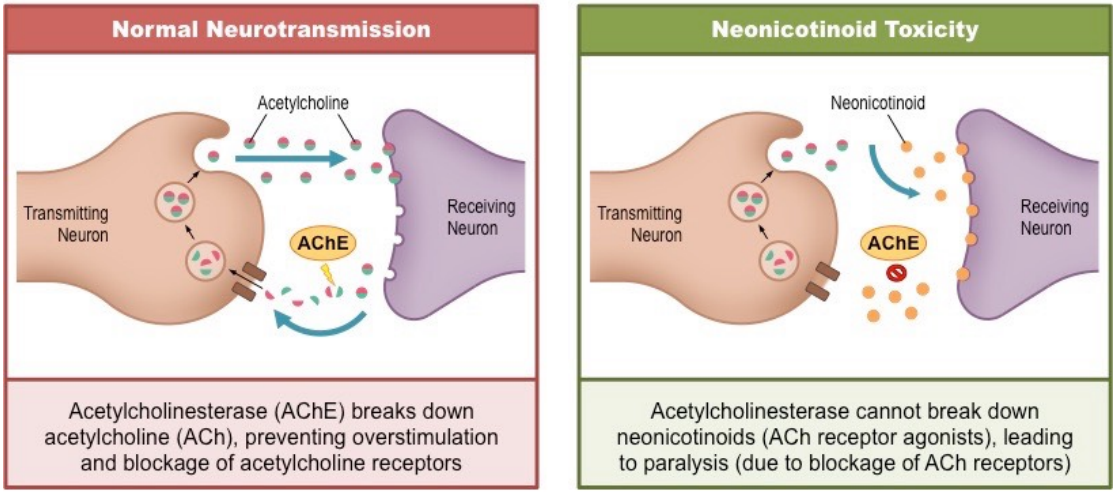
- The threshold potential is the critical level to which a membrane potential must be reach in order to initiate an action potential
- Neurons fire or a nerve impulse is generated by an "**all or nothing**"
- When a stimulus occurs, some Na^+ channels open causing the membrane potential to become more positive
- If enough Na^+ diffuses into the neuron and action potential is generated
- At a synapse, binding of a neurotransmitter at the post-synaptic membrane causes Na^+ to diffuse into the neuron (if excitatory)
- This can cause a depolarization of the neuron if enough neurotransmitters are released

Acetylcholine

- Acetylcholine is a **neurotransmitter**
- It is largely used at the neuromuscular junction, meaning it is released by motor neurons and binds to receptors on muscles
- It is also used in the autonomic nervous system
- Acetylcholine is created in the **pre-synaptic** terminal by combining a water soluble nutrient called **choline with an acetyl group**
- Acetylcholine is secreted by the pre-synaptic membrane of a neuron
- The neurotransmitter diffuses across the synapse and binds to a receptor on the post synaptic membrane (causing an action potential if a threshold is reached)
- Once it has released from the receptor, an enzyme called **acetylcholinesterase** breaks down into choline and acetate
- **Choline is reabsorbed back** into the pre-synaptic neuron where it is combined with another acetyl group to form another acetylcholine neurotransmitter

Pesticides using neonicotinoids

- **Neonicotinoids** bind to acetylcholine receptors in cholinergic synapses in the CNS of insects
- Acetylcholinesterase does not break down neonicotinoids therefore binding is **irreversible**
- Acetylcholine now can't bind and neural transmission is stopped
- The **insects** go through paralysis and then death
- A benefit to this pesticide is that it is very effective in killing pests and it is not highly toxic to humans and mammals
- The problem is that it also effects beneficial insects such as honey bees. There is conflicting evidence if this is the case or not
- Many places such as the EU and Ontario, Canada has banned neonicotinoid pesticides



6.6 Hormones, homeostasis and reproduction

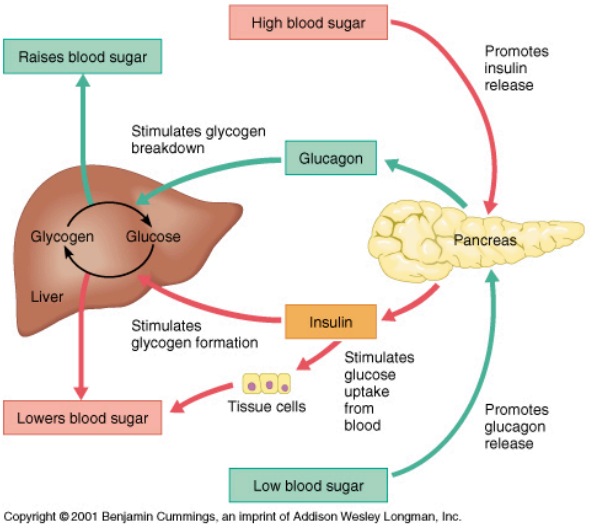
U1	Insulin and glucagon are secreted by beta and alpha cells of the pancreas respectively to control blood glucose concentration.
U2	Thyroxin is secreted by the thyroid gland to regulate the metabolic rate and help control body temperature.
U3	Leptin is secreted by cells in adipose tissue and acts on the hypothalamus of the brain to inhibit appetite.
U4	Melatonin is secreted by the pineal gland to control circadian rhythms.
U5	A gene on the Y chromosome causes embryonic gonads to develop as testes and secrete testosterone.
U6	Testosterone causes pre-natal development of male genitalia and both sperm production and development of male secondary sexual characteristics during puberty.
U7	Estrogen and progesterone cause pre-natal development of female reproductive organs and female secondary sexual characteristics during puberty.
U8	The menstrual cycle is controlled by negative and positive feedback mechanisms involving ovarian and pituitary hormones.
A1	Causes and treatment of Type I and Type II diabetes.
A2	Testing of leptin on patients with clinical obesity and reasons for the failure to control the disease.
A3	Causes of jet lag and use of melatonin to alleviate it.
A4	The use in IVF of drugs to suspend the normal secretion of hormones, followed by the use of artificial doses of hormones to induce superovulation and establish a pregnancy.
A5	William Harvey's investigation of sexual reproduction in deer.
S1	Annotate diagrams of the male and female reproductive system to show names of structures and their functions.

Blood sugar control

- Blood glucose concentration is carefully monitored by negative feedback mechanisms.
- Cellular respiration is constantly lowering blood glucose levels.
- Receptors in the pancreas sense when the blood glucose level is too low.
- **Alpha (α) cells** in the pancreas secrete **glucagon** into the bloodstream.
- Glucagon stimulates the liver to **breakdown stored glycogen into glucose** which is released into the bloodstream.
- Blood glucose levels rise back to their normal limits.
- If the glucose levels get too high, receptors sense the increased glucose levels causing the pancreas to secrete **insulin** by the **Beta cells (β)** in pancreas.
- Insulin stimulates the **absorption of glucose from the blood** into skeletal muscles and fat tissue, and thus allowing the liver to **convert glucose into glycogen** (animal carbohydrate storage molecule).
- Glucose levels decrease back to the normal range.

Type I diabetes

- Is an autoimmune disease characterized by the inability of the pancreas to produce insulin. The insulin producing **β cells** of the pancreas are attacked and **destroyed** by one's own immune system.
- This type of diabetes usually develops in **children**, but can occur at any age.
- Therefore, the body loses the ability to take up glucose into its cells and convert glucose into glycogen.
- People that have type I diabetes must take insulin shots or injections.



Type II diabetes

- Occurs when the **insulin receptors** on certain body cells lose their ability to process or respond to insulin, become **insensitive**.
- Pancreas still produces insulin.
- Type II diabetes is usually a result of **obesity**, age, lack of exercise and/or genetic predisposition.
- Type II diabetes is usually considered late onset as it usually occurs later on in life.
- Insulin injections are not needed. Diabetes II can be treated by lifestyle and diet changes.
- Most common form of diabetes.
- There is a strong hereditary relationship.

Metabolic rate regulation

- **Thyroxin** is a hormone secreted by the **thyroid gland** of the endocrine system
- Thyroxin contains iodine; therefore, prolonged deficiency to iodine in the diet prevents the production of thyroxin
- Thyroxin is important in the regulation of the body's **metabolic rate**
- The body's metabolic rate is the amount of energy a body uses at rest; combination of the catabolic and anabolic reactions
- Since thyroxin causes an increase in the body's metabolic rate, there is an increase in oxygen consumption and the hydrolysis of ATP; thereby causing an **increase in the body's temperature**
- Increase in thyroxin stimulates the breakdown of lipids and the oxidation of fatty acids
- Thyroxin also stimulates carbohydrate metabolism, including the uptake of glucose and the breakdown of glycogen into free glucose
- In a regular person, if the bodies temperature drops, a release in thyroxin will stimulate heat production causing the body's temperature to rise
- If there is an excessive amount of thyroxin in the body, **hyperthyroidism** can occur
- If there is an insufficient amount of thyroxin in the body, **hypothyroidism** can occur
- Some of the symptoms of hypothyroidism are weight gain, loss of energy, feeling cold all the time, forgetfulness and depression

Appetite control

- **Leptin** is a hormone made by **adipose cells** that helps to regulate energy balance by inhibiting hunger.
- Leptin acts on the receptors in the arcuate nucleus (collection of neurons) of the **hypothalamus** to regulate appetite in order to achieve energy homeostasis
- The concentration of leptin in the blood is controlled by food intake and the amount of adipose tissue in the body
- If the amount of adipose tissue in an individual increases, then their concentrations of leptin also increases, leading to long term suppression of appetite and reduced food intake
- In obese individuals a **decreased sensitivity to leptin** can occur, resulting in an inability to recognize when they are full
- Trials with humans have had mixed response since the **physiology** of humans is much different than mice
- Since most humans have quite a high leptin concentration, it was determined that the many of obesity cases where caused by a change in the **receptor protein for leptin**, not in the production of leptin

Circadian rhythms control

- Melatonin is a hormone made by the **pineal gland** in darkness, a small gland in the brain.
- The secretion of melatonin by the pineal gland is controlled by cells in the hypothalamus
- Light exposure to the retina is relayed to the suprachiasmatic nucleus (SCN) of the hypothalamus. These fibers from the hypothalamus relay a message to the nerve ganglia of the spinal cord which is relayed back to the pineal gland to release melatonin.
- Melatonin helps **control your sleep and wake cycles** (circadian rhythms).
- Melatonin levels generally begin to rise in the mid to late evening, remaining high for most of the night, and then drop in the early morning hours.

Jet lag

- The SCN of the hypothalamus and the pineal gland continually set the circadian rhythm of the place the person is departing from.
- Therefore, when a person lands in a country that is many time zones different than the origin, they feel sleepy in the day and awake at night
- Jet lag will only last a few days, as the body adjusts to the new times when the light is detected by the cells in the retina during a different time period

Sex determination

- The Y chromosome has a gene called the **SRY gene** that causes the embryonic gonads to become testes and begin secreting testosterone
- SRY codes for a protein called **TDF (testis-determining factor)** that stimulates the expression of other genes located on the Y chromosome that cause testis development
- If there are two X chromosomes, the gonads develop as ovaries
- TDF is a **DNA binding protein**, which promotes expression of other gens for the development of testis.

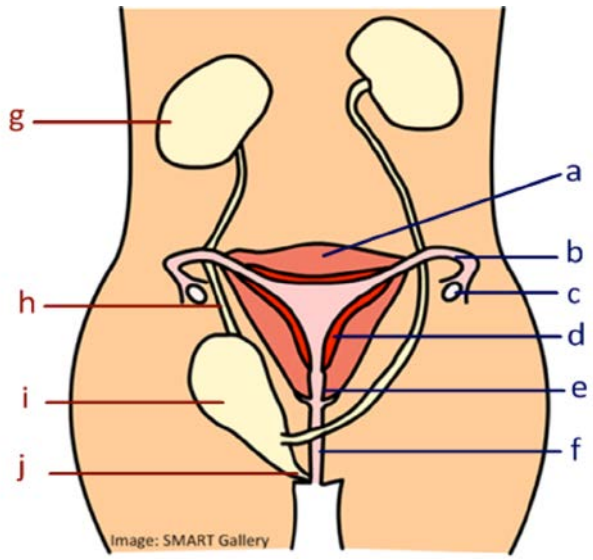
Testosterone

- Secreted in the **testes** of males or the early stage testosterone-secreting cells that will become testes.
- Aid in the development and maturation of the **male genitalia** as a fetus at about the 8th to 9th week.
- During puberty, testosterone aids in the development of male **secondary sexual characteristics** such as pubic and facial hair, enlarged penis, broad shoulders, muscle mass, deepening of voice and bone density.
- Stimulates production of sperm and promotes the male libido (sex drive).

Estrogen and progesterone

- Estrogen and progesterone which are secreted by the **mother's ovaries** and then by the placenta, will cause the female **reproductive organs** to develop **in the absence of testosterone**
- Absence of fetal testosterone and presence of maternal estrogen and progesterone will lead to the development of female reproductive system
- During puberty, estrogen and progesterone cause the development of **secondary sexual characteristics** in females, including breast development, menstrual cycle and pubic and armpit hair

Reproductive system

<table>
<tr><td> 
</td><td>a. uterus
• Provides protection, nutrients and waste removal for the developing fetus
• Muscular walls contract to aid birthing process</td></tr>
<tr><td></td><td>b. fallopian tube (oviduct)
• Connects the ovary to the uterus
• Fertilization of the egg occurs here</td></tr>
<tr><td></td><td>c. ovary
• (meiosis) eggs stored, develop and mature
• Produced estrogen and progesterone</td></tr>
<tr><td></td><td>d. endometrium (lining of the uterus)
• develops each month in readiness for the implantation of a fertilized egg
• (site of implantation becomes the placenta)</td></tr>
<tr><td>e. cervix
• Muscular opening/entrance to the uterus
• Closes to protect the developing fetus and opens to form the birth canal</td><td>f. vagina
• Accepts the penis during sexual intercourse and sperm are received here
• With the cervix forms the birth canal</td></tr>
<tr><td>g. kidney</td><td>h. ureter</td></tr>
<tr><td>i. bladder</td><td>j. urethra</td></tr>
</table>

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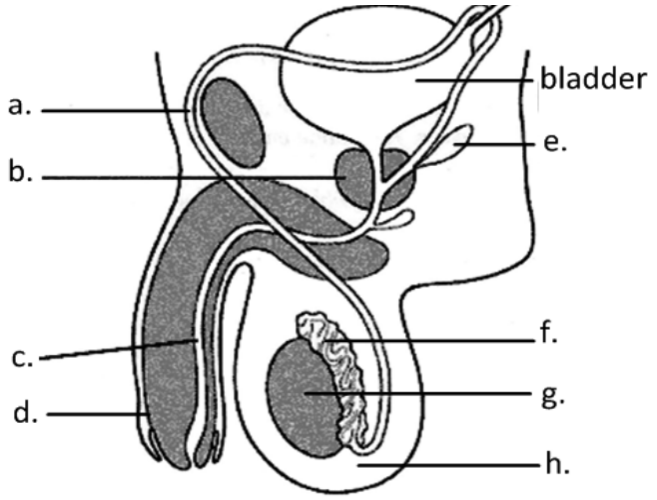
<tr><td> 

Image from QuestionBank CDRom</td><td>a. Vas deferens (sperm duct)
• carries sperm to the penis during ejaculation</td></tr>
<tr><td></td><td>b. Prostate gland
• Adds alkaline fluids that neutralize the vaginal acids</td></tr>
<tr><td></td><td>c. urethra
• Delivers semen during ejaculation and urine during excretion</td></tr>
<tr><td></td><td>d. Penis/erectile muscle
• Muscles become erect to penetrate the vagina during sexual intercourse
• Delivers sperm to the top of the vagina</td></tr>
<tr><td>e. Seminal vesicle
• adds nutrients including fructose sugar for respiration
• Adds mucus to protect sperm</td><td>f. epididymis
• Sperm mature here and become able to move
• Sperm stored awaiting ejaculation</td></tr>
<tr><td>g. testis (pl. testes)
• Produces (millions) of sperm (every day)
• Produces testosterone</td><td>h. scrotum
• Protects and holds the testes outside the body (to maintain a lower optimum temperature for sperm production)</td></tr>
</table>

Menstrual cycle

FSH (Follicle stimulating hormone)

- Produced and secreted by the anterior pituitary gland.
- Stimulates the **growth of the follicles** in the ovaries
- Stimulates egg maturity (egg development)
- Promotes the thickening of the follicle wall.
- Stimulates the secretion of the hormone **estrogen**.

LH (luteinizing hormone)

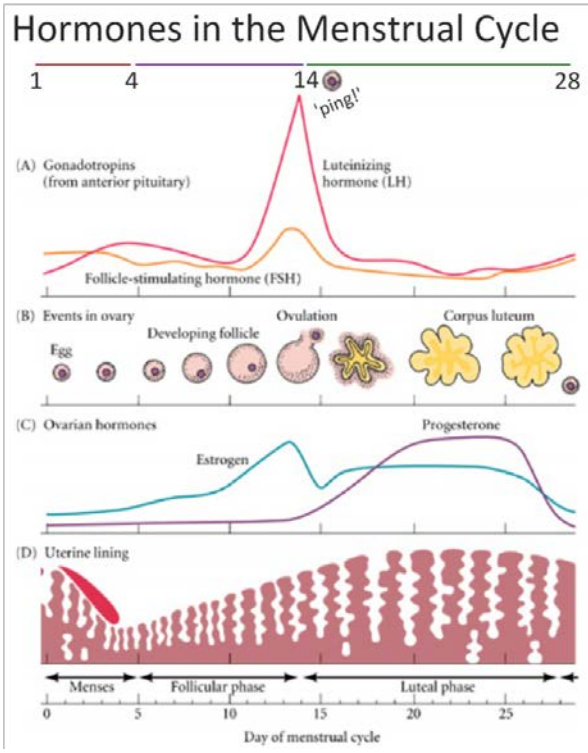
- Produced and secreted by the anterior pituitary gland.
- Triggers the **release of the egg** (ovulation).
- Stimulates the growth of the corpus luteum (secretes estrogen and progesterone).

Estrogen

- Stimulated by **FSH**
- Produced by the developing follicles in the ovaries and the **corpus luteum**.
- Promotes the **thickening of the uterine wall (endometrium)** and the growth of blood vessels, in preparation of egg implantation.
- **Stimulates LH** in pre-ovulation period
- **Inhibits FSH and LH** when the estrogen levels are high (around same time as ovulation). This would prevent the development and release of another egg.

Progesterone

- Produced by the ovaries and the **corpus luteum**.
- Helps **maintain the thickening of the uterine wall** (endometrium) for egg implantation.
- **Inhibit the production of FSH and LH**.



Day 1-4 (Follicular phase)
-Menstruation. Endometrium shed.
-FSH increases, stimulating follicle development.

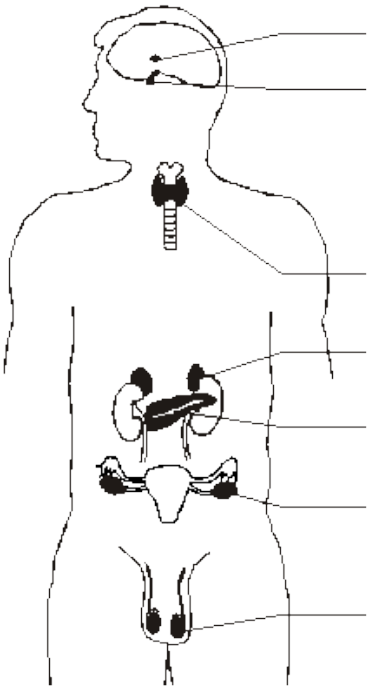
Day 5-14 (Ovulatory phase)
-FSH and follicle stimulate oestrogen release
- Oestrogen stimulates endometrium development
- Oestrogen stimulates LH
- Peak in LH causes ovulation (Day 14)

Day 14-28 (Luteal Phase)
- Fall in LH. Corpus luteum forms from now-empty follicle
- Corpus luteum releases progesterone
- Progesterone maintains the endometrium and inhibits FSH and LH

If no fertilisation and implantation occurs, progesterone and oestrogen drop, triggering menstruation and FSH release.

IVF (in vitro fertilisation)

- Generally, IVF treatment begins by taking drugs to halt the regular secretion of the hormones FSH and LH. This in turn stops the secretion of progesterone and estrogen and effectively allows the doctor to take control of the timing and egg production of the woman's ovaries
- The woman is then injected with large amounts of **FSH** to induce the production of many follicles.
- **LH** is also injected to **promote the release** of many ovules (eggs)
- This is called **superovulation**, which can produce between 10 and 20 eggs
- The eggs are then stimulated to mature by an injections of **HCG** (Human Chorionic Gonadotrophin), a hormone usually secreted by the developing embryo
- The eggs are surgically removed from the ovary of the woman.
- Sperm is collected from the male individual.
- Many sperm (50,000-100,000) are **mixed with the eggs in a petri dish**.
- The sperm and eggs in the petri dish are **incubated at 37ºC** (body temperature).
- The eggs are analyzed for successful fertilization (two nuclei inside the egg).
- Healthy embryos are selected and are transferred into the female **uterus for implantation** (up to 3 healthy embryos are transferred into the uterus to increase chance of implantation).
- Keep injecting progesterone after implantation
- Pregnancy test is given after about 2 weeks.



Gland	Hormone	Target organ	Function
Pineal gland	melatonin	Hypothalamus	biological clock
Pituitary gland	FSH	ovaries	menstrual cycle
	LH	ovaries	menstrual cycle
	ADH*	kidneys	water homeostasis
	growth hormone	many	stimulates cell division
	oxytocin	uterus	birth contractions
	prolactin	mammary glands	milk production
Thyroid gland	thyroxine*	Many	metabolic rate
Adrenal glands	adrenaline*	many	fight or flight
	cortisol	many	anti-stress
Pancreas	insulin*	liver	glucose homeostasis
	glucagon*	liver	glucose homeostasis
Ovaries	oestrogen	uterus	menstrual cycle
	progesterone	uterus	menstrual cycle
Testes	testosterone	many	male characteristics
Leptin	Adipose cells	Hypothalamus	Appetite Control

Topic 7: Nucleic acids (HL)

7.1 DNA structure and replication

U1	Nucleosomes help to supercoil the DNA.
U2	DNA structure suggested a mechanism for DNA replication.
U3	DNA polymerases can only add nucleotides to the 3' end of a primer.
U4	DNA replication is continuous on the leading strand and discontinuous onthe lagging strand.
U5	DNA replication is carried out by a complex system of enzymes.
U6	Some regions of DNA do not code for proteins but have other importantfunctions.
A1	Rosalind Franklin's and Maurice Wilkins' investigation of DNA structure by X-ray diffraction.
A2	Use of nucleotides containing dideoxyribonucleic acid to stop DNA replication in preparation of samples for base sequencing.
A3	Tandem repeats are used in DNA profiling.
S1	Analysis of results of the Hershey and Chase experiment providing evidence that DNA is the genetic material.
S2	Utilization of molecular visualization software to analyse the association between protein and DNA within a nucleosome.

Hershey & Chase experiment

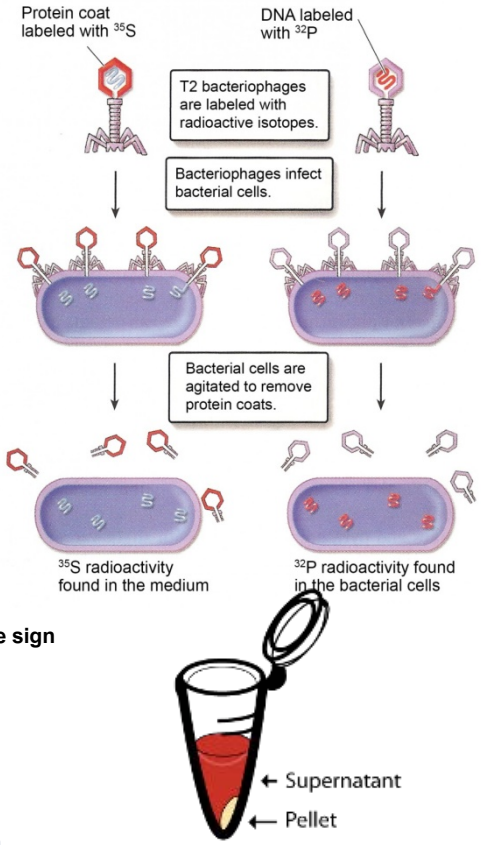
Experiment target: **T2 Bacteriophage** (a kind of virus, containing DNA and a protein coat) & **E.Coli bacteria**

How does virus work?

- Virus injects their genetic material into cell
- Non-genetic part of the virus (protein coat) remains outside the cell
- Infected cell produces large amount of viruses based on the genetic material in the cell
- The cell bursts releasing copied viruses

Experimental methodology:

- Amino acid containing radioactive isotopes were used to label the virus: ^{35}**S** is used for labelling the protein coat, and ^{32}**P** is used for labelling DNA
- Centrifuge is used for vigorous shaking in order to separate virus and infected bacteria: **Pellet** (solid) contains bacteria and **supernatant** (liquid) contains protein coat.

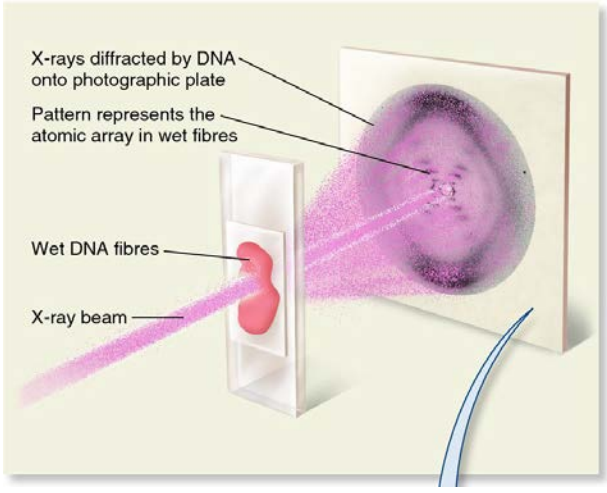


Findings:

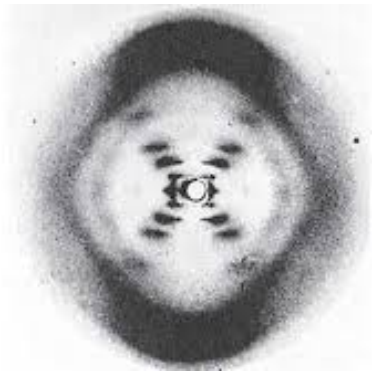
- When protein coat is only radioactively labelled, **new viruses made shown no radioactive sign**
- When DNA is only radioactively labelled, **new viruses made shown radioactive sign**

Hypothesis: DNA controls genetic information.

Rosalind Franklin's and Maurice Wilkins' investigation of DNAs tructure by X-ray diffraction

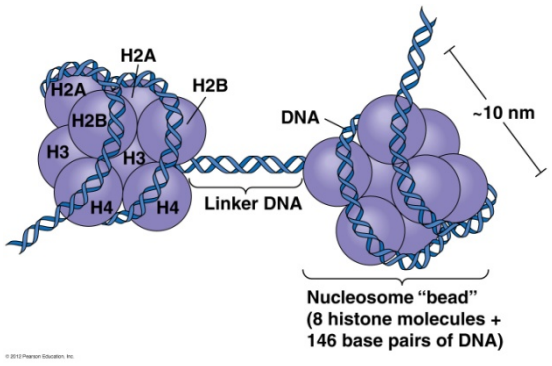


Rosalind Franklin is the first women to take a photo of DNA using x-ray diffraction. Her investigation leads to the findings that DNA is a **double helix**.

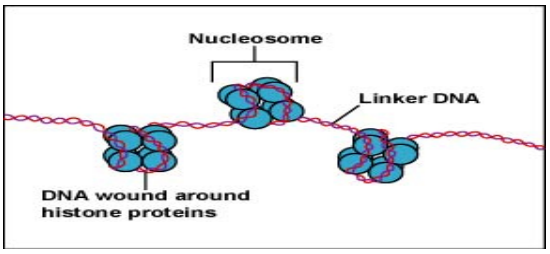


Nucleosome

- Eukaryotic DNA supercoiling is organized by nucleosome
- Nucleosomes are formed by wrapping DNA around **histone protein**
- Supercoiling in general helps regulate transcription because only **certain areas of the DNA are accessible** for the production of mRNA by transcription. This regulates the production of a polypeptide.
- Nucleosomes will be further supercoiled to form chromosome, which is only formed in cell division.

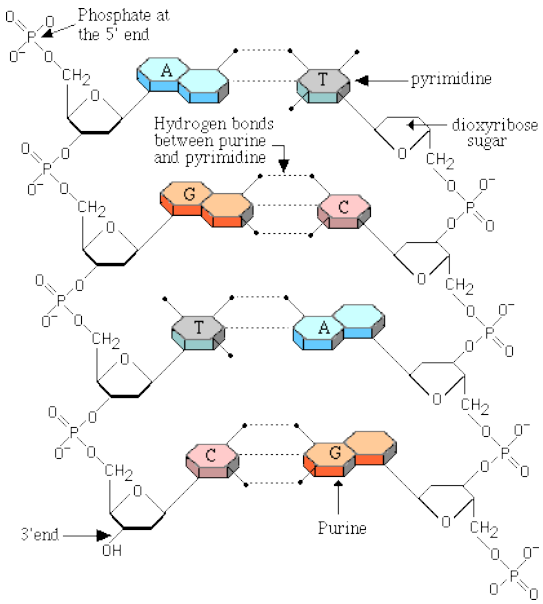


DNA will wrap around the histone protein (as shown as the blue ball in the diagram) first, histones will then stick together to form nucleosome (8 histone protein). Only the DNA connecting two nucleosome (Linker DNA in the diagram) is accessible and can be transcribed into mRNA to produce polypeptides



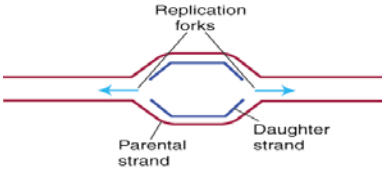
DNA Structure

- DNA is double stranded and shaped like a ladder, with the sides of the ladder made out of repeating phosphate and deoxyribose sugar molecules covalently bonded together.
- Each deoxyribose molecule has a phosphate covalently attached to a 3' carbon and a 5' carbon.
- The phosphate attached to the 5' of one deoxyribose molecule is covalently attached to the 3' of the next deoxyribose molecule forming a long single strand of DNA known as the DNA backbone.
- DNA strands run anti-parallel to each other with one strand running in a 5' to 3' direction and the other strand running 3' to 5' when looking at the strands in the same direction
- The rungs of the ladder contain two nitrogenous bases (one from each strand) that are bonded together by hydrogen bonds.
- Since these two strands are anti-parallel replication occurs in different directions on the DNA strand
- **Purines** are two ring nitrogenous bases and **pyrimidines** are single ring nitrogenous bases.
- Adenine and thymine has **two** hydrogen bonds; Guanine and Cytosine has **three** hydrogen bonds.



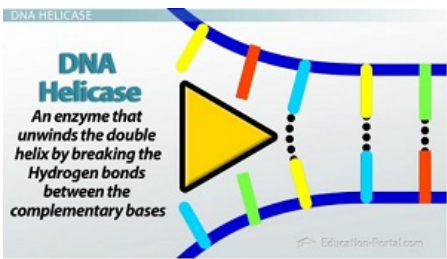
DNA replication

- DNA replication creates two identical strands with each strand consisting of one new and one old strand (**semi-conservative**).
- DNA replication occurs at many different places on the DNA strand called the origins of replication (represented by bubbles along the strand).



Several site "replication bubbles" starts together, so replication process is much faster. Replication starts at the **replication forks**.

- The DNA strand is unwound and separated (hydrogen bonds broken) by an enzyme called **helicase**.



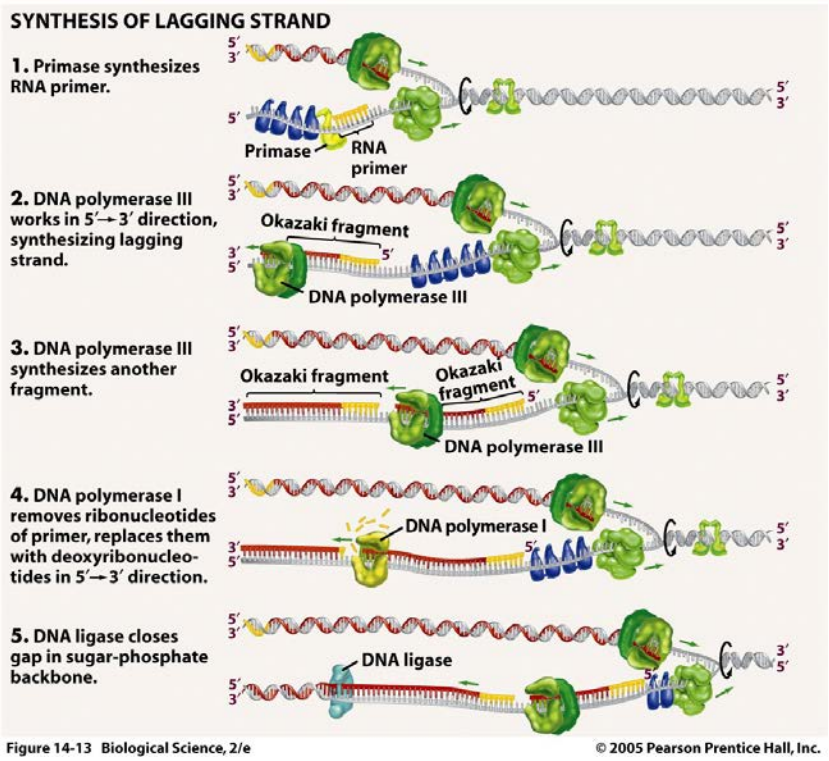
- DNA gyrase is an enzyme that relieves strain on the strand as it is being unwound by the helicase
- Single-stranded binding proteins bind to the open strands and keep the strands apart long enough to prevent the strands from re-annealing before the strands are copied

- **RNA primase** attaches a **RNA primer** to the DNA as starting point and attachment point since DNA polymerases can only add nucleotides to the 3' end of a primer
- **DNA polymerase III** adds free nucleotides found in the nucleus in the **5' to 3' direction** in the direction of the replication fork.

- This strand is called the **"leading strand"** because replication is **continuous** (keeps replicating until it meets another origin of replication).
- Because DNA polymerase III can only add nucleotides to a free 3' end (5'to 3' direction) the other strand is replicated in the opposite direction.
- This strand is called the **"lagging strand"** because replication is delayed until the helicase opens up available nucleotides, to allow replication "back" in the opposite direction to the leading strand. Replication in this direction is **discontinuous.**
- The lagging strand is therefore made as a series of fragments called "**Okazaki fragments**"

- **DNA polymerase I** replaces RNA primer with DNA
- **DNA ligase** glues the Okazaki fragments together to form a continuous strand

Sequence of replication	Protein required	Protein function
1st Step	Helicase	Unzips the DNA strands
2nd Step	Primase	Add an RNA primer on the DNA strand as a starting point of replication
3rd Step	DNA polymerase III	Binds to RNA primer and begins replication in **5' to 3' direction**
In **Leading strand** (helicase pointing 5' end)	DNA polymerase I	Replace RNA primer with DNA nucleotides
In **Lagging strand** (helicase pointing 3' end)	DNA polymerase I	Replace RNA primer with DNA nucleotides
	DNA ligase	Glue Okazaki fragments together to make a continuous DNA stand



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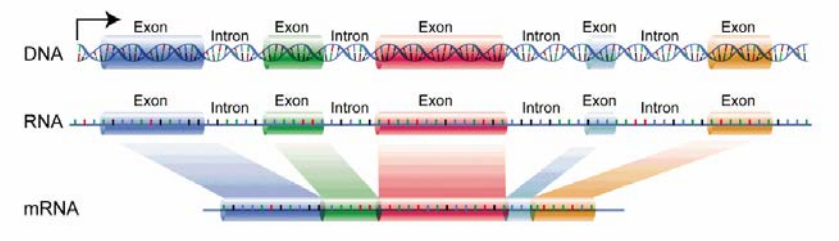
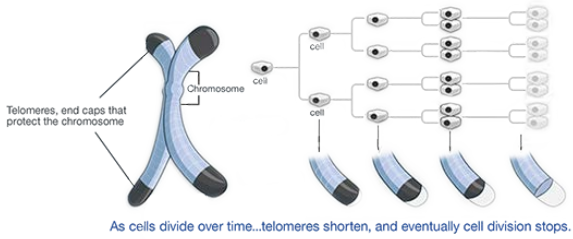
Non-coding genes

- Genes contained within DNA called coding sequences, code for polypeptides created during transcription and translation
- The majority of DNA are non-coding sequences that perform other functions such as regulators of gene expression, introns, telomeres.
- **Silencers** are DNA sequences that bind regulatory proteins called repressors that **inhibit transcription**

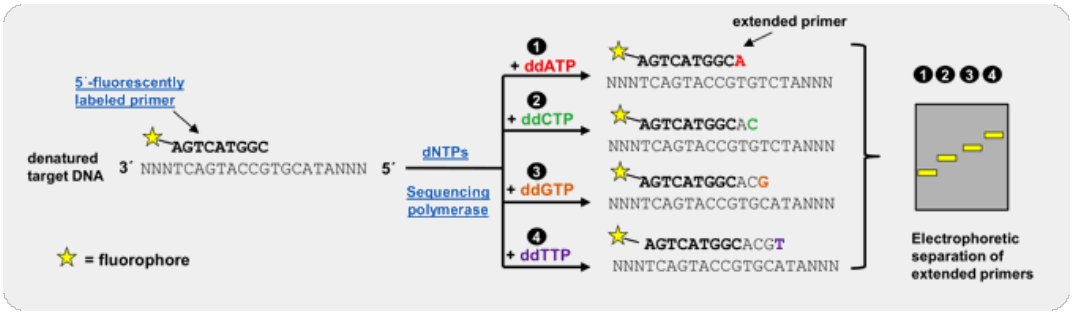
- **Promoters** are the attachment points for RNA polymerase to transcribe mRNA
- **Enhancers** are DNA sequences that increase the rate of transcription
- **Introns** are the area in DNA for non-coding regions
- **Extrons** are the area in DNA for coding regions
- **mRNA**only copies the information from the extrons and ignore what is in the introns. So only extrons' information can leave the nucleus
- In DNA there are also many repetitive sequences, especially in eukaryotic DNA, that can make up 5-60% of the genome; specifically, an area of repetitive sequences that occurs on the ends of eukaryotic chromosomes.
- These repetitive sequences called **telomeres**, protect the DNA during replication. Since enzymes can't replicate all the way to the end of the chromosome, the parts that aren't copied are part of the telomeres. This **prevents the DNA molecule from degradation during replication.**





Artificial DNA sequencing

Dideoxyribonucleotides (**DDNA**) inhibit DNA polymerase during replication, thereby stopping replication from continuing. Dideoxyribonucleotides with **fluorescent** markers, are used and incorporated into sequences of DNA, to stop replication at the point at which they are added. This creates different sized fragments with fluorescent markers that can be separated and analyzed by comparing the colour of the fluorescence with the fragment length.



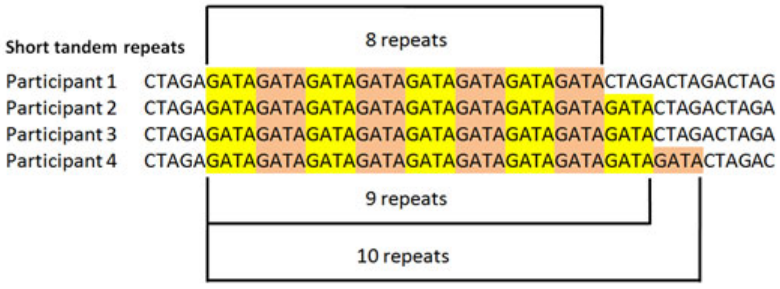
Tandem repeat

Short tandem repeats (STRs), also known as variable tandem repeats (VNTRs) are regions of non-coding DNA that contain **repeats of the same nucleotide sequence.** They are repeated numerous times in a head-tail matter. These short repeats show variations between individuals in terms of the **number of times** the sequences is repeated.

For example, CATACATACATACATACATACATA is a STR where the nucleotide sequence CATA is repeated six times for one individual. However, in another individual, this tandem repeat could occur only 4 times CATACATACATACATA. These variable tandem repeats are the basis for **DNA profiling** used in **crime scene investigations and genealogical tests** (paternity tests).

Paternity test: Mother's DNA – mitochondrion

Father's DNA – Y chromosome



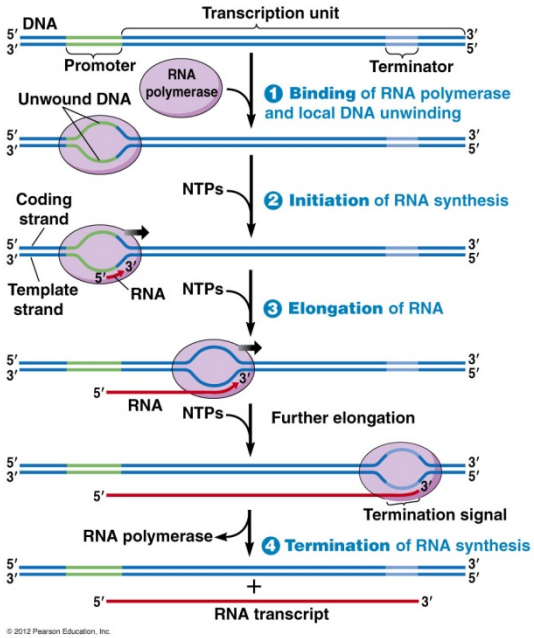
7.2 Transcription and gene expression

U1	Transcription occurs in a 5' to 3' direction.
U2	Nucleosomes help to regulate transcription in eukaryotes.

U3	Eukaryotic cells modify mRNA after transcription.
U4	Splicing of mRNA increases the number of different proteins an organism canproduce.
U5	Gene expression is regulated by proteins that bind to specific base sequencesin DNA.
U6	The environment of a cell and of an organism has an impact on geneexpression.
A1	The promoter as an example of non-coding DNA with a function.
S1	Analysis of changes in the DNA methylation patterns.

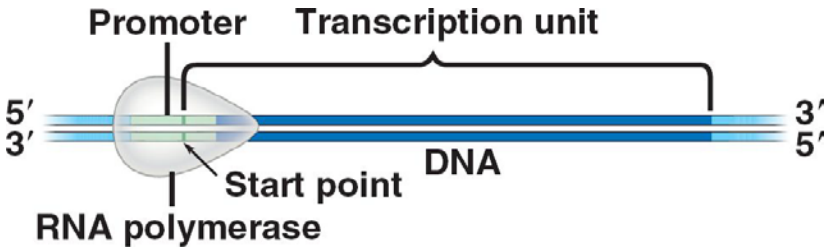
Transcription of RNA

- Transcription occurs in a 5' to 3' direction where the 5' end of the free RNA nucleotide is added to the 3' end of the RNA molecule that is being synthesized.
- Transcription consists of 3 stages called **initiation, elongation and termination**
- Transcription begins when the **RNA polymerase binds to the promoter** with the help of specific binding proteins



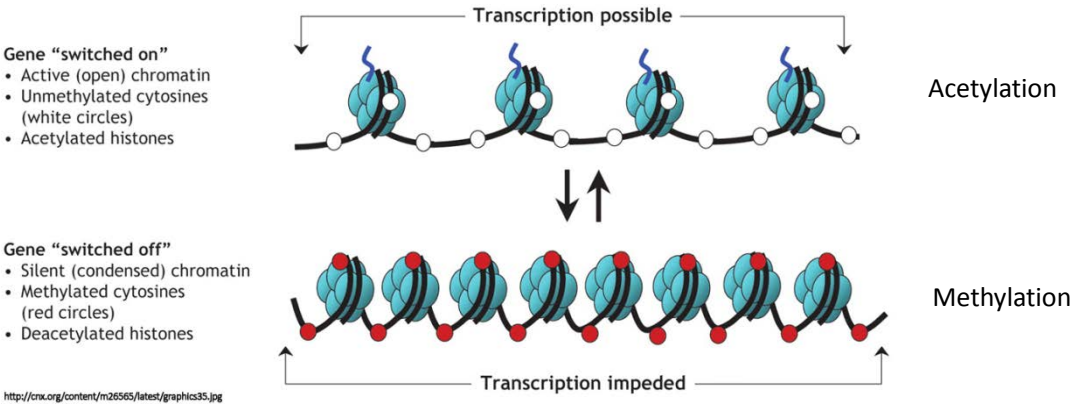
The **promoter region** is a DNA sequence that initiates transcription and is an example of non-coding DNA that plays a role in gene expression. Promoter region is also the **binding site** for RNA polymerase, is the starting point of transcription

Operator allows inhibitor protein to bind to stop the transcription, **Repressor protein** is bind to the operator to prevent RNA polymerase from transcribing genes



Nucleosome regulating gene transcription

- As explained previously in 7.1 eukaryotic DNA wraps around histone proteins and supercoils
- This supercoiling helps regulate transcription because only **certain areas** of the DNA are accessible for the production of mRNA by transcription.This regulates the production of a polypeptide.
- One of the main ways this occurs is through the modification of the histone tails
- **Acetylation**: When acetyl groups are added to the positively charged histone tails, they become negative and the DNA repels against them. This **opens up the nucleosome** so the DNA is not as close to the histone anymore and chromatin remodeling can occur. **Acetylation switches on genes**.
- **Methylation**: decreases transcription of the gene. It makes histone protein closer and tighter so less gene will be expressed. **Methylation switches off genes.**
- The amount of methylation can vary over an organisms lifetime and can be affected by environmental factors



Protein regulation of gene expression

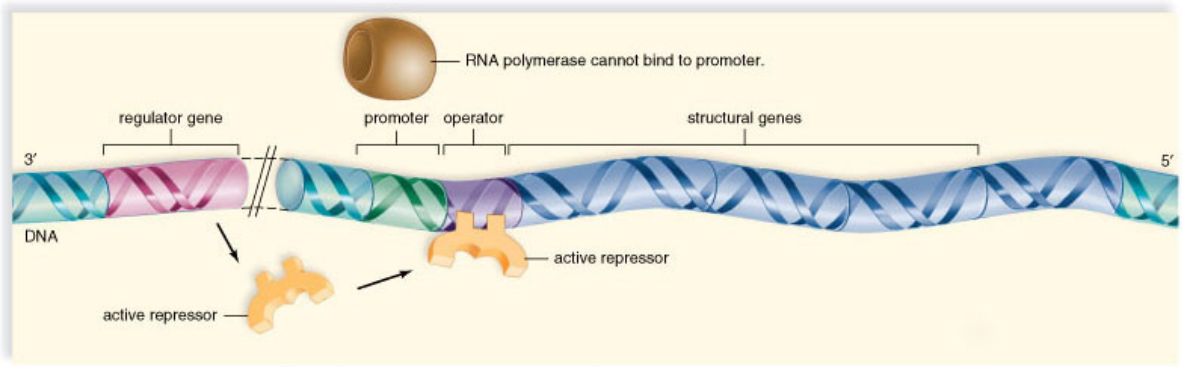
- Gene expression can also be regulated by the environment surrounding the gene that is expressed or repressed
- Specific proteins can regulate how much transcription of a particular gene will occur

- These regulatory proteins are unique to a particular gene
- Regulatory sequences on the DNA that increase the rate of transcription when proteins bind to them are called **enhancers**
- Regulatory sequences on the DNA that decrease the rate of transcription when proteins bind to them are called **silencers**
- Promoter-proximal elements have binding sites closer to the promoter and their binding is necessary to **initiate** transcription

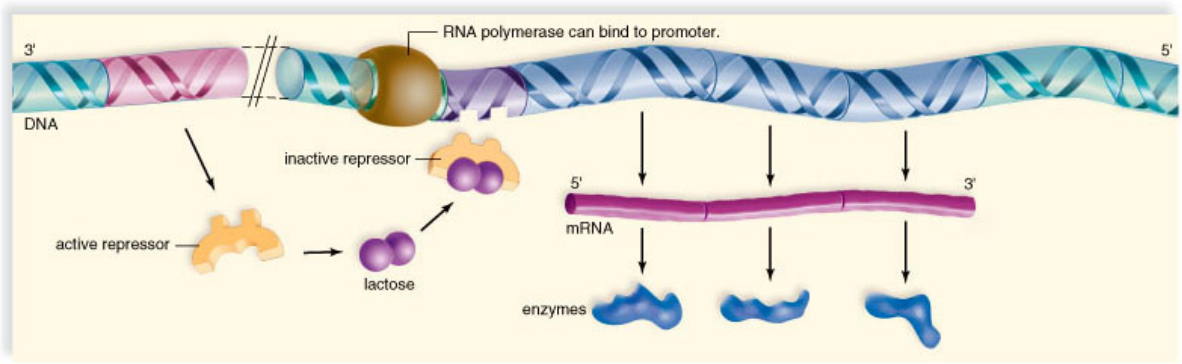
DNA Sequence	Binding protein	Function
Enhancers	Activator	Increase greatly the rate of transcribing genes
Silencers	Repressor	Either block or stop the rate of transcribing genes
Promoters	RNA polymerase	Binds to promoter and begins transcription in **5' to 3' direction**

Example: Lactose production

- In prokaryotic cells such as E.coli **repressor proteins** block the production the enzymes needed to break down lactose in the cell.
- However, when Lactose is present, it will bind to the repressor protein, causing it to fall off, and allowing transcription to occur.
- As transcription occurs, these enzymes are made and lactose is broken down into glucose and galactose. Since there is small amounts of lactose now in the cell, the **repressor** binds again to the operator, blocking transcription from taking place.
- This is an example of **negative feedback**



a. **Lactose absent.** Enzymes needed to take up and use lactose are not produced.



b. **Lactose present.** Enzymes needed to take up and use lactose are produced only when lactose is present.

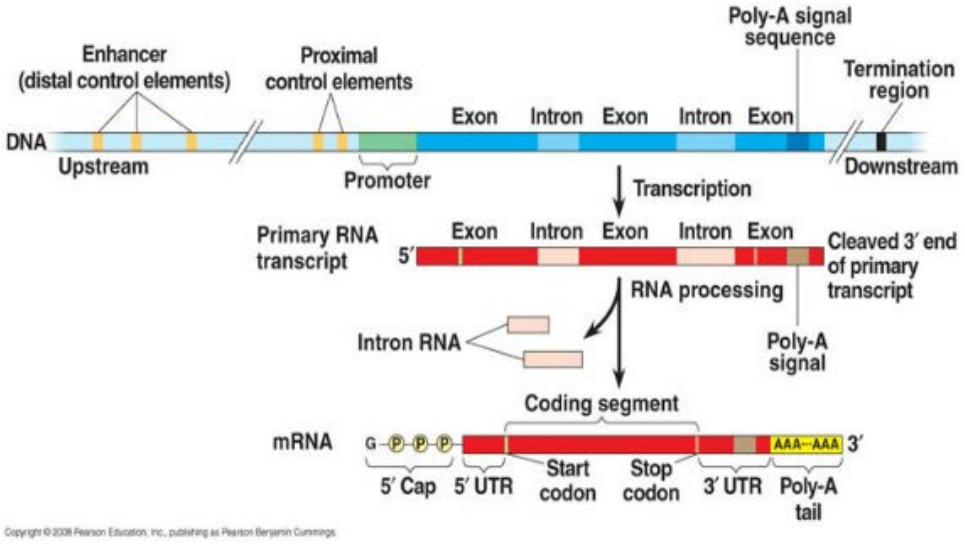
Environmental impact on gene expression

- The external environment in which the organism is located or develops, as well as the organism's internal world, which includes such factors as its **hormones and metabolism** can have an impact on gene expression
- **Temperature and light** are external conditions which can affect gene expression in certain organisms.
- For example, **Himalayan rabbits** carry the **C gene**, which is required for the development of pigments in the fur, skin, and eyes, and whose expression is regulated by temperature (Sturtevant, 1913).
- Specifically, the C gene is inactive above 35°C, and it is maximally active from 15°C to 25°C. This temperature regulation of gene expression produces rabbits with a distinctive coat coloring. In the warm, central part of the rabbit's body, the gene is inactive, and no pigments are produced therefore the fur color is white (picture below). In the rabbit's extremities (i.e., the ears, tip of the nose, and feet), where the temperature is much lower than 35°C, the C gene actively produces pigment, making these parts of the animal black.

- During embryonic development embryos contain chemicals called **morphogens,** which can affect **gene expression** and thereby affecting the fate of embryonic cells depending on their position within the embryo. **Morphogens regulate the production of transcription factors in a cell**
- An obvious example is how sunlight affects the production of skin pigmentation in humans
- A chemical example, was the use of Thalidomide by pregnant woman for morning sickness. It was thought it was harmless for humans but was not thoroughly tested. The drug was withdrawn too late to prevent severe developmental deformities in approximately 8,000 to 12,000 infants, many of whom were born with stunted limb development. Interestingly, despite the fact that thalidomide is dangerous during embryonic development, the drug continues to be used in certain instances yet today.

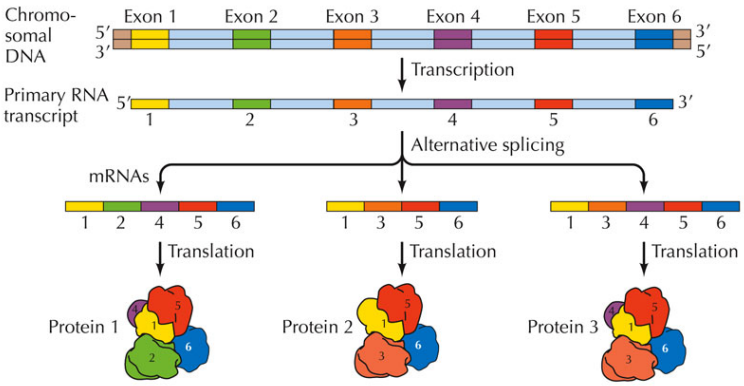
Modification of mRNA after transcription

- In eukaryotes, the locations for transcription and translation are separated by the nuclear membrane. This allows for post-transcriptional modification of the mRNA.
- The first product of transcription is pre-mRNA
- As eukaryotic mRNA travels from the nucleus to the ribosomes, non-coding strands of the mRNA called **introns are removed** to form functional mature mRNA.
- They are removed through **RNA splicing**
- The **exons are spliced together** to form mature mRNA
- Also a **poly A tail** consisting of approximately **100-200 adenine nucleotides** is added to one end of the mRNA and a **5' cap** is added to the other end (these help protect the mature mRNA transcript)



- **Alternative splicing** can also occur with genes that produce multiple proteins, which means that some **exons may also be removed during splicing**, thus producing different polypeptides

- For example, in mammals tropomyosin which is a protein involved in muscle contractions; however, the pre-mRNA is spliced to form 5 different forms of the protein. The mature mRNA that codes for tropomyosin in the smooth muscle of the intestines is missing exon 3 and 10,while the mRNA that codes for tropomyosin in skeletal muscle is missing exon 2.

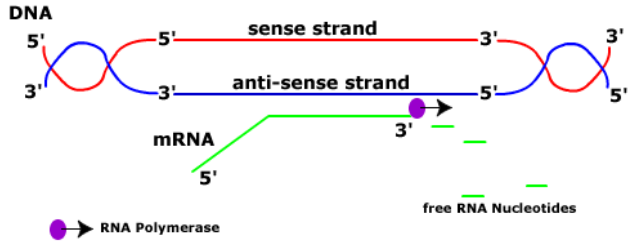


7.3 Translation

U1	Initiation of translation involves assembly of the components that carry outthe process.
U2	Synthesis of the polypeptide involves a repeated cycle of events.
U3	Disassembly of the components follows termination of translation.
U4	Free ribosomes synthesize proteins for use primarily within the cell.
U5	Bound ribosomes synthesize proteins primarily for secretion or for use inlysosomes.
U6	Translation can occur immediately after transcription in prokaryotes due tothe absence of a nuclear membrane.
U7	The sequence and number of amino acids in the polypeptide is the primarystructure.
U8	The secondary structure is the formation of alpha helices and beta pleatedsheets stabilized by hydrogen bonding.
U9	The tertiary structure is the further folding of the polypeptide stabilized by interactions between R groups.
U10	The quaternary structure exists in proteins with more than one polypeptide chain.
A1	tRNA-activating enzymes illustrate enzyme -- substrate specificity and the role of phosphorylation.
S1	Identification of polysomes in electron micrographs of prokaryotes and eukaryotes.
S2	The use of molecular visualization software to analyse the structure of eukaryotic ribosomes and a tRNA molecule.

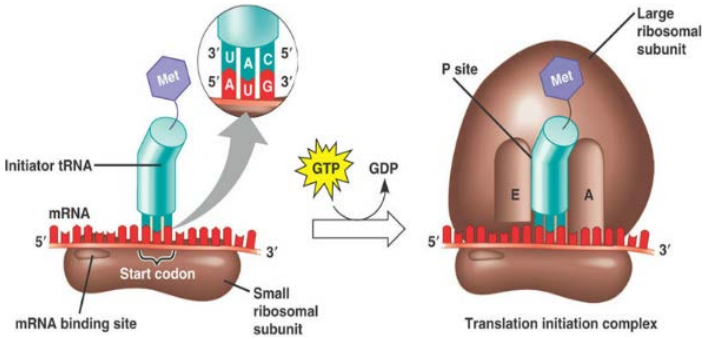
Transcription(revised)

- RNA polymerase binds to a site on DNA (promoter region) at the start of a gene.
- RNA polymerase separates the DNA strands and synthesises a complementary RNA strand.
- RNA copies from the **anti-sense** strand which contains the information on the **sense** strand.
- Once RNA is made, RNA polymerase detaches and DNA double helix reform.



Initiation of translation:

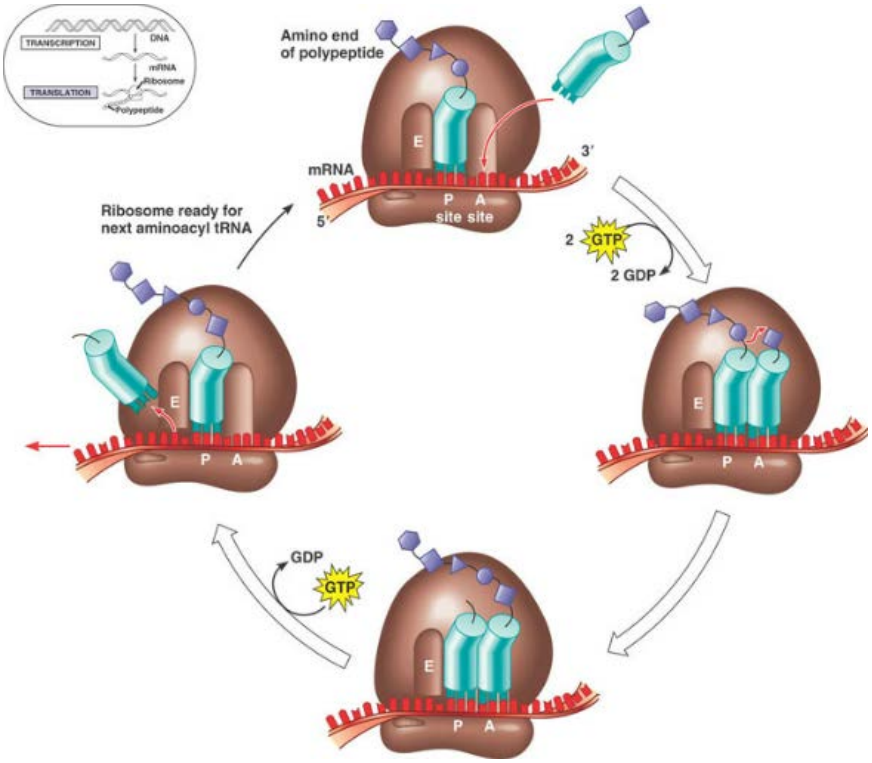
- mRNA binds to the **small (30 s) ribosoma**l sub-unit.
- tRNA carrying **Methionine** with the anticodon UAC binds to the codon **AUG** (**start codon**).
- This is called the initiation complex.
- The large ribosomal subunit binds to the small ribosome, with the tRNA containing methionine binding at the p-site of large subunit.



Elongation of translation

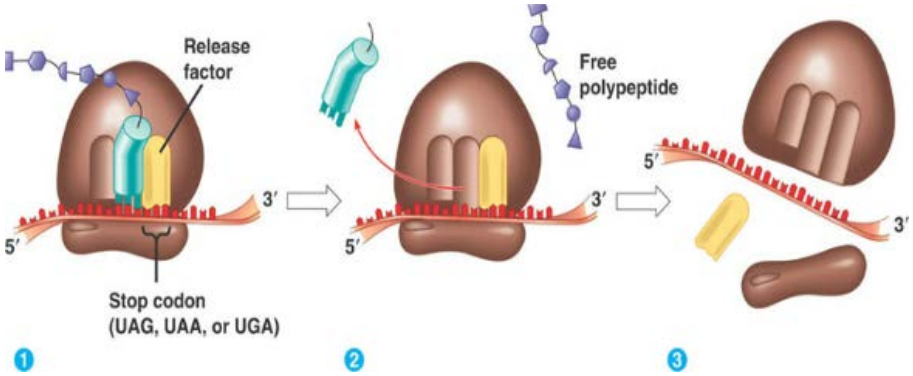
- While the first tRNA is still attached, a second tRNA attaches to the mRNA at the **A site** on the ribosome, carrying the amino acid that corresponds to the mRNA codon.
- The methionine amino acid at the P site binds to the amino acid carried by the second tRNA located at the A site.
- The two amino acids are joined together through a **condensation reaction** that creates a **peptide** bond between the two amino acids.
- The ribosome moves along the mRNA one codon shifting the tRNA that was attached to methionine to the **E site**.
- The tRNA is released back into the cytoplasm from the E site, allowing it to pick up another amino acid (methionine) to build another polypeptide.
- Another tRNA moves into the empty A site bringing the next amino acid corresponding to their RNA codon.

- Again, the amino acid is attached to the polypeptide forming a peptide bond, the ribosome slides across one codon and tRNA at the P site moves into the E site releasing it back into the cytoplasm.
- The ribosome continues to move along the mRNA adding amino acids to the polypeptide chain.
- This process continues until a stop codon is reached.



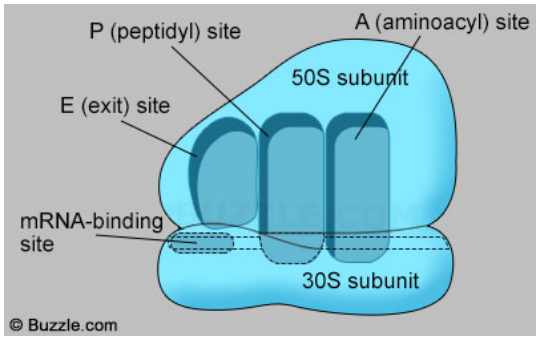
Termination of translation:

- Termination begins when 1 of the 3 stop codons (UAA, UGA, UAG) moves into the A site.
- These tRNA have no attached amino acids.
- When the stop codon is reached the ribosome dissociates and the polypeptide is released.



Ribosome

- Ribosomes are composed with two subunits – large and small subunit
- Large subunit sit on the top and small subunit holds the RNA
- Ribosomes have three sites:
- **A site**: check for the right tRNA matching mRNA, joining to the mRNA (**Activation**)
- **P Site**: form peptide bonds with growing amino acid chain (**Polypeptide**)
- **E site**: empty tRNA exit back to cytoplasm to pick up new amino acid (**Exit**)



tRNA Structure

- tRNA is a type of RNA molecule that transfers a specific **amino acid** to a growing polypeptide chain during translation (protein synthesis) at the ribosomes.
- Sections of the tRNA become **double stranded** through hydrogen bonds formed between base pairs creating **loop**s
- A triplet of bases form the **anticodon** which will bind to the corresponding triplet codon on the mRNA strand
- The base sequence of **CCA** at the **3'** end forms the **amino acid binding site**

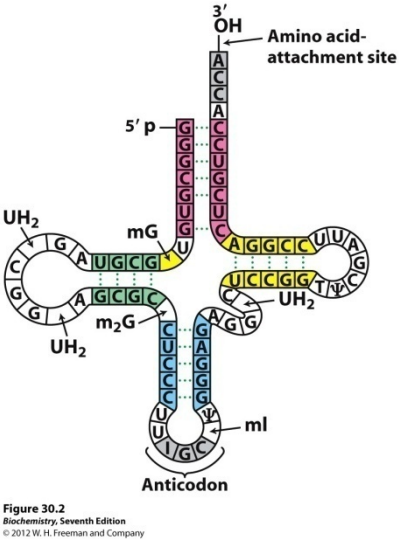


Figure 30.2
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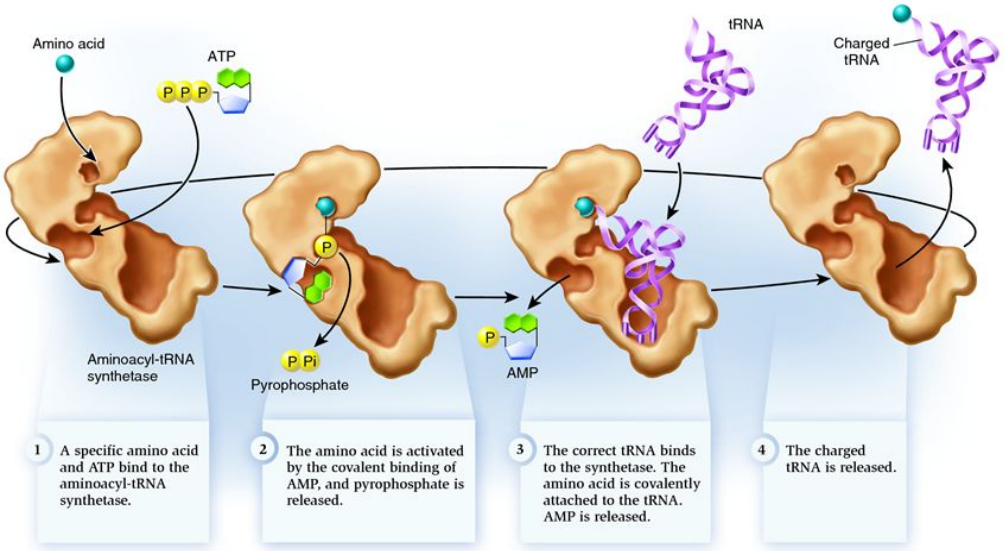
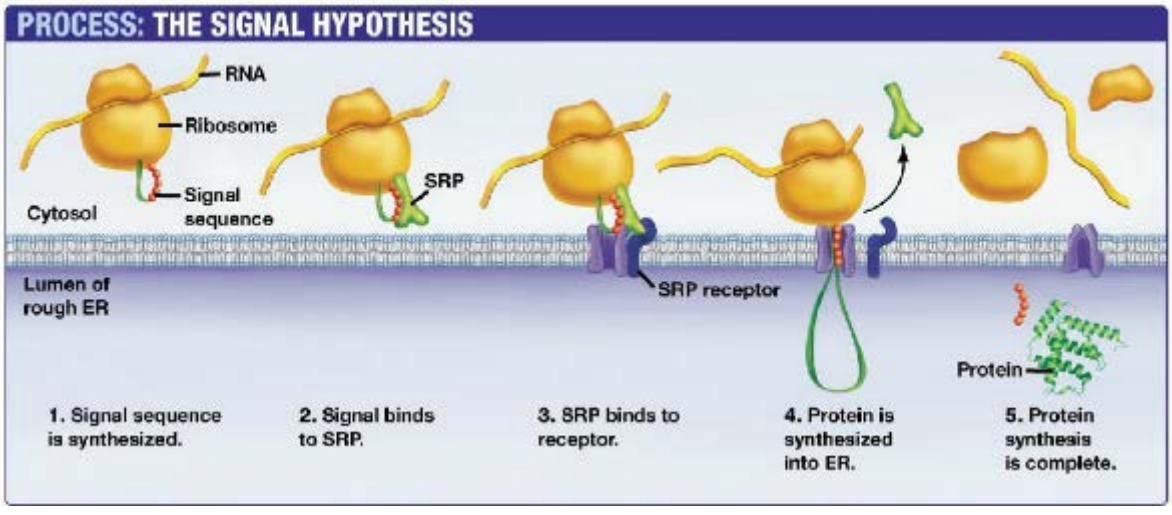
tRNA activating enzyme

- Each tRNA binds with a specific amino acid in the cytoplasm in a reaction catalyzed by **a specific tRNA-activating enzyme**.
- Each specific amino acid binds covalently to the **3'- terminal nucleotide (CCA)** at the end of the tRNA molecule.
- The binding of the specific amino acid to the tRNA requires energy from ATP.
- Energy between the tRNA and amino acid **(the bond)** will be used in translation to form a peptide bond between amino acids.

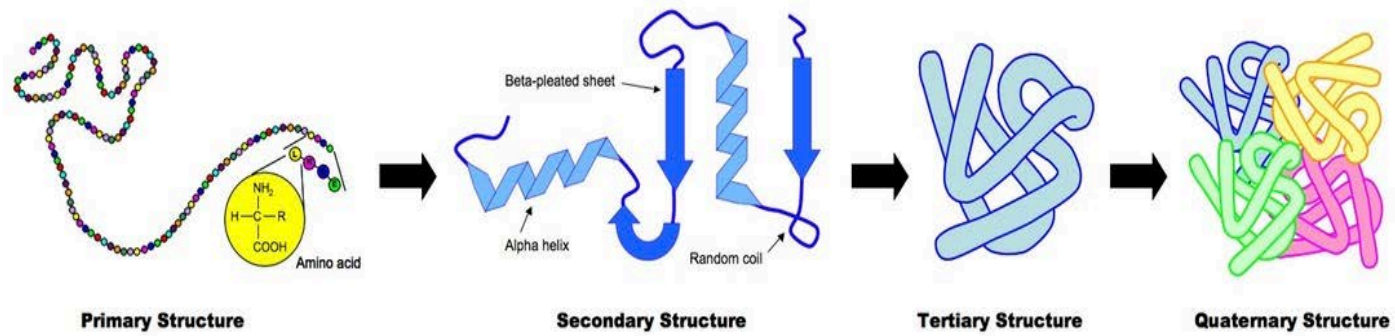


Ribosomes on rough endoplasmic reticulum synthesise protein for secretion

- Ribosomes attached to ER create proteins that are **secreted from the cell** by exocytosis or are used in lysosomes.
- Proteins perform many functions within specific compartments of the cell or in other parts of the body after they are secreted out of the cell
- Proteins that are destined to be used in **lysosomes**, ER, Golgi Apparatus, the plasma membrane or secreted by the cell are made by ribosomes **bound by the endoplasmic reticulum**
- Ribosomes that become bound to the ER are directed here by a signal sequence that is part of that specific polypeptide
- This signal sequence on the polypeptide binds to a **signal recognition protein (SRP)**
- The **SRP guides the polypeptide and ribosome to the ER** where it binds to an **SRP receptor**
- Translation can now continue and the polypeptide is deposited into the **lumen of the ER** as its created for transportation to the correct location



Four levels of protein structure



- **Primary** structure: **basic amino acid chain**
- **Secondary** structure: Held together by **hydrogen bonds** between (non-adjacent) amine (N-H) and carboxylic (C-O) groups, H-bonds provide a level of structural stability. (**alpha helix shape & beta pleated sheet**) (e.g. silk)
- **Tertiary** structure: The polypeptide folds and coils to form a complex **3D shape.** Caused by **interactions between R group**s including **ionic bonds, sulfur bridge, hydrophobic and hydrophilic interaction. Protein is globular in nature.**
- **Quaternary** structure: 2 or more polypeptide chains and/or an inorganic compound (**prosthetic group**) (e.g. hemoglobin)

Topic 8: Metabolism, cell respiration and photosynthesis (HL)

8.1 Metabolism

U1	Metabolic pathways consist of chains and cycles of enzyme-catalysed reactions.
U2	Enzymes lower the activation energy of the chemical reactions that they catalyse.
U3	Enzyme inhibitors can be competitive or non-competitive.
U4	Metabolic pathways can be controlled by end-product inhibition
A1	End-product inhibition of the pathway that converts threonine to isoleucine
A2	Use of databases to identify potential new anti-malarial drugs.

Definitions

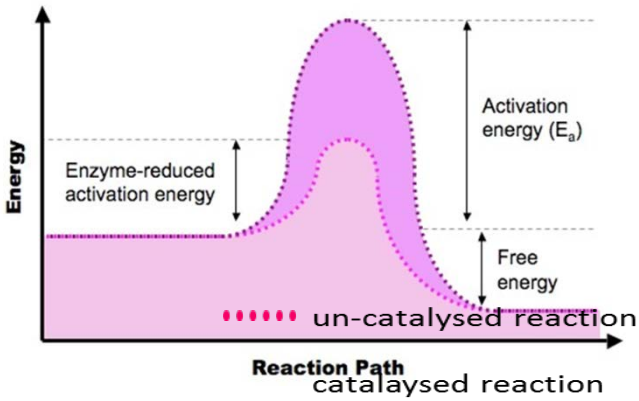
Metabolism: the sum total of all chemical reactions that occur within an organism.

Metabolic pathways: cycles or chains of enzyme catalysed reactions. The chemical change from one molecule to another often does not happen not in one large jump, but in a sequence of small steps. The small steps together form what is called a metabolic pathway, e.g. glycolysis is a metabolic chain and Calvin cycle is a metabolic cycle.

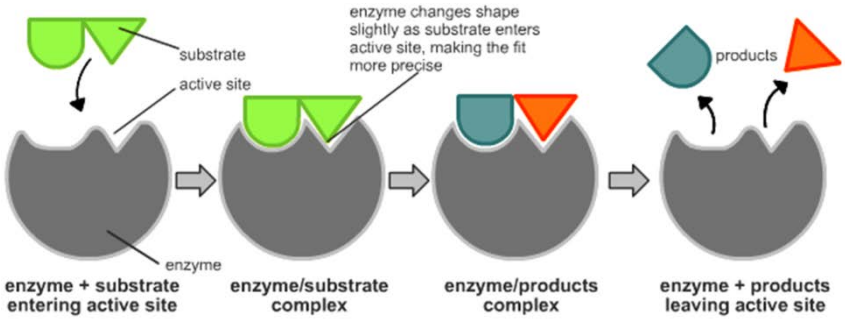
Metabolic chains and cycles

- Metabolism – the chemical reactions that occur in organisms in order for them to maintain life, such as the synthesis of ATP during cellular respiration.
- In metabolic pathways, enzymes catalyse each reaction along the pathway
- Some of these pathways are anabolic, which is building up of organic molecules (easy to remember as anabolic steroids help build muscle)
- The other pathways are catabolic, which means breaking down of large organic molecules into smaller ones (example – hydrolysis reactions during digestion)
- Some of these metabolic reactions are cycles (i.e. Krebs Cycle) and some are linear chains (i.e. Glycolysis)

Enzymes lower the activation energy



- The substrate binds to the enzymes' active site and the active site is altered to reach the transition state.
- Due to the binding the bonds in the substrate molecule are stressed/become less stable.
- The binding lowers the overall energy level of the transition state.
- The activation energy of the reaction is therefore reduced.
  Notice: the **net amount of energy released** by the reaction is unchanged
- Activation energy is the energy that must be overcome in order for a chemical reaction to occur.
- Activation energy more specifically can be defined as the **energy needed to weaken and break the chemical bonds of the substrate**.
- Enzymes work by lowering the activation energy needed for the reaction to occur.
- These reactions therefore occur faster and more substrates can be converted into more products (rate of reaction increases dramatically).



Enzyme inhibitors can be competitive or non-competitive

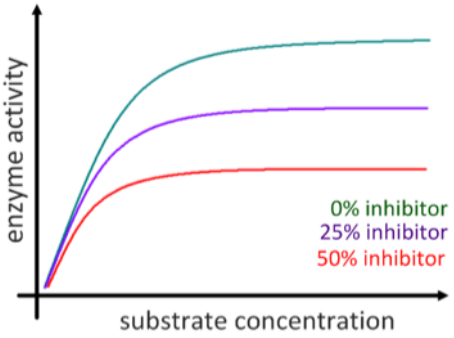
- Enzyme inhibition occurs when molecules bind to enzymes and decreases their activity.
- Two types of enzyme inhibition are competitive and non-competitive inhibition.

Definitions

Inhibitor: a molecule that binds to an enzyme and slows down or stops the enzyme's function.

Competitive inhibition

- Competitive inhibition occurs when a molecule that is structurally similar to the substrate competes directly with substrate for access to the active site, thus **decreasing the number of times a substrate interacts with an enzyme**.
- The inhibitor essentially blocks the substrate from binding to the enzyme.
- Since there is less enzyme/substrate interactions, the chemical reaction rate decreases.
- Competitive inhibition is usually **reversible** but can be irreversible in some cases.
- Competitive inhibition can be overcome by sufficiently increasing the concentrations of substrate, thereby out-competing the inhibitor.
- With **competitive inhibition**, the same maximum rate of reaction will be achieved if more substrates are added – because we haven't changed the number of available enzymes.



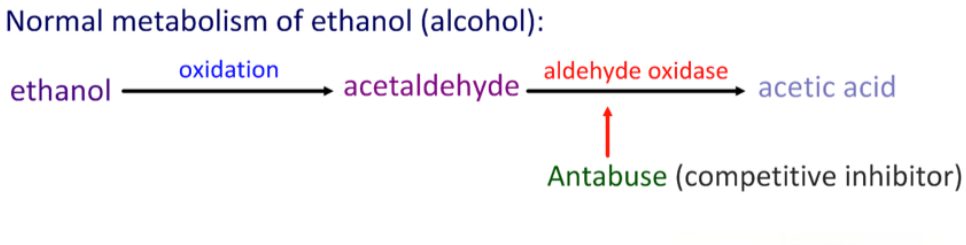
Non-competitive inhibition

- Non-competitive inhibition occurs when an inhibitor does not compete for the active site with the substrate, but instead binds to a separate site on the enzyme, binding to **allosteric site**
- When non-competitive inhibitor binds to the enzyme at the alternative site, it changes the conformational **shape of the enzyme** and thus the active site, so that the substrate can no longer bind to the enzyme for a reaction to occur.
- Non-competitive inhibition is usually reversible.
- Since the inhibitor binds to a site other than the active site, increasing the concentration of the substrate will not speed up the reaction or reduce the effect of the inhibitor.

As concentration of non-competitive inhibitor increases, the rate of reaction decreases. This is because there are fewer active sites available for reaction. The maximum rate of reaction is also reduced – with fewer functional active site, the enzyme has reduced ability to process the substrates, even if substrate concentration is increased.

Example

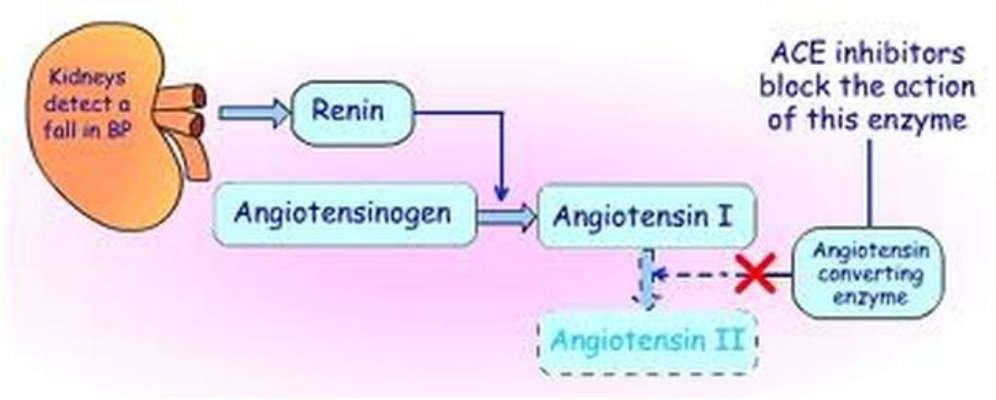
Overcoming alcoholism : an example of competitive inhibition.



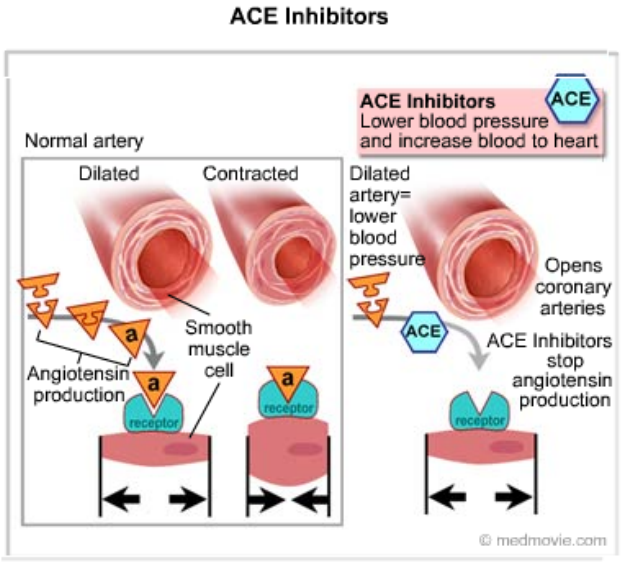
- **Antabuse** competes with **aldehyde oxidase** and prevents **acetaldehyde** from being converted into acetic acid.
- Acetaldehyde builds up and creates a good deterrent from drinking.
- Antabuse is a kind of daily pill, if patient stops taking it, he can drink again.
- Acetaldehyde is a kind of chemical which makes people hangover and sick.

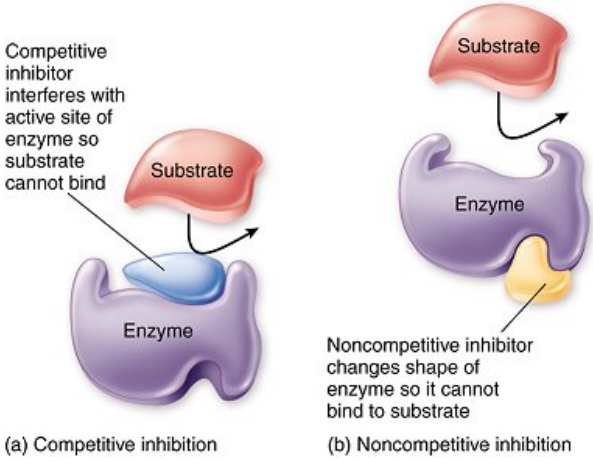
Example

ACE inhibitor (helping control blood pressure): an example of non-competitive inhibition.



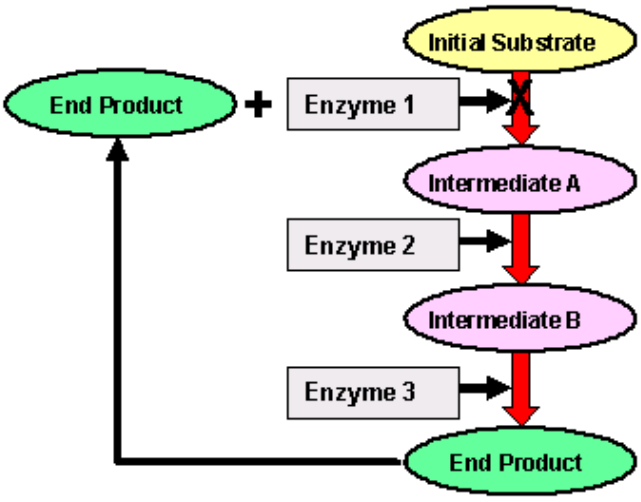
- The RAA system causes vasoconstriction (tightening of blood vessels) when blood pressure drops.
- In people with **hypertension** or heart failure, the Angiotensin II can make the condition worse.
- ACE Inhibitors are medications that inhibit Angiotensinogen Converting Enzymes – they prevent increasing blood pressure.
- ACE Inhibitors are non-competitive and reversible.





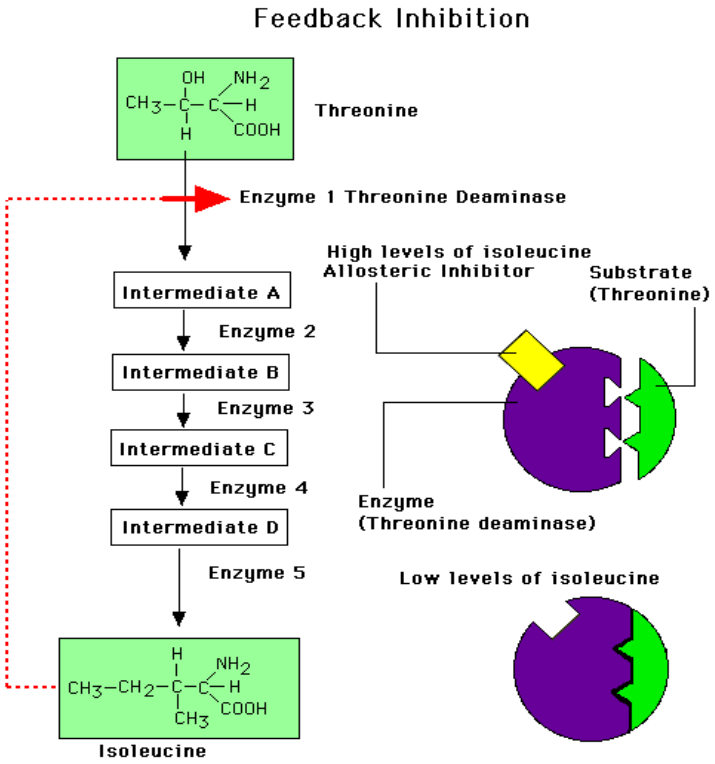
Metabolic pathways can be controlled by end-product inhibition (A.K.A. Feedback Inhibition)

- End-product inhibition prevents the cell from wasting chemical resources and energy by making more of a substance than it needs.
- If a cell is creating a specific product through a metabolic pathway and it makes too much of this product, this product will actually inhibit the first enzyme in the metabolic pathway, thus stopping the metabolic pathway from producing more unneeded product.
- Each step of the reaction is catalysed by a specific enzyme, and a specific end product is present.
- When product is in a sufficient quantity, it inhibits the 1st enzyme and slows down the reaction which means less product made.
- As concentration of product decreases, inhibition decreases and rate of reaction increases.



End-product inhibition of the pathway that converts threonine to isoleucine

- Isoleucine is an essential amino acid
- Bacteria synthesize **isoleucine** from **threonine** in a series of five enzyme-catalysed steps
- As the concentration of isoleucine increases, some of it binds to the allosteric site of threonine deaminase
- Isoleucine acts as a **non-competitive inhibitor** to threonine deaminase
- The pathway is then turned off, regulating isoleucine production.
- If the concentration of isoleucine later falls (as a result of its use) then the allosteric sites of threonine deaminase are emptied and the enzymes recommence the conversion of threonine to isoleucine takes place.



Use of databases to identify potential new anti-malarial drugs.

- Bioinformatics is an approach whereby multiple research groups can add information to a database enabling other groups to query the database.
- Bioinformatics has facilitated research into metabolic pathways is referred to as **chemogenomics**.
- Increasing drug resistance to **anti-malarial** drugs has lead to the use of bioinformatics and chemogenomics to try and identify new drugs.
- Malaria is a disease caused by the protist ***Plasmodium falciparum***
- The increased resistance of the pathogen ***P. falciparum*** to anti-malarial drugs such as chloroquine and the increasing global efforts to eradicate malaria have driven the need to produce new anti-malarial drugs
- P. falciparum strain 3D7 has been sequenced by scientists and is used to test chemicals for new possible medication
- One specific study tested over 300,000 chemicals against a chloroquine-sensitive 3D7 strain and a chloroquine-resistant K1 strain to determine if any of these chemicals inhibited metabolism
- The results showed that 19 new chemicals inhibited the enzymes normally targeted by anti-malarial drugs and 15 chemicals that bound to a total of 61 different malarial proteins.
- **This research provides starting points to produce possible new ant-malarial drugs**

8.2 Cell respiration

U1	Cell respiration involves the oxidation and reduction of electron carriers.
U2	Phosphorylation of molecules makes them less stable.
U3	In glycolysis, glucose is converted to pyruvate in the cytoplasm.
U4	Glycolysis gives a small net gain of ATP without the use of oxygen.
U5	In aerobic cell respiration pyruvate is decarboxylated and oxidized, andconverted into acetyl compound and attached to coenzyme A to form acetylcoenzyme A in the link reaction.
U6	In the Krebs cycle, the oxidation of acetyl groups is coupled to the reductionof hydrogen carriers, liberating carbon dioxide.
U7	Energy released by oxidation reactions is carried to the cristae of themitochondria by reduced NAD and FAD.
U8	Transfer of electrons between carriers in the electron transport chain in themembrane of the cristae is coupled to proton pumping.
U9	In chemiosmosis protons diffuse through ATP synthase to generate ATP.
U10	Oxygen is needed to bind with the free protons to maintain the hydrogengradient, resulting in the formation of water.
U11	The structure of the mitochondrion is adapted to the function it performs.
A1	Electron tomography used to produce images of activemitochondria.
S1	Analysis of diagrams of the pathways of aerobic respiration to deducewhere decarboxylation and oxidation reactions occur.
S2	Annotation of a diagram of a mitochondrion to indicate the adaptationsto its function.

Oxidation and reduction (OIL RIG)

Oxidation	Reduction
Lose electrons(energy)	Gain electron(energy)
Oxygen is gained	Oxygen is removed
Hydrogen is removed	Hydrogen is gained

Electron carrier in respiration

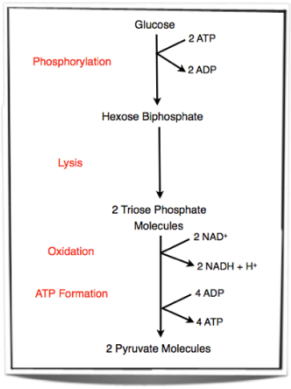
Electron carriers are substances that accept and give up electrons so they can transfer and save energy. There are two types of electron carriers involving in cell respiration

- NAD: $NAD^+ \leftrightharpoons NADH$(forward reaction in reduction)
- FAD: $FAD^+ \leftrightharpoons FADH_2$(forward reaction in reduction)
- During respiration NAD which actually exists as NAD^+ accepts 2 electrons and a proton (H^+) from the molecule being oxidized (like pyruvate) to form NADH with one extra H^+ leftover as a product, in which NAD^+ is reduced into NADH
- After the electron carriers are reduced, they will be transported to electron transport chain, in which, electron carriers will be oxidized and release protons and electrons into inter-membrane space

Glycolysis

Sequence of glycolysis	Explanation	Reaction	Energy
Phosphorylation	a phosphate molecule is added to an organic compound. Phosphorylation can make the molecule more reactive so unstable.	Glucose is added 2 phosphate group at each end (a.k.a. 2 times of phosphorylation) Glucose then is turned into hexose phosphate (6 carbon molecule)	2ATP→2ADP
Lysis	Splitting molecules	Hexose phosphate is splitted into 2 triose phosphate (3 carbon molecule)	n/a
ATP formation	Create ATP	Triose phosphate is turned into pyruvate	$2NAD^+ \rightarrow 2NADH$ 4ADP→4ATP

Summary of glycolysis



Net gain of ATP: 2

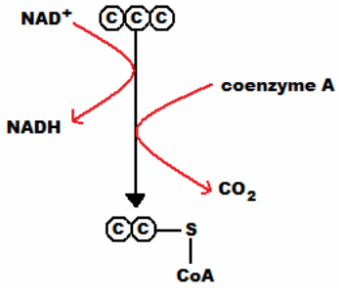
Site of reaction: cytoplasm

Link reaction

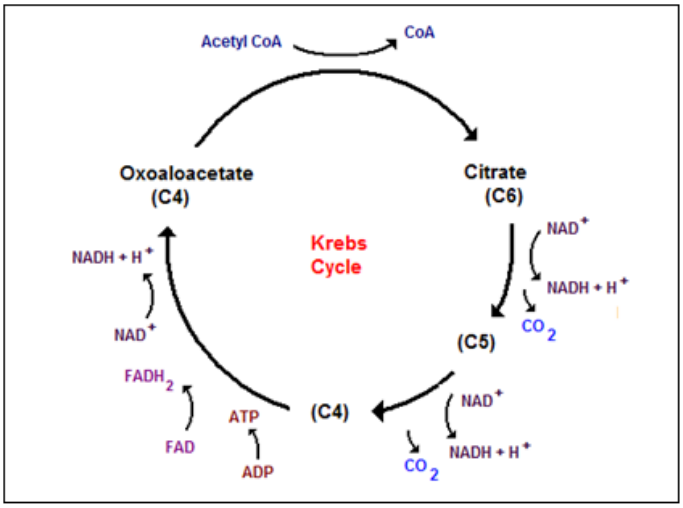
Pyruvate is not allowed to enter the mitochondria, so coenzyme A comes and breaks pyruvate (3 carbon molecule) Into acetyl CoA (2 carbon molecule) and a single carbon molecule, which is eventually bind with 2 oxygen atoms to form carbon dioxide. For every glucose molecule, it will go through **twice** link reaction

- Decarboxylation is a chemical reaction that removes a carboxyl group and releases carbon dioxide (CO_2).
- Oxidation is the *loss* of electrons or an *increase* in oxidation state by a molecule, atom, or ion. Pyruvate is oxidized by the by the removal of pairs of hydrogen atoms (with their electrons), which are passed on the NAD^+ and FAD

Krebs cycle



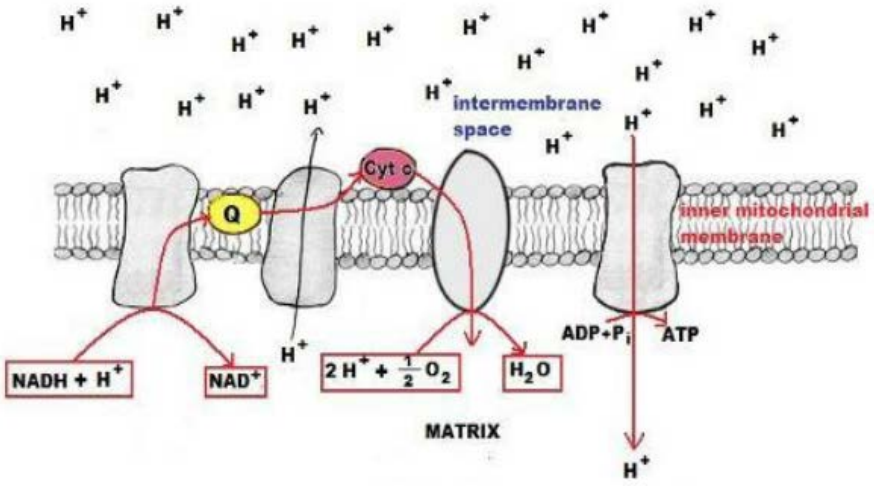
- Acetyl Co A is a two carbon molecule that transfers the acetyl group to the four carbon molecule oxaloacetate to form the six-carbon compound citrate (6C).
- Citrate is decarboxylated (released as carbon dioxide) and CO_2 is excreted as a waste product with the CO_2 from link reaction.
- Citrate is also oxidized and NAD^+ is reduced to form NADH.
- The C5 molecule formed is further oxidized and decarboxylated to form another CO_2 molecule (excreted as waste) and another NADH.
- At this point all the carbons from the original pyruvate molecule have been released as CO_2.
- The C4 molecule undergoes changes to regenerate the original oxaloacetate (C4) molecule, further producing a NADH, a $FADH_2$ and an ATP through a series of redox reactions.
- The products produced by the Krebs cycle are used in electron transport chain to make ATP.
- Final products for one glucose molecule: **2 ATP, 6 NADH, 2 $FADH_2$ and 4 CO_2(excreted).**
- For every glucose molecule, it will go through **twice** kerbs cycle



Electron Transport Chain and Chemiosmosis

- The chain is a series of electron carriers located in the inner membrane of mitochondria that pass electrons from one carrier to the next down an energy gradient.
- NADH supplies 2 electrons to the first carrier in the chain (reforming NAD^+). These electrons move along the chain of electron carriers giving up energy each time they pass from one carrier to the next.
- $FADH_2$ is also oxidized (forms FAD^+) releases its electrons a little later into the electron transport chain.
- Energy is released as the electrons are passed along the carrier proteins.
- This energy is used to pump H^+ ions across the inner mitochondrial membrane from the matrix to the inter-membrane space.
- This accumulation of H^+ ions in the inter-membrane space creates an H^+ concentration gradient between the matrix (less concentrated) and the inter-membrane space (more concentrated)
- Protons (H^+) flow back from the inter-membrane space to the matrix through special protein channels located in the inner mitochondrial membrane called **ATP synthase**.

- As the protons pass across the membrane, they release energy, which is used by the ATP synthase to produce ATP through a phosphorylation reaction.
- This process is called oxidative phosphorylation because oxygen is **the final electron acceptor** and the energy released by **reducing oxygen to water** is used to phosphorylate ADP and generate ATP.
- For each glucose molecule, about 32 molecules of ATP are produced.



Summative table of cell respiration

Reaction sequence	Location	Net Energy Gain per glucose	Enzyme	Waste production
Glycolysis	Cytoplasm	2 ATP,2 NADH	N/A	N/A
Link reaction	Cytoplasm	2 NADH	Coenzyme A	CO_2
Krebs cycle	Mitochondria	2 ATP, 6 NADH, 2 $FADH_2$	N/A	CO_2
Electron transport chain	Inner membrane of mitochondria	N/A	Protein carrier	N/A
Chemiosmosis	Inter-membrane space and matrix	32 ATP	ATP Synthase	H_2O
Respiration in general	Cell	36 ATP	N/A	CO_2,H_2O

Role of oxygen

- At the end of the ETC, electrons are given to oxygen. Oxygen accepts hydrogen ions and forms water (known as the terminal acceptor).
- If oxygen is not available, electron flow along the ETC stops and NADH + H^+ cannot be reconverted to NAD^+.
- Supplies of NAD^+ in the mitochondrion run out and the link reaction and Krebs cycle cannot continue.
- Glycolysis can continue because conversion of pyruvate into lactate or ethanol and carbon dioxide produces as much NAD^+ as is used in glycolysis.
- Therefore oxygen is necessary for aerobic respiration to take place.
- Also, by using up the hydrogen to form water, the proton gradient across the inner mitochondrial membrane is maintained.

Functions of different parts of mitochondria

Structure	Functions
Outer membrane	Separates the contents of the mitochondria from the rest of the cell creating a separate compartment
Inner membrane	Contains the ETC and the ATP synthase for oxidative phosphorylation reactions. The cristae membrane is highly folded to increase the surface area for these reactions

Inter-membrane space	The volume of the space is small to allow proton build-up to create a concentration gradient in order to create ATP through oxidative phosphorylation as the protons flow back into the matrix through ATP synthase
Matrix	Contains enzymes necessary for the reactions that take place; the Krebs cycle and the link reaction

8.3 Photosynthesis

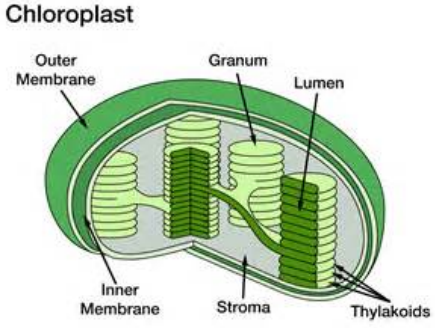
U1	Light-dependent reactions take place in the intermembrane space of thethylakoids.
U2	Light-independent reactions take place in the stroma.
U3	Absorption of light by photosystems generates excited electrons.
U4	Photolysis of water generates electrons for use in the light-dependentreactions.
U5	Transfer of excited electrons occurs between carriers in thylakoid membranes.
U6	Excited electrons from Photosystem II are used to contribute to generate aproton gradient.
U7	ATP synthase in thylakoids generates ATP using the proton gradient..
U8	Excited electrons from Photosystem I are used to reduce NADP.
U9	In the light-independent reactions a carboxylase catalyses the carboxylation of ribulose bisphosphate.
U10	Glycerate 3-phosphate is reduced to triose phosphate using reduced NADPand ATP.
U11	Triose phosphate is used to regenerate RuBP and produce carbohydrates.
U12	Ribulose bisphosphate is reformed using ATP.
U13	The structure of the chloroplast is adapted to its function in photosynthesis.
A1	Calvin's experiment to elucidate the carboxylation of RuBP.
S1	Annotation of a diagram to indicate the adaptations of a chloroplast toits function.

Structure of chloroplast

- The chloroplast has an outer membrane and an inner membrane
- The inner membrane encloses the interconnected membranes called the thylakoid membranes
- Chlorophyll molecules are grouped together into photosystems contained within the thylakoid membranes.
- The area within these thylakoid membranes is called the thylakoid space (lumen) and this is where the light-dependent reactions take place

Inside the thylakoid, green pigments can be found, which is mainly consisted ofhlorophyll A, chlorophyll B and carotenoids.

All those pigments are organized into photosystems



Structure	Function
Thylakoid membrane	Increased SA allows for greater absorption of light by the photosystems in the membrane
Stroma	Allows for the concentration of enzymes necessary for the Calvin cycle to occur
Thylakoid space (lumen)	Small space allows for the accumulation of protons to create a concentration gradient necessary for chemiosmosis to occur

Light-dependent reaction

Photosystem II:

- Photon of light is absorbed by pigments on photosystem II and the energy is transferred to chlorophyll A and excites one of its electron
- The electron is captured by an electron carrier to the electron transport chain (ETC)
- Water is splitted to replace lost electron, and produce H^+ ion, oxygen and electrons
- Water splitting process is called **photolysis**, which is happened in the enzymes called water splitting enzyme

Electron transport chain:

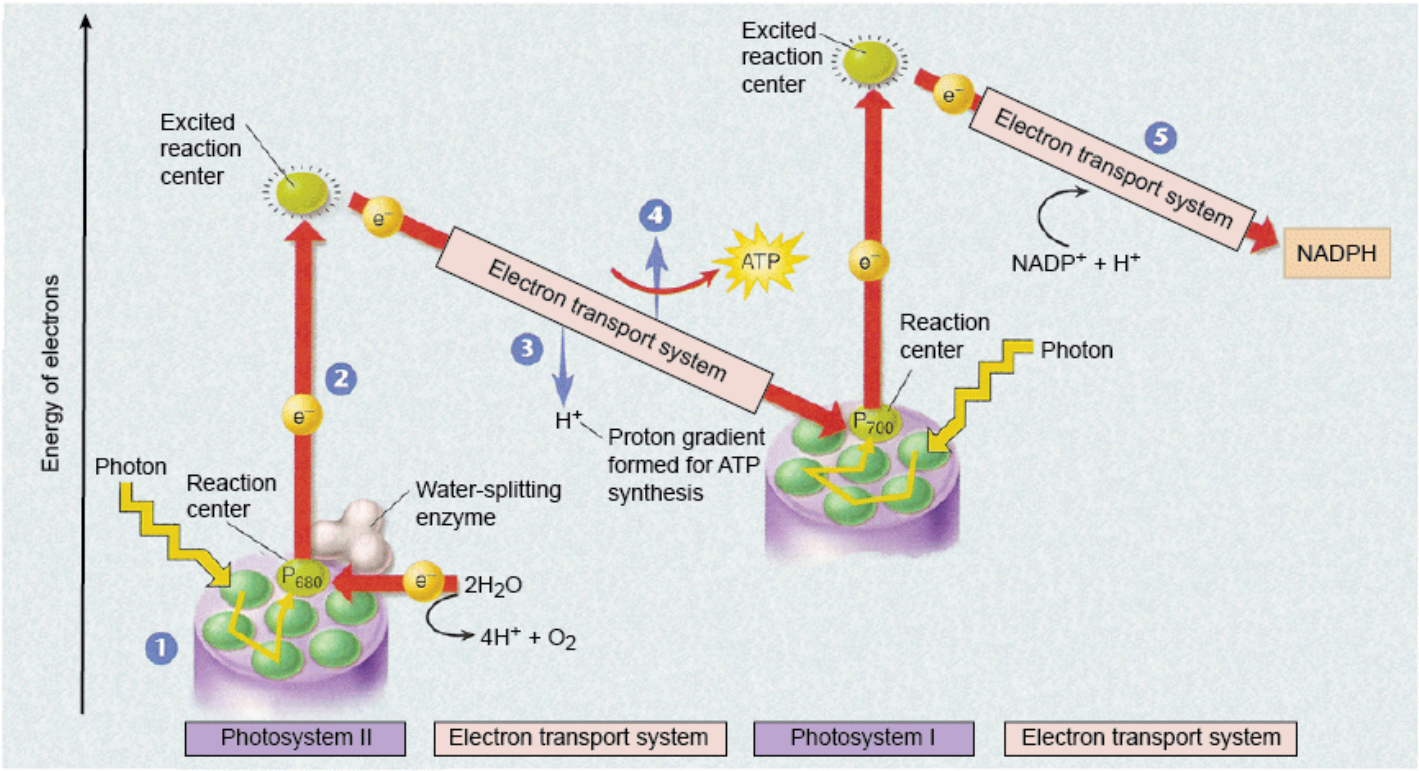
- Electrons (from photosystem II)are carried along the electron transport chain, actively transport H+ ion across the membrane. The de-energised electrons are passed to the photosystem I to replace lost electrons
- **Chemiosmosis**: H^+ ions create a concentration difference between the thylakoid space and stroma. Through normal diffusion along the concentration gradient, H^+ ions diffuse back into the thylakoid space (lumen) and then drive **ATP synthase** to produce ATP

Photosystem I:

- Photons excite electrons in photosystem I, moved by an electron acceptor to **ferredoxin**
- Lost electrons are replaced form electrons travelled from ETC, which is originally excited in photosystem II
- Electrons are used to reduce $NADP^+$ to NADPH by NADP reductase

Summative Light-dependent reaction table

Sequence of reactions	Products transfer	Site of reaction	Overall Products
Photosystem II	Electrons, oxygen, H^+ ions	Lumen (thylakoid space)	ATP, NADPH, O_2 (waste)
Electron transport chain	Electrons, H^+ ions (from photosystem II) → produce ATP by chemiosmosis	Thylakoid membrane	
Photosystem I	Get electrons from ETC, excites electron to ferredoxin then to NADP reductase, turing into NADPH	Lumen (thylakoid space)	

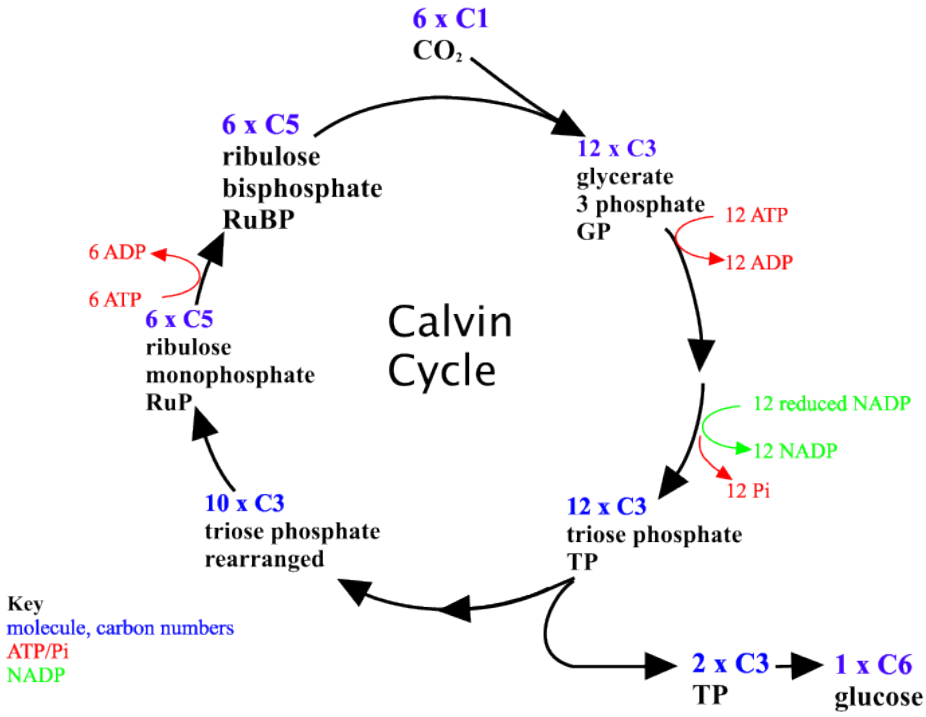


Light-independent reaction (Calvin Cycle)

- One CO_2 molecule enters the Calvin cycle and combines with a 5 carbon molecule called Ribulose bisphosphate (**RuBP**) to temporarily form a 6C molecule.
- This reaction is catalyzed by the enzyme **RuBP carboxylase (rubisco)**.
- This immediately breaks down into two 3C molecules called **glycerate-3-phosphate (G3P).**
- G3P molecules are reduced by adding hydrogen from NADPH using the energy from the breakdown of an ATP molecule, which will be turned into triose phosphate
- Two TP molecules are used to produce one six carbon glucose phosphate molecule, which can eventually be combined with other glucose phosphate to form starch.
- The other ten TP (3C) molecules are used to regenerate six RuBP (5C) using 6 ATP molecules for energy.
- So for every 6 triose phosphate molecules produced, 5 of these triose (3C) sugars are used to reform 3 RuBP (5C) molecules using 3 ATP molecules The one remaining triose phosphate forms half a glucose phosphate

Summative Light-independent reaction table

Sequence of reactions	Products transfer	Energy transfer	Overall Products
Carbon fixation	$6\ CO_2 + 6$ RuBP $\rightarrow$ 12 Glycerate-3-phosphate **RuBP carboxylase (Rubisco)**	N/A	1 Glucose (**1 glucose production per 6 carbon dioxide**)
Reduction	12 Glycerate-3-phosphate $\xrightarrow{\text{reduce}}$ 12 Triose phosphate	12 ATP + 12NADPH $\rightarrow$ 12 ADP, 12 H^+, 12$NAPD^+$	
Regeneration	12 Triose phosphate $\xrightarrow{\text{rearrange}}$ 6 RuBP ($\frac{1}{6}$ triose phosphate is used to produce glucose, others are used to rearrange to form RuBP, in this case 2 molecules)	6 ATP $\rightarrow$ 6 ADP	



Topic 9: Plant biology (HL)

9.1 Transport in the xylem of plants

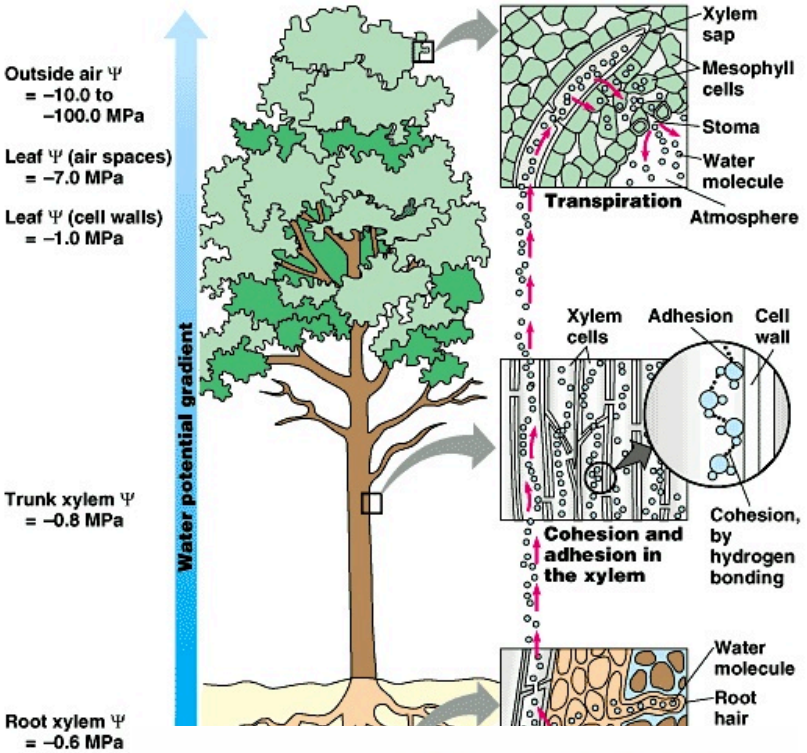
U1	Transpiration is the inevitable consequence of gas exchange in the leaf.
U2	Plants transport water from the roots to the leaves to replace losses from transpiration.
U3	The cohesive property of water and the structure of the xylem vessels allow transport under tension.
U4	The adhesive property of water and evaporation generate tension forces in leaf cell walls.
U5	Active uptake of mineral ions in the roots causes absorption of water by osmosis.
A1	Adaptations of plants in deserts and in saline soils for water conservation.
A2	Models of water transport in xylem using simple apparatus including blotting or filter paper, porous pots and capillary tubing.
S1	Drawing the structure of primary xylem vessels in sections of stems based on microscope images.
S2	Measurement of transpiration rates using potometers.
S3	Design of an experiment to test hypotheses about the effect of temperature or humidity on transpiration rates.

Water properties:

- **Cohesion**: like molecules attract to each other
- Water is a polar molecule that forms a **hydrogen bond** with other water molecules.
- The negatively charged oxygen atom of one water molecule forms a hydrogen bond with a positively charged hydrogen atom of another water molecule.
- This attractive force between these molecules is called cohesion which helps plants draw water from the root through the xylem to the leaf
- **Adhesion**: unlike molecules attract to each other
- Capillary action may occur: water will move up the capillary due to the interaction between water molecules and capillaries.

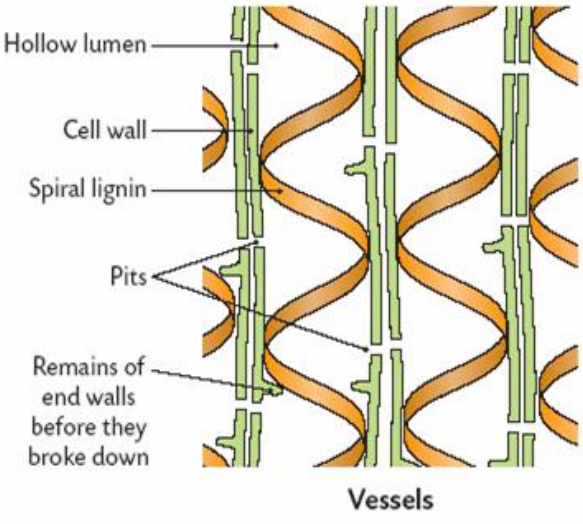
Transpiration:

- Evaporation occurs when some of the light energy absorbed by the leaf is converted to heat, thereby raising the temperature inside the leaf changing the water into water vapour.
- Transpiration is the evaporation of water from the leaves, stems and flowers. It is the movement of water vapour out of the leaf through **stomata**.
- The majority of water lost during transpiration is through openings on the bottom of the leaves called stomata.
- **Transpirational pull** results when water evaporates from the leaves and stems. More water is drawn up through the plant to replace the water that is lost.
- The loss of water generates a negative pressure and a **transpirational pull** on water molecules in the xylem.
- Transpirational pull results from the combined forces of cohesion and adhesion
- Water moves into the roots by osmosis through the cell walls and through the cytoplasm because the concentration of solutes inside the cells is greater than outside the root cells due to active transport of mineral and ions



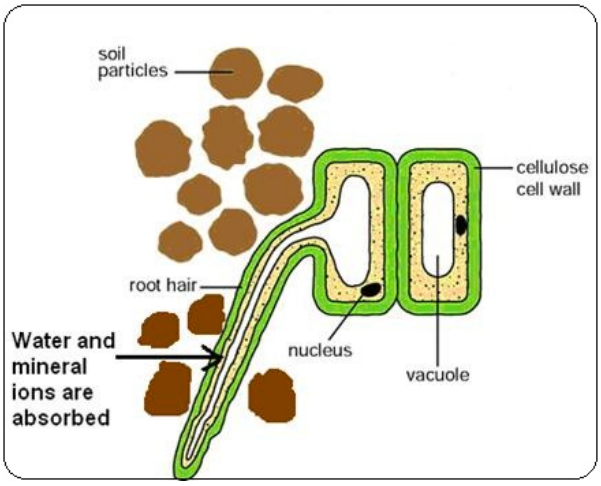
Structure of xylem:

- Xylem vessels are transport tissue found in vascular plants composed of a number of different types of cell, including long, continuous, thin, usually dead cells.
- Cell walls are **thickened** to make the xylem vessels stronger.
- The walls of the xylem are thickened and strengthened by a polymer called **lignin**
- Lignin may be deposited in different ways such as rings or spirals
- Since atmospheric pressure is greater than the pressure inside the xylem vessels, the ridged structure prevent them from collapsing
- The xylem is responsible for the transport of water and soluble mineral nutrients from the roots to the different parts of the plants that use water.



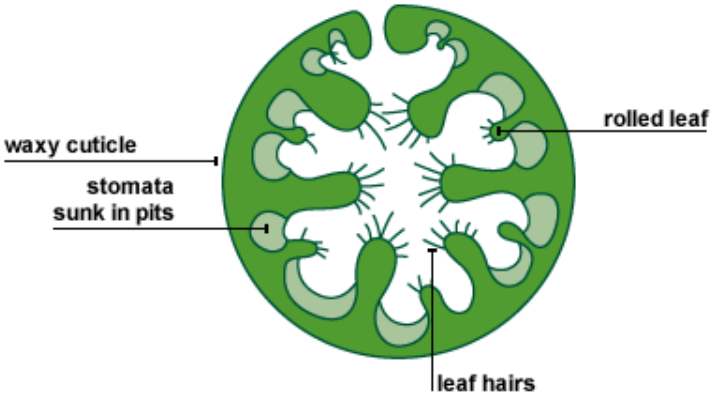
- This also allows minerals absorbed from the soil to be transported through the xylem to the leaves.

Active uptake of mineral ions:



- If the mineral ion concentration of a certain ion is greater inside the **root cell** than the surrounding soil, mineral ions have to be actively transported out of the root cell.
- Also the charged particles cannot directly cross the cell membrane because of the non-polar region inside the bilayer.
- **Proton pumps** use energy (ATP) to pump protons (H^+) out of the root cell into the surrounding soil.
- This results in a higher concentration of protons outside the root cells creating an electrochemical and concentration gradient.
- H^+ can combine with sucrose, NO_3^-, PO_4^{3-}, and other anions to bring them back into the root cell through **protein channels**, following the concentration gradient established by the proton pumps.
- K^+ ions can flow directly through special channels following the electrochemical gradient created by the proton pumps.
- Cations such as potassium can also enter the root cell through specialized potassium pumps that use ATP to pump K^+ directly into the cell.
- Since there is a greater concentration of ions or solutes inside the root cells, water will move into the root cells by osmosis
- Active uptake of mineral ions results in a higher concentration of minerals inside the root cells, thereby transporting water into the root cell by osmosis

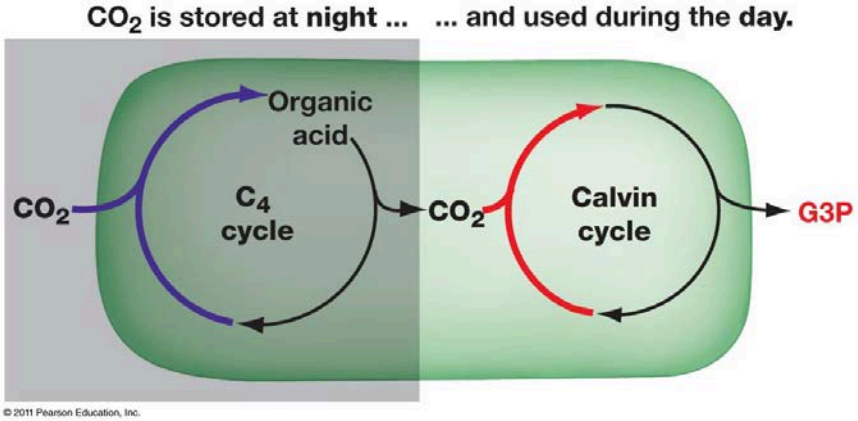
Xerophytes:



- Xerophytes are plants can survive in dry condition by reducing transpiration (water loss).
- **Reduced leaves**: conifers have needles and cacti have spines.
  This decreases the surface area available for transpiration, thus decreasing water loss.
- **Rolled leaves**: Stomata exist inside of rolled leaves. This creates local humidity within the rolled leaf, thus decreasing the leaf's exposure to air currents because water vapour evaporates into the small air space inside the rolled leaf rather than atmosphere. This decreases water loss through transpiration.
- **Reduced number of stomata:** Some xerophytes have a reduced number of stomata. By reducing the number of stomata, water loss through transpiration is decreased because there are fewer holes for evaporation to take place.
- **Thickened waxy cuticle**: Thick waxy cuticle makes the leaves and in some cases stems, more waterproof and impermeable to water. This prevents water loss through the epidermal cells.

CAM plants (Crassulacean acid metabolism):

- CO_2 is absorbed at night and store as C_4 compound
- During the day, photosynthesis can occur with stomata closed by using carbon storage C_4
- It can minimize the time period which stomata opens and loses water to surroundings.



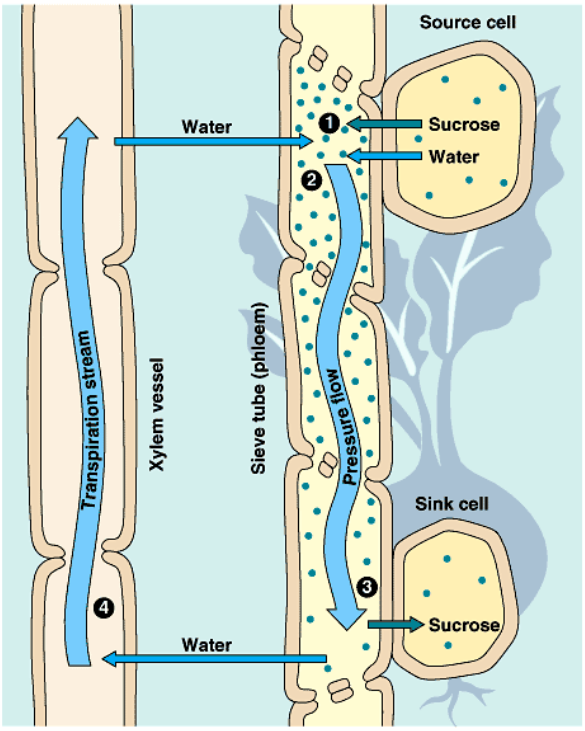
9.2 Transport in the phloem of plants

U1	Plants transport organic compounds from sources to sinks.
U2	Incompressibility of water allows transport along hydrostatic pressure gradients.
U3	Active transport is used to load organic compounds into phloem sieve tubes at the source.
U4	High concentrations of solutes in the phloem at the source lead to water uptake by osmosis.
U5	Raised hydrostatic pressure causes the contents of the phloem to flow towards sinks.
A1	Structure–function relationships of phloem sieve tubes.
S1	Identification of xylem and phloem in microscope images of stem and root.
S2	Analysis of data from experiments measuring phloem transport rates using aphid stylets and radioactively-labelled carbon dioxide.

Transportation in phloem:

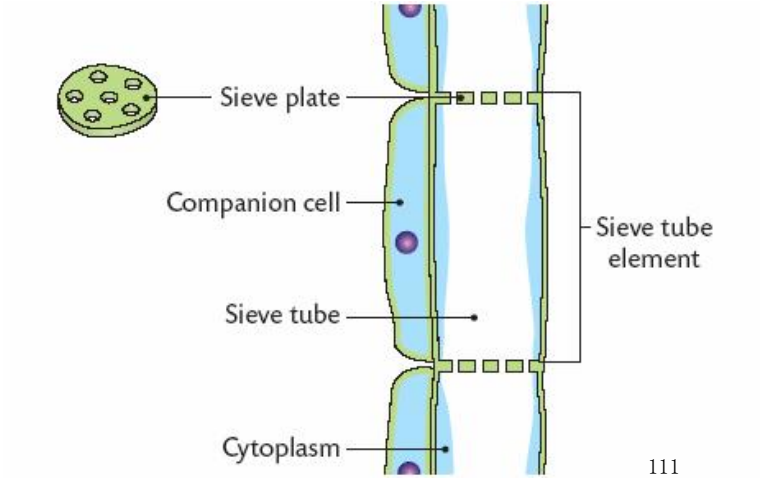
- Sources: site of photosynthesis
- **Sink**: storage of molecules
- Organic molecules such as sucrose and amino acids move from a source to a sink via phloem tubes in plants.
- Phloem tubes can carry sugars and amino acids in a variety of directions; depending on where the source and the sinks are located (sometimes roots can be sources or sinks).
- Sources produce sugars by photosynthesis in leaves or green stems or by hydrolysis of starch in storage vessels (germinating seeds or roots/tubers) and deliver these products via the phloem to the sink (roots, buds, stem, seeds, and fruits).
- At the source, sugar and other organic molecules are loaded into the sieve tube members thus increasing solute concentration within the sieve tube cells (deceases water potential).
- Water from surrounding tissues, enters the sieve tube members by osmosis following a concentration gradient.
- The water absorbed into the sieve tube creates hydrostatic pressure that forces the phloem sap to flow (bulk flow) towards the sink.

1. **Active transport** of sugar from leaves to phloem
2. Water concentration attracts water diffuses from xylem to phloem
3. High pressure is generated by water and sugar
4. Water and sugar moves down from leaves to root
5. **Active transport** moves sugar molecules to root cells
6. Water concentration decreases, water diffuses back to xylem
7. This will create low pressure, causing water to move up



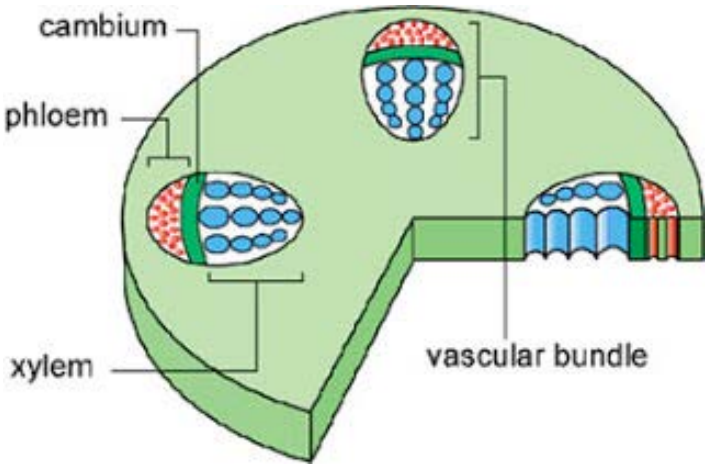
Structure of phloem:

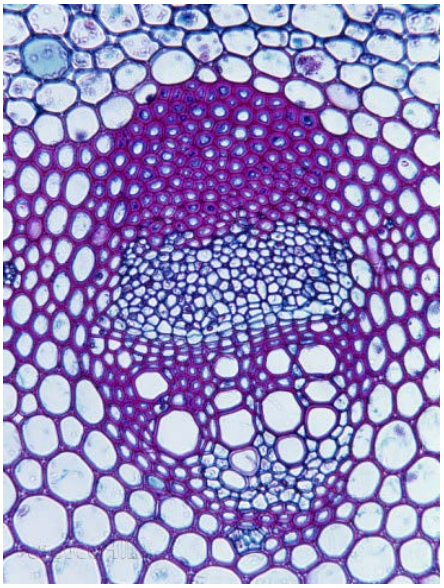
- Organic molecules such as sucrose and amino acids move from a source to a sink via phloem tubes in plants.
- Phloem is composed of living tissue called **sieve plates** (lack a nucleus) that are joined end to end to form a tube that conducts food materials throughout the plant. They are bordered by **companion cells** that carry out the cellular functions of a sieve-tube element.
- **Rigid cell walls** – building up for high pressure
- **Sieve plates** – large pores in cell wall speeding the transport between sieve element cells
- **Companion cells** – provide nutrients and energy to sieve element cells



Vascular bundle:

- Cambium layer – undifferentiated cells which can become xylem or phloem
- Pith – woody part in between vascular bundle
- Epidermis cells – surface cells
- Phloem – smaller tubes
- Xylem – larger tubes



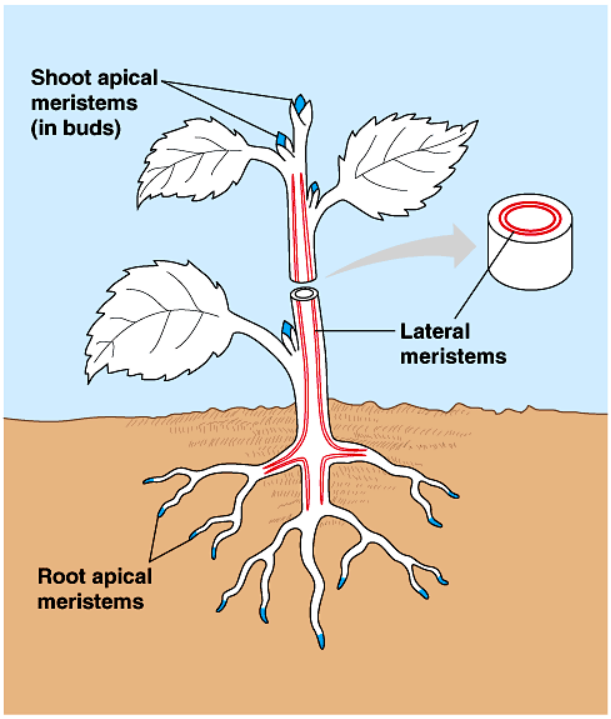


9.3 Growth in plants

U1	Undifferentiated cells in the meristems of plants allow indeterminate growth.
U2	Mitosis and cell division in the shoot apex provide cells needed for extension of the stem and development of leaves.
U3	Plant hormones control growth in the shoot apex.
U4	Plant shoots respond to the environment by tropisms.
U5	Auxin efflux pumps can set up concentration gradients of auxin in plant tissue.
U6	Auxin influences cell growth rates by changing the pattern of gene expression.
A1	Micropropagation of plants using tissue from the shoot apex, nutrient agar gels and growth hormones.
A2	Use of micropropagation for rapid bulking up of new varieties, production of virus-free strains of existing varieties and propagation of orchids and other rare species.

Meristem:

- Meristem tissues in all plants consist of undifferentiated cells (meristematic cells) that generate new cells for plant growth.
- Plant growth is generally indeterminate, which means cells will continue to grow indefinitely
- Meristems are areas where growth occurs and are composed of undifferentiated cells undergoing active cell division
- **Apical meristems** are at the tips of the roots and stems. They are responsible for primary growth of the plant
- **Lateral meristems** are responsible for secondary growth (increasing the diameter and thickness of the plant). They are located in **cambium layer**.
- Cells in the meristems undergo mitosis repeatedly to produce new cells and growth in a plant
- Root meristems are responsible for growth and extension of the root
- Shoot meristems creates cells responsible for shoot growth, but also create cells that will develop into flowers and leaves
- **Auxillary buds**: inactive meristem tissue. When the plant needs to grow a now branch, hormones will activate the bud and continue to grow.



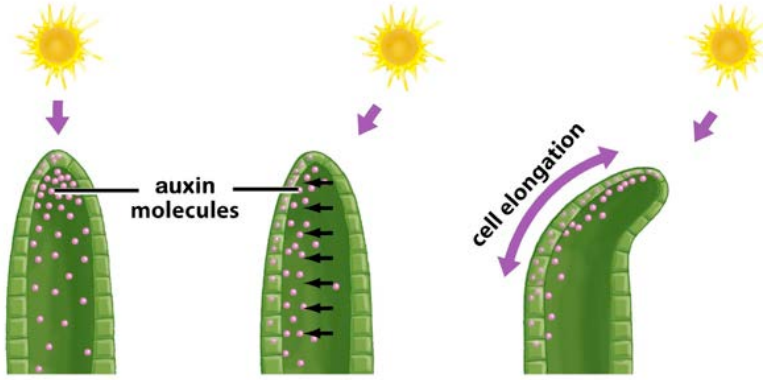
Hormones:

- Hormones are chemical messages produced and released by one part of an organism that has an effect in another location
- One of the main plant hormones is **auxin**
- Auxins initiate growth of roots, regulate leaf development, and influence the development of fruits
- High concentration of auxin promotes the growth in shoot.
- Auxin can change the **patterns of gene expression** in shoot cell.

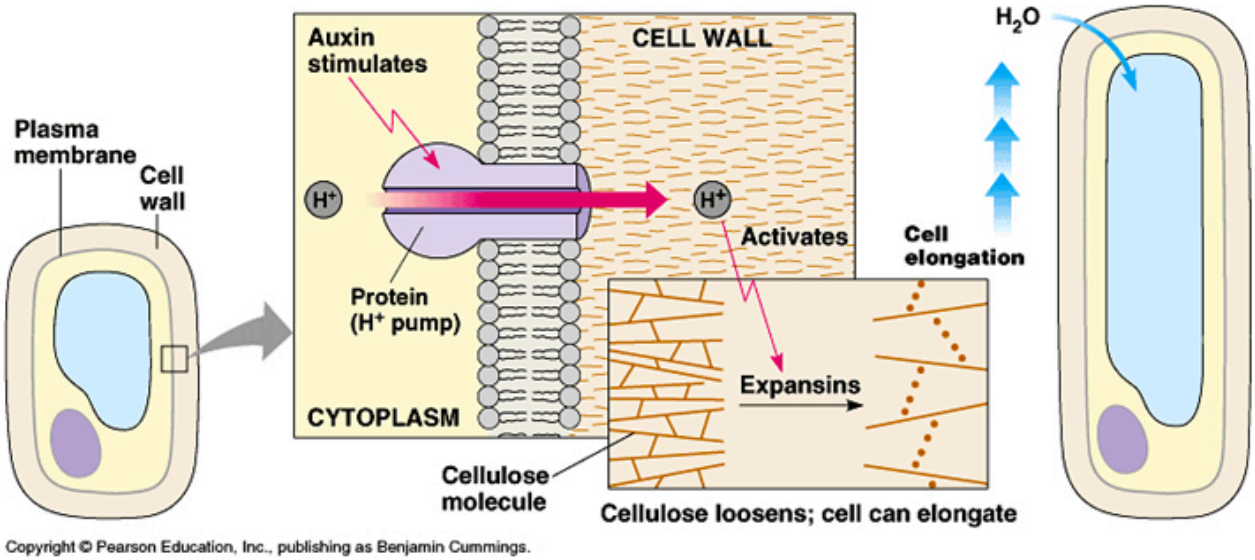
Tropisms:

- A tropism is growth or movement towards or away from an **external stimulus**, such as light, gravity or chemicals.
- Gravitropism is growth in response to gravity
- Phototropism is growth towards or away from an external light source.
- Generally in plants, shoots grow towards the light (**positive phototropism**) and roots grow away from the light (**negative phototropism**).
- Phototropism is essential for plants to make sure they grow towards the sunlight.
- Auxins are plant hormones that promote positive phototropism in plants
- Auxin concentration will increase in an area opposite to the direction of sunlight, thereby stimulating the fast growth of that area, leading to a turn of the shoot.

Auxin efflux pumps:



- **Phototropins** (light receptors) in the tips of the plant detect sunlight.
- Axuin enters the cell by diffusion, **influx transporter proteins**.
- Axuin moves out of the cell by **effiux transporter proteins**.
- Transporter proteins can be activated/inhibited by stimuli such as sunlight.
- If the amount of sunlight is greater on one side of the plant, the phototropins trigger reactions that will cause the redistribution of auxin by efflux pumps to the dark side of the plant.
- High concentrations of auxins cause cells on the shaded side of the cell to swell and elongate.
- When auxin binds to a receptor in the nucleus, this activates a **proton pump**
- The proton pump moves **H^+ ions** into spaces in the **cell wall**, decreasing the pH
- This results in the breaking of the hydrogen bonds between **cellulose fibres**, resulting in **the swelling and elongation of these cells**.
- As the cells elongate and swell on one side of the plant the stem starts to curve towards the light source because of this uneven growth.
- The plant now is growing towards the light source (phototropism).
- For gravitropism auxin is redistributed to the side of the gravity
- Auxin in this case inhibits cell elongation and as the top part of the root grows and extends, the root turns towards the direction of the gravitational pull
- This is opposite to phototropism



Micropropagation:

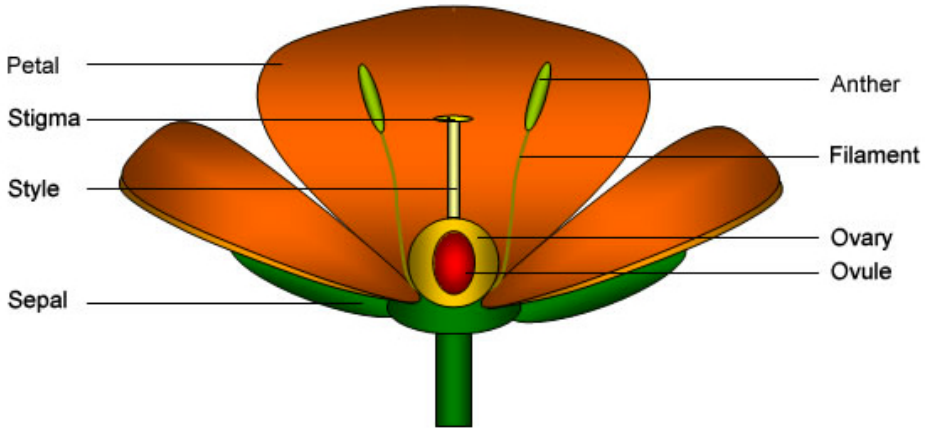
- Micropropagation is an in vitro process that produces large number of cloned identical plants
- Micropropagation depends on the totipotency of plant tissues
- Tissues from the stock plant are sterilized and cut into pieces called **explants**
- The explant is placed into a sterilized growth medium that contains plant growth hormones
- These hormones include auxin.
- Once the plant has roots and shoots, it can be transferred to soil
- Plant virus are usually transported in vascular tissue, which is not presented in meristems.
- Micropropagation of plants, allows for the production of **virus free strains** of plants
- It can also be used to produce plants with desirable characteristics much faster using less space
- You can also store little plantlets for long periods of times in liquid nitrogen, which would be valuable with endangered species.

9.4 Reproduction in plants

U1	Flowering involves a change in gene expression in the shoot apex.
U2	The switch to flowering is a response to the length of light and dark periods in many plants.
U3	Success in plant reproduction depends on pollination, fertilization and seed dispersal.
U4	Most flowering plants use mutualistic relationships with pollinators in sexual reproduction.
A1	Methods used to induce short-day plants to flower out of season.
S1	Drawing internal structure of seeds.
S2	Drawing of half-views of animal-pollinated flowers.
S3	Design of experiments to test hypotheses about factors affecting germination.

Structure of the flower

- Anther: create pollens
- Stigma: pollen landing site
- Style: where pollen tubes grow down
- Petals: for attraction
- Sepals: protecting growing flower
- Ovary: contains **ovules** (eggs)
- Filament: support for stigma



Control of flowering

- **Photoperiodism** is a plant's response to light involving the lengths of day and night; which causes flowering in plants.
- It has been determined that the length of the night (darkness) not the length of the day (light) determines flowering in short-day and long-day plants.
- **Phytochrome** is the photoreceptor or a pigment that plants use to detect light.
- It is sensitive to light in the **red** and **far red** region of the visible spectrum.
- Two forms of phytochrome exist; P_r (inactive form) and P_{fr} (active form).
- P_r absorbs red light (660 nm) while P_{fr} absorbs far red light (730 nm) of the visible spectrum.
- During **daylight** hours when P_r absorbs red light it is converted to P_{fr} and when P_{fr} absorbs far red light it is converted back to P_r. Because there is more red light in sunlight, during the daylight, there if a build-up of P_{fr}.
- At **night** P_{fr} is slowly converted back into P_r. Therefore after a long day of sunlight (**summer**), there will be more P_{fr} in the plant than after a short day of sunlight (winter).
- In long day plants (plants that flower in the summer) P_{fr} stimulates flowering, thus in the summer when there is a build-up of P_{fr}, long day plants flower at the right time.
- In short day plants (plants that flower in the spring or autumn) P_{fr} inhibits flowering, thus preventing these plants from flowering in the summer months when the days are long.

Length of the daylight	P_r level	P_{fr} level
Long (summer)	low	high
Short (winter)	high	low

- **Critical night length**: minimum darkness needed to flower.
- In long day plants, such as **iris**, they only flower when day length reaches a critical period. P_{fr} builds up to a critical point.

- In short day plants, such as **chrysanthemum**, they only flower when length below a critical period. P_{fr} falls below a critical point.

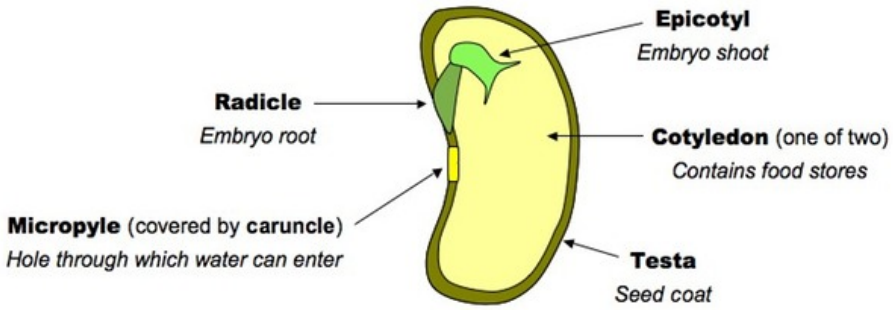
- Flowers, which allow the plant to sexually reproduce, develop from the shoot **apical meristem** and are called a reproductive shoot
- Temperature and day length (mostly period of darkness) can transform a leaf producing shoot into a flower producing shoot
- The amount of light a plant receives, play a role in the production of either **inhibitors or activators of genes** that control flowering
- In long day plants, the active form of the phytochrome pigment P_{fr}, leads to transcription of a gene that controls flowering (**FT gene**)
- The FT mRNA is transported to the shoot apical meristem in the phloem, where it is translated into the **FT protein**
- The protein binds to a transcription factor, which turns on many flowering genes, thus converting the leaf producing meristem into a flower producing reproductive meristem

Pollination:

- Pollination is the process in plants in which **pollen grains** (male gametes) are transferred to the female gametes (**ovules** contained within the carpel), thereby enabling fertilization and sexual reproduction.
- Seed dispersal is the movement or transport of seeds away from the parent plant. This decreases competition between parents and offspring and promotes diversity within the species. Seeds can be dispersed through gravity, wind, water and by animals.
- **Mutualism** is the relationship between two organisms, where both organisms benefit
- Sexual reproduction depends on the transfer of pollen stamen from one plant to the stigma of another plant
- Pollen can be transferred by wind and possibly water, but more commonly pollen is transferred by animals known as pollinators such as bees, butterflies, birds, and bats
- Pollinators gain food from nectar and the plant gains a method to transfer pollen to another plant to allow for sexual reproduction

Seed:

- Radicle: embryonic root
- Plumule: embryonic stem
- Micropyle: allow water to enter
- Scar: where the ovule to the ovary
- Testa: seed coat



- **Germination**: when seeds begin to grow.
- Water enters the seed through micropyle and activate the seed
- Hormones are activated, which will lead to the production of amylase.
- Amylase breaks down starch into maltose.
- Maltose is absorbed by plumuble and radicle.
- If the seed has a single leaf, it is **monocot**.
- If the seed has two leaves, it is **dicot**.

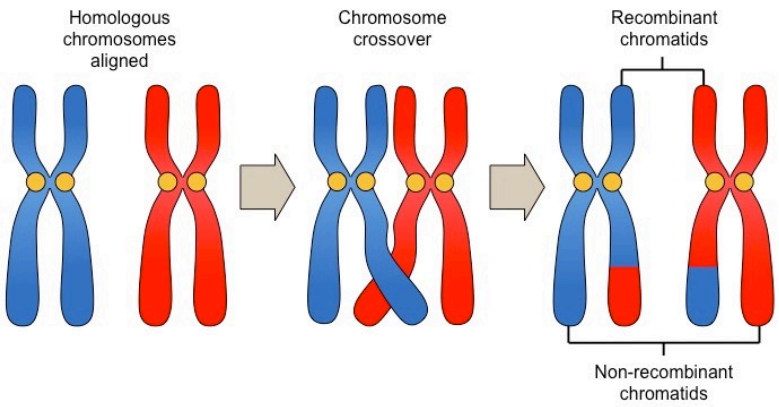
Topic 10: Genetics and evolution (HL)

10.1 Meiosis

U1	Chromosomes replicate in interphase before meiosis.
U2	Crossing over is the exchange of DNA material between non-sister homologous chromatids.
U3	Crossing over produces new combinations of alleles on the chromosomes of the haploid cells.
U4	Chiasmata formation between non-sister chromatids can result in an exchange of alleles.
U5	Homologous chromosomes separate in meiosis I.
U6	Sister chromatids separate in meiosis II.
U7	Independent assortment of genes is due to the random orientation of pairs of homologous chromosomes in meiosis I.
S1	Drawing diagrams to show chiasmata formed by crossing over.

Crossing-over:

- **Chiasmata** are points where two homologous non-sister chromatids exchange genetic material during crossing over in meiosis.
- Chromosomes intertwine and break at the exact same positions in non-sister chromatids.
- The two chromosomes are now attached at the same corresponding position on the non-sister chromatid.
- Many chiasmata can form between the chromatids.
- Once attached the non-attached portions of the chromatids actually repel each other.
- Chiasmata refer to the actual break of the phosphodiester bond during crossing over.
- The chiasmata are separated during anaphase 1 which can result in an **exchange of alleles** between the non-sister chromatids from the maternal and paternal chromosomes.



Independent assortment:

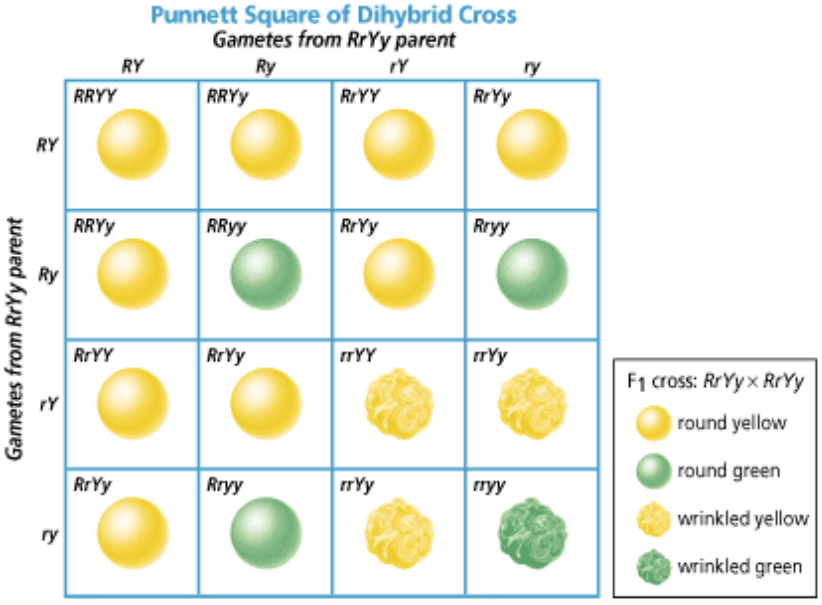
- Homologous chromosomes are separated in meiosis I
- Sister chromatids are separated in meiosis II
- When Mendel first did his experiments on pea plants, he looked at the traits that were passed on from generation to generation. He did not know how the traits were inherited in terms of meiosis.
- We now know that independent assortment is an essential component in explaining how chromosomes align themselves during meiosis.
- It also explains how unlinked genes are passed on from generation to generation.
- As explained above, when homologues line up along the equatorial plate in metaphase I, the orientation of each pair of is random; meaning the maternal or paternal homologue can orient towards either pole.
- Also the orientation of how one set of homologues line up has no effect on how any of the other homologues line up.
- For example, if chromosome pair one is heterozygous for a certain trait, there is a 50% chance that the gamete will receive the dominant trait and a 50% chance that the gamete will receive the recessive trait.
- Also if chromosome pair five is heterozygous for a particular trait, again there is a 50% chance that the gamete will receive the dominant allele and a 50% chance that it will receive the recessive allele.
- Both of these homologues line up independently during meiosis and have no effect on which gamete the other alleles will end up in.

10.2 Inheritance

U1	Gene loci are said to be linked if on the same chromosome.
U2	Unlinked genes segregate independently as a result of meiosis.
U3	Variation can be discrete or continuous.
U4	The phenotypes of polygenic characteristics tend to show continuous variation.
U5	Chi-squared tests are used to determine whether the difference between an observed and expected frequency distribution is statistically significant.
A1	Morgan's discovery of non-Mendelian ratios in *Drosophila*.
A2	Completion and analysis of Punnett squares for dihybrid traits.
A3	Polygenic traits such as human height may also be influenced by environmental factors.
S1	Calculation of the predicted genotypic and phenotypic ratio of offspring of dihybrid crosses involving unlinked autosomal genes.
S2	Identification of recombinants in crosses involving two linked genes.
S3	Use of a chi-squared test on data from dihybrid crosses.

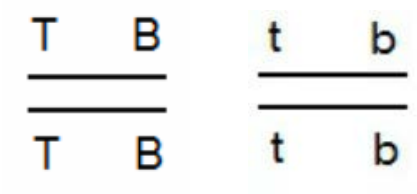
Dihybrid cross

- A dihybrid cross is a cross between two individuals that shows the inheritance of **two different genes** at the same time; usually involving unlinked autosomal genes.
- Note: The following example contains two **unlinked genes**, which means the genes are on different chromosomes. This means they follow **Mendel's law of independent assortment**.
- Mendel's law of independent assortment states allele pairs separate independently from other allele pairs during gamete formation (meiosis).
- Therefore, traits on different chromosomes are transmitted to the offspring independently of traits on other chromosomes.
- An exception to this rule is linked genes
- The standard ratio of phenotypes is 9:3:3:1

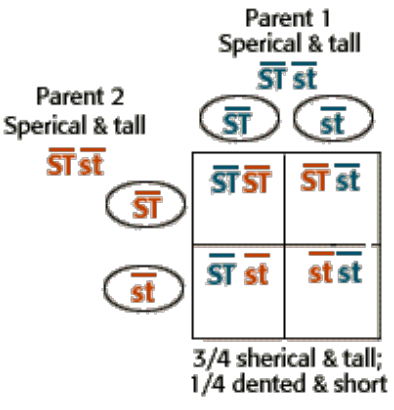


- **Test cross**: unknown genotypes crosses with homozygous receive
- **True breed**: homozygous

Linked genes:



- Location of genes are on the same chromosome
- The genotypes represented on the right show that T and B are on the same chromosome with one pair on the maternal chromosome and one pair on the paternal chromosome
- The horizontal line represents the homologous chromosomes
- The same can be said about the alleles t and b
- Crossing over can occur between the non-sister chromatids during prophase I of meiosis resulting in offspring with different genotypes
- The gametes Tb and tB could also occur with **crossing over**, resulting in the **recombinant** offspring TtBB and TTBb
- Recombinants have different alleles combinations than either of the parents
- When we do not consider crossing over happening, two linked genes will travel together to the gametes, which means, during the punnett square, they need to be considered as a single gene, which gives the **standard result** of 3:1



Types of variation:

- If variation is **discrete** it is controlled by alleles of a **single gene** or a small number of genes. The environment has little effect on this type of variation.
- In this case you either have the characteristic or you don't. Cystic fibrosis is a good example for this; either you have cystic fibrosis or you don't. Blood groups are another example of this type of variation. You are either blood type A, B, AB or O, there is no blending of these traits.
- Chi-squared calculations work well when using examples with discrete variation
- In **continuous variation** there is a **complete range of phenotypes** that can exist from one extreme to the other. Height is an example of continuous variation as there is a wide assortment of heights of individuals.
- Continuous variation is the combined effect of many genes (known as polygenic inheritance) and is often significantly affected by environmental influences. Skin colour is another example of continuous variation.

Polygenetic traits:

- When one gene controls the expression of a trait, the number of phenotypes that are expressed is limited to the dominant phenotype or recessive phenotype.
- If there is co-dominance, this adds another possible phenotype that can be expressed.
- With polygenic inheritance when **two or more genes control the expression** of a phenotype many possible phenotypes can exist.
- As the amount of genes that control one trait increase, the number of phenotypes increases to a point where it is impossible to determine the genotype by just observing the phenotype.
- Each additional gene has an additive affect, increasing the phenotypes. This is called continuous variation.
- For example, people's skin color varies dramatically around the world, between people of different races and within the same race. The multiple genes affect the intensity of the pigments in the skin.
- Another example is human height, which varies from person to person within the same race, and varies between different races. Height shows continuous variation.
- If you graphed the frequency of the occurrence of different phenotypic variations in a population, there should be a normal distribution.
- Continuing with human height, there will be some really tall people and some really short people, but the majority of people will be average height (normal distribution).
- As the number of genes that control a certain trait increases, the closer the distribution of the phenotypes represents a normal distribution.

Chi-square test:

- A chi-square test is a statistical test that can be used to determine whether **observed frequencies are significantly different from expected frequencies**
- These statistical tests enable us to compare observed and expected frequencies empirically and to decide if the results we see are statistically significant. Statistical significance in this case implies that the differences are not due to chance alone, but instead may be caused by other factors at work.
- This is the formula for a chi-squared test: $\chi^2 = \Sigma \frac{(o_i - e_i)^2}{e_i}$, where o means observed group and e means expected groups
- What it basically means is the sum of the (observed minus the expected) squared, divided by the expected.
- We can have two hypothesis out of Chi-square test
- **Null hypothesis**: data is due to chance and is random due to independent assortment – punnett square ratios are excepted.
- **Alternative hypothesis**: data is **not** due to chance and is not random, something influence the data
- Check the value with **degree of freedom** (0.05 column) corresponding the value of (number of set of data – 1) e.g. 2 phonotypes – 1 set of data.
- If the result is **less** than the critical value, accept null hypothesis
- If the result is **more** than the critical value, reject the null hypothesis

Table 1. Critical chi-square values for a p-value of 0.05. Reject the null hypothesis if $\chi^2_{calc} > \chi^2_{crit}$.

df	χ^2_{crit}
1	3.84
2	5.99
3	7.81
4	9.49
5	11.07
6	12.59
7	14.07
8	15.51
9	16.92
10	18.3

10.3 Gene pools and speciation

U1	A gene pool consists of all the genes and their different alleles, present in an interbreeding population.
U2	Evolution requires that allele frequencies change with time in populations.
U3	Reproductive isolation of populations can be temporal, behavioural or geographic.
U4	Speciation due to divergence of isolated populations can be gradual.
U5	Speciation can occur abruptly.
A1	Identifying examples of directional, stabilizing and disruptive selection.
A2	Speciation in the genus *Allium* by polyploidy.
S1	Comparison of allele frequencies of geographically isolated populations.

Gene pool:

- A **gene pool** is the total collection of different alleles in an interbreeding population.
- Evolution is the cumulative change in allele frequency or heritable characteristics in a population over time
- The cumulative change can occur as a result of genetic mutations and selective pressures which favour certain heritable characteristics over other less favourable characteristics
- **Allele frequency**: is the proportion of all copies of a gene that is made up of a particular gene variants (allele)
- These populations have to be reproductively isolated, thus preventing gene flow between populations
- If a population that has a certain allele or characteristic is quite small, random events such as disease or natural disasters can cause a drastic drop in this particular allele
- **Speciation**: the creation of new species.

Selective pressure:

Directional Selection:

Selection that removes individuals from one end of a phenotypic distribution and thus causes a shift in the distribution towards the other end. This occurs when natural selection favours one extreme end of the continuous variation of phenotypes. Over time, the favoured extreme will become more common and the other extreme will be less common or lost. For example, dark mice are favoured because they live in an area that favours that phenotype. **It leads to preference of a certain phenotype**.

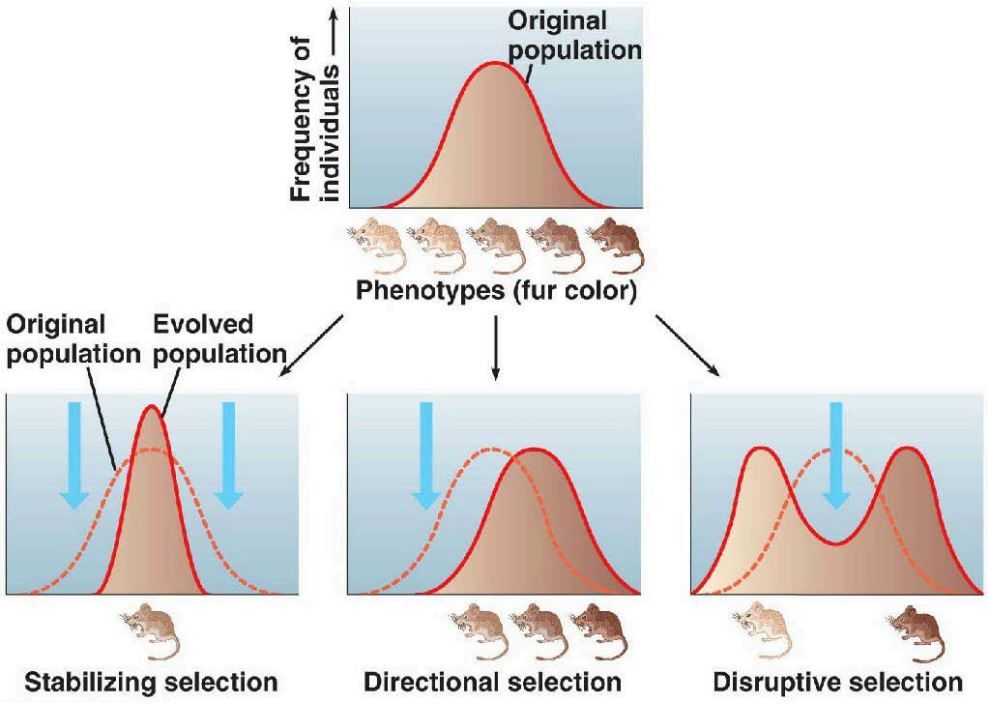
Stabilizing Selection:

A type of selection that removes individuals from both ends of a phenotypic distribution, thus maintaining the same distribution mean. This occurs when natural selection favours the intermediate phenotypes. Over time, the intermediate states become more common and each extreme variation will become less common or lost. Same mouse example where medium coloured fur is favoured over dark or light fur colour. **Concentrated in a single phenotype**.

Disruptive Selection:

A type of selection that removes individuals from the center of a phenotypic distribution and thus causes the distribution to become bimodal. This occurs when natural selection favours both ends of the phenotypic variation. Over time, the two extreme variations will become more common and the intermediate states will be less common or lost. Disruptive selection can lead to two new species. Light coloured and dark coloured mice might live in an environment with patches of light and dark vegetation making it hard for predators to spot those colours, while the middle coloured mouse doesn't blend into either background.

Selective pressure is on centre of phenotypes.



Reproductive isolation:

- **Temporal isolation**: separating pollination time (breeding time), prevent hybridizing with each others.
- **Geographical isolation**: separated by geographical event, prevent hybridizing
- **Behavioral isolation**: courting behaviors differs; they cannot recognize each other so they cannot interbreed.

Speciation:

- Simply stated, speciation can occur gradually over long periods of time, with several intermediate forms in between species leading to today's current species. This can be seen by some of the more complete fossil records, like the whale.
- However, in some species, large gaps were evident for certain species in the fossil record. This could be explained by possible imperfections in the fossil record, or perhaps, these species have not been discovered yet.
- Another explanation is through **abrupt speciation**.
- Formation of new species which is reproductively and ecologically isolated from the parental species as a result of a genetic mutation such as a **sudden change in chromosome** number or constitution
- Genetic mutations such **as non-disjunctions of an entire set of chromosomes** can cause a doubling of chromosomes (polyploidy) resulting in a different species
- Also interbreeding of two genetically different organisms can produce hybrids which are generally infertile

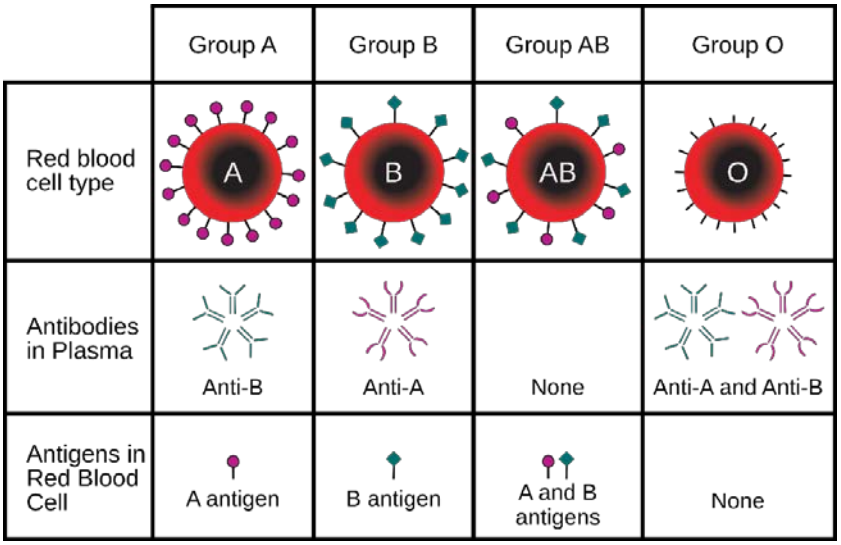
Topic 11: Animal physiology (HL)

11.1 Antibody production and vaccination

U1	Every organism has unique molecules on the surface of its cells.
U2	Pathogens can be species-specific although others can cross species barriers.
U3	B lymphocytes are activated by T lymphocytes in mammals.
U4	Activated B cells multiply to form clones of plasma cells and memory cells.
U5	Plasma cells secrete antibodies.
U6	Antibodies aid the destruction of pathogens.
U7	White cells release histamine in response to allergens.
U8	Histamines cause allergic symptoms.
U9	Immunity depends upon the persistence of memory cells.
U10	Vaccines contain antigens that trigger immunity but do not cause the disease.
U11	Fusion of a tumour cell with an antibody-producing plasma cell creates a hybridoma cell.
U12	Monoclonal antibodies are produced by hybridoma cells.
A1	Smallpox was the first infectious disease of humans to have been eradicated by vaccination.
A2	Monoclonal antibodies to HCG are used in pregnancy test kits.
A3	Antigens on the surface of red blood cells stimulate antibody production in a person with a different blood group.
S1	Analysis of epidemiological data related to vaccination programmes.

Surface protein

- All organisms have unique molecules or markers on the outer surface of the plasma membrane of their cells
- These highly variable molecules are generally glycoproteins and they identify a cell as being “self” or “non-self”
- These markers are called major histocompatibility complexes (MHC)
- These MHC proteins are genetically determined and are unique to that individual



- Blood groups such as A, B, AB and O are identified by cell surface antigens
- Rhesus (Rh) is another antigen that can be present on the surface of the blood cells, being either Rh positive (has antigen) or Rh negative (doesn’t have antigen)
- A blood transfusion given to an individual with the wrong blood type can stimulate an immune response called **agglutination** (**clumping or clotting of the blood cells**)
- This is followed by the destruction of the RBC (**hemolysis**)
- For example, someone with blood type A (antigen A on the surface) contains anti-B antibodies in their plasma. If they get a transfusion with blood type B, their immune system will attack and destroy the foreign blood cells with the B-antigen on the surface
- People with blood type O just have the basic antigen sequence that all blood cells have and are therefore not attacked by A or B antibodies; therefore, blood type O is known as the **universal donor** (O negative has no Rhesus factor)

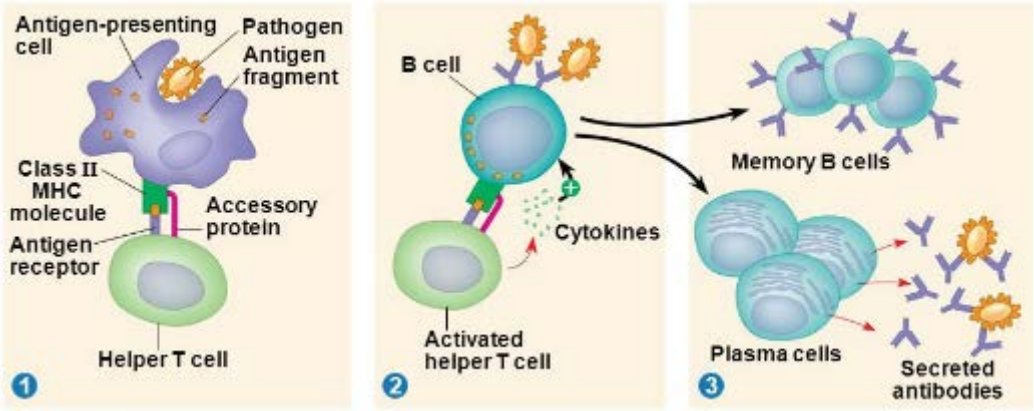
Types of pathogen

- Pathogens can be **species-specific** although others can **cross species barriers**.
- Invading organisms such as a virus or bacterium that enters the body and causes a disease are known as pathogens

- Pathogens are generally **species specific,** for example, humans are the only known organisms susceptible to pathogens such as polio, syphilis, measles and gonorrhea but are resistant to many pathogens that infect other organisms
- However, there are pathogens that can cross this species barrier and infect a range of hosts, such as the Rabies virus, bird flu and the Bubonic plague
- Diseases from other animals that can infect or be transmitted to humans is called **Zoonosis**
- The passing of diseases from different species is a growing global health concern

T lymphocytes

- When a pathogen enters the blood, the specific antigen on the surface of the membrane is identified.
- Specific phagocytes known as macrophages recognize a pathogen as a foreign entity because of the antigens on the surface.
- The macrophage engulfs and partially destroys the pathogen.
- The macrophage takes the antigens from the destroyed pathogen and **displays them on the surface** of the cell bound to a membrane protein called a MHC protein (called **antigen presentation**).
- Specific **T lymphocytes** receptors recognize and bind to the antigen presented by the macrophage, thus **activating the T-lymphocyte**.
- The activated T-cell binds to a **B-lymphocyte** specific to the antigen; **activating the B-cell** through the binding and the release of a signaling protein



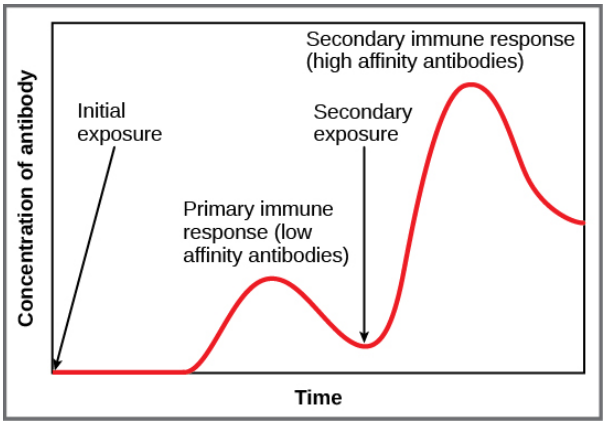
- The active B-cells begin to clone themselves producing cloned **plasma** B cells that produce antibodies and **memory** cells. Memory cells remain in the blood in case a second infection occurs to provide long term protection and a quick response to the new infection.
- The plasma cells created produce and release **mass amounts of antibodies** into the bloodstream.
- These antibodies surround and bind to the antigens on the foreign pathogens.
- Through a variety of different methods the pathogens are destroyed by the antibodies and other white blood cells.

Antibodies and destruction

1. Agglutination – antibodies cause the **sticking together** of pathogens by attaching to the antigens on the surface. These **clumped** masses of pathogens are then easily ingested and destroyed by phagocytes
2. Opsonization – antibodies make pathogens **recognizable** by binding to them and linking them to phagocytes, attach **biological markers** on pathogens
3. Neutralization – Antibodies **bind to toxins produced by pathogens** in the blood plasma preventing them from affecting susceptible cells.
4. Complement Activation – After a pathogen is identified by antibodies, **complement proteins** in the blood plasma form a membrane attack complex that destroys the cell membrane in the pathogen causing the cell to lyse
5. Bacteria and Virus Neutralization – Antibodies can bind to the surface of viruses, **preventing them from entering host cells**

Immunity

- Long term specific immunity depends upon the presence of memory cells created during a previous infection from the same pathogen
- Memory cells are long-lived cells that make an effective response to a **re-infection of the body by the same antigen (on the pathogen)**



Vaccination

- Vaccines are introduced to the body usually through an injection but can be administered through orally or through a nasal spray
- Vaccines contain a live **attenuated (weakened)** or killed version of the pathogen, its **toxins** or **one of its surface antigens**.
- Vaccines stimulate a primary immune response
- If the body encounters the actually pathogen, it will be destroyed right away by the antibodies during a secondary immune response
- Vaccines has made great contributions towards public health through the prevention of many deadly or dangerous **diseases such as tuberculosis, measles and smallpox**

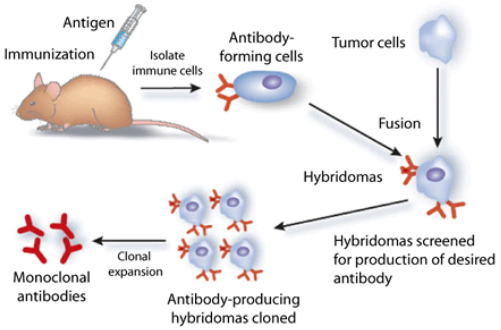
Histamine

- **Mast cells** found in connective tissue circulating in the blood **secrete histamine** in response to antigens from an infection or response to an allergen
- Histamines cause the blood vessels of the infected area to **dilate** and increase flow of fluid containing immune components to the infected area
- It increases the **permeability of capillaries** so white blood cells can reach the area of infection.

- **Allergies**: group of condition caused by hypersensitivity of immune system to something in the environment that causes little or no problem in most people
- A number of symptoms from **allergic reactions** are caused by histamines
- Cells throughout the body have histamine receptors
- The release of histamine causes many of the symptoms from an allergic response such as **inflammation**, sneezing, itching and mucous secretion
- Anti-histamine drugs, counteract these affects by blocking histamine receptors

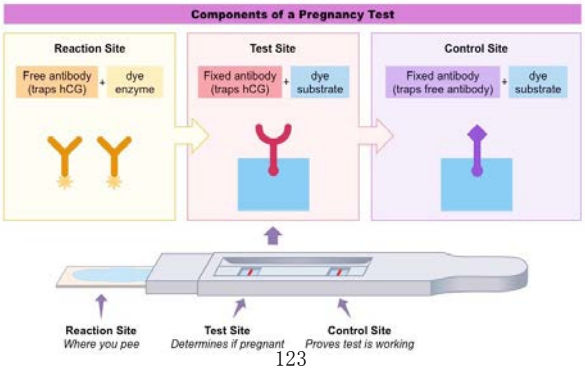
Monoclonal antibodies

- Monoclonal antibodies are **identical antibodies** produced by clones of a single parent immune cell that are specific to one type of antigen.
- A laboratory animal such as a mouse is injected with a specific antigen that corresponds with the needed antibodies.
- After the animal goes through a primary immune response, a **plasma B-cell cell** that produces the required antibody is removed from the **spleen**.
- **Myeloma (cancer) cells** are cultured in a petri dish.
- These dividing myeloma cells are mixed together with the plasma B-cells and are treated to promote a **fusion between the two cells**, forming a cell called a **hybridoma**.
- The successful hybridomas have characteristics of both cells; produce antibodies and divide rapidly for a long time.
- These hybridoma cells are cultured and allowed to divide, producing many clone cells that are able to produce large amounts of antibodies.
- Monoclonal antibodies can be extracted and used for many different applications.



Pregnancy test

- Human chorionic gonadotrophin (**HCG**) is produced by an embryo in early pregnancy.
- Monoclonal antibodies can be produced by injecting a lab animal with HCG, as it recognizes this as antigen.
- *HCG Antibodies* are combined with **color-changing enzymes**.
- When the mixture is introduced into a blood sample of a woman that is pregnant, the antibodies will bind to the HCG in the blood, causing a change in color.
- If the woman is not pregnant, no HCG will be present in her blood, and therefore there will be no color change.



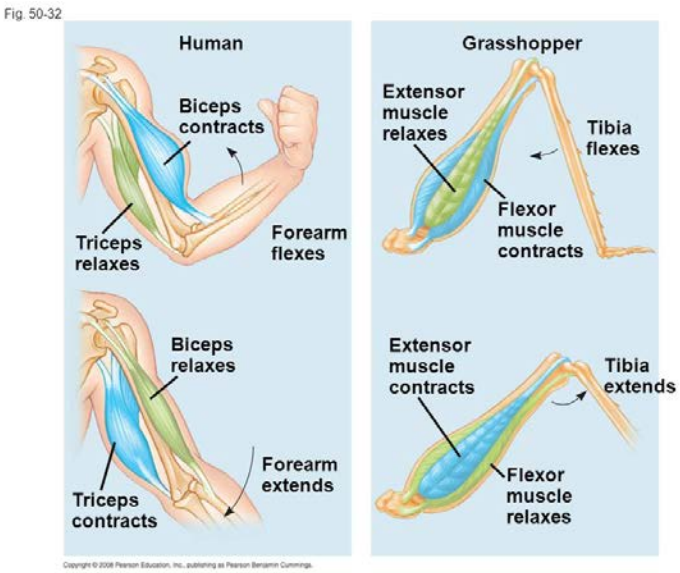
11.2 Movement

U1	Bones and exoskeletons provide anchorage for muscles and act as levers.
U2	Synovial joints allow certain movements but not others.
U3	Movement of the body requires muscles to work in antagonistic pairs.
U4	Skeletal muscle fibres are multinucleate and contain specialized endoplasmic reticulum.
U5	Muscle fibres contain many myofibrils.
U6	Each myofibril is made up of contractile sarcomeres.
U7	The contraction of the skeletal muscle is achieved by the sliding of actin and myosin filaments.
U8	ATP hydrolysis and cross bridge formation are necessary for the filaments to slide.
U9	Calcium ions and the proteins tropomyosin and troponin control muscle contractions.
A1	Antagonistic pairs of muscles in an insect leg.
S1	Annotation of a diagram of the human elbow.
S2	Drawing labelled diagrams of the structure of a sarcomere.
S3	Analysis of electron micrographs to find the state of contraction of muscle fibres.

Exoskeleton

- Bones act as levers so the body can move and provide structural support (skeleton).
- **Ligaments** are strong bands that connect **bone to bone** strengthening the joint during movement.
- **Tendons** have dense connective tissue that connects **muscles to bones**, allowing movement of the bone when a muscle contracts.
- Muscles provide the force for movement by contracting (shortens the muscle fibers)
- Skeletons allow movements by providing attachment site for muscles and working as lever.
- The joint acts as a pivot point
- Muscle works as **antagonistic pair** (one contracts, one relaxes)

Insect leg dissection

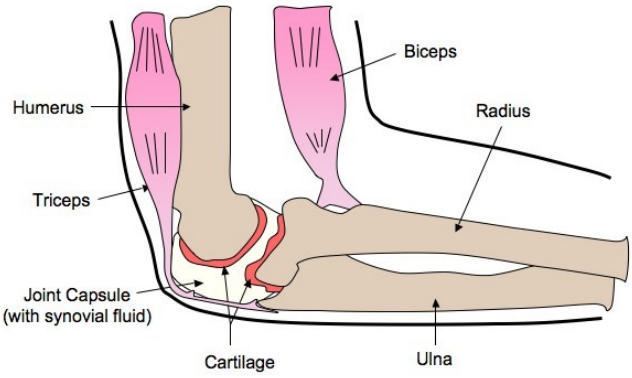


- Extensor muscle relaxes and flexor muscle contracts → tibia contracts
- Extensor muscle contracts and flexor muscle relaxes → tibia extends
- Step one and step two gives insect **jump action**.

Elbow Joint

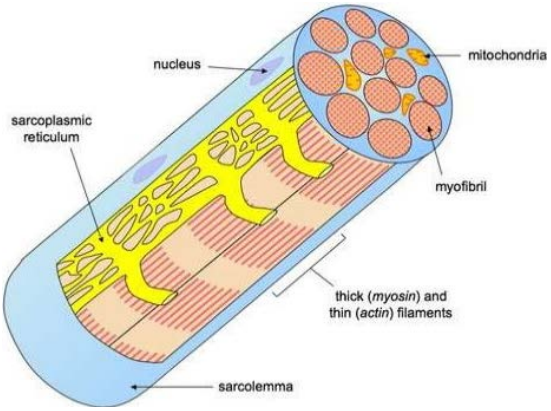
- The type of joint determines the amount of movement that is possible
- For **ball and socket joints**, such as the hip or the shoulder, movement through all three planes are possible. At the hip joint, the head of the femur is the ball the fits into the socket of the pelvis. The movements possible at the joint are flexion, extension, rotation, abduction and adduction.
- For **hinge joints**, such as the knee, flexions (bending) and extensions (straightening) are the possible movements (movement in one plane); however, slight side to side movements are possible
- Elbow joint is an example of a hinge joint

- **Cartilage**: reduces friction in the joint, provides high tensile strength and support, and absorbs compression
- **Synovial fluid**: reduces friction by providing lubrication between the cartilage and other tissues in joints during movement
- **Joint capsule**: seals the joint space and provides stability to the joint by limiting movements
- **Tricep**: contracts and causes extension (arm straightening)
- **Bicep**: contracts and causes flexion (arm bending)
- **Radius**: Lever attached to the biceps. When the biceps contract, the radius provides a solid structure for lifting
- **Ulna**: Lever connected to the triceps. When the triceps contract, the ulna provides support as a lever as the arm straightens out
- **Humerus**: arm bone
- **Ligament**: connects bones together
- **Tendon**: connects bones with muscles



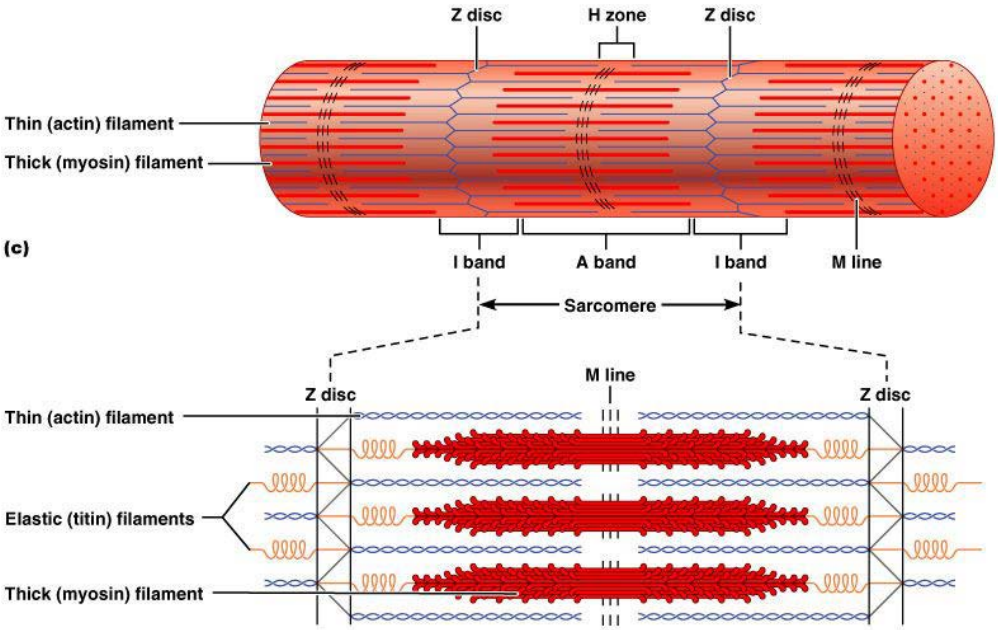
Muscle cells

- Skeletal muscles are composed of bundles of muscle fibers and have a striped appearance because of areas of thick and thin filaments (myosin and actin)
- Muscle cells have **many nuclei**(mutinucleated) and are long because the embryonic muscle cells fuse together.
- Muscle fibers are composed of many parallel elongated fibers called **myofibrils**.
- A modified endoplasmic reticulum, called the **sarcoplasmic reticulum** (fluid-filled membranous sacs), extends throughout the muscle fibre, wrapping around each myofibril, sending a signal to the all parts of the muscle fibre to contract at the same time
- **Myofibrils** – rod-shaped parallel bodies consisting of actin and myosin filaments
- **Sarcolemma** – plasma membrane of the muscle cell.
- **Mitochondria** – large numbers; found dispersed around individual myofibrils.



Sacromere

- is the repeating unit of a striated muscle cells.
- Lies between two **Z lines** which are dense protein discs.
- Contains the **thick filament (myosin) and thin filament (actin)**.
- Myosin contains a head which binds to the binding site on the actin; interaction between myosin and actin (cross-bridge) is responsible for muscle contraction.
- **Myosin is seen as dark bands while actin is seen as light bands**.

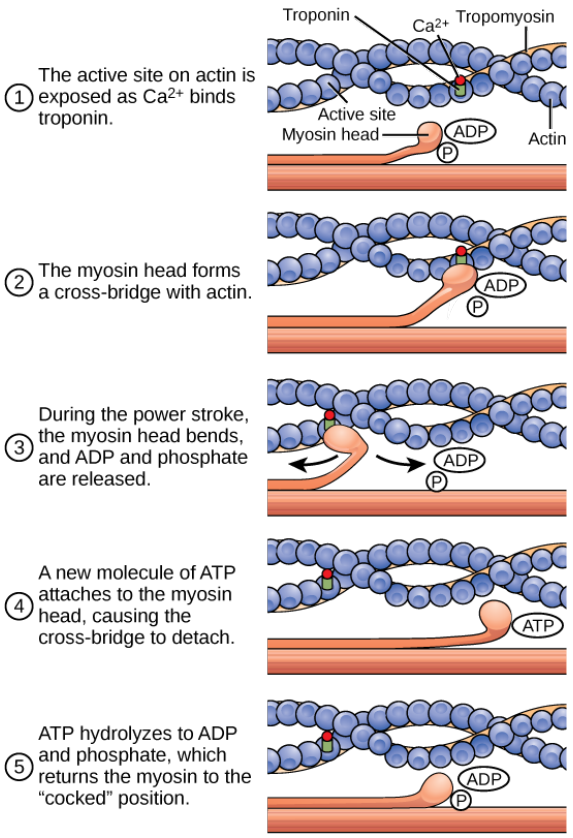


* no need to know titin; M line; H zone; I band, A band, M line. Only needs to remember Z line; myosin and actin filaments and their construction pattern

Muscle contraction mechanism

- During a muscle contraction, myosin filaments pull actin filaments towards the centre of the sarcomere
- This shortens the sarcomere and the overall length of the muscle fibre
- When this occurs, the myosin heads bind to sites on the actin filaments, creating **cross-bridges**, pulling (sliding) the actin filaments along the myosin filaments with energy from ATP

1) Action potential causes **sarcoplasmic reticulum** to release Ca^{2+}
2) Influx of Ca^{2+} into sarcoplasm and binds to **troponin**
3) Binding of troponin releases **tropomyosin**, which exposes **myosin binding sites** on actin
4) Myosin heads are bound to actin binding sites making a **cross-bridge**
5) ATP releases the myosin head
6) Hydrolysis of ATP to ADP causes a **change in shape** (**power stroke**)
7) The myosin heads bind to actin filaments forming cross-bridges at a site **one position further** from the centre of the sarcomere
8) Myosin head forms a new cross-bridge with a different actin binding site pulling the myosin **towards the centre of the sarcomere**, continuing the contraction.
9) The step 5,6,7,8 repeats, pulling the Z lines together and contracting the entire muscle.



11.3 The kidney and osmoregulation

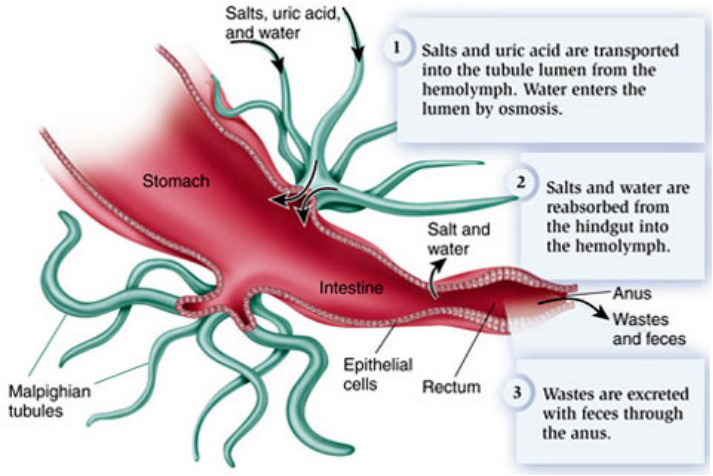
U1	Animals are either osmoregulators or osmoconformers.
U2	The Malpighian tubule system in insects and the kidney carry out osmoregulation and removal of nitrogenous wastes.
U3	The composition of blood in the renal artery is different from that in the renal vein.
U4	The ultrastructure of the glomerulus and Bowman's capsule facilitate ultrafiltration.
U5	The proximal convoluted tubule selectively reabsorbs useful substances by active transport.
U6	The loop of Henle maintains hypertonic conditions in the medulla.
U7	ADH controls reabsorption of water in the collecting duct.
U8	The length of the loop of Henle is positively correlated with the need for water conservation in animals.
U9	The type of nitrogenous waste in animals is correlated with evolutionary history and habitat.
A1	Consequences of dehydration and overhydration.
A2	Treatment of kidney failure by hemodialysis or kidney transplant.
A3	Blood cells, glucose, proteins and drugs are detected in urinary tests.
S1	Drawing and labelling a diagram of the human kidney.
S2	Annotation of diagrams of the nephron.

Osmolarity: how much solute are dissolved in a solution

- **Osmoregulators** maintain a constant **internal solute concentration**,
- All terrestrial animals, freshwater animals and some marine organisms are osmoregulators
- **Osmoconformers** are animals that have similar internal solute concentration in comparison to the solute concentration of their surrounding environment

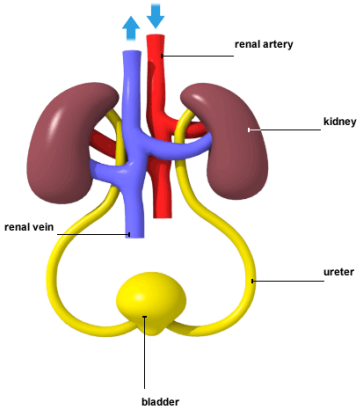
Malpighian tubule

- Insects have a circulating fluid known as **hemolymph**, that combines the features of blood and tissue fluid
- Osmoregulation is a form of homeostasis to keep the concentration of hemolymph or blood within a certain range
- **Nitrogenous waste** is created by the breakdown of amino acids and is toxic to the organism
- In insects the waste is in the form of **uric acid** and in mammals it is urea
- Insects have Malpighian tubules that branch off from their intestinal tract to get rid of this waste
- Cells in these tubules **actively transport the uric acid and ions** from the hemolymph into the lumen of the tubules
- Water is then drawn into the lumen by **osmosis** due to a high concentration in Malpighian tubule
- The tubules empty into the gut
- When it reaches the **hindgut**, water and salts are **reabsorbed** and the nitrogenous waste is excreted in the feces of the insect



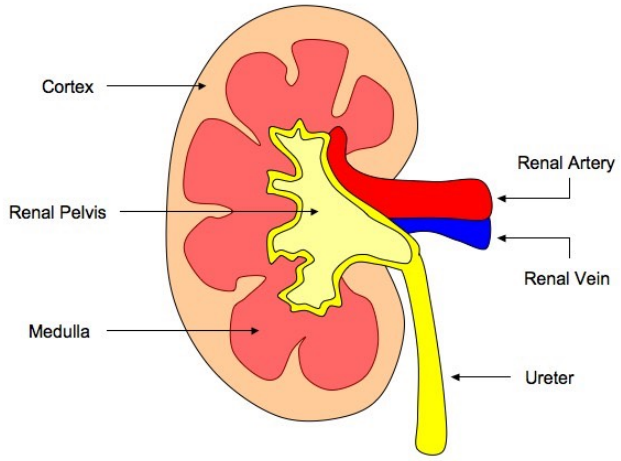
Renal System

- Filter the blood off excess salts, water and the **complete removal of urea**
- Regulates the acidity of the blood
- 25% of blood flows through a kidney per minute
- blood in renal artery is more oxygenated than the blood in the renal vein / oxygenated versus deoxygenated
- blood in renal artery contains **more urea** than the blood in the renal vein
- variable water / salt content in renal artery but constant / correct / regulated content in vein



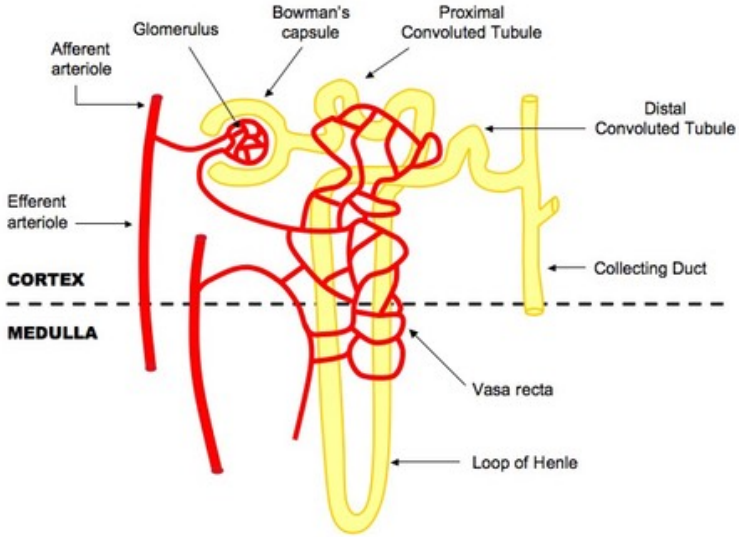
- Toxins and other substances that are ingested and absorbed but are not yet fully metabolized by the body are present in higher con centrations in the renal artery than in the renal vein

Diagram of kidney



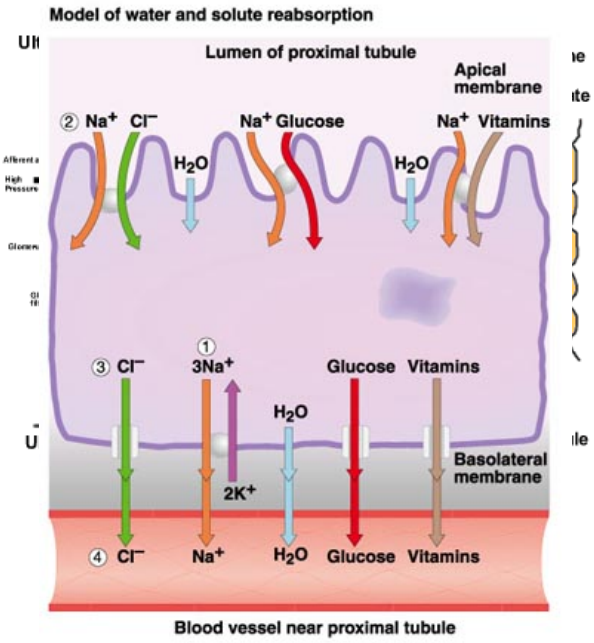
Nephron

- Filtering units of the kidney
- Located within the **cortex and medulla**
- Highly vascular for absorption
- Consisted of glomerulus, Bowman's capsule, proximal convoluted tubule, loop of Henle, distal convoluted tubule, collecting duct



Renal capsule – untrafilteration

- **Ultrafiltration** is the **non-specific filtration** of the blood as it enters the Bowman's capsule of the kidney in which created by the **high pressure** in the **glomerulus** (capillaries) forces a liquid against a **semi-permeable membrane**.
- As blood enters the kidney through the afferent arteriole it becomes a **knot-like capillary bed** known as the glomerulus.
- Because of the **high pressure** created in the capillaries as the blood vessel become smaller and because the glomerulus has **fenestrations** (small pores), large suspended solids and solutes such as **proteins** are retained. Water and small solutes such as salts, glucose and waste (urea) pass through the membrane into the Bowman's capsule.
- The **large surface area, high pressure and pores in the membrane** enables ultrafiltration



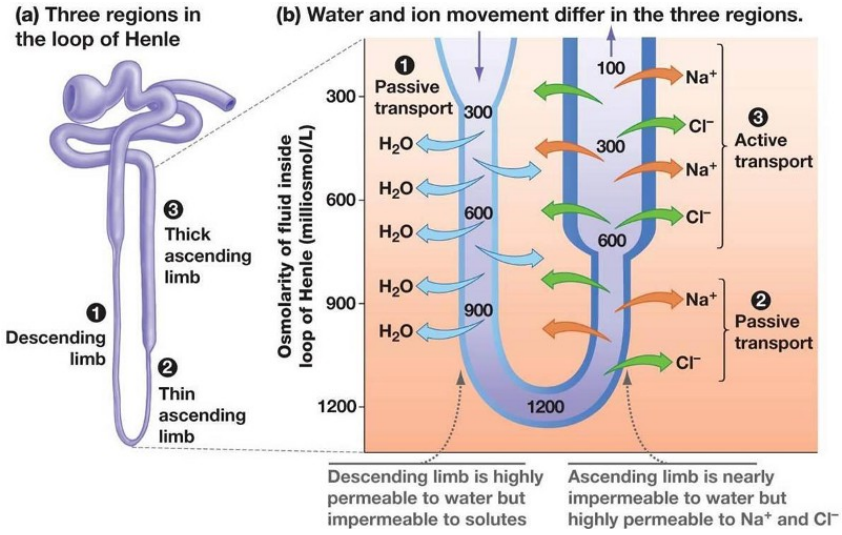
Proximal convoluted tubule

- While ultrafiltration is non-specific with regards to the molecules that leave the blood (based on size, no specific channels), **selective reabsorption** in the proximal convoluted tubule (PCT) is very specific with regards to the molecules that are reabsorbed.
- Active transport of **Na^+ ions** from PCT cells to the blood
- **Diffusion** of Na^+ ions from the **lumen of PCT** into the PCT cells (concentration gradient)
- **Cotransport** of **amino acids** and **glucose** to PCT cells with Na^+ ions
- **Facilitated diffusion** of amino acids and glucose from PCT cells to blood
- Water moves back to the blood by **osmosis**, since there will be higher solute concentration in the blood.

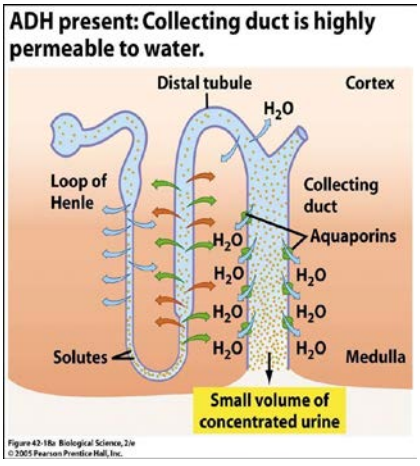
- The wall of the proximal convoluted tubule is only **one cell thick** allowing for efficient movement of molecules across a **short distance**.
- The wall also contains **microvilli** (similar to the small intestine) that increase the **surface area** for reabsorption of important molecules.

Loop of Henle

- The **descending loop** of Henle is permeable to **water but impermeable to salt ions**.
- The **ascending loop** of Henle is permeable to **salt ions but impermeable water**.
- As the filtrate flows up the ascending loop **Na^+ ions** are pumped out of the filtrate into the medulla thus increasing the solute concentration in the medulla.
- As the filtrate flows down the descending loop (before the ascending loop) water **flows out of the filtrate** into the medulla by **osmosis** following the concentration gradient creating by pumping Na^+ ions out of the ascending loop.
- Therefore the medulla has a very high concentration of **Na^+ ions**
- This system is **countercurrent** because the flow of the filtrate in the descending and ascending loop is in opposite directions. This allows for a **greater concentration** gradient to be created in the medulla.
- Overall, salts are removed and solute concentration decreases. Some water is also removed



Collecting duct



- Reabsorb water to blood
- Controlled by **antidiuretic hormone (ADH)**
- If the solute concentration in the blood is too high, osmoreceptors in the **hypothalamus** sense this and signal the pituitary gland to produce a hormone called ADH (anti-diuretic hormone).
- ADH causes special pores called **aquaporins** in the collecting duct to open, allowing water to be reabsorbed back into the blood, thus making the blood more dilute.
- If the solute concentration in the blood is too low, osmoreceptors in the hypothalamus sense this and signal the pituitary gland to reduce its production of ADH.
- This causes the aquaporins in the collecting duct to close, keeping the excess water in the filtrate, which excreted as dilute urine.
- This is called osmoregulation.
- So, the increase in ADH causes more **aquaporins**, thus more water will be **absorbed**, resulting in a more **concentrated** urine

The length of loop of Henle

- The **longer** the loop of Henle, the **more water** will be reabsorbed
- Therefore, animals that live in dry habitats such as the desert have a long loop of Henle
- This means the medulla of the kidney is also thicker

Nitrogen waste

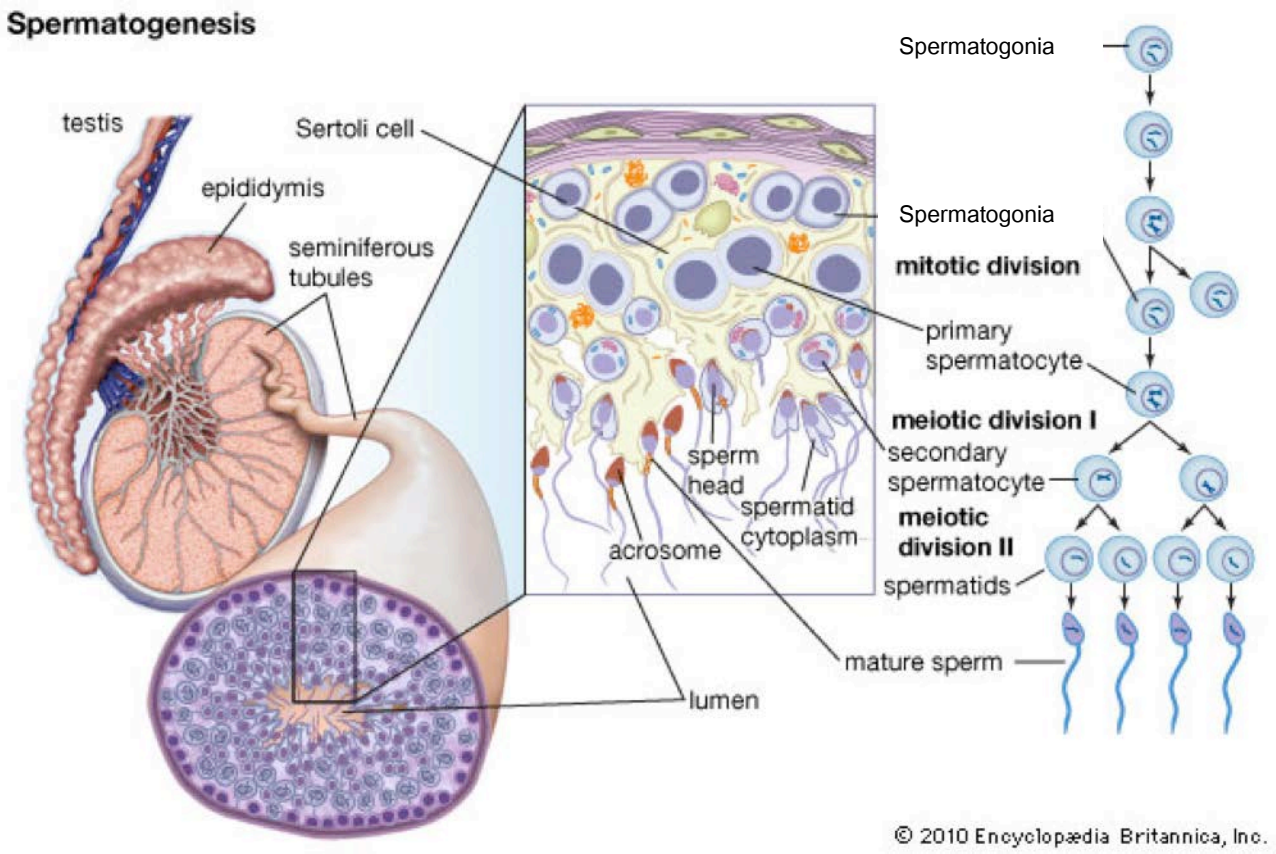
- When animals breakdown amino and nucleic acids, nitrogenous waste is formed in the form of **ammonia**
- Ammonia is highly basic, toxic and can be very reactive
- Marine and **freshwater organisms** can release the ammonia directly into the surrounding water
- Terrestrial organisms convert ammonia into a less toxic form (urea or uric acid) before excretion
- What form depends on the animals evolutionary history and habitat
- Amphibians release waste as ammonia as larvae and **urea** as adults
- Birds and insects release ammonia as **uric acid**. Uric acid **does not require water** and is highly concentrated but **cost more energy**.
- Mammals release their waste in the less toxic form known as **urea**

11.4 Sexual reproduction

U1	Spermatogenesis and oogenesis both involve mitosis, cell growth, two divisions of meiosis and differentiation.
U2	Processes in spermatogenesis and oogenesis result in different numbers of gametes with different amounts of cytoplasm.
U3	Fertilization in animals can be internal or external.
U4	Fertilization involves mechanisms that prevent polyspermy.
U5	Implantation of the blastocyst in the endometrium is essential for the continuation of pregnancy.
U6	HCG stimulates the ovary to secrete progesterone during early pregnancy.
U7	The placenta facilitates the exchange of materials between the mother and fetus.
U8	Estrogen and progesterone are secreted by the placenta once it has formed.
U9	Birth is mediated by positive feedback involving estrogen and oxytocin.
A1	The average 38-week pregnancy in humans can be positioned on a graph showing the correlation between animal size and the development of the young at birth for other mammals.
S1	Annotation of diagrams of seminiferous tubule and ovary to show the stages of gametogenesis.
S2	Annotation of diagrams of mature sperm and egg to indicate functions.

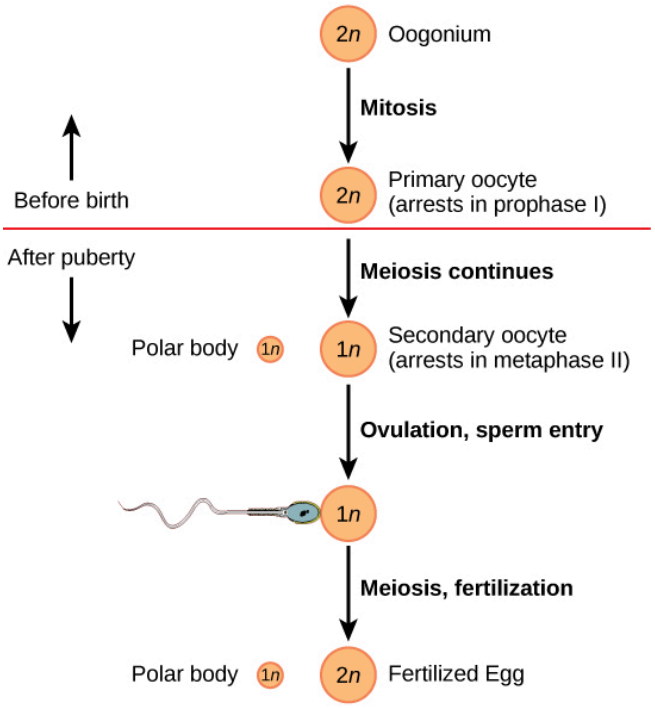
Spermatogenesis:

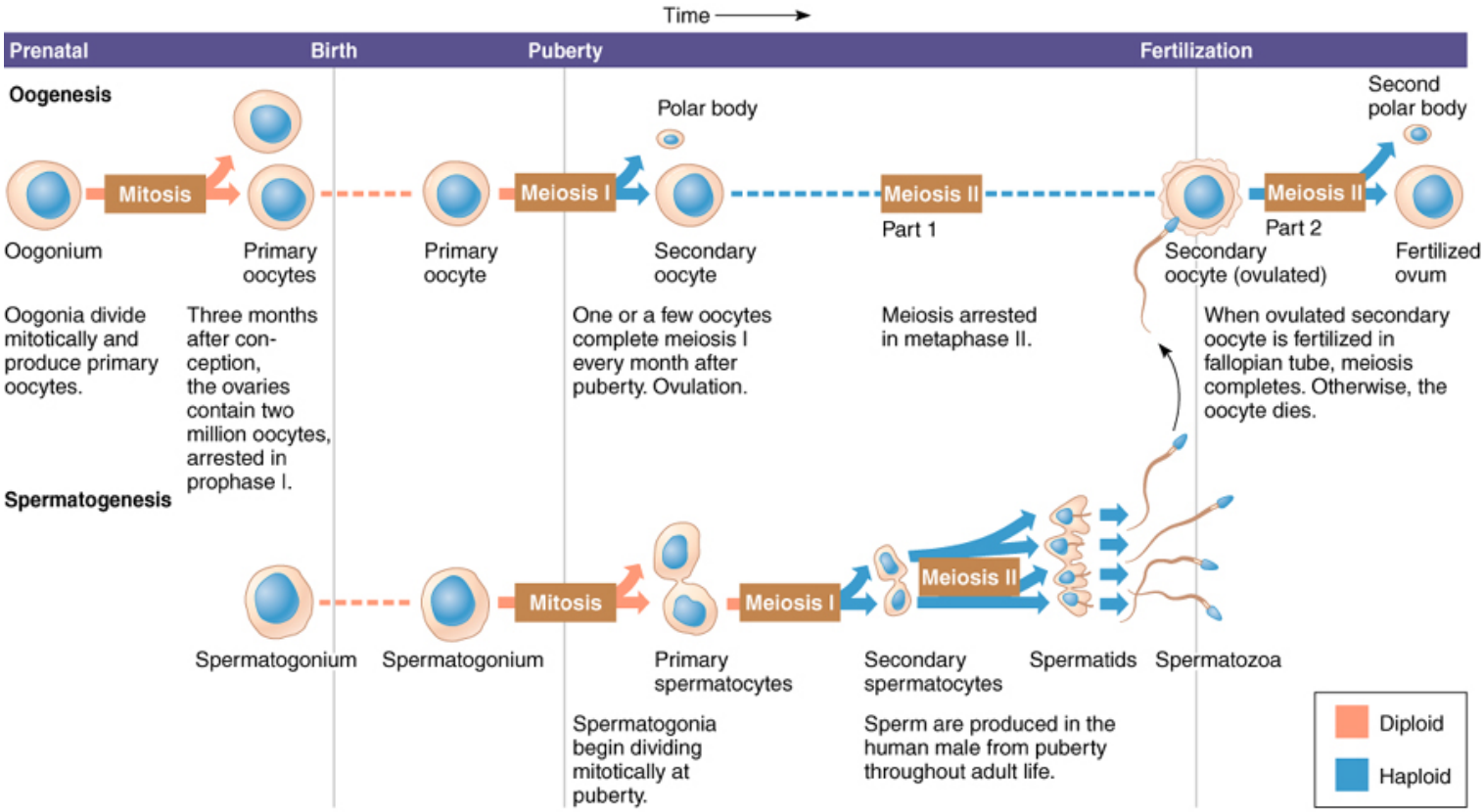
- Spermatogenesis is basically the **production of sperm** (male gametes) through meiosis.
- Occurs in the testes of male
- Spermatogonia (stem cells of the sperm - 2n) are located at the periphery of each **seminiferous tubules**.
- Developing sperm move towards the central opening of the tubule (lumen) as they undergo meiosis and differentiation.
- Mature sperm will be stored in **epididymis**.
- Spermatogonia is first divided by **mitosis** to form more 2n cells, called **primary spermatocytes**.
- Primary spermatocytes undergo meiosis I to form two **secondary spermatocytes**.
- Two secondary spermatocytes undergo meiosis II to form four **early spermatids**.
- Early spermatids will go through cell differentiation and form mature sperms.
- **Sperms are released** into the **lumen of the seminiferous tubules** where they are transported to the **epididymis**. The sperm attain full motility in the epididymis.
- Cells in between the developing spermatocytes called **Leydig cells, which produce testosterone in the presence of LH** (luteinizing hormone) to aid in the development of the sperm
- **Sertoli cells** nourish the spermatids as they mature and differentiate into sperms.



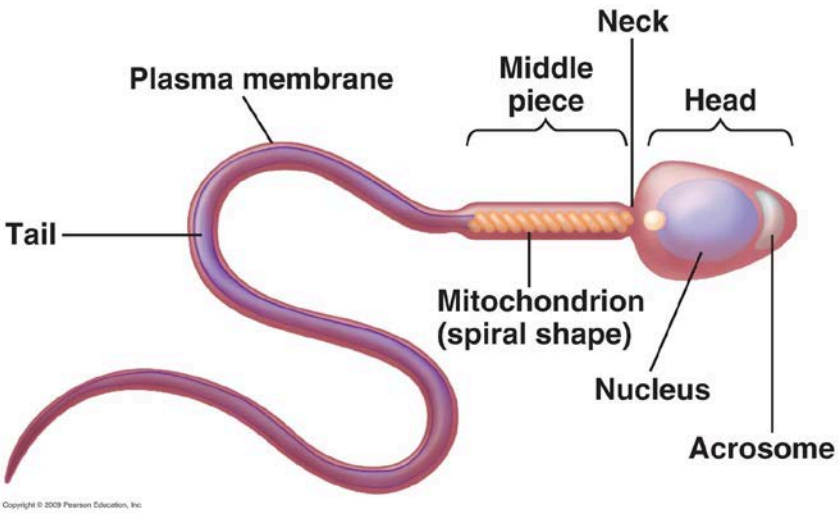
Oogenesis:

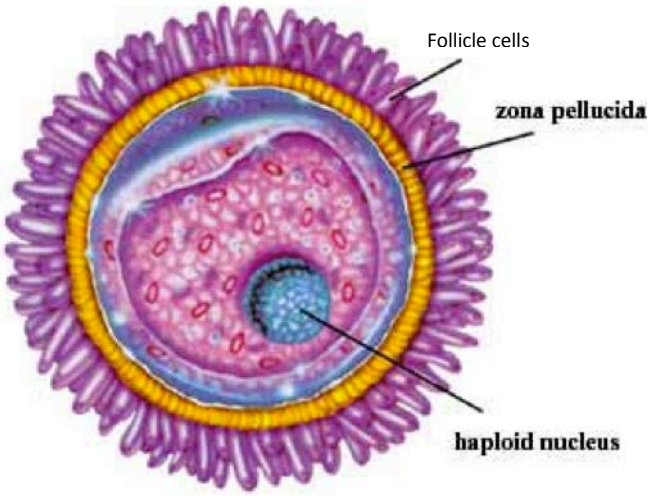
- Oogenesis is basically the production of female eggs (female gametes) through meiosis.
- **Germ cells (2n)** in the fetal ovary divide by **mitosis to produce many 2n germ cells** called **oogonia.**
- Oogonia will grow in the cortex until they are large enough and ready to go through meiosis; they are called **primary oocytes**.
- The primary oocytes begin to go through the first division of meiosis, which is arrested (stopped) in **prophase I**
- This is called the **primary oocytes** (about 400,000 in a female when she is born).
- These oocytes remain in the first stage of meiosis until the girl reaches puberty and begins her menstrual cycle.
- Every month a **primary follicle finishes meiosis I to form two haploid (n) cells** (one haploid cell is much larger than the other cell). This development is stimulate by FSH.
- The large cell is a **secondary oocyte** and the small cell is called the **polar body**.
- The secondary oocyte develops inside what is known as the **mature follicle**
- As the large secondary oocyte begins to go through the second meiotic division, it is **released from the ovary**.
- It will not complete the second meiotic division unless the oocyte is fertilized.
- When meiosis II is complete you have an ovum and another polar body.
- **Follicle cells** are providing nourishment.





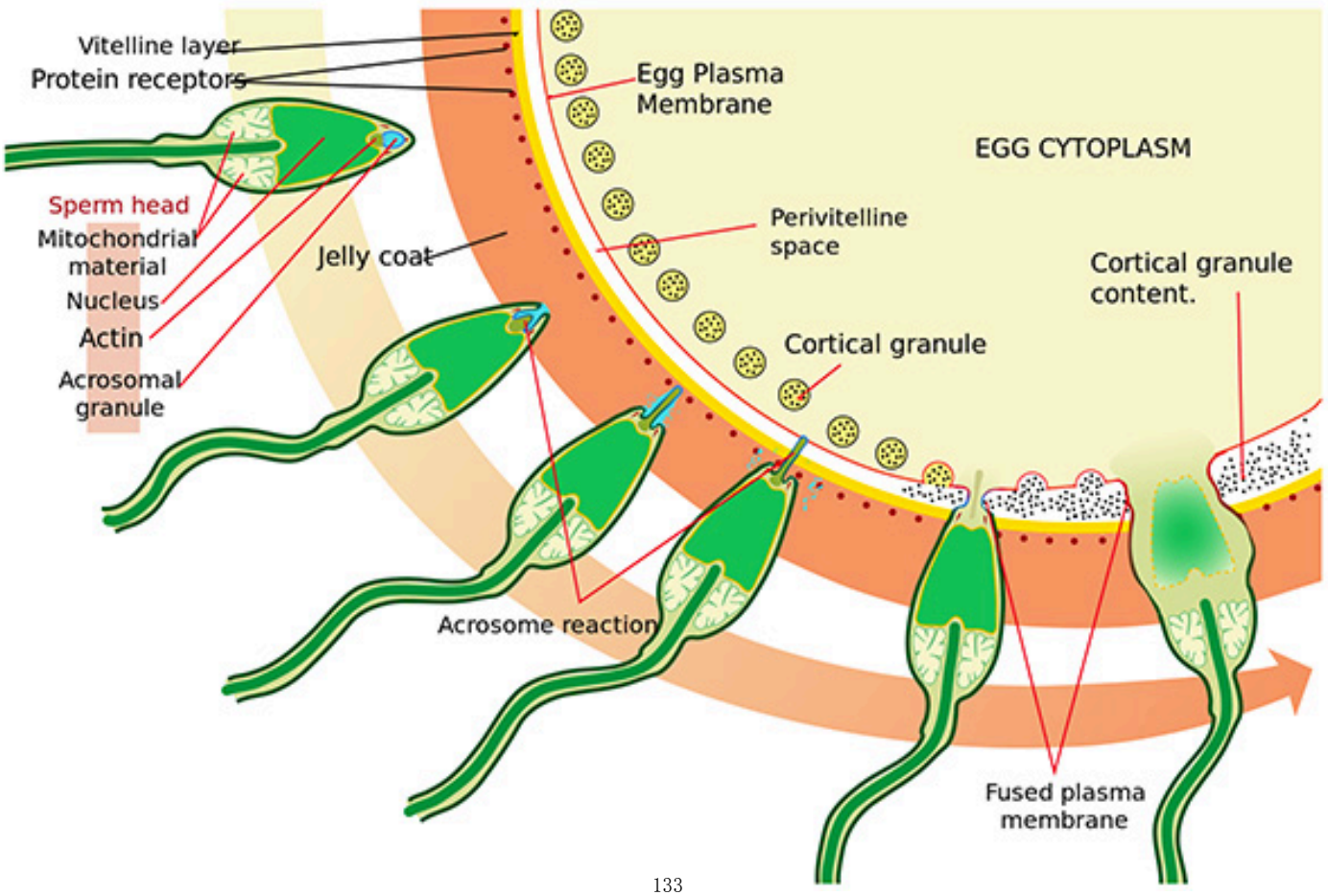
Structure of sperms and eggs





Fertilisation:

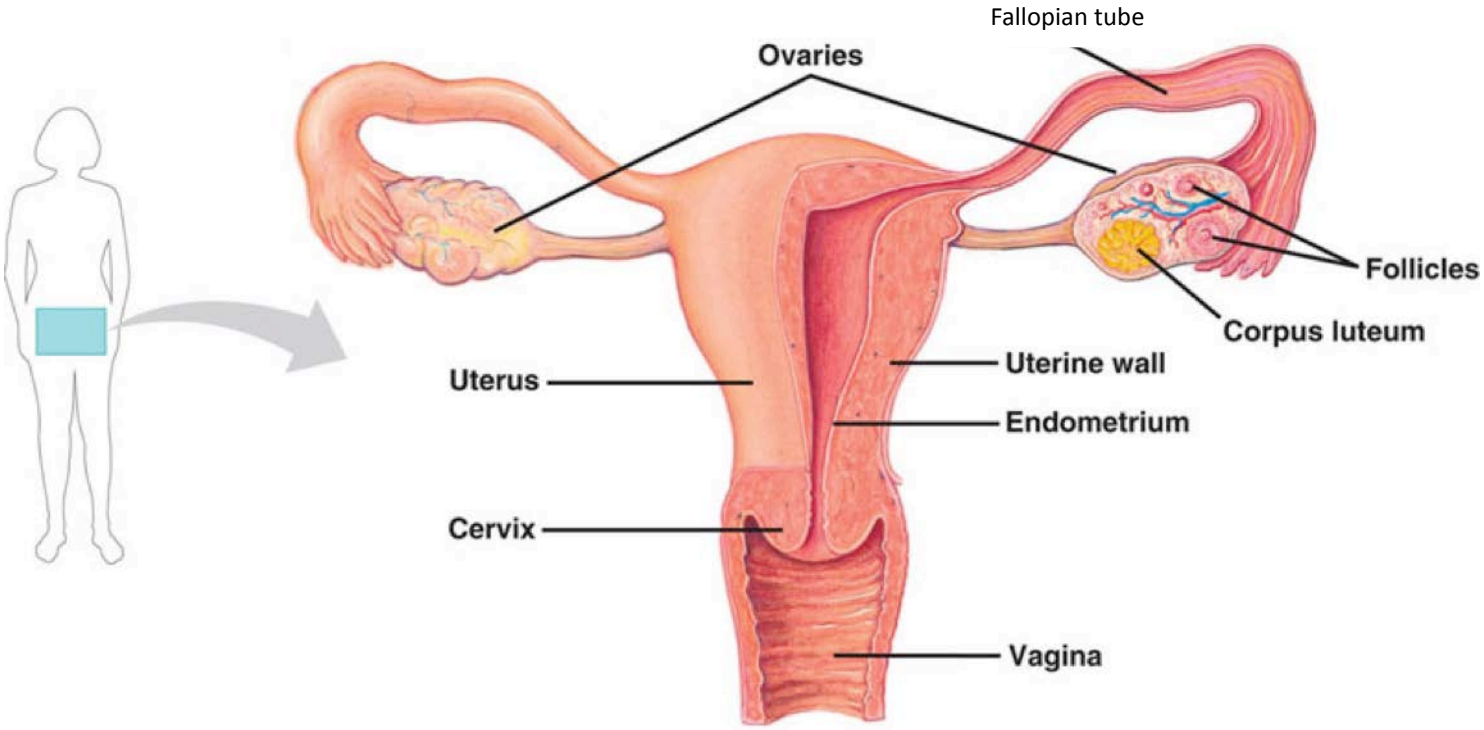
- Fertilization is the combining of the male and female gametes to produce **a zygote**.
- Sperm are ejaculated into the vagina of a female and are stimulated to swim by calcium ions in the vaginal fluids.
- The sperm follow chemical signals produced by the egg, until they reach the **fallopian tubes**, which is where the majority of fertilizations take place.
- When the sperm reaches the egg, a reaction called the ***acrosome reaction*** takes place that allows the sperm to break through the layer of glycoproteins.
- The acrosome in head of the sperm **releases hydrolytic enzymes** onto the **glycoprotein layer** surrounding the egg **called the zona pellucida**.
- This digests the layer allowing the sperm to force their way through the zona pellucida through vigorous tail beating.
- The first sperm that makes it through comes into contact and fuses with the egg's membrane (The membrane at the tip of the sperm has special proteins that can bind to the now exposed membrane of the egg), releasing the sperm's nucleus into the egg cell.
- The entry of sperm will stimulate meiosis II and release **Ca^{2+} ions**, which will stimulate the release of cortical granules.
- When the membranes fuse together, **cortical granules** near the surface of the egg membrane are **released by exocytosis**.
- The **chemicals in the granules combine with the glycoproteins** in the zona pellucida.This causes the glycoproteins in the zona pellucida to cross-link with each other, **creating a hard layer impermeable to the other sperm**.
- This prevents fertilization of an egg by more than one sperm.



Internal/external fertilisation:

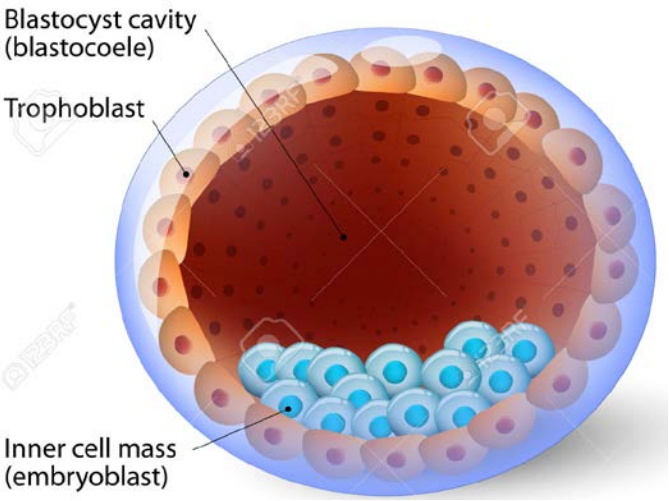
- Without water to prevent drying out of the egg and sperm, terrestrial animals rely on internal fertilization
- This insures the close proximity of the sperm and egg in order to insure fertilization takes place
- Most **aquatic organisms** generally rely on external fertilization, which involves releasing the sperm and egg at a close proximity, into the water outside the female's body
- External fertilization increases the risk of successfully creating offspring
- Several risks include predation and changes to the external environment (pH, pollution and temperature etc.)

Structure of the ovary



Embryonic development:

- After the male and the female gametes combine to form a **zygote**, the zygote divides by mitosis to form a **two-cell embryo.**
- They two cells grow and replicate their DNA, and undergo another cell division through mitosis to form a four-cell embryo.
- As the embryo is developing, it is moving along the fallopian tube towards the uterus.
- The four-cell embryo continues to divide by cell division until it reaches **16 cells**; called the **morula**.
- After continued cell divisions a **blastocyst** consisting of **100 to 128 cells** is formed and is ready for **implantation into the endometrium**.
- The blastocyst consists of an **inner cell mass** that will develop into the body of the embryo, a group of cells surrounding the embryo called the **trophoblast** that will develop into the placenta.

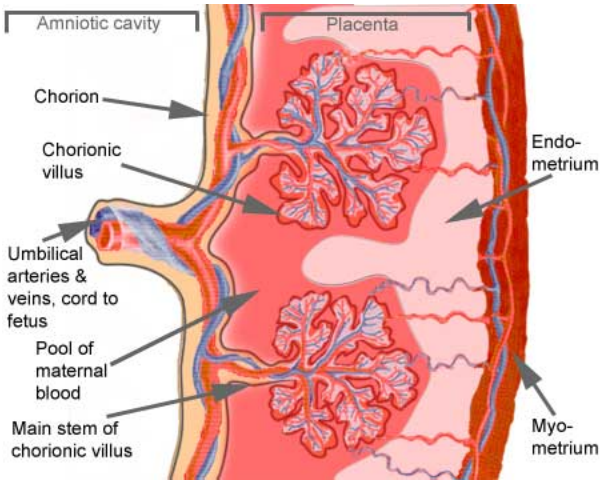


- Morula is the ball of totipotent stem cells, while blastocyst is already differentiated into **inner cell mass** and **trophoblast**, which is pluripotent stem cells.
- The blastocyst must implant into the endometrium to develop the placenta and continue growing.
- If the blastocyst implants into the fallopian tube, it will cause severe complication and even death for mother.

HCG hormones:

- When a human embryo is implanted into the endometrium or the uterine lining, it starts to produce the hormone, **HCG**.
- We can test HCG level for pregnancy.
- HCG promotes the maintenance of the **corpus luteum** and prevents its disintegration.
- This allows for the continued production of **progesterone and estrogen** which is critical for pregnancy.
- Progesterone and estrogen will inhibit the production of FSH and LH, thereby stopping the release of new egg.
- Progesterone maintains the **endometrium** while blastocyst develops into placenta and embryo
- HCG might repel the immune cells of the mother thus protecting the fetus during early development.

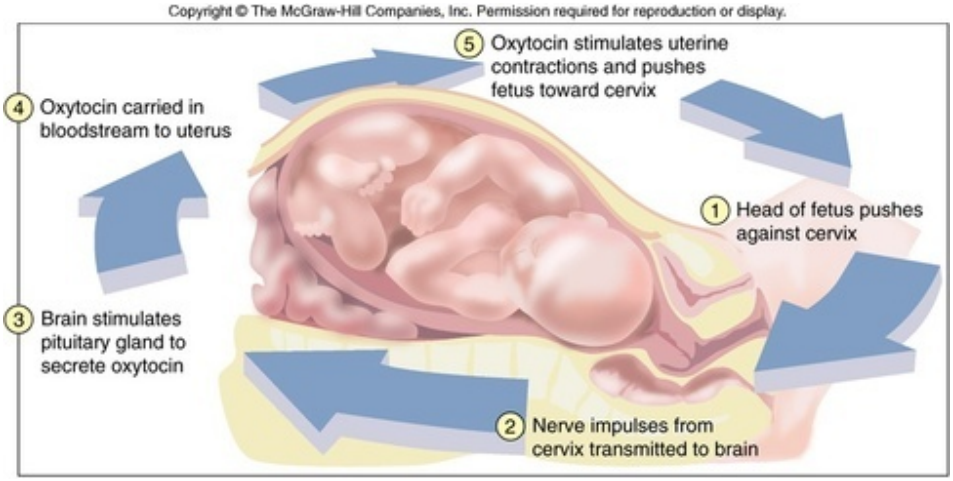
Placenta:



- The placenta develops from the **trophoblast** layer of the blastocyst.
- When developed three blood vessels contained within umbilical cord connect the placenta to the growing fetus.
- Two umbilical arteries carry deoxygenated blood and waste away from the fetus to the placenta.
- As maternal blood enters the placenta it leaves the arteries and enters the inter-villous space, where it pools and surrounds the **placental villi**.
- The placental villi are finger-like fetal tissues that have **a large surface area for the exchange of materials** such as gases, nutrients and wastes.
- Fetal blood that circulates in capillaries within the villi and microvilli isvery close to the surface, allowing for **efficient exchange of materials** between the fetal and maternal blood.
- Materials such as oxygen, nutrients and vitamins diffuse into the fetal capillaries from the maternal blood in the inter-villous space, while carbon dioxide and wastes diffuse out of the fetal capillaries into the inter-villous space.
- One umbilical vein carries oxygenated and nutrient rich blood back to the fetus from the placenta.
- The cells that separate the fetal and maternal blood form a semi-permeable **placental barrier**
- The placenta also starts to produce progesterone and estrogen after about 9 weeks taking over from the corpus luteum. The placenta produces enough of these steroids to maintain the pregnancy and the corpus luteum is no longer needed.
- These hormones are necessary to maintain the rich blood supply needed by the placenta.

Giving birth

- When the pregnancy is at term, the **fetus secretes hormones** that **signal the placenta** to **stop producing progesterone** (progesterone inhibits the secretion of oxytocin by the pituitary gland).
- Baby's head engages with the cervix
- The stretch receptors on the cervix will send signal to produce oxytocin
- **Oxytocin secreted** stimulates the muscle fibers in the uterus to begin to contract.
- As the muscles in uterus contract, stretch receptors sends stronger signal to produce more oxytocin.
- **More oxytocin increases the frequency** and intensity of the contractions, thus stimulating the production of even more oxytocin.
- This is an example of **positive feedback**.
- Contractions of the muscles of the uterus will cause the amniotic sac to break, releasing the amniotic fluid (This is when the "water breaks" in childbirth).
- Relaxation of the muscles in the cervix causes it to **dilate**, eventually allowing the increasing contractions to push the baby out through the vagina and the cervix.
- When baby gets out, umbilical cord is clamped and cut.
- The placenta is expelled "afterbirth" about 15 min after the baby is born.



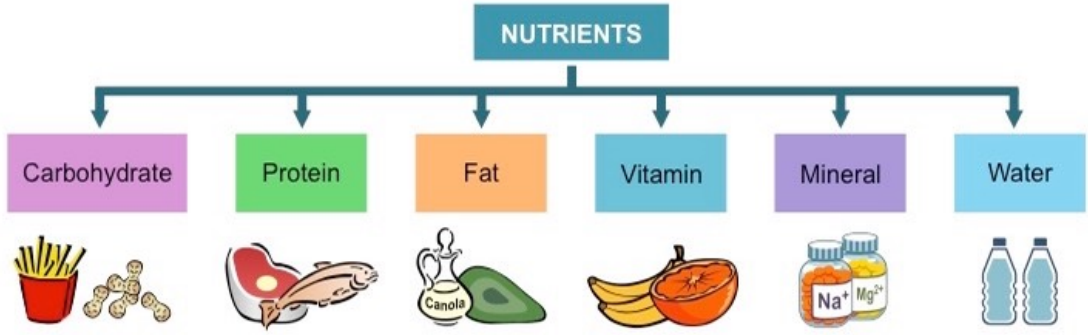
Option D: Human Physiology

D.1 Human nutrition

U1	Essential nutrients cannot be synthesized by the body, therefore they have to be included in the diet.
U2	Dietary minerals are essential chemical elements.
U3	Vitamins are chemically diverse carbon compounds that cannot be synthesized by the body.
U4	Some fatty acids and some amino acids are essential.
U5	Lack of essential amino acids affects the production of proteins.
U6	Malnutrition may be caused by a deficiency, imbalance or excess of nutrients in the diet.
U7	Appetite is controlled by a centre in the hypothalamus.
U8	Overweight individuals are more likely to suffer hypertension and type II diabetes.
U9	Starvation can lead to breakdown of body tissue.
A1	Production of ascorbic acid by some mammals, but not others that need a dietary supply.
A2	Cause and treatment of phenylketonuria (PKU).
A3	Lack of Vitamin D or calcium can affect bone mineralization and cause rickets or osteomalacia.
A4	Breakdown of heart muscle due to anorexia.
A5	Cholesterol in blood as an indicator of the risk of coronary heart disease.
S1	Determination of the energy content of food by combustion.
S2	Use of databases of nutritional content of foods and software to calculate intakes of essential nutrients from a daily diet.

Essential nutrients

- A **nutrient** is a chemical substance found in foods that is used in the human body
- ***Essential nutrients*** are those that cannot be synthesised by the body and must be ingested as part of the diet including essential amino acids, essential fatty acids, vitamins, minerals and water.
- Non-essential nutrients can be made by the body or have a replacement nutrient which serves the same dietary purpose



Malnutrition

- **Malnutrition** is a health condition caused by a deficiency, imbalance or excess of nutrients in the diet
- It can be caused by an improper dietary intake of nutrients – e.g. overnutrition (too much) or undernutrition (not enough)
- It can be caused by the inadequate utilisation of nutrients by the body – e.g. due to illness or disease
- Common signs of malnutrition included stunted growth and wasting (undernutrition), as well as obesity (over nutrition)

Phenylketonuria(PKU)

- Phenylketonuria (PKU) is a rare genetic metabolic disorder
- It is an autosomal recessive disease caused by a mutation to the gene encoding the enzyme *phenylalanine hydroxylase*
- People who suffer from PKU lack an **enzyme** that is needed to process the amino acid **phenylalanine**. They are unable to make the liver enzyme tyrosine hydroxylase, which converts phenylalanine into another non-essential amino acid called tyrosine
- **Phenylalanine** is essential for normal growth but if too much builds up in the blood, brain damage can result
- Children who are identified as having PKU must be given a **special diet** that is low in protein and especially low in the amino acid phenylalanine.
- They must avoid many common, high protein foods such as milk and dairy products, nuts, fish and meat.
- PKU only affects children until puberty. After this, they can have a normal diet

Minerals and Vitamins

- Vitamins are organic molecules with complex chemical structures that are quite diverse and hence categorised by groups
- **Water soluble vitamins** need to be constantly consumed as any excess is lost in urine (e.g. vitamins B, C)
- **Fat soluble vitamins** can be stored within the body (e.g. vitamins A, D, E, K)
- Many vitamins are essential as they cannot be synthesised by the body and their absence may cause a deficiency disease except **vitamin D.**

- **Vitamin C**
    - **Ascorbic acid** is a form of vitamin C that is required for a range of metabolic activities in all animals and plants
    - **Most animals** can synthesise vitamin C but there are a few notable exceptions including bats, guinea pigs, monkeys, apes and humans
    - Maintains connective tissue
    - Help wound heals
    - Maintains healthy immune system
    - A shortage of the vitamin leads to the de ciency disease called **scurvy** – the loss of connective tissue

- **Vitamin D**
    - Vitamin D (calciferol) is needed to ensure that sufficient **calcium** is absorbed in the digestive system to build healthy bones
    - Vitamin D can be naturally synthesised by the body when a chemical precursor is exposed to UV light
    - Lack of vitamin D can cause **ricket** – softening in bones and lead to skeletal deformation in childrens
    - Lack of vitamin D can also cause **osteomalacia** - similar symptoms of ricket in adults

- **Vitamin A**
    - Used in vision
    - Helps cell division
    - Synthesis of glycoprotein
    - Maintain epithelial cell differentiation

- **Dietary minerals** are chemical elements required as essential nutrients by organisms
- Minerals present in common organic molecules are not considered essential – e.g. C, H, O, N, S
- Minerals include calcium (Ca), magnesium (Mg), iron (Fe), phosphorus (P), sodium (Na), potassium (K) and chlorine (Cl)
- **Minerals in Human Development**
    - Some of the important functions played by minerals are listed below:
    - Major constituents of structures such as teeth and bones (e.g. Ca, P, Mg)
    - Important components of body fluids (e.g. Na, K, Cl)
    - **Cofactors** for specific enzymes or components of proteins and hormones (e.g. Fe, P, I)
    - A deficiency in one or more dietary mineral can result in a disorder (e.g. lack of calcium can affect bone mineralisation)

- **Minerals in Plant Development**
- **Magnesium** is an important component of chlorophyll (required for photosynthesis)
- **Potassium** is an inorganic salt found within the sap of a plant (maintains water potential)
- **Calcium** is important for plant root and shoot elongation

Amino acids and fatty acids

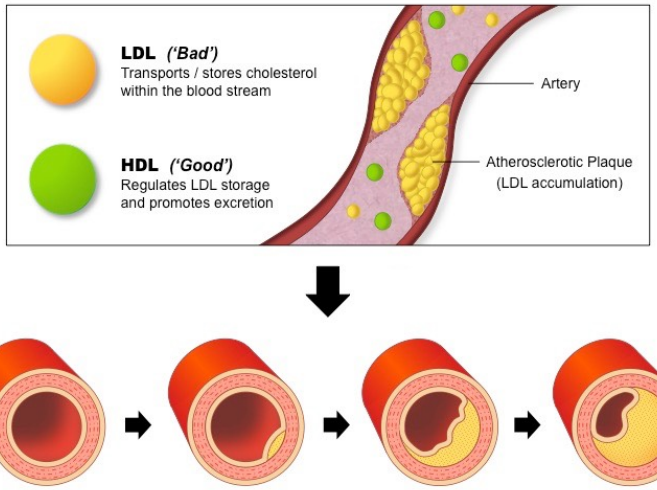
- There are **20** different amino acids which are universal to all living organisms
- Amino acids can be either essential, non-essential or conditionally non-essential according to dietary requirements
- ***Essential* amino acids cannot** be produced by the body and must be present in the diet
- ***Non-essential* amino acids can** be produced by the body and are therefore not required as part of the diet
- ***Conditionally non-essential* amino acids** can be produced by the body, but at rates **lower** than certain conditional requirements (e.g. during pregnancy or infancy) – they are essential at certain times only
- A shortage of one or more essential amino acids in the diet will prevent the production of specific proteins
- This is known as protein deficiency malnutrition and the health effects will vary depending on the amino acid shortage

- Humans can synthesise ***most* fatty acids** from carbohydrates, but two (*cis*)-polyunsaturated fatty acids are considered essential
- Alpha-linolenic acid (an **omega-3 fatty acid**) and linoleic acid (an **omega-6 fatty acid**) cannot be synthesised by the body
- This is because humans lack the enzyme required to introduce double bonds at the required position of the carbon chain

- Essential fatty acids are modified by the body to make important lipid-based compounds (such as **signalling molecules**)
- There is evidence to suggest dietary deficiencies of these fatty acids may be linked to **impaired brain development** (e.g. depression) and **altered maintenance of cardiac tissue** (e.g. abnormal heart function) – although this evidence is contested
- Foods rich in essential fatty acids (omega-3 and omega-6) include fish, leafy vegetables and walnuts

Cholesterol in blood

- **Fats and cholesterol** cannot dissolve in the bloodstream and so are packaged with proteins (to form lipoproteins) for transport
- **Low density lipoproteins (LDLs)** carry cholesterol from the liver to the body (hence raise blood cholesterol levels)
- **High density lipoproteins (HDLs)** carry excess cholesterol back to the liver for disposal (hence lower blood cholesterol levels)
- The mix of fatty acids consumed as part of a diet directly influences the levels of cholesterol in the bloodstream
- **Saturated fats** increase LDL levels within the body, raising blood cholesterol levels
- **T*rans* fats** increase LDL levels and lower HDL levels, **significantly** raising blood cholesterol levels
- C*is*-polyunsaturated fats raise HDL levels, lowering blood cholesterol levels
- High cholesterol levels in the bloodstream lead to the **hardening and narrowing of arteries (atherosclerosis)**



Appetite Control

- The appetite control centre is found in the **hypothalamus** at the base of the brain.
- The release of hormones can be used to trigger the feeling of huger.
- Stretch receptors in the **stomach** and **intestine** become activated when ingested food distends these organs
- **Adipose tissue** releases hormones in response to fat storage (leptin)
- The **pancreas** will release hormones in response to changes in blood sugar concentrations

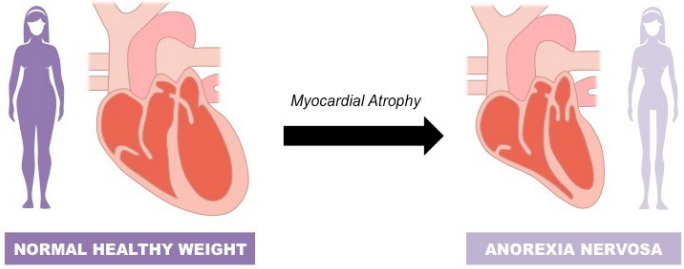
Obesity

- Individuals who are overweight or obese are more likely to suffer from **hypertension** (abnormally high blood pressure)
    - Excess weight places more strain on the heart to pump blood, leading to a faster heart rate and higher blood pressure
    - High cholesterol diets will lead to **atherosclerosis**, narrowing the blood vessels which contributes to raised blood pressure
    - **Hypertension** is a common precursor to the development of **coronary heart disease (CHD)**

- Individuals who are overweight or obese are also more likely to suffer from **type II diabetes** (non-insulin dependent)
    - Type II diabetes occurs when pancreatic beta cells become **unresponsive** to insulin (insulin insensitivity)
    - This typically results from a diet **rich in sugars** causing the progressive overstimulation of the beta cells
    - Hence overweight individuals who have a high sugar intake are more likely to develop type II diabetes
    - **Symptoms**: high glucose levels in the blood; glucose in the urine; frequent need to urinate, which leads to dehydration and increased thirst; tiredness and fatigue

Starvation

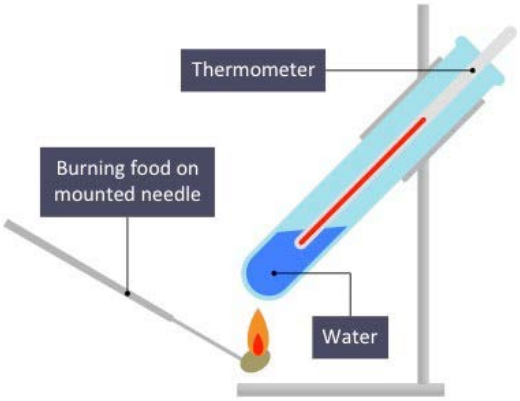
- Starvation describes the severe restriction of daily energy intake, leading to a significant loss of weight
- As the body is not receiving a sufficient energy supply from the diet, **body tissue is broken down as an energy source**
- This leads to **muscle loss** (as muscle proteins are metabolised for food) and eventually **organ damage** (and death)
- **Anorexia nervosa** is an eating disorder in which individuals severely limit the amount of food they intake



- The condition has **psychological causes** and people with the disorder are unable to appreciate that they have a problem, often perceiving themselves as overweight despite being normal or underweight.
- In severe anorexia, the body begins to break down **heart muscle**, making heart disease the most common cause of death
- Blood flow is reduced and blood pressure may drop as heart tissue begins to starve
- The heart may also develop dangerous arrhythmias and become physically diminished in size

Energy Content

- The energy content of food can be estimated by **burning** a sample of known mass and measuring the energy released via *calorimetry*
- Combustion of the food source causes the stored energy to be released as heat, which raises the temperature of water
- The amount of energy required to raise 1 g of water by 1ºC is 4.18 J – this is the specific heat capacity of water
- The equation for calculating the energy content of a food source via calorimetry is as follows:
- **Energy (joules) = Mass of water (g) × 4.2 (J/gºC) × Temperature increase (ºC)**
- The biggest source of error in calorimetry is usually caused by the unwanted loss of heat to the surrounding environment
- The food sources should be burnt at a constant distance from the water to ensure reliability of results



- Carbohydrates are preferentially used as an energy source because they are easier to digest and transport
- Lipids can store **more energy** per gram but are harder to digest and transport (hence are used for long-term storage)
- Protein metabolism produces **nitrogenous waste products** which must be removed from cells

D.2 Digestion

U1	Nervous and hormonal mechanisms control the secretion of digestive juices.
U2	Exocrine glands secrete to the surface of the body or the lumen of the gut.
U3	The volume and content of gastric secretions are controlled by nervous and hormonal mechanisms.
U4	Acid conditions in the stomach favour some hydrolysis reactions and help to control pathogens in ingested food.
U5	The structure of cells of the epithelium of the villi is adapted to the absorption of food.
U6	The rate of transit of materials through the large intestine is positively correlated with their fibre content.
U7	Appetite is controlled by a centre in the hypothalamus.
U8	Materials not absorbed are egested.
A1	The reduction of stomach acid secretion by proton pump inhibitor drugs.
A2	Dehydration due to cholera toxin.
A3	*Helicobacter pylori* infection as a cause of stomach ulcers.
S1	Identification of exocrine gland cells that secrete digestive juices and villus epithelium cells that absorb digested foods from electron micrographs.

Digestive juice

Digestive juice	Site of production	Contents
saliva	salivary glands in the mouth	• water • mucus • salivary amylase
gastric juice	gastric glands in the stomach wall	• water • mucus • pepsin secreted as pepsinogen • hydrochloric acid
pancreatic juice	exocrine cells in the pancreas	• water • pancreatic amylase • trypsin secreted as trypsinogen • pancreatic lipase • carboxypeptidase chymotrypsin • hydrogencarbonate (HCO_3^-) ions

- The secretion of digestive juices is controlled by both **nervous and hormonal mechanisms**
- These mechanisms control both the volume of secretions produced and the specific content (e.g. enzymes, acids, etc.)

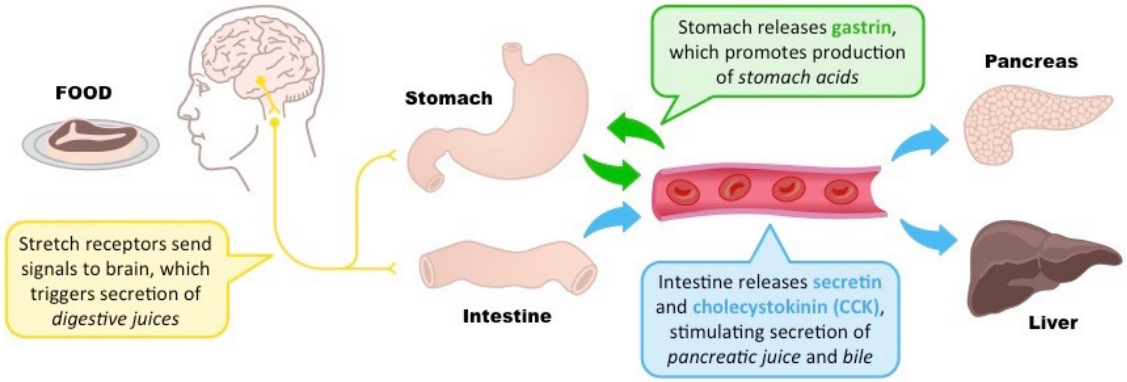
Nervous Mechanism:

- The sight and smell of food triggers an immediate response by which gastric juice is secreted by the stomach pre-ingestion
- When food enters the stomach it causes distension, which is detected by **stretch receptors** in the stomach lining
- Signals are sent to the brain, which triggers the release of digestive hormones to achieve sustained gastric stimulation

Hormonal Mechanism:

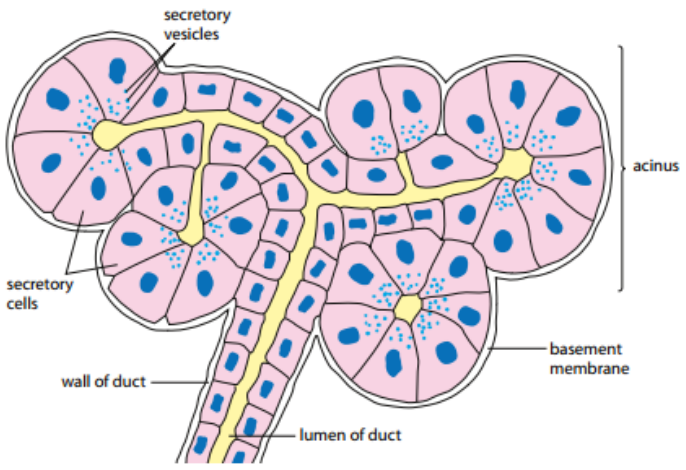
- **Gastrin** is secreted into the bloodstream from the gastric pits of the stomach and stimulates the release of stomach acids
- If stomach pH drops too low (becomes too acidic), gastrin secretion is inhibited by gut hormones (secretin and somatostatin)
- Hormone **enterogasterone** is also released. This hormone decreases the flow of gastric juice and delays the exit of fat-containing food from the stomach.
- When digested food (chyme) passes into the small intestine, the duodenum also releases digestive hormones:
- **Secretin and cholecystokinin (CCK)** stimulate the pancreas and liver to release digestive juices
- Pancreatic juices contain **bicarbonate ions**(HCO_3^-) which neutralise stomach acids, while the liver produces bile to emulsify fats

Hormone	Site of production	Effect of hormone
gastrin	stomach wall	• stimulates production of hydrochloric acid (HCl) and gastric juices
enterogasterone	stomach wall	• slows flow of gastric juice • slows exit of fats from stomach
secretin	small intestine	• stimulates the pancreas to release hydrogen carbonate (HCO_3^-) ions to neutralise acidic chyme (partly digested food) from the stomach
CCK-PZ (cholecystokinin)	small intestine	• stimulates the release of bile from the gall bladder (Subtopic **D3**) • and the release of pancreatic enzymes into the small intestine



Exocrine gland

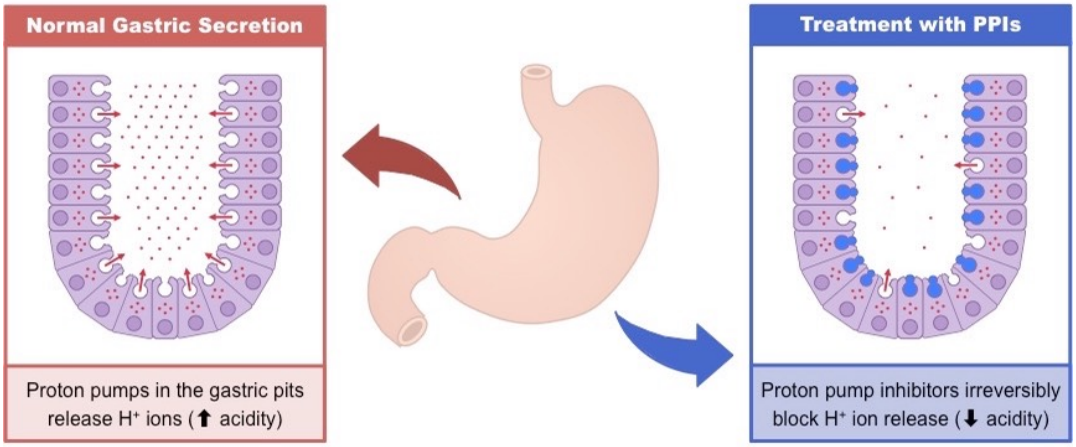
- Digestive juices are produced in exocrine glands in the mouth (salivary glands), in the stomach wall (gastric glands) and in the exocrine tissue of the pancreas.
- Exocrine glands produce and secrete substances via **a duct onto an epithelial surface to:**
    - The *surface of the body* (e.g. sweat glands, sebaceous glands)
    - The lumen of the digestive tract / gut (e.g. digestive glands)
- Exocrine glands are composed of a cluster of **secretory cells** which collectively form an **acinus** (plural = acini)
- The acini are surrounded by a basement membrane and are held together by tight junctions between secretory cells
- The secretory cells possess a **highly developed ER and golgi network** for material secretion and are rich in mitochondria
- Exocrine products are released (via secretory vesicles) into **a duct**, which connects to an epithelial surface
- These ducts may arise from a convergence of smaller ductules (each connected to an acinus) in order to enhance secretion



Stomach acid

- The gastric glands that line the stomach wall secrete an acidic solution that creates a low pH environment within the stomach
- The normal pH of the stomach is roughly **1.5 – 2.0**, which is the optimum pH for hydrolysis reactions by stomach enzymes
- The acid conditions in the stomach serve a number of functions:
    - Assists in the digestion of food (by dissolving chemical bonds within food molecules)
    - Activates stomach **proteases** (e.g. pepsin is activated when **pepsinogen** is converted to pepsin in the stomach when in the presence of **hydrochloric acid**)
    - Prevents pathogenic infection (stomach acids destroy microorganisms in ingested food)
- The stomach wall is lined by a layer of **mucus**, which protects the stomach lining from being damaged by the acid conditions
- The pancreas releases **bicarbonate ions** into the duodenum which neutralises the stomach pH (intestinal pH ~7.0 – 8.0)
- Certain foods (e.g. antacids) may also neutralise stomach acids, impairing digestion and increasing chances of infection

- The low pH environment of the stomach is maintained by **proton pumps** in the parietal cells of the gastric pits
- These proton pumps secrete H^+ ions (via active transport), which **combine with Cl^- ions** to form hydrochloric acid
- Certain medications and disease conditions can increase the secretion of H^+ ions, lowering the pH in the stomach
- **Proton pump inhibitors (PPIs)** are drugs which irreversibly bind to the proton pumps and prevent H^+ ion secretion
- This effectively raises the pH in the stomach to prevent gastric discomfort caused by high acidity (e.g. acid reflux)
- Individuals taking PPIs may have increased susceptibility to gastric infections due to the reduction of acid secretion



Dietary Fibre

- Dietary fibre is the **indigestible portion** of food derived principally from plants and fungi (cellulose, chitin, etc.)
- Humans lack the necessary enzymes to break down certain plant matter (e.g. lack *cellulase* required to digest cellulose)
- The rate of transit of materials through the large intestine is ***positively correlated* with their fibre content**:
    - Dietary fibres provides bulk in the intestines to help keep materials moving through the gut
    - Dietary fibres also absorbs water, which keeps bowel movements soft and easy to pass
- There are several health benefits associated with diets rich in dietary fibre:
    - It reduces the frequency of constipation and lowers the risk of colon and rectal cancer
    - It lowers blood cholesterol and regulates blood sugar levels (by slowing the rate of absorption)
    - It aids in weight management (contributes few calories despite consisting of a large volume of ingested material)

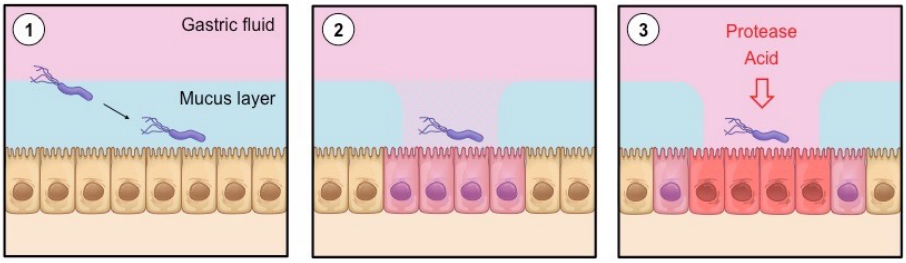
Egestion

- Materials that are not absorbed by the small and large intestines are ultimately egested from the body as faeces
- A large portion of human faeces consists of **dietary fibre**, such as cellulose and lignin
- Also present in faeces are the remains of intestinal epithelial cells, bile pigments and human flora (intestinal bacteria)

Stomach ulcers

- **Stomach ulcers** are inflammed and damaged areas in the stomach wall, typically caused by exposure to gastric acids
- There is a strong positive correlation between ***Helicobacter pylori*** infection and the development of stomach ulcers
- ***Helicobacter pylori*** is a bacterium that can survive the acid conditions of the stomach by penetrating the mucus lining
- *H. pylori* anchors to the epithelial lining of the stomach, underneath the mucus lining

- An **inflammatory immune response** damages the epithelial cells of the stomach – including the mucus-secreting goblet cells
- This results in the degradation of the **protective mucus lining**, exposing the stomach wall to gastric acids and causing ulcers
- The prolonged presence of stomach ulcers may lead to the development of stomach cancer over many years (20 – 30 years)
- *H. pylori* infections can be treated by **antibiotics** (previously, stomach ulcers were considered stress related and not treatable)



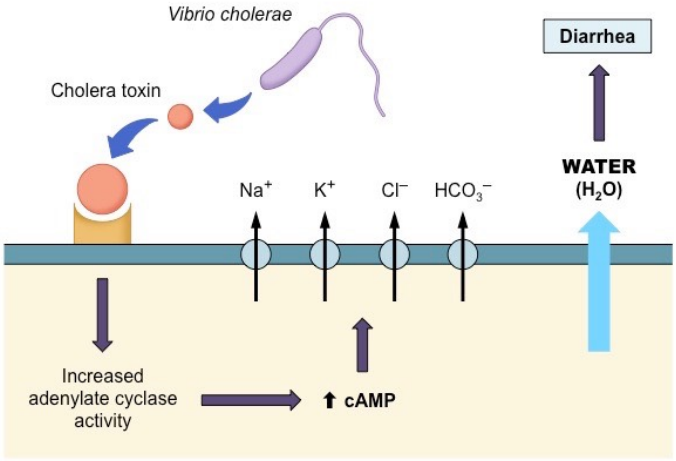
Helicobacter pylori penetrates the mucus layer lining the stomach

H. pylori damages the goblet cells responsible for mucus production

Loss of mucus exposes cells to stomach acids, causing ulcers

Cholera

- ***Vibrio cholerae*** is a bacterial pathogen that infects the intestines and causes acute **diarrhoea and dehydration**
- The associated disease – cholera – can kill within hours unless treated with oral rehydration therapies
- *V. cholerae* releases a toxin that binds to **ganglioside receptors** on the surface of intestinal epithelium cells
- This toxin is internalised by endocytosis and triggers the production of **cyclic AMP** (a second messenger) within the cell
- Cyclic AMP (cAMP) activates specific ion channels within the cell membrane, causing an **efflux of ions from the cell**
- The build up of ions in the intestinal lumen **draws water from cells and tissues via osmosis** – causing acute diarrhoea
- As water is being removed from body tissues, dehydration will result if left untreated

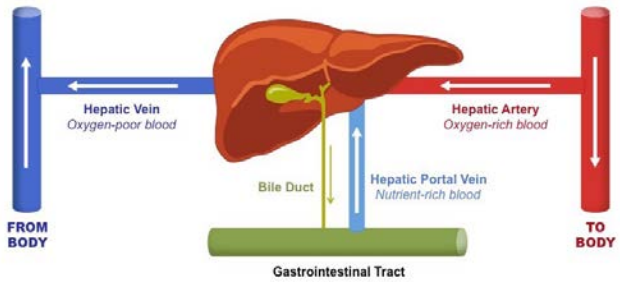


D.3 Liver functions

U1	The liver removes toxins from the blood and detoxifies them.
U2	Components of red blood cells are recycled by the liver.
U3	The breakdown of erythrocytes starts with phagocytosis of red blood cells by Kupffer cells.
U4	Iron is carried to the bone marrow to produce hemoglobin in new red blood cells
U5	Surplus cholesterol is converted to bile salts
U6	Endoplasmic reticulum and Golgi apparatus in hepatocytes produce plasma proteins.
U7	The liver intercepts blood from the gut to regulate nutrient levels.
U8	Some nutrients in excess can be stored in the liver.
A1	Causes and consequences of jaundice.
A2	Dual blood supply to the liver and differences between sinusoids and capillaries

Liver blood flow

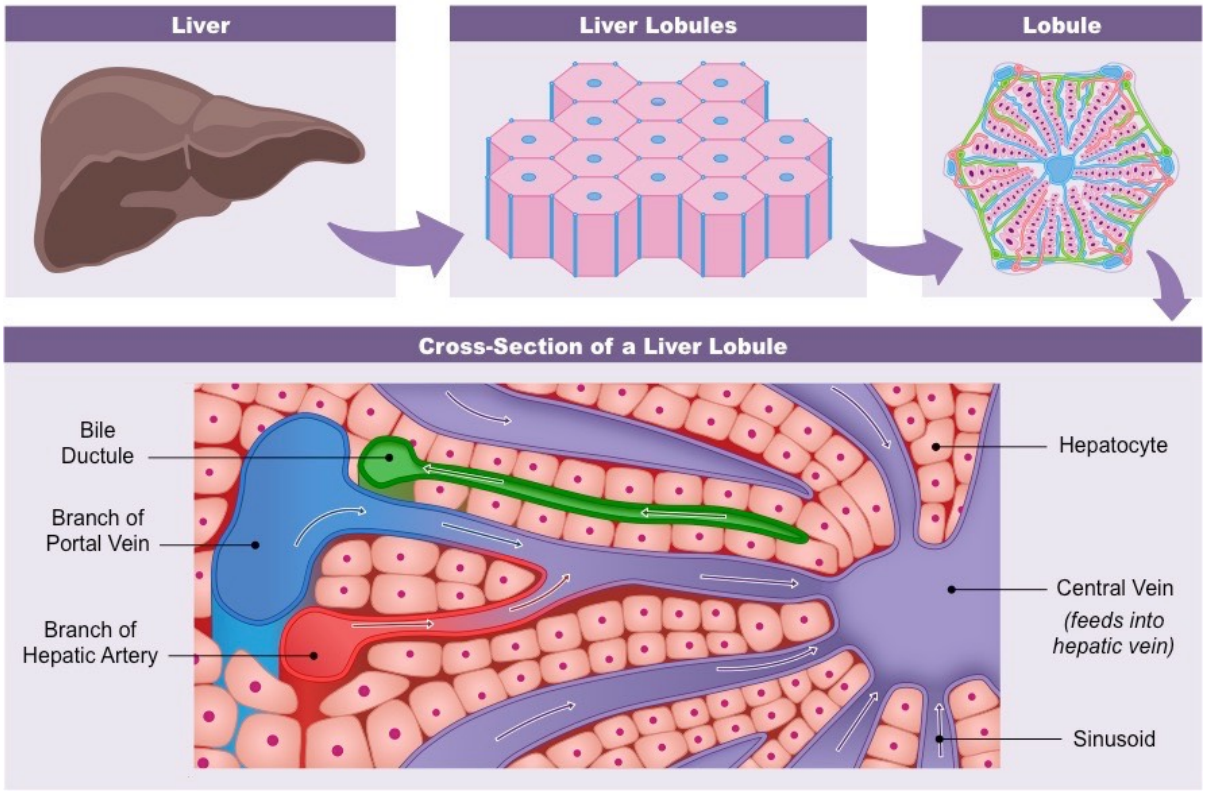
- It receives *oxygenated blood* from the heart via the **hepatic portal artery**, which is used to sustain liver cells (**hepatocytes**)
- It also receives *nutrient rich blood* from the gut and stomach via the **portal vein**
- *Deoxygenated blood* is transported from the liver via the **hepatic vein**
- The liver functions to process the nutrients absorbed from the gut and hence regulates the body's metabolic processes



- It is responsible for the **storage and controlled release of key nutrients** (e.g. glycogen, cholesterol, triglycerides)
- It is responsible for the **detoxification** of potentially harmful ingested substances (e.g. amino acids, medications, alcohol)
- It produces **plasma proteins** that function to maintain sustainable osmotic conditions within the bloodstream
- It is responsible for the breakdown of **red blood cells** and the **production of bile salts**

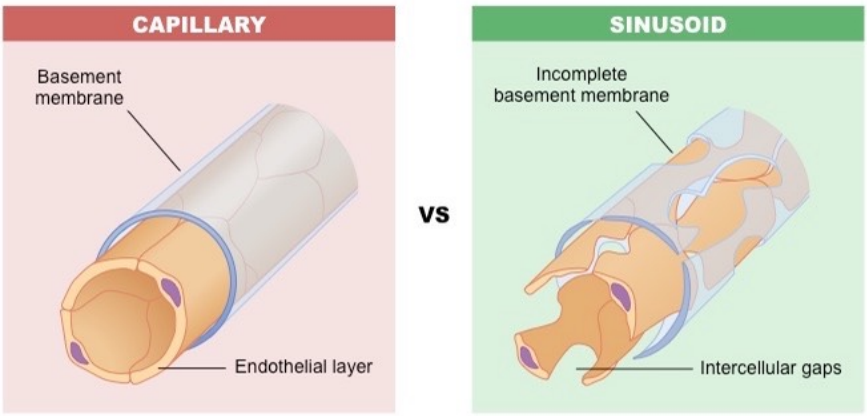
Liver structure

- The liver is composed of smaller histological structures called **lobules**, which are roughly hexagonal in shape
- Each lobule is surrounded by branches of the hepatic artery (provide oxygen) and the portal vein (provide nutrients)
- These vessels drain into capillary-like structures called **sinusoids**, which exchange materials directly with the hepatocytes
- The sinusoids drain into a central vein, which feeds deoxygenated blood into the hepatic vein
- Hepatocytes also produce bile, which is transported by vessels called **canaliculi** to **bile ducts**, which surround the lobule



Sinusoids

- Sinusoids are a type of small blood vessel found in the liver that perform a similar function to capillaries (material exchange)
- Sinusoids have **increased permeability**, allowing larger molecules (e.g. plasma proteins) to enter and leave the bloodstream
- The increased permeability of sinusoids is important for liver function and is due to a number of structural features:
- The surrounding diaphragm (basement membrane) is **incomplete or discontinuous** in sinusoids (but not in capillaries)
- The endothelial layer contains large **intercellular gaps** and fewer tight junctions (allowing for the passage of larger molecules)



Nutrients in liver

- Nutrients absorbed by the small intestine are transported by the hepatic portal vein to the liver for metabolism
- The liver converts these nutrients into forms that can be stored or used and mediates their transport to various tissues
- Nutrients stored within the liver include **glycogen, iron, vitamin A and vitamin D**
- Excess glucose in the bloodstream (e.g. after meals) is taken up by the liver and stored as glycogen controlled by hormone **insulin and glycogen**
- When blood glucose levels drop, the liver breaks down glycogen into glucose and exports it to body tissues
- The body cannot store **amino acids**. All the excess break down, releasing **amine group (NH_2)**, which is harmful to the body. The amine groups are transported to the liver to be broken down into urea, which is removed from the body by the kidney.
- The liver is the major site for converting excess carbohydrates and proteins into fatty acids and triglycerides
- It is also responsible for the synthesis of large quantities of phospholipids and cholesterol
- **Surplus cholesterol** is converted by the liver into **bile salts**, which can be eliminated from the body via the bowels

Detoxification

- Toxins are converted into **less harmful chemicals** by oxidation, reduction and hydrolysis reactions
- The converted chemical is then attached to another substance (e.g. cysteine) via a conjugation reaction
- Many of these toxic compounds are fat soluble, making them difficult for the body to excrete
- These compounds are converted into less harmful and more soluble forms, which are then excreted from the body

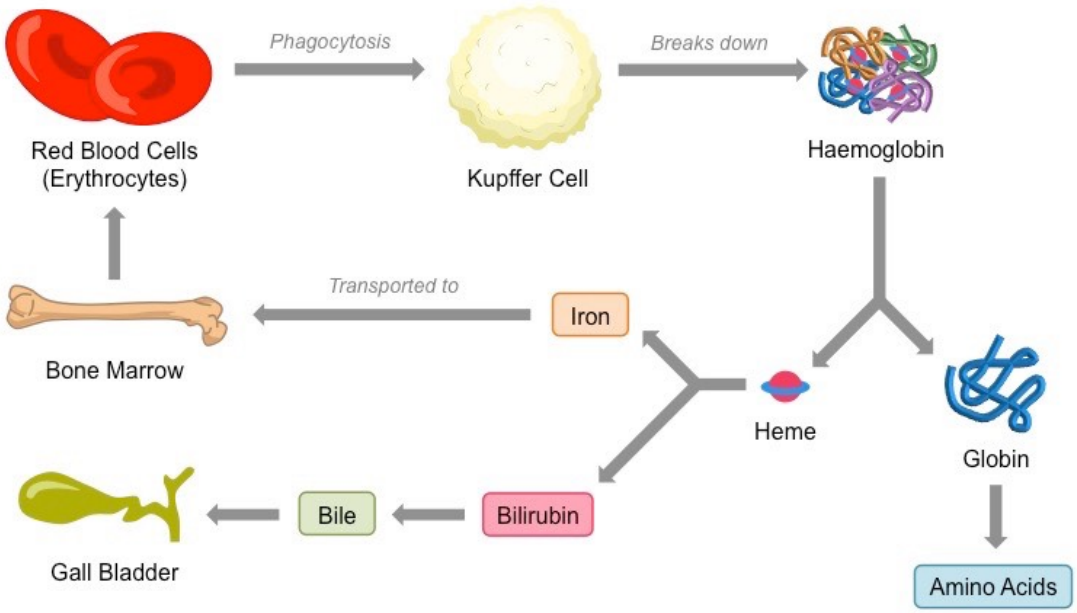
Plasma protein

- Plasma proteins are proteins present in the blood plasma and are produced by the liver
- The proteins are produced by the rough ER in hepatocytes and exported into the blood via the Golgi apparatus
- Plasma proteins are responsible for
    - Regulate the osmotic pressure of the blood
    - Involved in clotting process (**fibrinogen**, which turns into fibrin by **thrombin** *see 6.3 for details*)
    - Protein transport

Red blood cell recycling

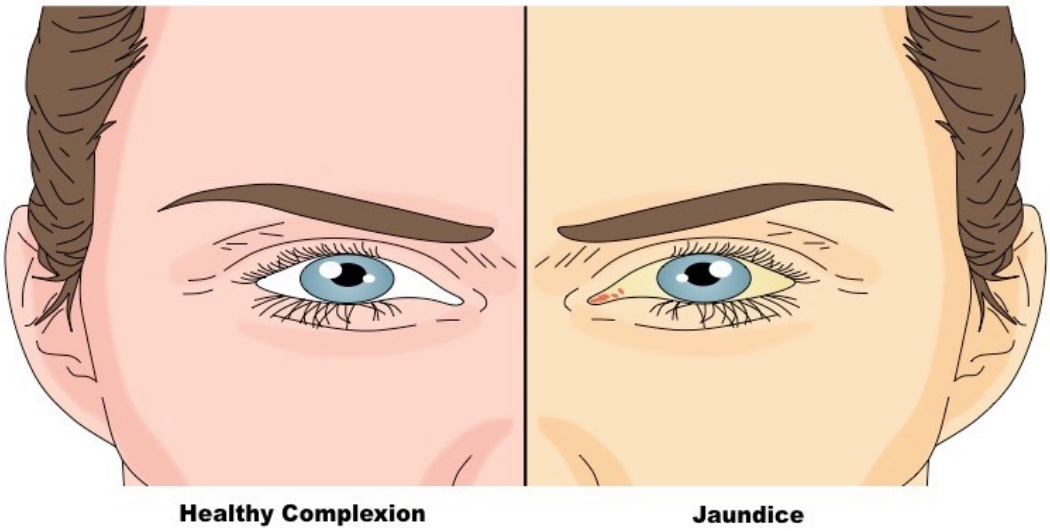
- In humans, red blood cells possess minimal organelles and no nucleus in order to carry more **haemoglobin**
- Consequently, red blood cells have a short lifespan (~120 days) and must be constantly replaced
- The liver is responsible for the breakdown of red blood cells and recycling of its components
- These components are used to make either new red blood cells or other important compounds (e.g. bile)
- **Kupffer cells** are specialised phagocytes within the liver which engulf red blood cells and break them down
- Kupffer cells break down **haemoglobin** into **globin** and iron-containing **heme groups**
- Kupffer cells can be found on the wall of **sinosoids**

- Globin is digested by peptidases to produce **amino acids** (which are either recycled or metabolised by the liver)
- Heme groups are broken down into **iron** and **bilirubin** (bile pigment)
- Iron can be stored by the liver within a protein shell of *ferritin*
- Iron can be transported to the bone marrow (where new haemoglobin is produced) within the protein *transferrin*
- **Bilirubin** is the yellow pigments, which defines the colour of human feces



Jaundice

- Jaundice is a condition caused by an excess of bile pigment – ***bilirubin*** – within the body
- Bilirubin is produced as part of the natural breakdown of haemoglobin by the liver
- Normally, the liver conjugates this bilirubin to other chemicals and then secretes it in bile
- When there is an excess of bilirubin, it may leak out into surrounding tissue fluids
- Jaundice may be caused by any condition which **impairs the natural breakdown of red blood cells**, including:
    - Liver disease – impaired removal of bilirubin by the liver may cause levels to build within the body
    - Obstruction of the gall bladder – **preventing the secretion of bile** will cause bilirubin levels to accumulate
    - Damage to red blood cells – **increased destruction of erythrocytes** (e.g. anemia) will cause bilirubin levels to rise
- The main consequence of jaundice is a **yellowish discoloratio**n of the skin and whites of the eyes (sclera)
- Other common symptoms include itchiness, paler than usual stools and darkened urine
- Jaundice may be resolved by treating the underlying cause for the buildup of bilirubin within the body

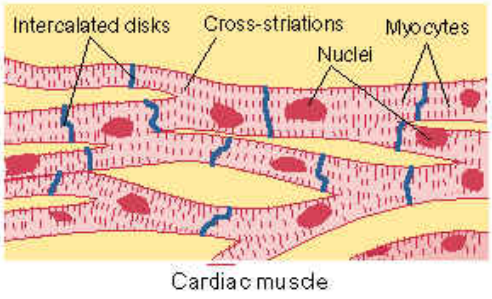


D.4 The heart

U1	Structure of cardiac muscle cells allows propagation of stimuli through the heart wall.
U2	Signals from the sinoatrial node that cause contraction cannot pass directly from atria to ventricles.
U3	There is a delay between the arrival and passing on of a stimulus at the atrioventricular node.
U4	This delay allows time for atrial systole before the atrioventricular valves close.
U5	Conducting fibres ensure coordinated contraction of the entire ventricle wall.
U6	Normal heart sounds are caused by the atrioventricular valves and semilunar valves closing causing changes in blood flow.
A1	Use of artificial pacemakers to regulate the heart rate.
A2	Use of defibrillation to treat life-threatening cardiac conditions.
A3	Causes and consequences of hypertension and thrombosis.
S1	Measurement and interpretation of the heart rate under different conditions.
S2	Interpretation of systolic and diastolic blood pressure measurements.
S3	Mapping of the cardiac cycle to a normal ECG trace.
S4	Analysis of epidemiological data relating to the incidence of coronary heart disease.

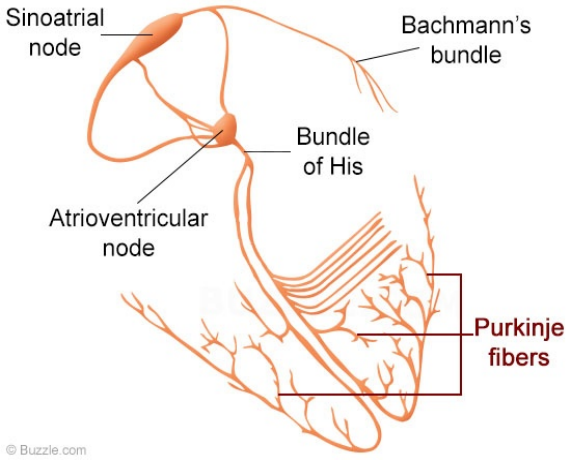
Cardiac muscle

- Branched and interconnected
- Have many mitochondria
- Have high O_2 supply
- **Structurally and functionally electronically connected**
- Contain only one nucleus
- **Involuntary** muscle and never become **fatigable**
- They have **intercalated disk**, which allows **electric impulse** to move rapidly to adjacent cells. They enable cells to work as one.
- **Systole** – contraction of cardiac muscle
- **Diastole** – relaxation of cardiac muscle



Sino-atrial(SA) node

- Located at the junction of right atrium and vena cava
- Creates **electric impulses** to cardiac muscle cells in the **left and right atrium**, allow them to contract at the same time.
- The sinoatrial node acts as a *primary pacemaker*, controlling the rate at which the heart beats (i.e. pace 'making')
- It sends out electrical signals which are propagated throughout the entire atria via gap junctions in the intercalated discs
- In response, the cardiac muscle within the atrial walls contract simultaneously (atrial systole)
- **Artificial pacemaker** can override the SA nodes and control the heart beat.
- **Defibrillation** uses strong voltage and current to **reset** SA nodes



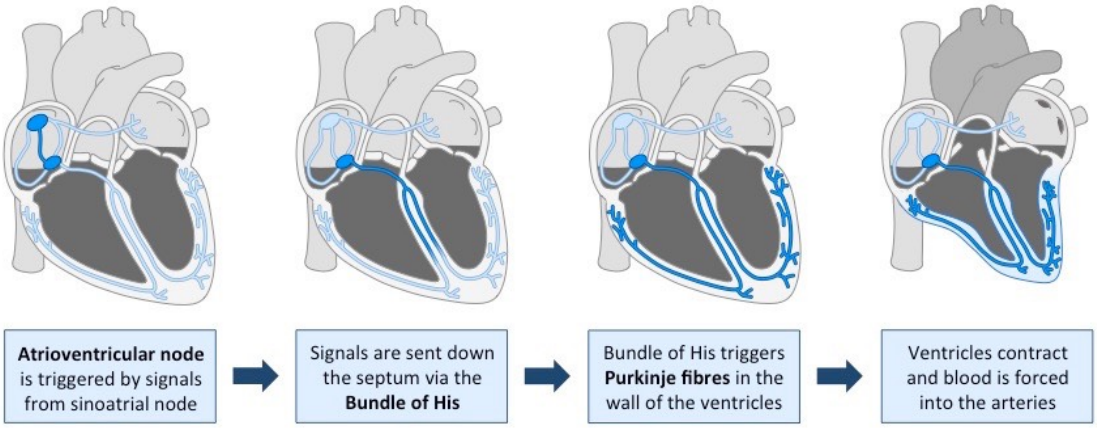
- The atria and ventricles of the heart are separated by a fibrous cardiac skeleton composed of connective tissue
- This **connective tissue** functions to anchor the heart valves in place and **cannot** conduct electrical signals
- The signals from the sinoatrial node must instead be relayed through a second node located within this cardiac skeleton

Atrio-ventricular(AV) node

- Receive signals from the SA nodes
- AV nodes **delay** the signal before passing them to the ventricle.
- The delay is necessary to allow the continued movement of blood from atrium to ventricle.

Bundles of His and Purkinje fibers

- To ensure **simultaneous** ventricular cardiac muscle contraction, signals need to move fast
- **Bundle of His** are **connecting fibres**, reaching every cells and conduct signals quickly.
- **Purkinje fibre** transmits signals from AV nodes to ventricular muscle.



Diastole

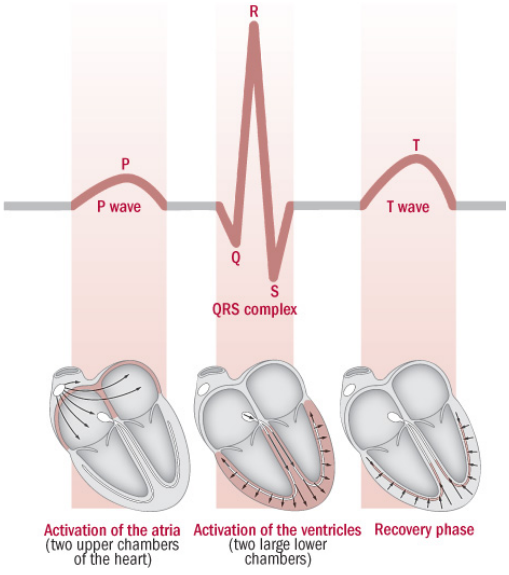
- After every contraction of the heart, there is a period of insensitivity to stimulation (i.e. a refractory period)
- This recovery period (diastole) is relatively long, and allows the heart to passively refill with blood between beats
- This long recovery period also helps prevent heart tissue **becoming fatigued**, allowing contractions to continue for life

Heart sound

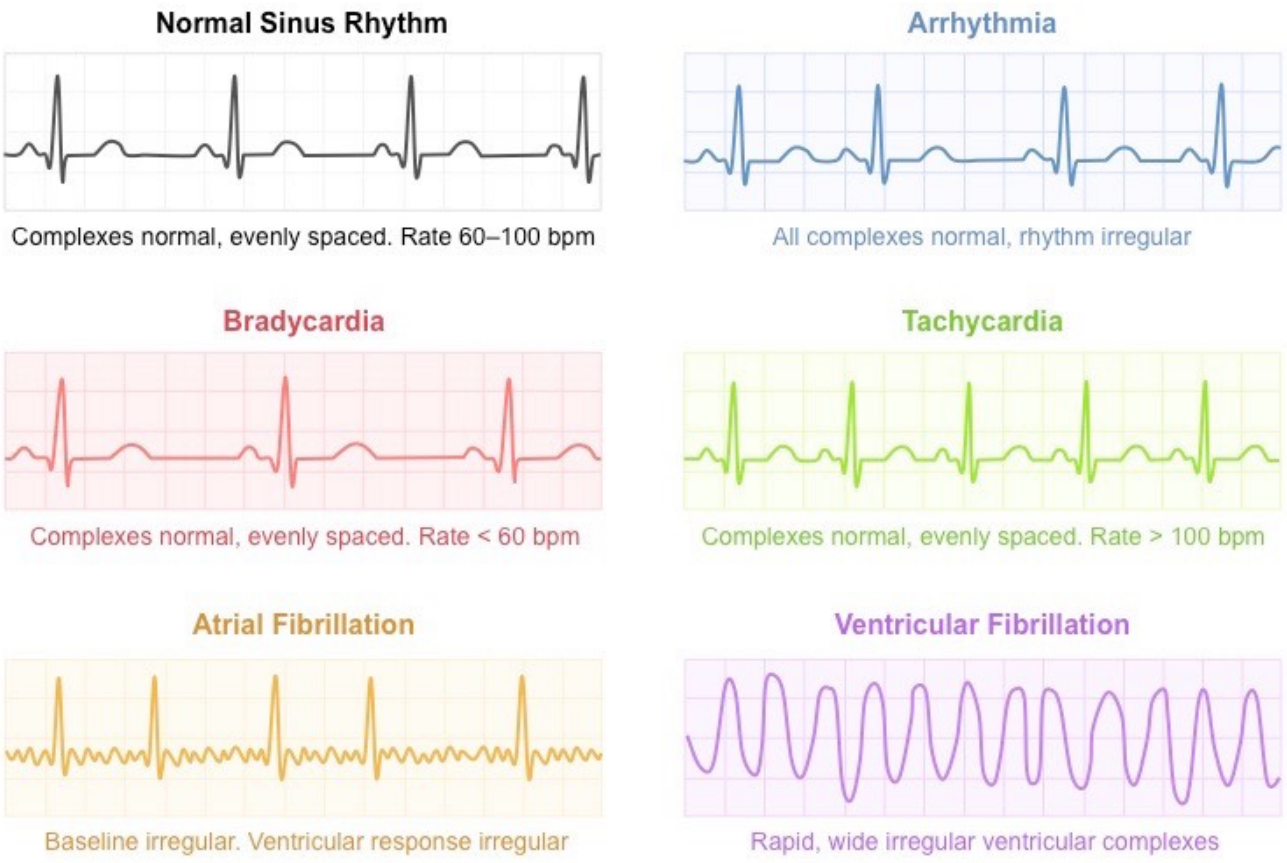
- Heart sound is caused by closing of heart valves.
- There are two sets of valves located within the heart:
  - **Atrioventricular valves** (tricuspid and bicuspid) prevent blood in the ventricles from flowing back into the atria
  - **Semilunar valves** (pulmonary and aortic) prevent blood in the arteries from flowing back into the ventricles
- Heart sounds are made when these two sets of valves close in response to pressure changes within the heart
  - The first heart sound is caused by the closure of the atrioventricular valves at the start of ventricular systole
  - The second heart sound is caused by the closure of the semilunar valves at the start of ventricular diastole
- lub – **tricuspid and bicuspid** valve closing
- dub – aortic and plumontary valve closing

Echocardiograph (ECG)

- visual recording of the electrical impulse that move through heart.
- P – contraction of **atrium** (depolarization from SA nodes)
- R – contraction of **ventricle** (depolarisation from AV nodes)
- T – relaxation of **cardiac muscle** (repolarisation - diastole)
- QRS – time for conduction through Punkinje fibre



- Data generated via electrocardiography can be used to identify a variety of heart conditions, including:
- ***Tachycardia*** (elevated resting heart rate = >120 bpm) and ***bradycardia*** (depressed resting heart rate = < 40 bpm)
- ***Arrhythmias*** (irregular heart beats that are so common in young people that it is not technically considered a disease)
- ***Fibrillations*** (unsynchronised contractions of either atria or ventricles leading to dangerously spasmodic heart activity)



Cardiac output

- **Cardiac output** describes the amount of blood the heart pumps through the circulatory system in one minute
- Cardiac Output (CO) = Heart Rate (HR) × Stroke Volume (SV)
- **Heart rate** describes the speed at which the heart beats, measured by the number of contractions per minute (or bpm)
    - Heart rate can be affected by a number of conditions – including exercise, age, disease, temperature and emotional state
    - Heart rate is increased by the sympathetic nervous system and decreased by parasympathetic stimulation (vagus nerve)
    - Heart rate can also be increased hormonally via the action of adrenaline / epinephrine
- **Stroke volume** is the amount of blood pumped to the body (from the left ventricle) with each beat of the heart
    - Changes in stroke volume will affect the blood pressure – more blood or more resistance will increase the overall pressure
    - Blood pressure measurements typically include two readings – representing systolic and diastolic blood pressures
    - **Systolic blood pressure** is higher, as it represents the pressure of the blood following the contraction of the heart
    - **Diastolic blood pressure** is lower, as it represents the pressure of the blood while the heart is relaxing between beats
    - Blood pressure readings will vary depending on the site of measurement (e.g. arteries have much higher pressure than veins)

Hypertension

- Hypertension is defined as an abnormally high blood pressure – either systolic, diastolic or both (e.g. > 140/90 mmHg)
- Common causes of hypertension include a sedentary lifestyle, salt or fat-rich diets and excessive alcohol or tobacco use
- High blood pressure can also be secondary to other conditions (e.g. kidney disease) or caused by some medications
- Hypertension itself does not cause symptoms but in the long-term leads to consequences **caused by narrowing blood vessels**

Thrombosis

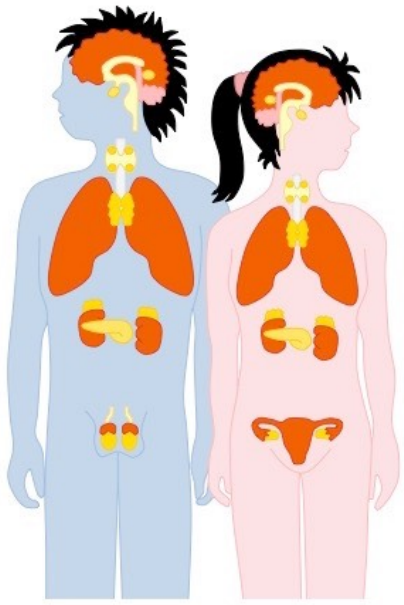
- **Thrombosis** is the formation of a clot within a blood vessel that forms part of the circulatory system
- Thrombosis occurs in arteries when the vessels are damaged as a result of the deposition of **cholesterol** (atherosclerosis)
- Atheromas (fat deposits) develop in the arteries and significantly reduce the diameter of the vessel (leading to hypertension)
- The high blood pressure damages the arterial wall, forming lesions known as atherosclerotic plaques
- If a plaque ruptures, blood clotting is triggered, forming a thrombus that restricts blood flow
- If the thrombus becomes dislodged it becomes an embolus and can cause blockage at another site
- Thrombosis in the coronary arteries leads to heart attacks, while thrombosis in the brain causes strokes

D.5 Hormones and metabolism (HL)

U1	Endocrine glands secrete hormones directly into the bloodstream
U2	Steroid hormones bind to receptor proteins in the cytoplasm of the target cell to form a receptor–hormone complex.
U3	The receptor–hormone complex promotes the transcription of specific genes.
U4	Peptide hormones bind to receptors in the plasma membrane of the target cell.
U5	Binding of hormones to membrane receptors activates a cascade mediated by a second messenger inside the cell.
U6	The hypothalamus controls hormone secretion by the anterior and posterior lobes of the pituitary gland.
U7	Hormones secreted by the pituitary control growth, developmental changes, reproduction and homeostasis.
A1	Some athletes take growth hormones to build muscles.
A2	Control of milk secretion by oxytocin and prolactin.

Endocrine Gland

- Endocrine glands secrete their product (hormones) **directly into the bloodstream**, rather than through a duct (e.g. exocrine gland)
- Major endocrine glands include the pancreas, adrenal gland, thyroid gland, pineal gland and the gonads (ovaries and testes)
- The hypothalamus and pituitary gland are **neuroendocrine** glands and function to link the nervous and endocrine systems
- Some organs may also secrete hormones despite not being endocrine glands (e.g. adipose tissue secretes leptin)

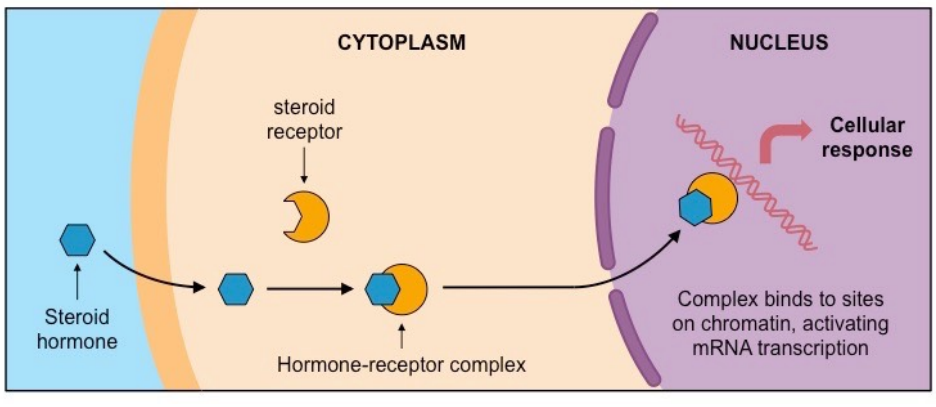


Gland	Hormone	Target Organ	Function
Pineal gland	melatonin	many	biological clock
Pituitary gland	FSH / LH ADH growth hormone oxytocin prolactin	ovaries kidneys many uterus breast tissue	menstrual cycle osmoregulation growth & division birth contractions milk production
Thyroid gland	thyroxin	liver	metabolic rate
Adrenal glands	adrenaline cortisol	many many	fight or flight anti-stress
Pancreas	insulin / glucagon	liver	blood sugar levels
Ovaries	estrogen / progesterone	uterus	menstrual cycle
Testes	testosterone	many	male characteristics

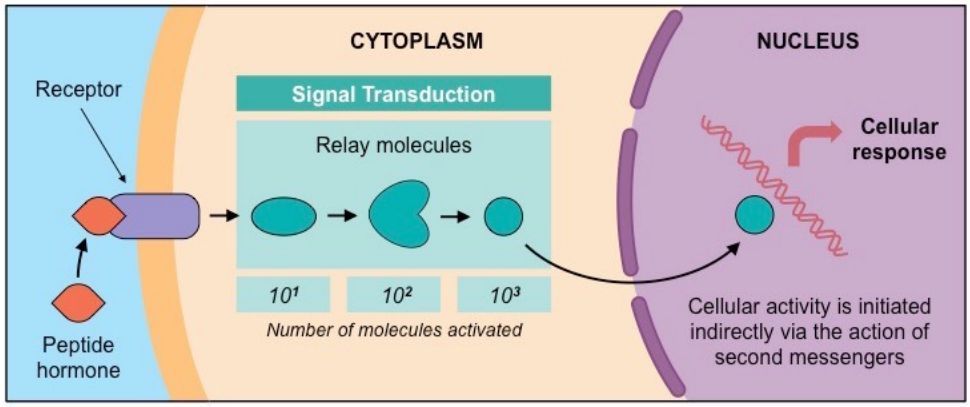
- A **hormone** is a chemical messenger that is transported indiscriminately via the bloodstream to act on distant target cells
- Hormones are *specific* and will only activate cells or tissues that possess the appropriate target receptor
- The endocrine system is **slower to initiate**, but has a **more prolonged response** when compared to the nervous system

Type of hormone

- **Steroid Hormones**
  - Steroid hormones are lipophilic (fat-loving) – meaning they can freely **diffuse across the plasma membrane of a cell**
  - They **bind to receptors** in either the cytoplasm or nucleus of the target cell, to form an active **receptor-hormone complex**
  - This activated complex will move into the nucleus and bind directly to DNA, acting as a **transcription factor for gene expression**
  - Examples of steroid hormones include those produced by the gonads (i.e. estrogen, progesterone and testosterone)



- **Peptide Hormones**
  - Peptide hormones are hydrophylic and lipophobic (fat-hating) – meaning they **cannot freely cross the plasma membrane**
  - They bind to **receptors on the surface of the cell**, which are typically coupled to internally anchored proteins (e.g. G proteins)
  - The receptor complex activates a series of intracellular molecules called **second messengers**, which initiate cell activity
  - This process is called **signal transduction**, because the external signal (hormone) is transduced via internal intermediaries
  - Examples of second messengers include **cyclic AMP (cAMP)**, calcium ions (Ca^{2+}), nitric oxide (NO) and protein kinases
  - The use of second messengers enables the **amplification of the initial signal** (as more molecules are activated)
  - Peptide hormones include insulin, glucagon, leptin, ADH and oxytocin

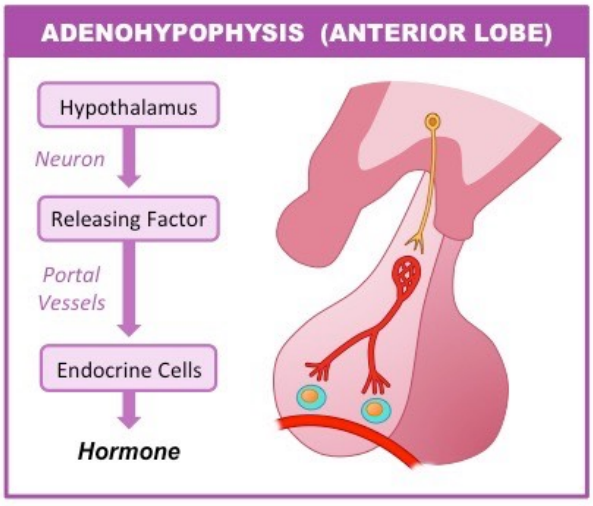


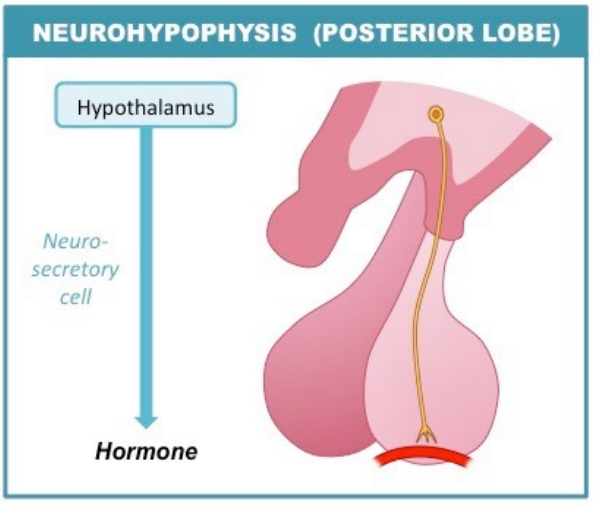
Hypothalamus

- It receives information from nerves throughout the body and other parts of the brain and initiates endocrine responses
- It secretes **neurochemicals** (called releasing factors) into a portal system which target the ***anterior* lobe of the pituitary gland**
- It also secretes **hormones** directly into the blood via neurosecretory cells that extend into the ***posterior* pituitary lobe**

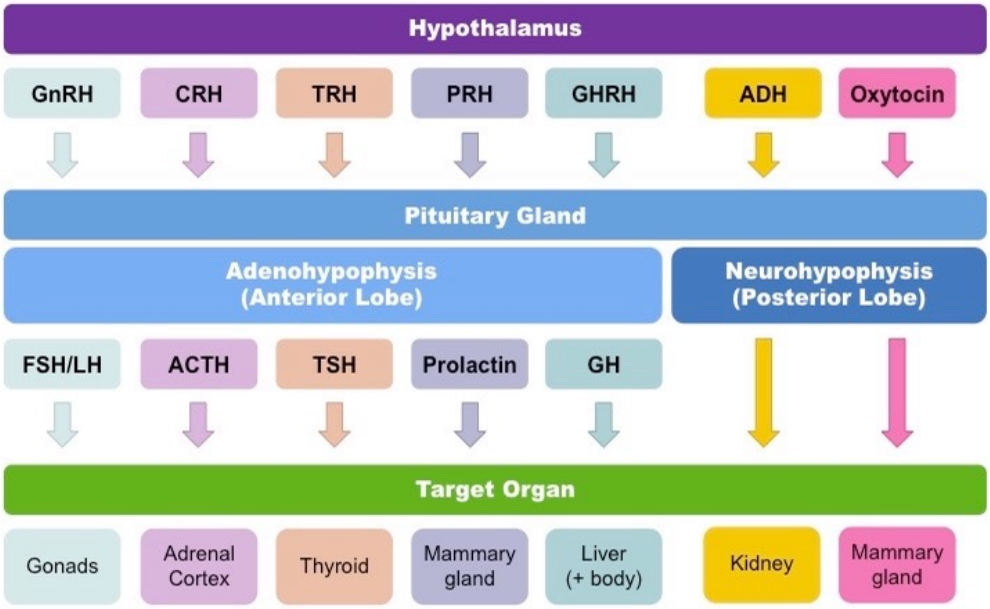
Pituitary gland

- **Anterior Lobe**
  - The anterior lobe is also called the **adenohypophysis** ('adeno' = relating to glands)
  - The hypothalamus produces *releasing factors*, which are released into portal vessels by neurosecretory cells
  - The releasing factors cause endocrine cells in the anterior pituitary to release specific hormones into the bloodstream
  - An example of a releasing factor is **GnRH**, which triggers the release of LH and FSH from the anterior pituitary
- **Posterior Lobe**
  - The posterior lobe is also called the **neurohypophysis** ('neuro' = relating to nerves)
  - The posterior lobe releases **hormones** produced by the hypothalamus itself (via neurosecretory cells)
  - These neurosecretory cells extend into the posterior lobe from the hypothalamus and release hormones into the blood





- Pituitary hormones will often target endocrine glands in other organs (e.g. gonads, pancreas, thyroid, mammary gland)
- Pituitary hormones hence control many vital body processes, including:
    - **Metabolism** (e.g. TSH activates thyroxin)
    - **Adult Development** (e.g. LH / FSH trigger puberty)
    - **Reproduction** (e.g. LH / FSH control menstruation)
    - **Growth** (e.g. growth hormone promotes growth)
    - **Equilibrium / Homeostasis** (e.g. ADH and water balance)



Growth Hormone

- Growth hormone (also known as somatotropin) is an anabolic peptide hormone that stimulates growth
- It acts directly to **reduce the formation of adipose cells** (i.e. less nutrients stored as fat)
- It acts indirectly via insulin growth factor (IGF) – produced by the liver – to increase **muscle mass and bone size**
- Due to its role in promoting growth and regeneration, it is used by some athletes as a performance enhancer
- Since it is a **natural hormone**, it is very hard to test the use of growth hormone and traditional urine test cannot test growth hormone

Lactation

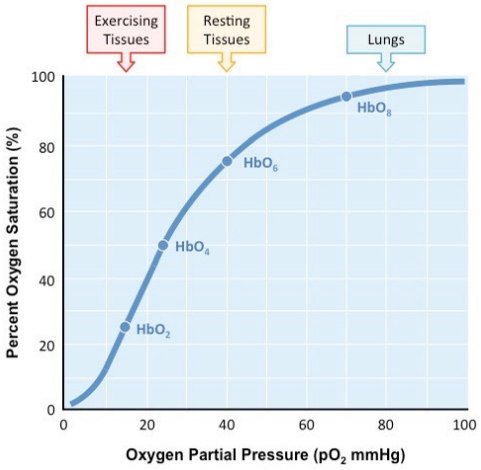
- The production and secretion of milk by maternal mammary glands following birth is called **lactation**
- **Prolactin** is responsible for the **development of the mammary glands** and the production of milk
    - It is secreted by the **anterior pituitary** in response to the release of PRH (prolactin releasing hormone) from the hypothalamus
    - The effects of prolactin are **inhibited by progesterone**, which prevents milk production from occurring prior to birth
- **Oxytocin** is responsible for the ***release* of milk** from the mammary glands (milk ejection reflex)
    - It is produced in the hypothalamus and secreted by **posterior pituitary**
    - Oxytocin release is triggered by stimulation of sensory receptors in the breast tissue by the suckling infant
    - This creates a positive feedback loop that will result in continuous oxytocin secretion until the infant stops feeding

D.6 Transport of respiratory gases (HL)

U1	Oxygen dissociation curves show the affinity of hemoglobin for oxygen.
U2	Carbon dioxide is carried in solution and bound to hemoglobin in the blood.
U3	Carbon dioxide is transformed in red blood cells into hydrogencarbonate ions.
U4	The Bohr shift explains the increased release of oxygen by hemoglobin in respiring tissues.
U5	Chemoreceptors are sensitive to changes in blood pH.
U6	The rate of ventilation is controlled by the respiratory control centre in the medulla oblongata.
U7	During exercise the rate of ventilation changes in response to the amount of CO_2 in the blood.
U8	Fetal hemoglobin is different from adult hemoglobin allowing the transfer of oxygen in the placenta onto the fetal hemoglobin.
A1	Fetal hemoglobin is different from adult hemoglobin allowing the transfer of oxygen in the placenta onto the fetal hemoglobin.
A2	pH of blood is regulated to stay within the narrow range of 7.35 to 7.45.
A3	Causes and treatments of emphysema
S1	Analysis of dissociation curves for hemoglobin and myoglobin.
S2	Identification of pneumocytes, capillary endothelium cells and blood cells in light micrographs and electron micrographs of lung tissue.

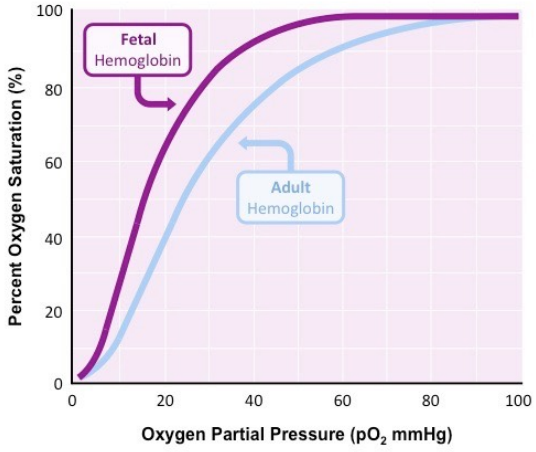
Oxygen dissociation curve

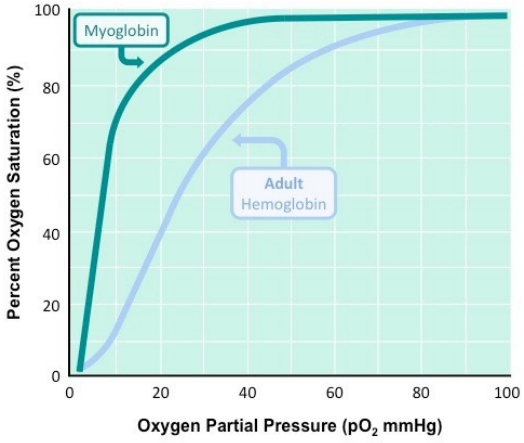
- **Oxygen dissociation curves** show the relationship between oxygen levels (as partial pressure) and haemoglobin saturation
- As each O_2 molecule binds, it alters the conformation of haemoglobin, making subsequent binding easier (*cooperative binding*)
- This means haemoglobin will have a **higher affinity for O_2 in oxygen-rich areas** (like the lung), promoting oxygen loading
- Conversely, haemoglobin will have a **lower affinity for O_2 in oxygen-starved areas** (like muscles), promoting oxygen unloading



Fetal haemoglobin

- The haemoglobin of the foetus has a slightly different molecular composition to adult haemoglobin
- Consequently, it has a ***higher* affinity for oxygen** (dissociation curve is shifted to the *left*)
- This is important as it means fetal haemoglobin will load oxygen when adult haemoglobin is unloading it (i.e. in the placenta)
- In capillaries of placenta, partial pressure of oxygen is low. Mother's haemoglobin will release oxygen, which is picked by fetal haemoglobin



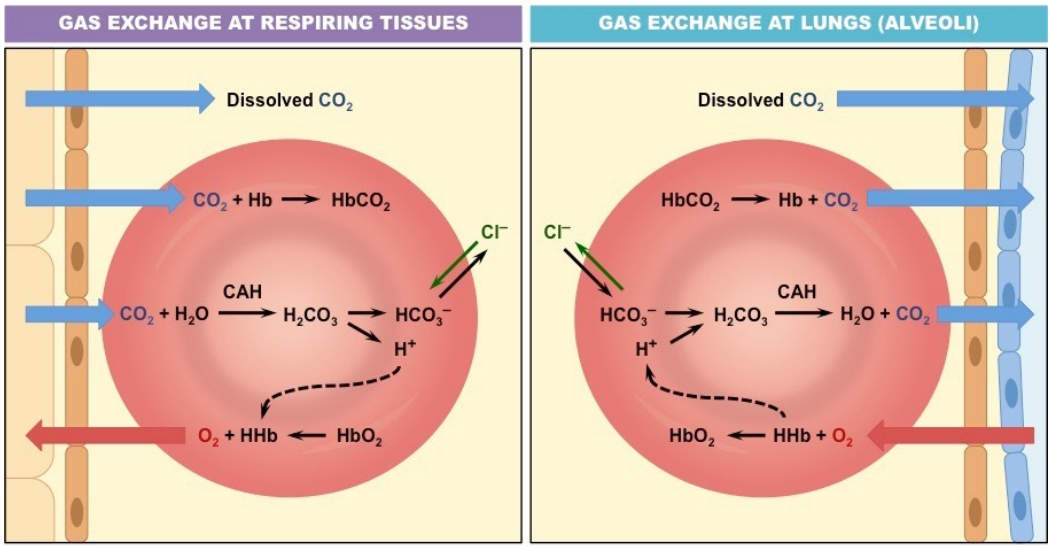


Myoglobin

- Myoglobin is an oxygen-binding molecule that is found in **skeletal muscle tissue**
- It is made of a single polypeptide with only **one heme group** and hence is **not** capable of cooperative binding
- Myoglobin has **a higher affinity for oxygen than adult haemoglobin and becomes saturated at lower oxygen levels**
- Myoglobin will **hold onto its oxygen supply until levels in the muscles are very low** (e.g. during intense physical activity)
- The delayed release of oxygen helps to slow the onset of anaerobic respiration and lactic acid formation during exercise
- Myoglobin will store oxygen and release them at very low oxygen level to keep the muscle working aerobically.

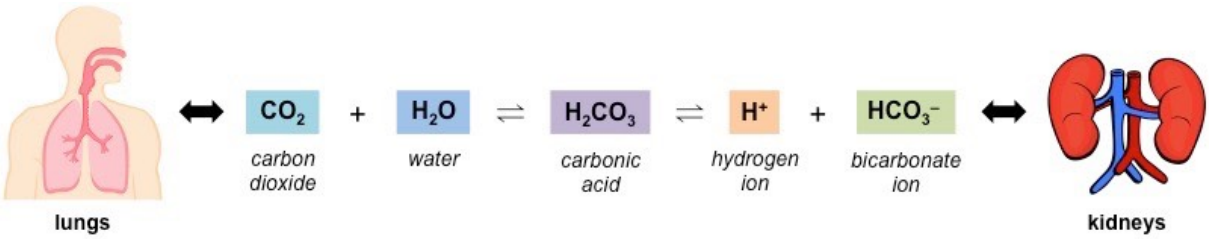
Transport of carbon dioxide

- Carbon dioxide is transported between the lungs and the tissues by one of three mechanisms:
    - Some is **bound to haemoglobin** to form $HbCO_2$ (carbon dioxide binds to the globin and so doesn't compete with O_2 binding)
    - A very small fraction gets dissolved in water and is carried in solution (~5% – carbon dioxide dissolves poorly in water)
    - The majority (~75%) diffuses into the **erythrocyte (red blood cells)** and gets converted into **carbonic acid**
- The binding of carbon dioxide to haemoglobin will release the oxygen on the haemoglobin
- When CO_2 enters the erythrocyte, it combines with water to form carbonic acid (reaction catalysed by carbonic anhydrase)
- The carbonic acid (H_2CO_3) then dissociates to form hydrogen ions (H^+) and **bicarbonate (HCO_3^-)**
- Bicarbonate is pumped out of the cell in exchange with **chloride ions** (exchange ensures the erythrocyte remains uncharged)
- The bicarbonate in the blood plasma combines with sodium to form sodium bicarbonate ($NaHCO_3$), which travels to the lungs
- The hydrogen ions within the erythrocyte make the environment less alkaline, causing haemoglobin to release its oxygen
- The haemoglobin absorbs the H^+ ions and acts as a buffer to maintain the intracellular pH
- When the red blood cell reaches the lungs, bicarbonate is pumped back into the cell and the entire process is reversed



Blood pH

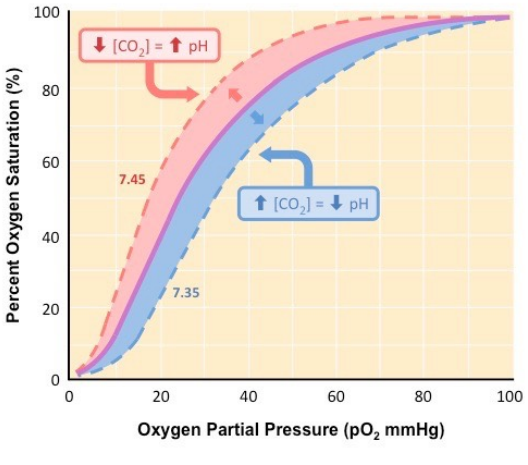
- Aqueous carbon dioxide may combine with water in blood plasma to form carbonic acid (H_2CO_3)
- Carbonic acid may then lose protons (H^+) to form bicarbonate (HCO_3^-) or carbonate (CO_3^{2-})
- The released hydrogen ions will function to **lower the pH of the solution**
- **Chemoreceptors** are sensitive to changes in blood pH and can trigger body responses in order to maintain a balance
- The **lungs** can regulate the amount of carbon dioxide in the bloodstream by changing the rate of ventilation
- The **kidneys** can control the reabsorption of bicarbonate ions from the filtrate and clear any excess in the urine



- The pH of blood is required to stay within a very narrow tolerance range (**7.35 – 7.45**) in order to avoid the onset of disease
- This pH range is, in part, maintained by plasma proteins which act as **buffers**

Bohr Shift

- **pH changes** alter the affinity of haemoglobin for oxygen and hence alters the uptake and release of O_2 by haemoglobin
- Carbon dioxide lowers the pH of the blood (by forming carbonic acid), which causes haemoglobin to release its oxygen
- This is known as the **Bohr effect** – a decrease in pH shifts the oxygen dissociation curve to the *right*
- Cells with increased metabolism (i.e. respiring tissues) release greater amounts of



carbon dioxide (product of cell respiration)

- Hence haemoglobin is promoted to release its oxygen at the regions of greatest need (oxygen is an input of cell respiration)
- Higher CO_2 – lower pH – curve will shift to the right – more oxygen will be released

Respiratory Control

- The respiratory control centre in the **medulla oblongata** responds to stimuli from **chemoreceptors** in order to control ventilation
- **Central chemoreceptors** in the medulla oblongata detect changes in CO_2 levels (as changes in pH of cerebrospinal fluid)
- **Peripheral chemoreceptors** in the carotid and aortic bodies also detect CO_2 levels, as well as O_2 levels and blood pH
- During exercise metabolism is increased, which results in a build up of carbon dioxide and a reduction in the supply of oxygen
- These changes are detected by chemoreceptors and impulses are sent to the respiratory control centre in the brainstem
- Signals are sent to the diaphragm and intercostal muscles to increase the rate of ventilation (this process is involuntary)
- As the **ventilation rate increases, CO_2 levels in the blood will drop**, restoring blood pH (also O_2 levels will rise)

High Altitude

- **Partial pressure** is the pressure exerted by a single type of gas when it is found within a mixture of gases
- At high altitudes, air pressure is *lower* and hence there is a **lower partial pressure of oxygen** (less O_2 because less air overall)
- This makes it more difficult for haemoglobin to take up and transport oxygen (lower Hb % saturation)
- Over time, the body may begin to acclimatise to the lower oxygen levels at high altitudes:
    - Red blood cell production will **increase** in order to maximise oxygen uptake and transport
    - Red blood cells will have a **higher haemoglobin count** with a higher affinity for oxygen
    - Muscles will produce **more myoglobin** and have increased vascularisation to improve overall oxygen supply
    - People living permanently at high altitudes will have a **greater lung surface area** and larger chest sizes
- Professional athletes will often incorporate high altitude training in order to adopt these benefits prior to competition