



BIOLOGY

A-LEVEL

VW SCHOOLS

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1BIOL-1

BIOLOGICAL MOLECULES AND MICROSCOPY



ELEMENTS IN BIOLOGICAL MOLECULES

- **Carbohydrates**- C, H, O- ratio--> $C_x(H_2O)_x$ (where x is the number of atoms of each element)
- **Lipids**- C, H, O
- **Proteins**- C, H, O, N, S
- **Nucleic Acids**- C, H, O, N, P

C- carbon, H- hydrogen, O- oxygen, N- Nitrogen,
S- sulfur

POLYMERS AND MONOMERS

- **Polymers**- long chain molecules made by linking of multiple individual units (called **monomers**)

WATER- A POLAR MOLECULE

- O atom is electronegative (see chemistry notes)
 - H atom is electropositive
 - O atom attracts the electron density of the covalent bond towards itself
 - High electron density at O and low electron density at H- polarised-->allows Hydrogen Bonding
- [Insert Diagram]

WATER- FEATURES

- **High boiling point**- abundant hydrogen bonds- strong collectively despite being weak individually-->lots of energy needed to overcome most H (hydrogen) bonds and evaporate-->water is liquid at room temperature (25 degrees celsius)
- **Ice is less dense than water**- as water cooled below 4 degrees celcius H bonds fix positions of the polar molecules slightly further apart than in liquid state-->produces a giant, open, rigid structure-->tetrahedral
- **Cohesive**- moves as one mass as water molecules attracted to one another- eg, drinking water through straw, transpiration in plants
- **Solvent**- cytosol of cells is water-->dissolves amino acids, nucleic acids
- **Medium for chemical reactions**-->helps transport substances in and out of the cell
- **Efficient transport medium**- due to cohesive forces, produces capillary action (where water moves up narrow tube against gravity)
- **Coolant**- buffers temp changes due to high specific heat capacity-->crucial to prevent enzyme denaturation when environment changes

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BIOLOGICAL MOLECULES AND MICROSCOPY



CELL THEORY

- Plant and animal cells have cells
- Cells = basic unit of life
- Cells ONLY develop from existing cells

LIGHT MICROSCOPY

- 2 lenses- objective and eyepiece
- **Objective** magnifies once, **eyepiece** second time
- Combination of two allows: higher magnification, lower chromatic aberration
- **Magnification**- how many times larger the image is compared to the actual size of the object being viewed
- **Resolution**- ability to see individual objects as separate entities
- **Diffraction**- tendency of light waves to spread as they pass close to physical structures such as those in specimen
- **Why some structures not seen**- structures in specimen are very close to each other and light reflected from individual structures can overlap due to diffraction
- **How to increase resolution**- using beams of electrons with a wavelength thousands of times shorter than light- electrons still diffracted but the shorter wavelength means that individual beams can be much closer before they overlap

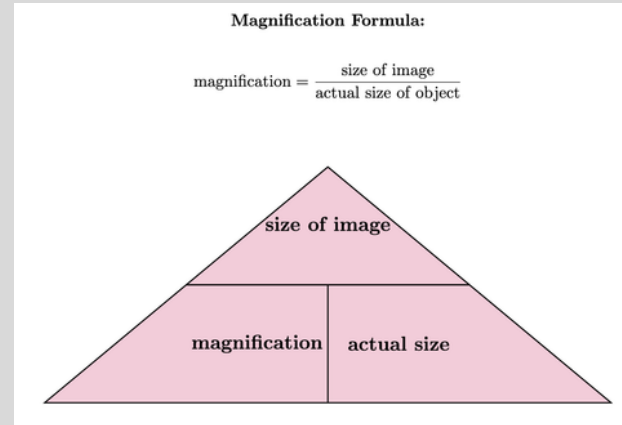
BONDING

- **Covalent bond**- shared pair of electrons
- **Ion**- atom or molecule in which the total electron number is not equal to the total proton number-->**cations** are positively charged, **anions** are negatively charged

ROLES OF CATIONS IN BIOLOGY

Ca ²⁺	nerve impulses, muscle contraction
Na ²⁺	nerve impulses, kidney function
K ⁺	nerve impulses, stomatal opening in plants
H ⁺	catalysis, pH
NH ₄ ⁺	nitrate ion production by bacteria

MAGNIFICATION:



ADVANCED MICROSCOPY

- **TEM (transmission electron microscopy)**- beam of electrons transmitted through specimen and focused, best resolution (power=0.5nm)
- **SEM (scanning electron microscopy)**- beam of electrons sent across surface of specimen, reflected electron collected, resolving power=5-10nm, 3D images
- **Fluorescent microscopes**- higher light intensity used to illuminate a specimen that has been treated with a fluorescent dye, lighter of a longer wavelength and lower energy emitted--> magnified
- **Laser scanning confocal microscope**- moves a single spot of focused light across a specimen- **point illumination**--> fluorescence from components labelled with dye produced, filtered through pinhole aperture, only light radiated from very close to focal plane is detected, different focal planes can be analysed to give 3D image

Roles of anions in Biology

NO ₃ ⁻	amino acid/protein production
HCO ₃ ⁻	maintains blood pH
Cl ⁻	balance Na ⁺ and K ⁺ positive charge in cells
PO ₄ ³⁻	forms cell membrane, forms nucleic acid/cell membrane, bone formation
OH ⁻	catalysis, pH determination

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BIOLOGICAL MOLECULES AND MICROSCOPY

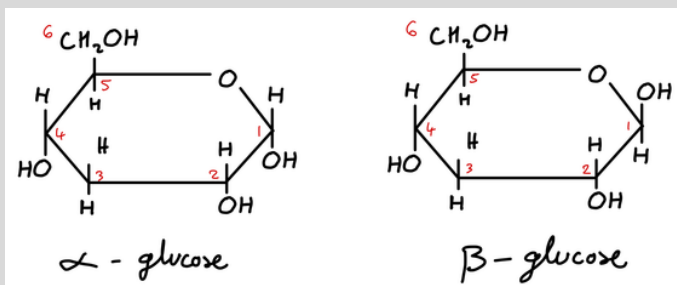


CARBOHYDRATES

- Contain C, H, O with a general formula of $C_x(H_2O)_y$
- Monosaccharide**- single sugar molecule, which are linked to form **polysaccharides**
- Glucose, Fructose, Ribose**

GLUCOSE

- $C_6H_{12}O_6$
- Hexose monosaccharide (six carbons)
- polar, soluble in water (hydrogen bonds between OH of glucose and water molecules)-->important as glucose needs to dissolve in cytosol

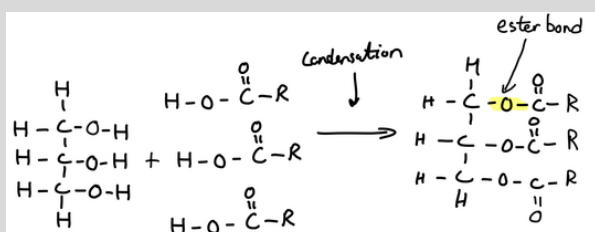


STARCH AND GLYCOGEN

- Starch**- many alpha glucose molecules joined by glycosidic bonds, two conformations- amylose and amylopectin, storage molecule in plants
- Amylose (starch)**- alpha glucose joined together by 1,4-glycosidic bonds, no branching so less soluble (less H bonds)
- Amylopectin (starch)**- has 1-4 glycosidic bonds as well as 1,6-glycosidic bonds (branching), more soluble
- Glycogen**- storage molecule in animals (liver and muscle), more branched than starch, more compact due to coiling, branching so more ends for enzyme activity (animals have higher metabolic rate)

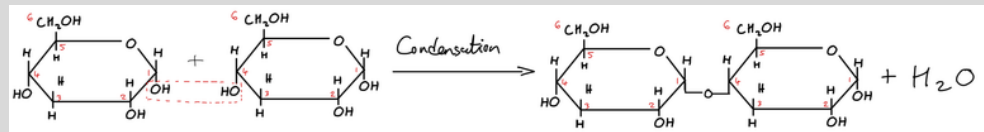
TRIGLYCERIDES

- Triglycerides**- 1 triglyceride is made by combining one glycerol (alcohol) molecule with 3 fatty acids (carboxylic acid)



CONDENSATION AND HYDROLYSIS

- Condensation**- formation of a covalent bond with simultaneous release of a water molecule, eg. formation of a glycosidic bond between glucose monosaccharides

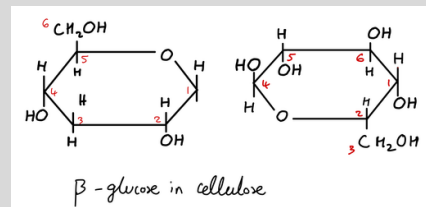


- Hydrolysis**- breaking of a bond by the addition of a water molecule

OTHER SUGARS

- Maltose**- two glucose molecules
- Sucrose**- fructose and glucose
- Lactose**- galactose and glucose

CELLULOSE



- Formed from beta glucose molecules which are alternatively orientated (each one is upside down compared to previous one)
- As if they were all right way up--> OH groups too far away to react
- Microfibrils**- cellulose molecules make H bonds with each other
- Macrofibrils**- microfibrils joined together
- These fibres are strong, insoluble and are used to make cell walls

SATURATED AND UNSATURATED FATS

- Saturated**- no double bonds in between C atoms
- Unsaturated**- some double bonds between C atoms, if one double bond--> **monounsaturated**, if >2 double bonds--> **polyunsaturated**, liquid at room temp as double bonds cause molecule to kink--> don't pack closely
- Plants contain unsaturated fatty acids

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BIOLOGICAL MOLECULES AND MICROSCOPY



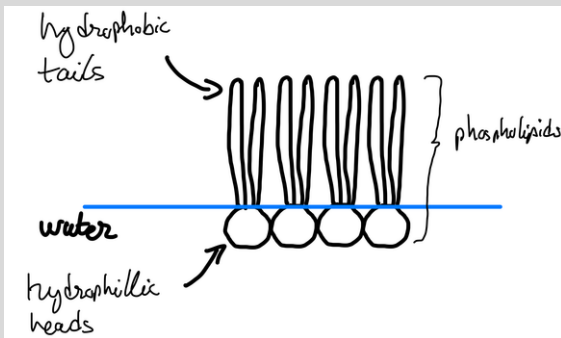
PHOSPHOLIPIDS

- Glycerol backbone, 2 fatty acids, phosphate group (negatively charged--> able to form H bonds with water--> soluble)
- **[Insert phospholipid diagram here]**
- Non-polar fatty acid tails--> repelled by water--> **hydrophobic**
- Charged phosphate heads--> **hydrophilic** (mix with water)



PHSOPHOLIPIDS FUNCTIONS

- **Surfactants**- phosphate in the water and fatty acids sticking out of water

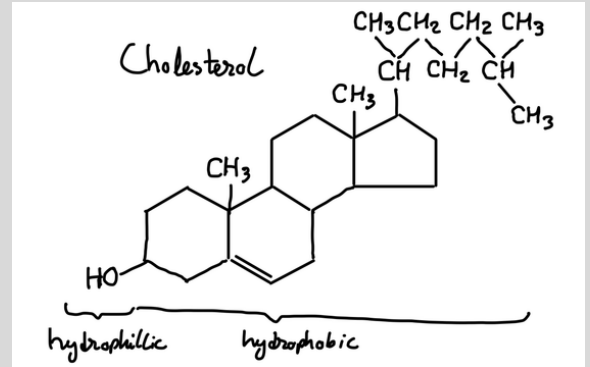


- **Phospholipid Bilayer**- hydrophobic tails point towards centre- cell membranes

LEVELS OF PROTEIN STRUCTURE

- **Primary structure**- sequence of amino acids, determined by DNA sequence
- **Secondary structure**- hydrogen bonding between oxygen of C=O group of one amino acid and hydrogen of N-H group of another amino acid--> forms alpha helices and beta pleated sheets
- **Tertiary structure**- specific 3D structure/shape of proteins, involves R groups: hydrophobic/hydrophilic interactions between R groups (weak), H bonds (weakest), ionic bonds between oppositely charged R groups (strong), disulfide bridges- covalent (strongest), occur between R groups which have sulfur
- **Quaternary structure**- results from association of two or more individual proteins called subunits- eg haemoglobin has 4 subunits (shown on the right)

STEROLS



- Complex alcohols with hydrophilic/hydrophobic properties
- OH group polar (hydrophilic) and rest of molecule is hydrophobic
- Eg. cholesterol

LIPIDS FUNCTIONS

- Membrane formation and forming hydrophobic barriers
- Hormone production
- Electrical insulation
- Waterproofing
- Thermal insulation to prevent heat loss
- Cushioning to protect vital organs such as heart and kidneys (pericardium of heart)

AMINO ACIDS AND PEPTIDES

- Amine and carboxylic acid groups react
- Hydroxyl in carboxylic acid group of one amino acid reacts with hydrogen in the amine group of another amino acid--> peptide bond is formed
- **Polypeptide**- many peptides joined together
- Formation of polypeptide catalysed by peptidyl transferase enzyme in ribosomes (site of protein synthesis)

HAEMOGLOBIN

- Has 4 iron containing haem groups
- Binds O2 reversibly



GLOBULAR PROTEINS

- Compact, water soluble, spherical in shape
- Hydrophobic R groups are pointed towards the inside of protein and hydrophilic groups pointed towards the outside--> **soluble** in water
- Eg. **insulin**--> decreases blood glucose concentration

CONJUGATED PROTEINS

- Proteins with prosthetic group (non-protein)
- Eg glycoprotein (protein and carbohydrate), lipoprotein (lipid and protein), haem group of haemoglobin/catalase
- **Haemoglobin, Catalase**

CATALASE

- Has 4 prosthetic haem groups, allows interaction with hydrogen peroxide and speed up its breakdown
- Hydrogen peroxide is toxic to cells and is a byproduct of metabolism--> catalase prevents its buildup

WHAT IS A NUCLEOTIDE?

- 3 components: pentose sugar, phosphate group, nitrogenous base
- Phosphodiester bond between the phosphate at the 5th carbon atom of one nucleotide and the OH group of the 3rd carbon of the adjacent nucleotide--> phosphodiester backbone

DNA

- Deoxyribonucleic acid
- **Pyrimidines**- smaller bases containing single carbon ring structures- Thymine and Cytosine (T and C)
- **Purines**- larger bases, containing double ring structures- Adenine and Guanine (A and G)

FIBROUS PROTEINS

- Formed from long, insoluble molecules
- Amino acids have lots of hydrophobic R groups in their primary structures
- Have limited range of amino acids, with small R groups
- Amino acid sequence is repetitive--> organised structure
- **Keratin, Elastin, Collagen**

KERATIN

- In hair, nails and skin
- Large proportion of cysteine (has sulfur)--> forms disulfide bridges
- Hair has few disulfide bonds--> flexible
- Skin has a lot of disulfide bonds

ELASTIN

- Present in walls of arteries and arterioles and in alveoli
- Made from tropoelastin--> flexible

COLLAGEN

- Forms connective tissue of tendons, skin, ligaments and nervous system
- Forms long, rope structure with high flexibility

FEATURES OF THE DOUBLE HELIX

- **Antiparallel**- two strands are arranged so that they run in opposite directions
- H bonds between base pairs--> hereditary
- **Complementary base pairing**- A with T and C with G--> pyrimidines always binds to purines, equal percentages of A, T (2 H bonds) AND C, G (3 H bonds- stronger)

RIBONUCLEIC ACID

- Uracil (U) instead of Thymine
- Ribose instead of deoxyribose
- DNA too big to leave nucleus for protein synthesis so transcribed into mRNA

SEMI-CONSERVATIVE REPLICATION (PART 1)

- Two new molecules of DNA produced
- Each one consists of one old strand and one new strand of DNA

SEMI-CONSERVATIVE REPLICATION (PART 2)

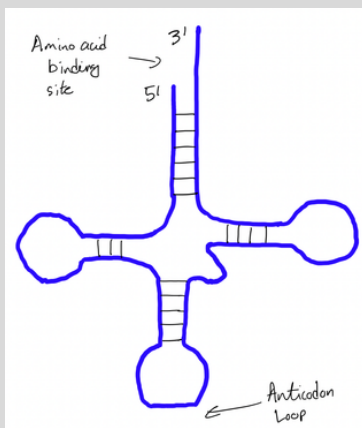
- **DNA Helicase**- enzyme that breaks H bonds between bases, unwinds/unzips strands
- Free nucleotides pair with
- **DNA Polymerase**- catalyses the formation of phosphodiester bonds between new nucleotides



- DNA polymerase (DNA pol) only travels in the 3 prime to 5 prime direction
- Only the leading strand of DNA can be replicated continuously as the DNA unwinds
- Lagging strand has to be replicated in the opposite direction in short sections--> Okazaki fragments
- [INSERT DIAGRAM HERE]
- **Mutation**- spontaneous change in bases due to mismatch

ROLE OF TRNA

- tRNA anticodon binds to a complementary codon on mRNA
- corresponding amino acid brought together in the correct sequence to form primary structure of protein (sequence of amino acids)
- Ribosomes act as the binding site for mRNA and tRNA and catalyse protein synthesis (so are sometimes termed **ribozymes**)



DEFINITIONS ABOUT THE GENETIC CODE

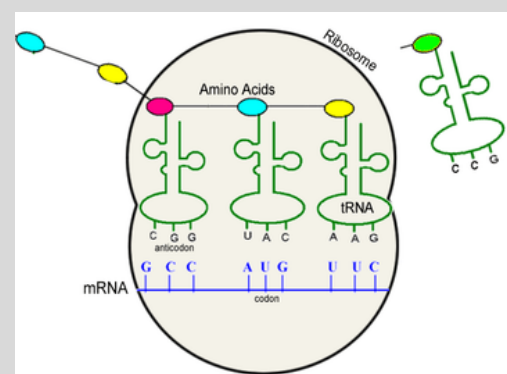
- **Triplet code**- sequence of 3 bases codes for 1 amino acid--> also called a **codon**
- **Gene**- section of DNA that contains the complete sequence of bases to code for a whole protein
- Genetic code is **universal**- all organisms use the same code
- **Degenerate**- 20 different amino acids, 64 different possible codons--> more codons than amino acids. A single amino acid can be coded for by more than one codon

TRANSCRIPTION

- **DNA Helicase** breaks H bonds between complementary base pairs--> unzips
- **Antisense strand** acts as a template for new RNA bases to bind (complementary to sense strands which has base sequence coding for the protein)
- RNA nucleotides bind to template antisense strand
- U with A and C with G
- **RNA Polymerase** joins new RNA nucleotides via phosphodiester bonds
- Forms pre-mRNA
- pre-mRNA spliced to remove introns (non-coding parts of genes)
- forming mRNA with ONLY exons (coding genes)

TRANSLATION

- mRNA binds to the small subunit of ribosome at start codon (AUG)
- tRNA with the complementary anticodon (UAC) binds to the mRNA start codon--> this tRNA carries the amino acid methionine
- Another tRNA with anticodon binds to next codon with corresponding amino acid
- Methionine forms peptide bond with second amino acid--> catalysed by peptidyl transferase (rRNA component of ribosome)
- Ribosome moves along mRNA--> releasing first tRNA and second tRNA becomes the first
- Many ribosomes follow on the mRNA behind the first --> multiple identical polypeptides can be synthesised



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BIOLOGICAL MOLECULES AND MICROSCOPY



BIOLOGICAL PROCESSES THAT REQUIRE ATP

- Muscle contraction
- Cell division
- Transmission of nerve impulses
- Memory formation

WHAT DO CELLS NEED ATP FOR?

- **Synthesis**- eg. large molecules such as proteins
- **Transport**- eg pumping molecules or ions across cell membranes by active transport
- **Movement**- eg protein fibres in muscle cells that cause muscle contraction
- Cells use **ATP (adenosine triphosphate)** as their energy currency

HOW DOES ATP RELEASE ENERGY?

- Hydrolysis of ATP to ADP and inorganic phosphate releases energy

[INSERT ATP HYDROLYSIS DIAGRAM HERE]

FEATURES OF ATP

- Small- moves in and out of cells easily
- Water soluble- chemical reactions happen in aqueous environments
- Bonds between phosphate groups have medium energy- large enough for cellular reactions, not too large for heat energy waste to be produced
- Energy released in small quantities--> suitable for cell needs
- Easily regenerated



REACTION DEFINITIONS

- **Anabolic**- reactions needed for growth, building larger molecules from smaller ones
- **Catabolic**- breakdown of larger molecules to smaller ones- eg digestion
- **V_{max}**- maximal rate of reaction--> enzymes can increase the rate of a reaction up to this point
- **Enzyme specificity**- each enzyme can only catalyse a specific biochemical reaction
- **Activation energy**- minimum energy needed for a reaction to start

WHAT IS NEEDED FOR A REACTION TO HAPPEN (2)

- Energy of molecules > Activation energy
- Molecules must collide in correct orientation

Two hypothesis of enzyme action



LOCK AND KEY HYPOTHESIS

- Area within **specific 3D tertiary structure** of enzyme **complementary** to shape of specific substrate--> active site
- **Enzyme-substrate complex** formed when substrate binds to active site
- Substrate reacts--> **enzyme-product complex** formed
- Product released--> enzyme **unchanged** at the end--> biological catalyst

INDUCED FIT HYPOTHESIS

- Initial interaction between substrate and active site of enzyme weak
- Weak interactions rapidly induce changes in specific 3D tertiary structure of enzyme active site--> strengthens binding--> puts strain on substrate bonds
- Weakens substrate bonds--> lowers activation energy for a reaction

INTRACELLULAR AND EXTRACELLULAR ENZYMES

- **Intracellular enzymes**- enzymes that act within cells, eg. **catalase**
- **Extracellular enzymes**- enzymes that act outside of cells--> yeast and bacteria release enzymes into immediate environment, multicellular organisms need them for digestion

HOW DO ENZYMES INCREASE THE RATE OF REACTION?

- Puts strain on substrate bonds when substrate binds to active site
- Lowers activation energy of the reaction
- Greater proportion of molecules have energy greater than or equal to the activation energy
- So greater proportion of collisions are successful

DIGESTION OF STARCH

- **Amylase** produced in salivary glands (saliva) break down most starch into maltose in mouth
- **Amylase** produced in pancreas break down remaining starch--> maltose in small intestine
- **Maltase** is a membrane bound enzyme in the small intestine which breaks down maltose--> glucose
- Glucose small enough to be absorbed by cells

DIGESTION OF PROTEINS

- **Trypsin**--> protease
- Produced in pancreas and released in pancreatic juice into small intestine
- Breaks down proteins--> amino acids

FACTORS AFFECTING ENZYME ACTIVITY

- Temperature
- pH
- Substrate concentration
- Enzyme concentration

TEMPERATURE

- Increase temp--> increase kinetic energy of molecules
- Increased frequency of collisions and proportion of successful collisions--> increased rate of reaction
- Greater proportion of molecules have energy greater than or equal to the activation energy
- **Temperature coefficient (Q₁₀)**- states that rate of reaction doubles with every 10 degrees celcius increase in temperature
- **Denaturation**- bonds vibrate very fast as temp increases until eventually there is too much strain and the bonds break
- Changes specific 3D tertiary structure of the active site--> non-functional
- Temp coefficient doesnt apply any more

ENZYME ADAPTION TO EXTREME TEMPERATURES

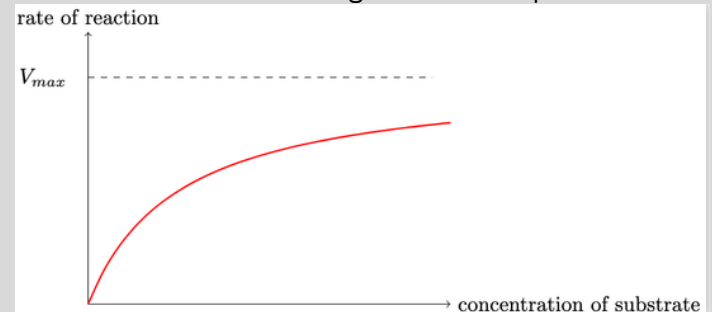
- Extremely cold temp--> enzymes are less stable as these enzymes tend to have more flexible structures
- Thermophiles**- organisms adapted for hot temperatures, more H bonds and disulfide bridges--> denatures less readily

EFFECT OF PH ON ENZYMES

- H bonds and ionic bonds are altered with a change of pH (change in proton concentration)
- Optimum pH--> concentration of hydrogen ions which give the correct shape of the active site
- Hydrogen ions interact with polar and charged R groups--> changing pH changes the interactions
- More hydrogen ions present (low pH), the less the R-groups are able to interact with each other--> bonds break and shape of enzyme changes--> reverse is true for high pH

EFFECT ON ENZYME ACTIVITY WHEN SUBSTRATE AND ENZYME CONCENTRATION IS CHANGED

- Increased substrate concentration--> increased collisions and more molecules in a given area or volume, more enzyme-substrate complexes formed--> increased rate
- Increased enzyme concentration--> increased collisions, increased number of active sites in a given area or volume so rate of reaction increases
- V_{max} reached--> limiting factor is temperature

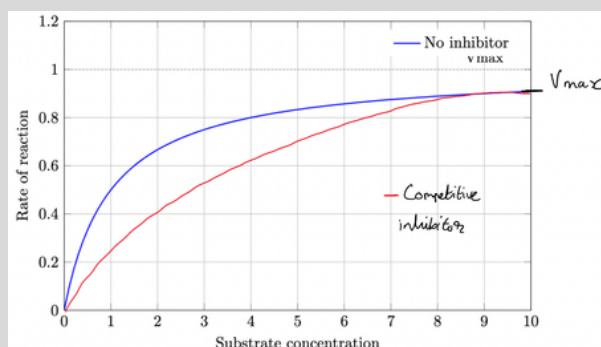


ACTION OF DIFFERENT ENZYMES AT VARIOUS POINTS IN THE DIGESTIVE SYSTEM

	Site of action	pH	Enzymes	Function
Saliva	mouth/throat	neutral (pH 7-8)	amylase	starch → maltose
Gastric juice	stomach	acidic (pH 1-2)	pepsin	proteins → polypeptides
Pancreatic juice	small intestine/duodenum	slightly alkaline (pH 8)	trypsin	proteins → polypeptides
			lipase	triglycerides → glycerol + fatty acids
			amylase	starch → maltose
			maltase	maltose → glucose

COMPETITIVE INHIBITION

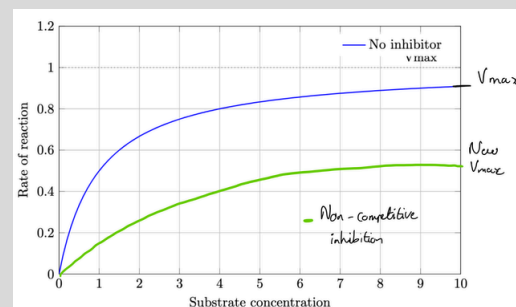
- Inhibitor has similar shape to substrate so is complementary to active site of enzyme
- Blocks substrate bonding--> prevents enzyme substrate complex formation
- Reversible--> increasing substrate concentration removes inhibition



- Eg: statins are a drug class used against cholesterol--> competitively inhibits the enzyme HMG-CoA (catalyses the rate-determining step of cholesterol biosynthesis)

NON-COMPETITIVE INHIBITION

- Inhibitor binds to a site other than active site--> allosteric site
- Binding causes specific 3D tertiary structure to change--> active site changes shape
- No longer complementary to substrate--> can't form enzyme-substrate complex



- Eg: organophosphates--> inhibit acetyl cholinesterase--> muscle cramps
- PPIs (proton pump inhibitors--> used to treat stomach ulcers)



END-PRODUCT INHIBITION

- Product of reaction inhibits the enzyme that produces it--> example of **negative feedback**
- Eg: in glycolysis (first step of respiration that **produces ATP**), glucose phosphorylated twice to trigger its breakdown, second phosphorylation catalysed by enzyme called PFK (phosphofructokinase)--> inhibited by ATP (which is the product of glycolysis)

PRECURSOR ACTIVATION

- Precursor enzymes--> enzyme in an inactive form--> **zymogen/proenzyme**
- Change in environment (pH/temp) OR cleavage by other proteases needed for activation
- Eg, pepsinogen (inactive) released into stomach--> low pH changes structure and produces active form

COFACTORS VS COENZYMES

- **Cofactors**- non protein helper groups that transfer molecules from other reactions OR forms part of the enzyme itself--> eg. amylase contains chloride ion cofactor
- **Coenzyme**- if the cofactor is an organic molecule, many derived from vitamins (**vitamin B3** used to synthesis NAD/NADP, **vitamin B5** used to make coenzyme A)

PROSTHETIC GROUPS

- Permanent part of enzyme, bind tightly
- Eg, zinc ions in carbonic anhydrase enzyme--> metabolises CO₂

WHAT IS COMPARTMENTALISATION?

- Formation of separate membrane-bound areas in a cell
- Needed as metabolism involves many different and often incompatible reactions

MEMBRANE STRUCTURE

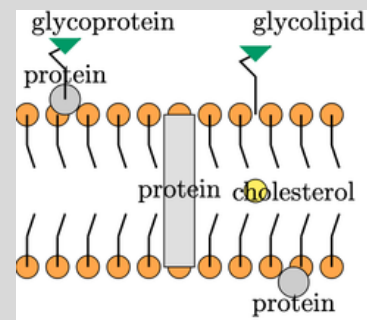
- Membranes formed from phospholipid bilayer
- Hydrophilic phosphate heads form both inner and outer surface of membrane--> sandwiching the fatty acid tails of the phospholipids to form a hydrophobic core inside the membrane
- Cells exist in aqueous environments, inside of cells and organelles are also usually aqueous
- Hydrophilic heads are able to interact with water

MEMBRANE PROTEINS

- **Intrinsic and Extrinsic**
- **Intrinsic**- transmembrane proteins, hydrophobic R groups that keep them embedded through both layers of membrane--> **channel, carrier proteins, glycoproteins, glycolipids**
- **Channel**--> provides hydrophilic channel that allows diffusion of polar molecules
- **Carriers**- both passive and active transport (involves changing of protein shape)
- **Glycoproteins**- have a carbohydrate attached with varying length/shape, act as **receptors** (for neurotransmitters and peptide hormones)
- **Glycolipids**- lipid attached to proteins, cell markers which are recognised by immune system as being self or non-self
- **Extrinsic**- present on one side of bilayer, polar R groups interacting with hydrophilic groups
- **Cholesterol**- hydrophilic and hydrophobic end, positioned between phospholipids in bilayer, hydrophilic end interacts with phosphate heads, hydrophobic end interacts with tails--> pulls them together--> **membrane stability**, ALSO prevents membranes becoming too solid by **stopping phospholipid molecules from grouping too closely and crystallising**

FLUID MOSAIC MODEL

- Singer and Nicolson (scientists) proposed this
- As phospholipids are free to move within the layer relative to each other--> giving flexibility
- Proteins embedded in bilayer vary in shape, size, and position



Glycoprotein:

- Function: Branching carbohydrate portion of a protein which acts as a recognition site for chemicals, e.g., hormones.

Glycolipid:

- Function: Acts as a recognition site, e.g., for cholera toxins.

Cholesterol:

- Function: Provides stability and flexibility to the membrane.
- Protein Molecule (Partly Embedded / Extrinsic Protein):
- Function: Sits on the surface of the membrane or partly embedded.

Protein Molecule (Spanning the Phospholipid Layer / Intrinsic Protein):

- Function: Forms pores and spans the entire phospholipid bilayer.

Hydrophilic Heads of Phospholipid Molecules:

- Function: Point outward (toward aqueous environments).

Hydrophobic Tails of Phospholipid Molecules:

- Function: Point inward (away from water).

TEMPERATURE

- Increase in temp:
- Increased fluidity as phospholipids move more--> more permeable
- Carrier and channel proteins denatured--> affects permeability



SOLVENTS

- Alcohols/non-polar solvents/organic solvents dissolve the membrane
- Increased fluidity/permeability

- Movement of particles from high to low concentration
- Passive
- Down concentration gradient
- Happens as particles are always moving randomly

FACTORS AFFECTING THE RATE OF DIFFUSION

- Temperature- higher the temperature higher the rate of diffusion--> particles have more kinetic energy and move at higher speeds
- Concentration difference- greater the difference faster the rate of diffusion



FACTORS AFFECTING THE RATE OF DIFFUSION

- Temperature- higher the temperature higher the rate of diffusion--> particles have more kinetic energy and move at higher speeds
- Concentration difference- greater the difference faster the rate of diffusion



FACTORS AFFECTING THE RATE OF DIFFUSION ACROSS A MEMBRANE

- Surface area- large the area of an exchange surface higher the rate of diffusion
- Thickness of membrane- thinner the exchange surface, the higher the rate of diffusion

FACILITATED DIFFUSION

- Diffusion across a membrane through protein channels
- Also may involve carrier proteins
- Dependent on temp, concentration gradient, membrane surface area and thickness, number of protein channels present

ACTIVE TRANSPORT (INTRO)

- Movement of molecules from low to high concentration against a concentration gradient
- Uses hydrolysis of ATP
- Selective for specific molecules

ACTIVE TRANSPORT (DETAIL)

- Molecule or ion to be transported binds to receptors in the channel of the carrier protein on outside of cell
- On inside of cell ATP binds carrier protein and is hydrolysed to ADP and Pi
- Binding of phosphate to carrier protein-->changes shape and opens up on the inside of cell
- Molecule released to inside of cell
- Phosphate released from carrier--> rejoins ADP to form ATP
- Causing carrier to return to its original shape

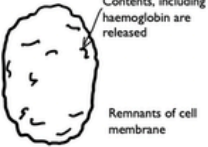
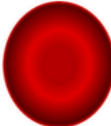
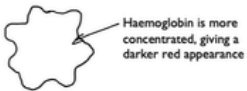
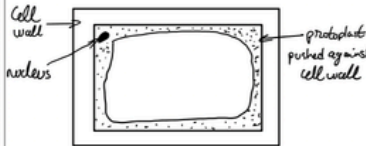
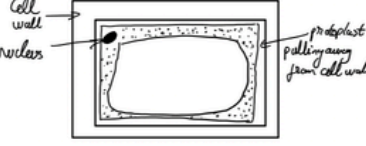
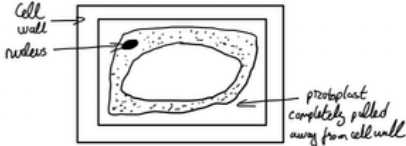
BULK TRANSPORT

- **Endocytosis and exocytosis**
- **Endocytosis:** transporting material into cells--> **solids by phagocytosis and liquids by pinocytosis**--> cell membrane invaginates--> forms vesicle, vesicle pinches off and moves into cytoplasm
- **Exocytosis:** vesicles move towards and fuse with inside of cell membrane (vesicles formed by golgi for eg)

OSMOSIS

- Movement of water across a partially permeable membrane down a water potential gradient
- **Water potential-** pressure exerted by water molecules as they collide with a membrane or container

EFFECTS OF OSMOSIS ON PLANT AND ANIMAL CELLS

Water potential (Ψ) of external solution compared to cell solution	Higher (less negative)	Equal	Lower (more negative)
Net movement of water	Enters cell	Water constantly enters and leaves, but at equal rates	Leaves cell
State of cell	Swells and bursts	No change	Shrinks
	 Normal red blood cell	 Normal red blood cell	 Shrivelled red blood cell (crenated)
Explanation	Contents, including haemoglobin, are released	Normal red blood cell	Haemoglobin is more concentrated, giving cell a darker appearance
Further explanation	Remains of cell surface membrane	(empty)	Cell shrunken and shrivelled
Water potential (Ψ) of external solution compared to cell solution	Higher (less negative)	Equal	Lower (more negative)
Net movement of water	Enters cell	Water constantly enters and leaves, but at equal rates	Leaves cell
Condition of protoplast	Swells and becomes turgid	No change	Plasmolysis, contents shrink
	 Protoplast pushed against cell wall	 Protoplast beginning to pull away from cell wall	 Protoplast completely pulled away from the cell wall
Explanation	Protoplast pushed against cell wall	Protoplast beginning to pull away from cell wall	Protoplast completely pulled away from the cell wall
Further explanation	Nucleus, cellulose cell wall, protoplast	(empty)	Space filled with external solution of lower water potential

PHASES OF THE CELL CYCLE

- Interphase (I)
- Prophase (Pee)
- Metaphase (Mainly)
- Anaphase (At)
- Telophase (Trees)



INTERPHASE

- DNA replication happens and is checked for errors in nucleus
- Protein synthesis happens in cytoplasm
- Mitochondria grow and divide, increasing in number in the cytoplasm
- Chloroplasts grow and divide in plant and algal cytoplasm
- Metabolism still continues

MITOTIC STAGES

- Mitosis- nucleus divides
- Cytokinesis- cytoplasm divides and two cells are produced

CELL CYCLE- HOW IS IT CONTROLLED?

- Controlled via checkpoints: **G1, G2, spindle assembly checkpoint**
- **G1**- end of G1 phase before entry into S phase, check for cell size, nutrients, growth factors and DNA damage
- **G2**- end of G2. phase, checks for cell size, DNA replication, DNA damage
- **Spindle assembly**- chromosome attachment to spindle

WHY DOES THE CELL CYCLE NEED TO BE CONTROLLED

To ensure:

- cell has grown to right size
- no DNA damage
- chromosomes are in the correct position

3 STAGES OF INTERPHASE

- **G1**- first growth phase--> proteins from which organelles are synthesised are produced and organelles replicate--> cell increases in size
- **S**- synthesis phase--> DNA replicated in nucleus
- **G2**- second growth phase--> cell increases in size, energy stores increased and replicated DNA checked for errors

3 STAGES OF INTERPHASE

- **G1**- first growth phase--> proteins from which organelles are synthesised are produced and organelles replicate--> cell increases in size
- **S**- synthesis phase--> DNA replicated in nucleus
- **G2**- second growth phase--> cell increases in size, energy stores increased and replicated DNA checked for errors

WHAT IS G0

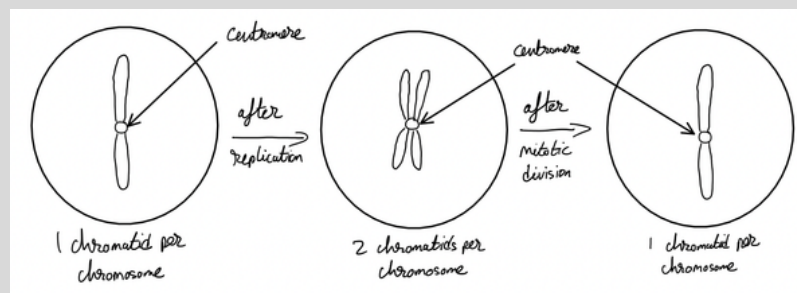
- G0 is when the cell leaves the cycle
- **Why would the cell leave the cell cycle:** differentiated (becomes specialised), DNA damaged, ageing

WHY IS MITOSIS NEEDED

- Ensure daughter cells are genetically identical
- Asexual reproduction

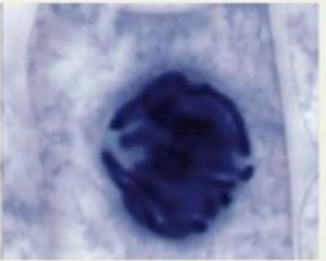
BEFORE WE GET INTO IT...CHROMOSOME DEFINITIONS

- **Chromatids**- two identical DNA molecules
- **Centromere**- place where 2 chromatids are joined together



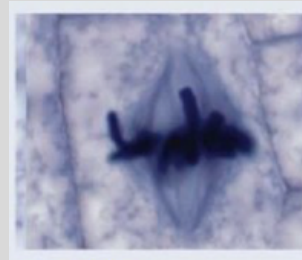
1- PROPHASE

- Chromatin coils and condenses--> chromosomes become visible under light microscope
- Nucleolus disappears
- Nuclear membrane breaks down
- Microtubules form spindle fibres
- Centrioles migrate to opposite poles of cells- help in formation of spindle
- Spindle fibres attach to specific areas on centromeres and start to move chromosomes to centre of cell
- Nuclear envelope disappears



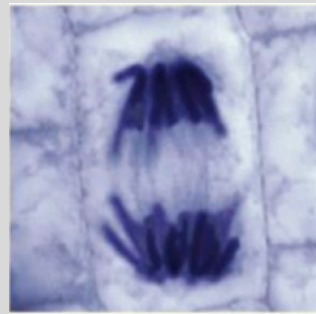
2- METAPHASE

- Chromosomes line up at the equator of the cell/**metaphase plate of the cell**



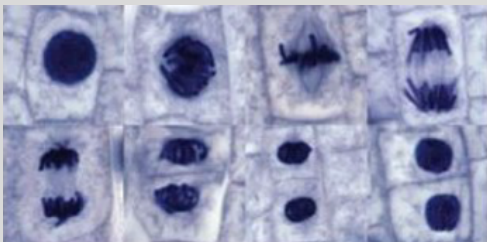
3- ANAPHASE

- Centromeres divide
- Pulling each chromatid to opposite poles of the cell by shortening/contracting the spindle fibres



4- TELOPHASE

- Chromatids reached poles--> now called chromosomes
- Nuclear envelope reforms
- Chromosomes start to uncoil and the nucleolus is formed
- Cytokinesis/cell division begins

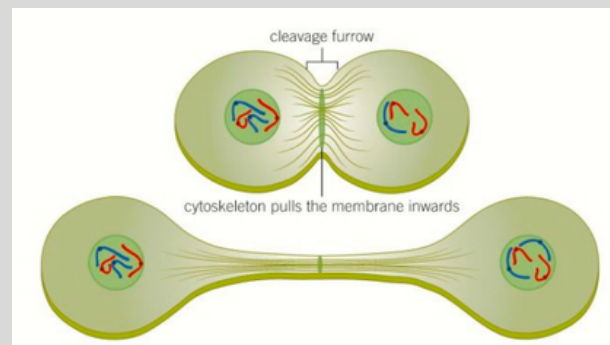


5- CYTOKINESIS (PLANT CELLS)

- Plant cells have cell walls--> cleavage furrow can't form
- Vesicles from the golgi assemble in the same place as where metaphase plate is formed (equator)
- Vesicles fuse with each other and cell surface membrane--> dividing cell into 2
- New sections of cell wall form around new sections of cell membrane

5- CYTOKINESIS (ANIMAL CELLS)

- Cleavage furrow forms around the middle of cell
- Cell surface membrane pulled inwards by cytoskeleton until it's close enough to fuse around the middle--> forming two cells



MEIOSIS DEFINITIONS

- **Diploid**- 2 chromosomes of each type (paternal and maternal)
- **Gametes**- sex cells with half the diploid number-->**haploid**
- **Zygote**- fertilised egg containing diploid number
- **Reduction division**- formation of haploid cells from diploid cells
- **Homologous chromosomes**- matching set of maternal and paternal chromosomes
- **Allele**- one of a different form/variant of a gene

MEIOSIS STAGES

- **Meiosis I**- reduction division, homologous pairs of chromosomes are separated into two cells
- **Meiosis II**- pairs of chromatids present in each daughter cell are separated, forming two more cells--> 4 haploid daughter cells produced in total

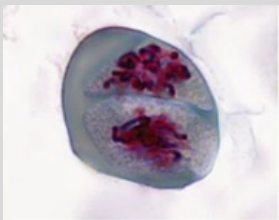
How does meiosis give rise to genetic variation

- Independent assortment
- Chiasmata formation--> recombination to give a different combination of alleles to original in homologous chromosome pair

MEIOSIS II

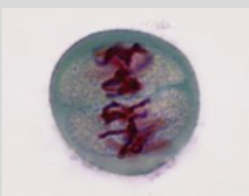
Prophase

- Chromosomes condense, become visible
- Nuclear envelope breaks down
- Spindle forms



METAPHASE

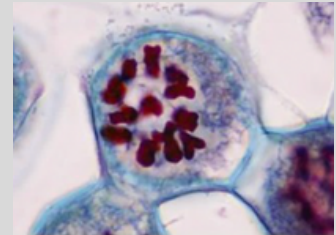
- Individual chromosomes assembled on the metaphase plate
- Independent assortment--> genetic variation



MEIOSIS I

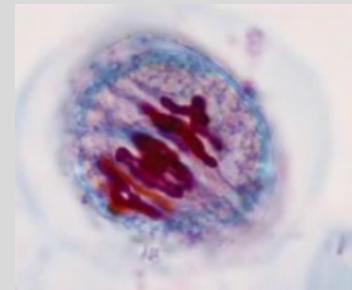
Prophase

- Chromosomes condense, nuclear envelope disintegrates, nucleus disappears, and spindle formation begins
- Homologous chromosomes pair up, become entangled--> crossing over



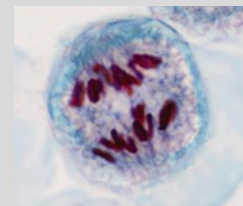
METAPHASE

- Homologous chromosomes line up at metaphase plate/equator
- Orientation of each homologous pair is **random and independent of any other pair**--> **independent assortment**



ANAPHASE

- Sections of DNA that became entangled break off and rejoin
- Points at which chromatids break and rejoin--> **chiasmata**
- **Recombinant chromatids** are formed--> with a different combination of alleles from the original chromatid



TELOPHASE

- Chromosomes assembled at each pole
- Nuclear membrane reforms
- Chromosome uncoil
- Cytokinesis occurs--> two haploid cells form



MEIOSIS II (continued)

ANAPHASE

- Chromatids of the individual chromatids are pulled to opposite poles of the cell

Telophase

- Chromatids assemble at poles
- Chromosomes uncoil and form chromatin again
- Nuclear envelope reforms and nucleolus becomes visible
- Cytokinesis--> 4 daughter cells that are haploid, genetically different

FIRST LEVEL OF ORGANISATION- SPECIALISED CELLS (PLANTS)

Palisade cell

- **Rectangular box shaped**- closely packed into a continuous layer
- **Thin cell walls**- increases the rate of diffusion of CO₂
- **Large vacuole**- maintain turgor pressure
- **Chloroplasts able to move**- within cytoplasm to areas of high light intensity

Root hair cells

- Present at root surfaces near **growing tips**
- **Have long extensions** called root hairs--> increase surface area of cell
- Maximises rate of **uptake of water and minerals** from the soil

Guard cells

- On **surfaces of leaves**--> form stomata
- Guard cells lose water--> become less swollen due to osmosis--> prevent further water evaporation through stomata
- Cell wall **thicker on one side**- don't change shape symmetrically

EXAMPLE OF CONNECTIVE TISSUE

Cartilage

- Connective tissue found in outer ear, nose and at ends of bones
- Contains elastin and collagen
- Flexible, composed of chondrocyte cells embedded in an extracellular matrix
- Prevents bones from rubbing together

HOW ARE MULTICELLULAR ORGANISMS ORGANISED?

- Specialised cells--> tissues--> organs--> organ systems--> whole organism

FIRST LEVEL OF ORGANISATION- SPECIALISED CELLS (HUMANS)

Erythrocytes

- **flattened/biconcave**: increases SA: V ratio--> needed for efficient O₂ transport
- **no nuclei**--> increases space for haemoglobin
- **flexible**- able to squeeze through small capillaries

Neutrophils

- Immune cell
- Multi-lobed nucleus--> easier to squeeze through small gaps to get to infected sites
- Granular cytoplasm has lysosomes containing enzymes used to attack pathogens

Sperm cells

- **Tail/flagella**- motile to egg
- **Many mitochondria**- supply energy needed to swim
- **Acrosome**- on head of sperm to digest protective layers around ovum and allow sperm to penetrate--> fertilisation

CATEGORIES OF ANIMAL TISSUE

- **Nervous tissue**
- **Epithelial tissue**
- **Muscle tissue**
- **Connective tissue**



EXAMPLE OF EPITHELIAL TISSUE

Squamous epithelium

- flat, thin--> one cell thick
- On surface of lungs--> rapid diffusion

Ciliated Epithelium

- Cilia on one surface that move in a rhythmic manner
- Mucus is swept away from the lungs
- Goblet cells are present, releases mucus to trap any unwanted particles present in air
- Prevents bacteria from reaching the lungs



SPECIALISED PLANT TISSUE

Epidermis

- Single layer of closely packed cells over plant surfaces
- Covered by waxy, waterproof cuticle to reduce the loss of water
- Stomata present--> open and close to allow CO₂, water and oxygen in and out

Xylem

- Transports water and minerals throughout plants
- Tissue composed of elongated dead cells
- Strengthened with lignin--> provides structural support

Phloem

- Transports organic nutrients (sucrose) from leaves and stems to other parts of the plant
- Composed of columns of sieve tube elements separated by perforated walls--> sieve plates

REPLACEMENT OF RED AND WHITE BLOOD CELLS

- RBCs- lack of nucleus and organelles--> have a lifespan of 120 days--> need to be replaced constantly
- Neutrophils have lifespan of 6hrs

Sources of animal stem cells

- **Embryonic stem cells**- present at a very early stage of embryo development--> totipotent, at blastocyst stage--> pluripotent
- **Tissue stem cells**- present throughout life from birth--> bone marrow, umbilical cord, able to be harvested to become pluripotent

Uses of stem cells

- Heart disease
- Type I diabetes
- Parkinsons disease/Alzheimers disease--> regenerate dopaminergic neurons
- Macular degeneration
- Birth defects
- Spinal injuries
- Burn treatments

WHAT IS AN ORGAN, ORGAN SYSTEM?

- **Organ**- Collection of tissues adapted to perform a particular function in an organism
- **Organ system**- composed of a number of organs working together to carry out body function--> digestive system, cardiovascular system etc

WHAT IS AN ORGAN, ORGAN SYSTEM?

- **Organ**- Collection of tissues adapted to perform a particular function in an organism
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STEM CELLS

- Stem cells are undifferentiated cells, able to self renew
- **Totipotent**- able to differentiate into any type of cell, zygote or blastocyst (8-16 cell stage)
- **Pluripotent**- able to form all tissue types but not whole organisms
- **Multipotent**- only form a range of cells within a certain type of tissue--> eg haematopoietic cells--> all blood cells are derived from bone marrow

SOURCES OF PLANT STEM CELLS

- Present in **meristems** (wherever growth is occurring in plants)
- Meristems also present sandwiched between phloem and xylem tissues--> vascular cambium

1BIOL-4

Exchange surfaces and breathing



Main reasons why specialised exchange surfaces not in single celled organisms

- Low metabolic activity
- SA:V ratio is large

FEATURES OF SPECIALISED EXCHANGE SURFACES

- **Increased surface area**- eg. root hairs in plant and villi in intestine
- **Thin layers**- alveoli, villi
- **Good blood supply**- alveoli, gills of fish, villi--> maintains concentration gradient
- **Ventilation**- alveoli--> maintains concentration gradient

Feature of trachea

- Made up of incomplete rings of flexible cartilage
- Ciliated epithelium with mucus producing goblet cells--> swallowed--> pathogens destroyed by stomach acid

ALVEOLI

- 200-300 micrometers in diameter
- Layer of flattened epithelial cells, with some collagen and elastic fibres
- Elastic allow alveoli to stretch as air is drawn in
- When they return to their resting state--> air is squeezed out--> elastic recoil

INSPIRATION

- External intercostal muscles contract and the internal intercostal muscles relax
- Diaphragm contracts--> flattening and lowering
- Ribs move upwards and outwards
- Volume of thorax increases so pressure inside < pressure outside
- Air moves into lungs through nasal passage, trachea, bronchi and bronchioles into lungs
- Down gradient

Main reasons why specialised exchange surfaces are needed in multicellular organisms

- High metabolic activity
- Large diffusion distances for oxygen
- Small SA: V ratio

HUMAN GASEOUS EXCHANGE SYSTEM

- Nasal cavity
- Trachea
- Bronchus
- Bronchioles
- Alveoli

FEATURES OF NASAL CAVITY

- Large surface area with a good blood supply, which warms air to body temp
- Hairly lining--> mucus secreted to trap bacteria
- Moist surface--> increases humidity and reduces evaporation

FEATURES OF BRONCHIOLES

- Bronchi--> bronchioles
- No cartilage rings, walls have smooth muscle, bronchioles constrict when smooth muscle contracts
- Flattened epithelium--> short diffusion distance

ADAPTATIONS OF ALVEOLI

- Large surface area--> 300-500 million alveoli per adult lung
- Thin layers--> one cell thick--> short diffusion distance between air in alveolus and blood
- Good blood supply--> maintains concentration gradient
- Good ventilation--> maintains concentration gradient
- Lung surfactant--> enables lung to remain inflated

EXPIRATION

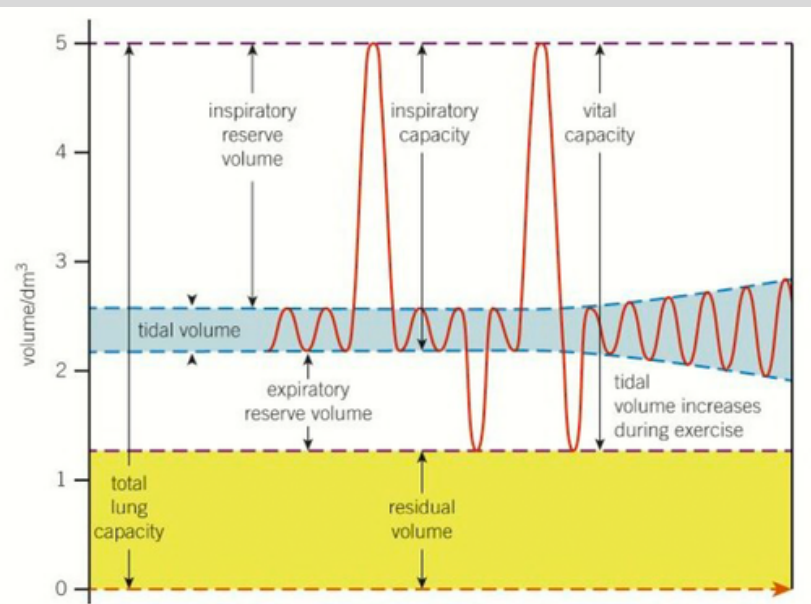
- Internal intercostal muscles contract and external intercostal muscle relaxes
- Diaphragm relaxes and moves upwards
- Ribs move down and inwards
- Pressure in thorax increases as volume decreases so pressure inside > pressure outside
- Air moves out down a gradient

EQUIPMENT USED TO MEASURE LUNG CAPACITY

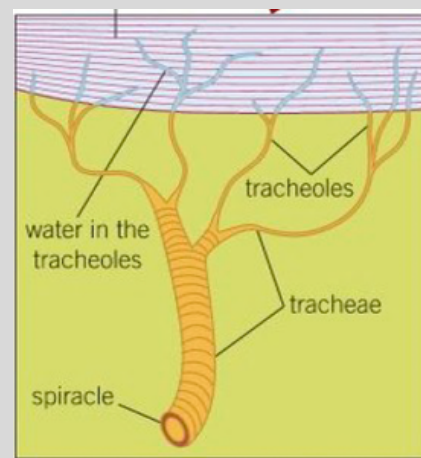
- Peak flow meter--> shows the rate at which air can be expelled from lungs
- Vitalographs--> produces graph of the amount of air they breathe out and how quickly
- Spirometer--> investigate breathing patterns

COMPONENTS OF THE LUNG VOLUME

- **Tidal volume**- volume of air that moves into and out of lungs with each resting breath--> 500cm^3 for most adults
- **Vital capacity**--> volume of air breathed in when strongest possible exhalation is followed by deepest possible intake of breath
- **Inspiratory reserve volume**--> maximum volume of air you can breath in over and above a normal inhalation
- **Expiratory reserve volume**--> extra amount of air you can force out of your lungs over and above the normal tidal volume of air you breathe out
- **Residual volume**- volume of air that is left in lungs when you have exhaled as hard as possible--> cannot be measured directly
- **Total lung capacity**- sum of the vital capacity and the residual volume
- Ventilation rate = tidal volume x breathing rate (per minute)



GASEOUS EXCHANGE SYSTEMS IN INSECTS



- **Spiracles**- openings along thorax and abdomen where air moves in, water evaporates out--> closed during low activity when metabolic demands low, open when metabolic demands high
- **Tracheae**- largest diameter tubes (up to 1mm in diameter)
- **Chitin**- material making up waxy cuticle on insect surface
- **Tracheoles**- branching of trachea, run in between cells so most gas exchange happens here, **give large SA**
- Oxygen dissolves in moisture on walls of tracheoles and diffuses into surrounding cells
- At end of tracheoles--> **tracheal fluid present**, which limits the penetration of air for diffusion. But when oxygen demands build up, lactic acid builds up in tissues--> water moves out of tracheoles by osmosis
- Exposing more SA for gas exchange

HOW TO INCREASE VENTILATION IN INSECTS

- **Mechanical ventilation of tracheal system**- air actively pumped into system by muscular pumping movements of thorax/abdomen--> Change volume of body--> pressure in tracheae/tracheoles changed--> Air drawn into tracheae
- **Collapsible enlarged tracheae/air sacs**--> act as reservoirs and used to increase the amount of air moved through gas exchange system--> inflated and deflated by ventilating movements of thorax and abdomen



RESPIRATORY SYSTEMS IN BONY FISH

- **Gills**--> large surface area, good blood supply and thin layers
- Protected by **operculum** (bony flap) which is active maintaining a flow of water over gills
- **Ram ventilation**- primitive fish (sharks) rely on moving to keep continuous water flow over gills
- Mouth closes--> operculum opens and sides of opercular cavity move inwards
- Increase pressure in opercular cavity and force water over gills and out of operculum
- Floor of buccal cavity steadily moved up, maintaining a flow of water over the gills

EFFECTIVE GAS EXCHANGE IN WATER

- Tips of adjacent gill filaments overlap--> resistance to flow of water over gills increased--> slows down movement of water--> increasing diffusion time
- Water moving over gills and blood in the gill filaments flow in different directions--> countercurrent exchange mechanism--> steep concentration gradient for diffusion of oxygen between blood and water--> 80% of oxygen from water transferred into blood

1BIOL-4

Exchange surfaces and breathing



WHY DO ANIMALS NEED SPECIALISED TRANSPORT SYSTEMS

- High metabolism
- SA: V ratio small
- Hormones or enzymes made in one place but needed in another
- Food digested in one organ system, needs to be transported to every cell for use in respiration and other aspects of cell metabolism
- Waste products of metabolism need to be removed from cells and transported to excretory organs

TYPES OF CIRCULATORY SYSTEMS

- Open circulatory systems
- Closed circulatory systems
- Single closed circulatory systems
- Double closed circulatory systems

Closed circulatory system

- Blood enclosed in blood vessels
- Heart pumps blood under high pressure, quickly, returns back to heart
- Found in all vertebrates
- **Single closed, double closed circulatory systems**

SINGLE CLOSED CIRCULATORY SYSTEM

- Blood flows through heart and is pumped to travel all around body before returning to heart
- Blood travels only once through heart for each complete circulation of body
- Blood passes through 2 sets of capillaries--> 1st set: exchanges oxygen and CO₂, 2nd set: exchanges nutrients--> BP drops a lot--> blood returned slowly--> inefficient--> supports only those with low metabolism

WHAT ABOUT FISH?

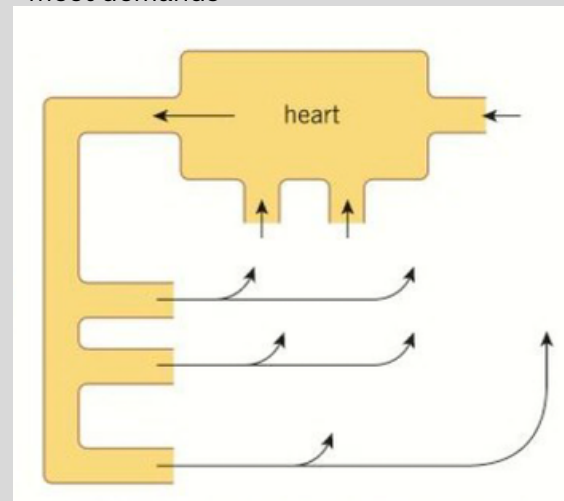
- Fish are very active with a single closed circulatory system--how?
- Countercurrent exchange, body weight supported by water--> very efficient

FEATURES OF CIRCULATORY SYSTEMS

- Liquid transport medium
- Vessels carrying medium
- Pumping mechanism to move medium

FEATURES OF CIRCULATORY SYSTEMS

- **Open circulatory system**- few vessels to contain transport medium--> pumped straight from heart into body cavity of animal
- **Haemocoel**- open body cavity, transport medium is under low pressure, comes into direct contact with tissues and cells
- This is where exchange takes place between transport medium and cells
- Transport medium returns to heart through an open ended vessel
- Found in invertebrates, have **haemolymph** which transports food and nitrogenous waste--> no steep gradients, and amount of haemolymph flowing cannot be varied to meet demands



DOUBLE CLOSED CIRCULATORY SYSTEM FEATURES

- Blood pumped from heart to lungs to pick up oxygen and unload CO₂--> returns to heart
- Blood flows through heart and is pumped out to travel all around body before returning to heart again
- Blood travels twice through the heart for each circuit of the body

1BIOL-4

Exchange surfaces and breathing



MATERIALS OF BLOOD VESSELS (COMMON TO ALL)

- Elastic fibres--> composed of elastin which can stretch and recoil
- Smooth muscle--> contracts or relaxes which changes the size of lumen
- Collagen--> provides structural support to maintain shape and volume of vessel

CAPILLARIES

- Link arterioles with venules
- Small lumen--> RBCs flow in single file
- Fenestrations (gaps in wall)
- Single endothelial cell thick--> short diffusion distance
- Capillaries in CNS have very tight junctions between cells

HOW ARE CAPILLARIES ADAPTED FOR THEIR ROLE

- Large SA: V ratio for diffusion of substances into and out of blood
- Cross-sectional area > area of arteriole--> slows blood flow--> more time for diffusion
- Single endothelial cell thick walls--> very thin diffusion distance

VEINS AND VENUES

- Carry deoxygenated blood (**except pulmonary vein and umbilical vein**), **towards heart**
- Deoxygenated blood in capillaries--> venules --> veins-- heart via vena cava
- Don't have a pulse--> up to 60% of blood volume in veins
- Blood pressure lower compared to arteries
- Walls contain lots of collagen and little elastic fibres
- Wide lumen, smooth endothelium --> smooth blood flow

Relative proportions of:	Large vein:	Medium sized vein:	Venule:
Elastin			
Smooth muscle			
Collagen			

ARTERIES AND ARTERIOLES

- Carry oxygenated blood (except for **pulmonary artery, umbilical artery**)
- Carry blood away from heart
- Elastic fibres:** enable arteries to withstand the force of blood pumped out of heart and stretch to take larger blood volume, elastic fibres recoil between heart contractions, smooths out flow of blood/continuous
- Arterioles: more smooth muscle and less elastin--> as they need to constrict or dilate to control flow of blood into individual organs

Relative proportions of:	Aorta:	Medium sized artery:	Arteriole:
Elastin			
Smooth muscle			
Collagen			

ADAPTATIONS OF VEINS

- Valves--> prevents backflow of blood away from heart
- Venous return by muscle contraction
- Breathing movements act as pump--> returning blood towards heart

COMPONENTS OF BLOOD PLASMA

- Glucose, hormones, amino acids, mineral ions, plasma proteins (albumin), fibrinogen, globulins, RBCs, WBCs, platelets
- Platelets--> fragments of megakaryocytes

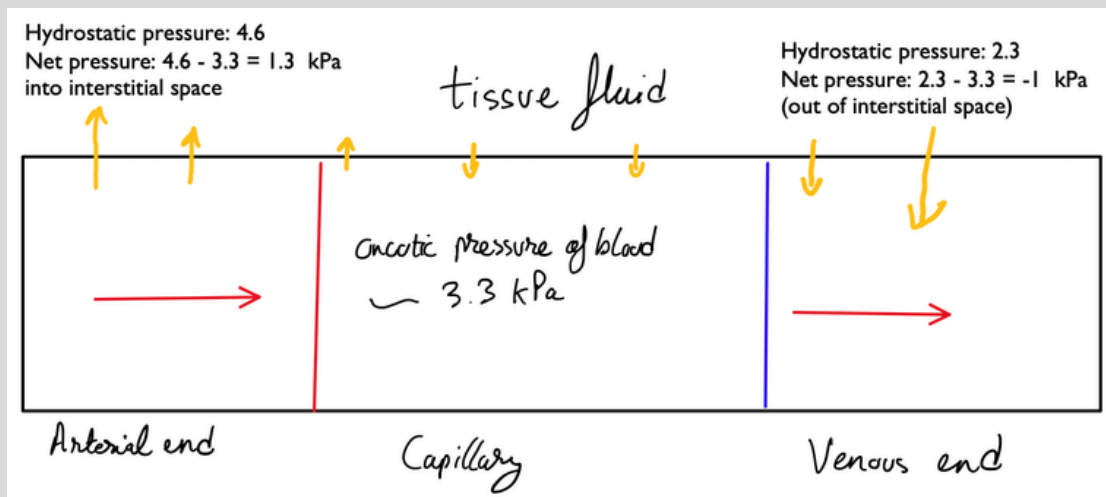
FUNCTIONS OF BLOOD

Transport of:

- Oxygen to, and carbon dioxide from, the respiring cells
- Digested food from small intestine
- Nitrogenous waste
- Chemical messages (hormones)
- Food molecules from storage compounds to cells that need them
- Platelets to damaged areas
- Immune components

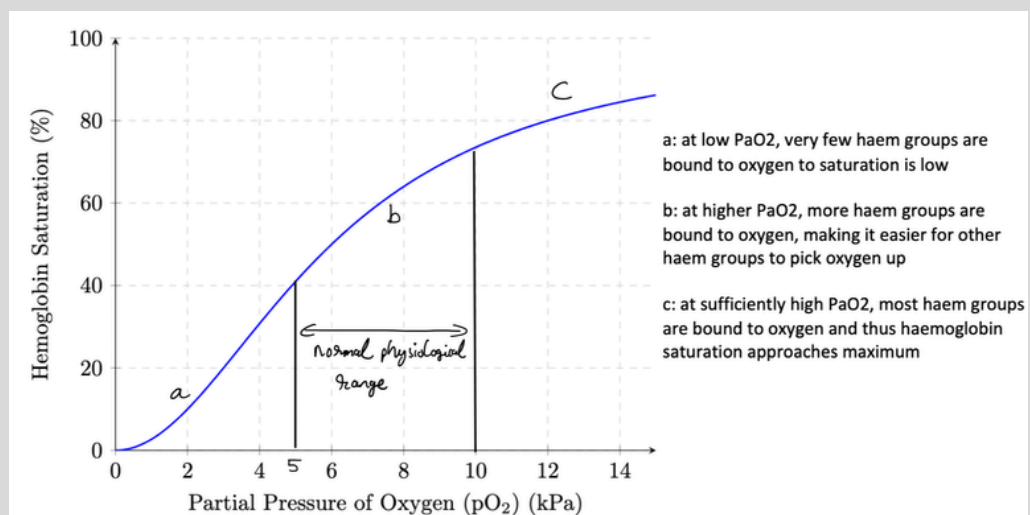
TISSUE FLUID (ALL YOU NEED TO KNOW)

- Plasma proteins can't pass through fenestrations of capillaries--> give high solute potential (low water potential) compared to surrounding fluid--> water has a tendency to move into the blood in capillaries from surrounding fluid by osmosis
- Tendency of water to move into blood by osmosis--> called **oncotic pressure**
- As blood moves through arterioles into capillaries--> still under pressure from surge caused by heart contraction--> **hydrostatic pressure**
- At arterial end--> **hydrostatic pressure out (4.6 kPa) > oncotic pressure in-->** fluid moves out--> fills space between cells and is called **tissue fluid**
- As blood flows through capillaries towards veins--> **hydrostatic pressure out (2.3 kPa) < oncotic pressure in (3.3 kPa)-->** water moves back into capillaries by osmosis at venous end--> returning tissue fluid back into circulation
- 10% of tissue fluid not returned--> drained by lymph capillaries which have one way valves and lymph moves by contraction of muscles--> returned back into circulation at left and right subclavian veins



OXYGEN TRANSPORT

- One oxygen molecule binds to Fe (II) in Hb (haemoglobin)--> molecule changes shape (specific 3D tertiary structure)
- Makes it easier for next O₂ to bind--> **positive cooperativity**
- As oxygen bound to haemoglobin, free O₂ concentration inside erythrocyte stays low--> steep concentration gradient
- When Hb/RBC reaches tissues--> low O₂ in tissues and high in erythrocyte so O₂ diffuses out
- O₂ dissociation curve (left) show affinity of Hb for O₂



1BIOL-4

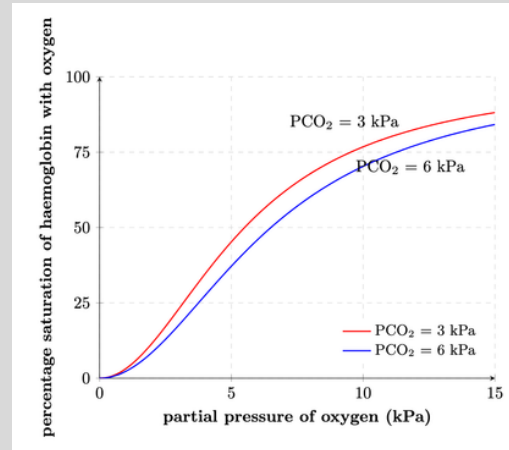
Exchange surfaces and breathing

EFFECT OF CO₂ ON HB

- **Bohr effect**- O₂ dissociation curve moves to the right--> reduced affinity for O₂

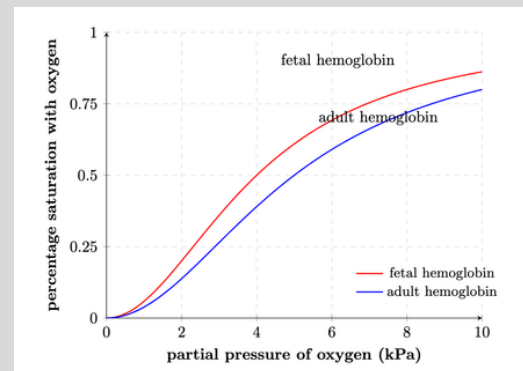
Why is the Bohr effect important?

- In active tissues with a high partial pressure of CO₂--> Hb gives up its oxygen more readily
- In the lungs where the proportion of CO₂ in the air is low--> O₂ binds Hb molecules more easily



FETAL HB

- Oxygenated blood from mother runs close to deoxygenated fetal blood in placenta
- If fetal Hb same as maternal Hb--> no O₂ can be transferred
- So fetal Hb affinity (O₂) > adult Hb (O₂), i.e. there is a left shift



TRANSPORTING CO₂

- 5% dissolved in plasma
- 10-20% combined with amino groups in polypeptide chains of Hb to form carbaminohaemoglobin
- 75-85% converted to carbonate ions (HCO₃⁻) in cytoplasm of RBCs (reaction shown below), catalysed by **carbonic anhydrase**

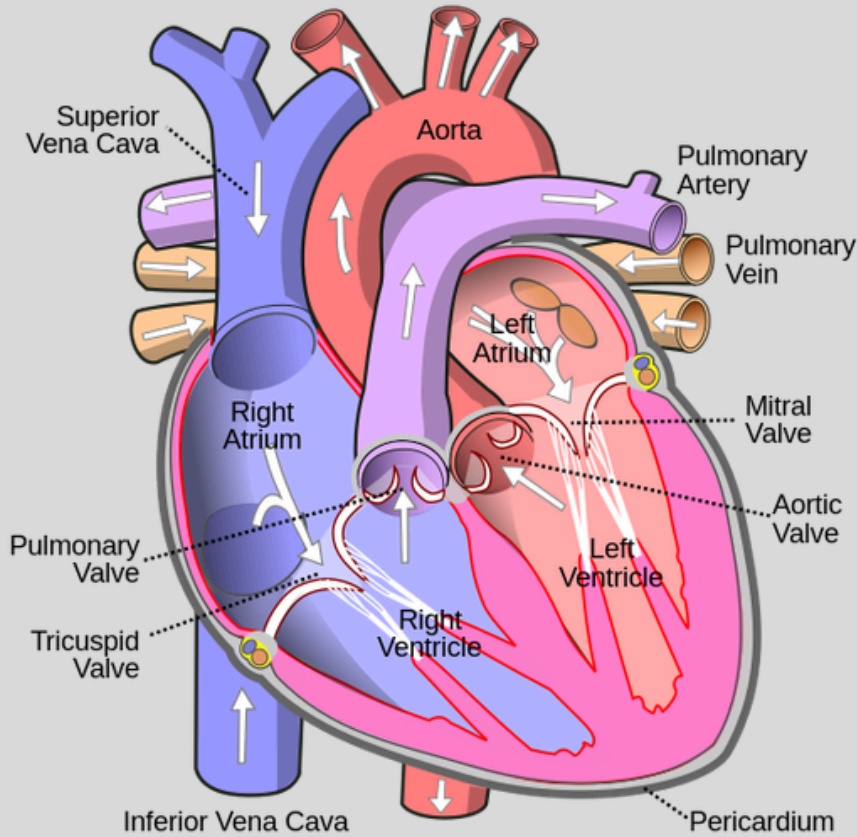


- Protons accepted by Hb to form **haemoglobinic acid**
- Acts as a **buffer**

CHLORIDE SHIFT

- The negatively charged HCO₃⁻ ions formed move out of RBCs by diffusion
- Cl⁻ ions move back in to maintain electroneutrality
- Also by removing CO₂ by reacting it with H₂O--> RBCs maintain steep concentration gradient for CO₂ to be removed

Human Heart



- Oxy blood from lungs enters **left atrium** from **pulmonary vein**
- Pressure in atrium increases--> bicuspid valve opens between **left atrium and left ventricle** so ventricle fills with oxy blood
- When both atrium and ventricle are full--> atrium contracts forcing all oxygenated blood into **left ventricle**
- **Left ventricle** contracts and pumps oxygenated blood through **semilunar valves** into the **aorta** and around the body
- As the ventricle contracts--> **tricuspid valve closes** to prevent backflow of blood

STRUCTURE OF HEART RELATED TO FUNCTION

- Muscular wall of left side of heart thicker than right side
- Lungs close to heart--> right side has to pump blood relatively short distance, only has to overcome pulmonary resistance

MAIN FEATURES OF HUMAN HEART

- Oxygenated blood on left, deoxy on right
- Cardiac muscle--> contracts and relaxes at a regular beat
- Doesn't get fatigued
- Supplied by coronary arteries
- Heart surrounded by inelastic pericardium which prevents over-distension of heart with blood

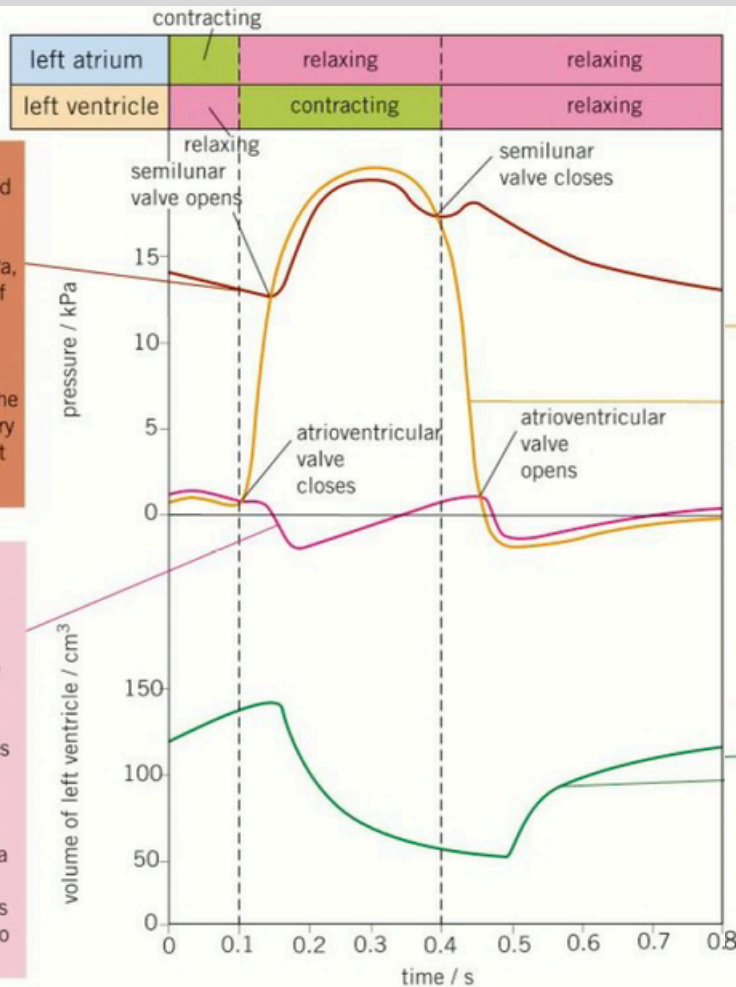
FUNCTION OF HEART

- Deoxy blood enters right atrium from vena cava
- Atria have thin muscular walls and as blood flows in, slight pressure builds up until the **tricuspid valve** opens to allow blood flow into **right ventricle**
- Stretches ventricle walls
- **Right ventricle** starts to contract, tricuspid valve closes preventing backflow into atria
- **Tendinous cords** ensure valves are not turned inside out by pressure exerted when ventricle contracts
- Right ventricle contracts fully and pumps deoxy blood through **semilunar valves** into **pulmonary artery**
- Semilunar valves prevent backflow of blood into ventricles

CARDIAC CYCLE- DEFINITIONS

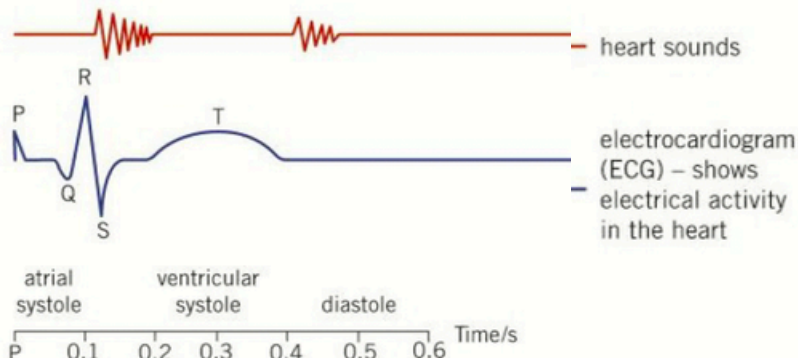
- **Diastole**- heart relaxes, atria and ventricles fill with blood, volume and pressure of blood in heart increases as heart fills with blood, but pressure in arteries is low
- **Systole**- atria contract, pressure inside heart increases, blood forced out of right side of heart to lungs, left side of heart to rest of body, volume and pressure of blood in heart are low at the end of systole and the blood pressure in arteries are at a minimum

CARDIAC CYCLE



ventricular pressure is low at first, but gradually increases as the ventricles fill with blood as the atria contract. The left atrioventricular valves close and pressure rises dramatically as the thick muscular walls of the ventricle contract. As pressure rises above that of the aorta, blood is forced into the aorta past the semilunar valves. Pressure falls as the ventricles empty and the walls relax.

ventricular volume rises as the atria contract and the ventricles fill with blood, and then drops suddenly as blood is forced out into the aorta when the semilunar valve opens. Volume increases again as the ventricles fill with blood.



Heart Sounds

- Lub dub
- Lub- blood forced against the AV valves (trio-ventricular)
- Dub- closure of semilunar valves in aorta and pulmonary arteries

BASIC RHYTHM OF THE HEART

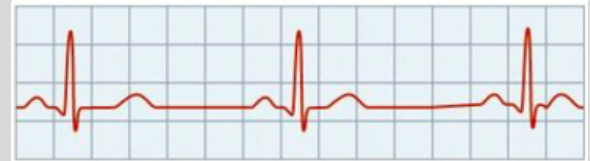
- Cardiac muscle is **myogenic** (has an intrinsic rhythm)
- Wave of electrical excitation begins in SAN (sino-atria node)-- causing atrial contraction
- Layer of non-conducting tissue prevents excitation passing directly to ventricles
- Electrical activity from SAN is picked up by AVN (atrioventricular node)
- Slight delay in conduction from AVN to bundle of His (conducting tissue made up of Purkinje fibres)--> which penetrate through the septum between the ventricles
- Bundle of His splits into two branches and conducts wave of excitation to apex of heart
- At apex--> Purkinje fibres spread out through walls of ventricles on both sides
- Spread of excitation triggers contraction of ventricles, starting at apex and moving upwards --> efficient

WHAT IS AN ECG?

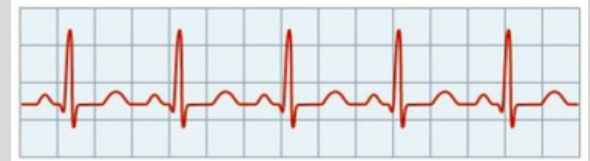
- Electrocardiogram--> records electrical activity of heart



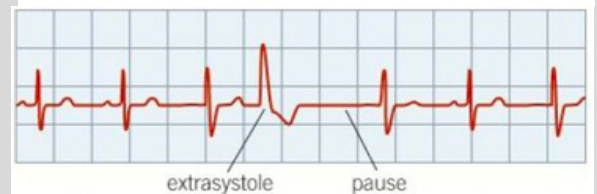
(a) Normal ECG – beats evenly spaced, rate 60–100/min



(b) Bradycardia – slow heart rate – beats evenly spaced, rate <60/min



(c) Tachycardia – fast heart rate – beats evenly spaced, rate >100/min



(d) Ectopic heart beat – altered rhythm, extra beat followed by longer than normal gap before the next beat



(e) Atrial fibrillation – abnormal irregular rhythm from atria, ventricles lose regular rhythm

NEED FOR PLANT TRANSPORT SYSTEMS

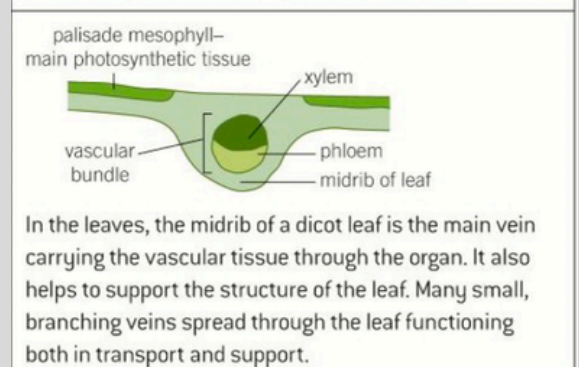
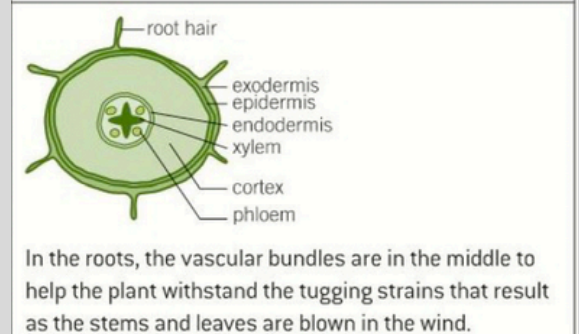
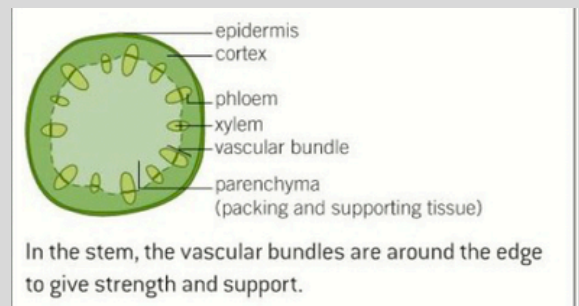
- **Metabolic demands**- cells of green parts of plant make own glucose by respiration and oxygen by photosynthesis--> BUT underground plants can't so need it transported to them, need mineral ions transported, need hormones transported
- **Size**- need transport systems to move substances from roots to tip of leaves
- **SA: V ratio**- low--> cant rely on just diffusion

NEED FOR PLANT TRANSPORT SYSTEMS

- **Dicotyledonous plants (dicots)**- make seeds that contain 2 cotyledons (organs that act as food stores for the developing embryo plant and form first leaves when seed germinates)
- **Herbaceous dicots**--> soft tissues and a relatively short life cycle
- **Woody dicots**--> hard, lignified tissues, long life cycle

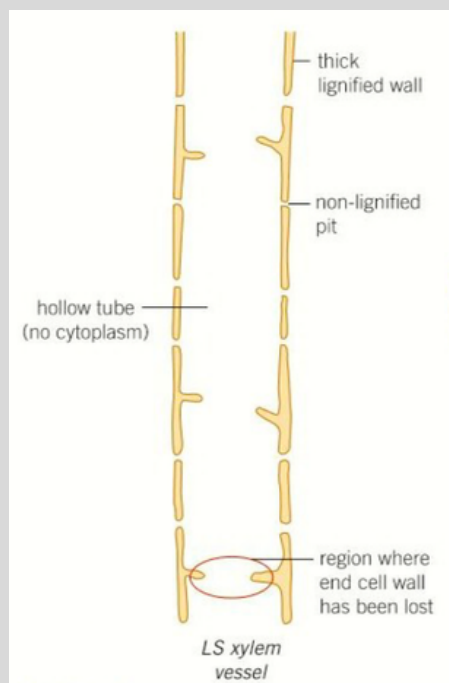


VASCULAR BUNDLE



STRUCTURE AND FUNCTION OF XYLEMS

- Non living
- Transports water and mineral ions, supports plant
- Flow is one way: up from roots to the shoots and leaves
- Long, hollow tubes, made by columns of cells fusing together end to end
- Thick walled xylem parenchyma packs around xylem vessels, storing food and containing tannin deposits (chemical that protects plants from attack by herbivores)
- Parallel lignin fibres--> support



STRUCTURE AND FUNCTION OF PHLOEMS

- Living tissue that transports organic solutes made by photosynthesis--> needed for respiration
- Bidirectional flow
- Sieve tube elements--> main transporting vessels of phloem--> joined end to end
- No lignin
- Sieve plates--> walls perforated
- Mature phloem cells have no nucleus
- Companion cells (have nucleus and organelles, very active) closely linked to sieve tube elements by plasmodesmata
- Sclerids--> supporting tissue

1BIOL-4

Exchange surfaces and breathing



FUNCTION OF WATER IN PLANTS

- Produces turgor--> drives expansion which allows plants to force themselves through tarmac and concrete
- Evaporation keeps plants cool
- Mineral ions and products of photosynthesis are transported in aqueous solutions
- Water is reactant in photosynthesis

Movement of water into the root

- Root hair cells take up water from soil into plants--> long and has thin extensions

SYMPLAST PATHWAY

- Water moves through symplast--> continuous cytoplasm of living plant cells that are connected via plasmodesmata by osmosis
- Root hair cell water potential > next cell along--> water diffuses by osmosis
- Process continues until xylem reached

MOVEMENT OF WATER INTO XYLEM

- Water moves across root in apoplast and symplast pathways until it reaches endodermis (layer of cells surrounding the vascular tissue of the roots)
- Endodermis is particularly noticeable in roots due to effects of the **Casparian strip**
- **Casparian strip**- band of waxy material called **Suberin** that runs around each of endodermal cells forming waterproof layer
- From here, water from apoplast pathway can't go any further so is forced into cytoplasm of cell joining symplast pathway
- Diversion to cytoplasm is significant as to get there water has to pass through selectively permeable cell surface membranes
- Once inside the vascular bundle, water returns to the apoplast pathway to enter the xylem itself and move up the plant
- **Root pressure** created by active pumping of minerals into xylem to produce movement of water by osmosis--> pushes water up xylem

ADAPTATIONS OF ROOT HAIR CELLS

- Microscopic size means that they can penetrate easily between soil particles
- Large SA: V ratio
- Thin--> short diffusion distance
- High concentration of solutes in cytoplasm--> maintains water potential gradient for water to move into the cell

MOVEMENT OF WATER ACROSS ROOT

Once water moved into root hair cells, water moves across root to xylem in 2 ways:

- **symplast pathway**
- **apoplast pathway**

APOPLAST PATHWAY

- Movement is through the cell walls and intercellular spaces--> **apoplast**
- Water fills spaces between cellulose fibres of cell wall
- As water moves through into xylem--> more pulled through apoplast due to cohesive forces
- Continuous flow with little resistance

FEATURES OF THE ENDODERMAL CELLS

- Solute concentration is low
- Move mineral ions by active transport into xylem
- So water potential of xylem < endodermal cells

FEATURES OF THE ENDODERMAL CELLS

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EVIDENCE FOR THE ROLE OF ACTIVE TRANSPORT IN ROOT PRESSURE

- Cyanide uncouples ATP production in mitochondria--> ATP needed for active transport--> if cyanide applied--> no root pressure
- Root pressure increases with a rise in temperature and falls with a fall in temperature--> chemical reactions involved
- If levels of oxygen or respiratory substrates fall--> root pressure falls
- Xylem sap exudes from cut end of stems at certain times--> guttation



TRANSPIRATION

- Transpiration- loss of water vapour from leaves and stems of plants
- **Transpiration stream**- water enters the roots of the plant by osmosis and is transported up in the xylem until it reaches the leaves, moves by osmosis across membranes and by diffusion in apoplast pathway from xylem through leaf cells--> evaporates from freely permeable cellulose cell walls of the mesophyll cells in leaves into air spaces--> water vapour moves into external air through stomata along diffusion gradient

So, how does the transpiration stream work? The Cohesion-Tension theory

- Water molecules evaporate from surface of mesophyll cells into air spaces in leaf
- Water moves out of stomata into the surrounding air by diffusion down a concentration gradient
- Loss of water by evaporation from a mesophyll cell lowers water potential of the cell--> water moves into cell from an adjacent cell by osmosis--> along both apoplast and symplast pathways
- Repeated across lead to xylem--> water moves out of xylem by osmosis into leaf cells
- Water molecules form H bonds with carbohydrates in cells of xylem walls--> adhesion, H₂O also form H bonds with each other--> cohesion
- Cohesion and adhesion--> capillary action of water which pulls water up xylem in one continuous stream--> **transpiration pull** against gravity
- Transpiration pull--> tension in xylem due to negative pressure against xylem wall

EVIDENCE FOR THE COHESION-TENSION THEORY

- Diameter of trees change--> transpiration highest during the day--> tension in xylem at its highest--> tree shrinks in diameter due to negative pressure. When transpiration is at its lowest--> tension in xylem vessels is lowest--> diameter of tree highest due to least pulling inwards/sucking/negative pressure
- When xylem broken--> air drawn in rather than water leaking out
- If xylem vessel broken--> continuous stream of water broken due to no cohesion and adhesion so water not pulled up

FACTORS AFFECTING TRANSPIRATION

- **Light:** light opens stomata for photosynthesis--> gas exchange and water evaporation whereas in dark most stomata closed--> increased rate of transpiration
- **Humidity:** Increased water potential outside stomata--> reduced water potential gradient between inside of leaf and air--> reduced water evaporation--> reduced rate of transpiration
- **Temperature:** increased kinetic energy of water--> increased rate of evaporation of water out of stomata--> increased rate of transpiration, increased concentration of water vapour that external air can hold before it becomes saturated
- **Air movement:** increased movement of water vapour away from outside stomata--> increased water potential gradient--> increased rate of transpiration
- **Soil-water availability:** if dry--> plant under water stress--> decreased rate of transpiration



TRANSLLOCATION- FROM SOURCES TO SINKS

- **Source**- leaves that make organic compounds
- **Sink**- tissues that need them
- **Assimilates**- products of photosynthesis, main one is sucrose

TRANSLLOCATION STAGES

- Phloem loading (symplast and apoplast route)
- Phloem unloading

PHLOEM LOADING

- **Symplast route:** sucrose from source moves through cytoplasm of mesophyll cells onto sieve tubes by diffusing through plasmodesmata--> water follows by osmosis--> pressure created that moves sucrose by mass flow
- **Apoplast route:** Sucrose from source travels through cell walls and inter-cell spaces to companion cells and sieve elements down concentration gradient---> sucrose moved into cytoplasm of companion cells actively: **hydrogen ions** actively pumped out of companion by using ATP--> they diffuse back into companion cell down concentration gradient via a co-transport protein (sucrose co-transported in)--> water moves in by osmosis due to increase in sucrose--> creates turgor pressure that moves assimilates up plant by mass flow

ADAPTATIONS OF COMPANION CELLS FOR PHLOEM LOADING

- Invaginations--> increase SA: V ratio
- Lots of mitochondria--> ATP--> Active transport

Phloem unloading

- Sucrose diffuses from phloem to surrounding cells--> converted to storage molecule (starch)
- Decrease in solute concentration increases water potential in phloem at sink--> water moves into xylem down water potential gradient

Evidence for translocation

- Microscopy advances--> able to see active transport in companion cells
- If mitochondria poisoned--> translocation stops (eg with cyanide)
- Flow of sugars in phloem 10,000 times faster compared to diffusion alone (shows active process involved in mass flow)
- Aphid studies: positive pressure in phloem, higher concentration of sucrose at source, pressure higher at source

Evidence against translocation

- Not all solutes in phloem move at same rate
- Sucrose moves at same rate regardless of concentration in sink
- Role of sieve plates unknown

MAIN SOURCES IN A PLANT

- Green leaves and green stems
- Storage organs such as tubers and tap roots
- Food stores in seeds when they germinate

MAIN SINKS IN A PLANT

- Roots that are growing and/or actively absorbing minerals
- Meristems
- Developing seeds, fruits, storage organs



NORMAL PLANT ADAPTATIONS TO PREVENT WATER LOSS

- Waxy cuticle--> reduce transpiration
- Stomata on underside of leaf--> prevent loss of water vapour
- Roots that grow down to water in soil

WHAT ARE XEROPHYTES?

- Plants that live in dry habitats
- Lots of adaptations that allow them to live and reproduce in places where water availability is very low
- Cacti

XEROPHYTE ADAPTATIONS

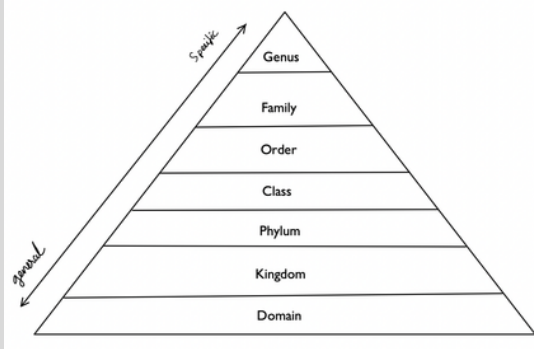
- Thick waxy cuticle
- Sunken stomata: stomata in pits--> reduce air movement, produces microclimate of still, humid air--> reduces water vapour potential gradient--> reduces transpiration
- Reduced stomata number/density
- Reduced leaves: reduced SA: V ratio, reduced stomata number
- Hairy leaves: trap moist air--> reduced water potential gradient--> reduced rate of transpiration
- Curled leaves: trap moist air--> reduced water potential gradient--> reduced rate of transpiration
- Succulents: swollen, fleshy appearance--> water is stored
- Root adaptations: long tap roots allow deep penetration into soil, mass of widespread, short roots--> large SA: V ratio

WHAT IS A HYDROPHYTE?

- Plants that live in water (submerged or on surface)
- Need adaptations to cope with growing in water or in permanently saturated soil
- Eg: water lilies, cress

HYDROPHYTE ADAPTATIONS

- Very thin/no waxy cuticle
- Many always open stomata--> maximise gas exchange
- Reduced structure to plants: water supports plant
- Wide, flat leaves: capture as much light as possible
- Small roots: water diffuses directly into stem and leaf tissue so there is less need for uptake by roots
- Large SA of stems and roots under water--> maximised area for photosynthesis and for oxygen to diffuse into submerged plants
- Air sacs: enables floating on water surface
- Aerenchyma: specialised parenchyma tissue forms in leaves, stems and roots of hydrophytes--> formed by apoptosis of mesophyll cells--> makes leaves and stems buoyant, forms a low-resistance internal pathway for movement of substances such as O₂ to tissues below water--> helps plant to survive low O₂ environments by transporting O₂ to tissues



Classification is the process of grouping organisms based on shared features. The system is arranged in a hierarchy with each group known as a taxonomic group.

- The traditional hierarchy consists of seven taxonomic levels:

1. Kingdom (largest and broadest group)
2. Phylum (plural: phyla)
3. Class
4. Order
5. Family
6. Genus (plural: genera)
7. Species (smallest and most specific group)

- Each organism belongs to only one group at each level of the hierarchy. Linnaean classification, developed by Carl Linnaeus in the 18th century, is still widely used but has evolved with modern discoveries.

- Now includes a classification above kingdom: *domain*

WHY DO SCIENTISTS CLASSIFY ORGANISMS?

- Identification: A clearly defined classification system allows scientists to identify species easily.
- Prediction of characteristics: Species in the same group share similar characteristics, making it likely that characteristics can be predicted across species.
- Evolutionary links: Classification helps identify evolutionary relationships, with species in the same group likely sharing a common ancestor.

A standardized classification system enables global collaboration among scientists, facilitating shared research and allowing links between species to be recognized across different continents.

NAMING ORGANISMS

- Before the establishment of classification systems, organisms were given common names based on physical characteristics or habitat (e.g., blackbirds, song thrushes). However, this system was problematic for scientific communication:
 - Common names vary by language and region.
 - They do not convey evolutionary relationships or taxonomic groupings (e.g., blackbirds, song thrushes, and fieldfares all belong to the genus *Turdus* but this is not evident from their common names).

HOW ARE ORGANISMS CLASSIFIED?

The classification hierarchy begins by separating organisms into the three domains:

- Archaea
- Bacteria
- Eukarya

These are the broadest groups. As you move down the hierarchy (e.g., from phylum to species), groups become more specific, containing fewer organisms with shared characteristics.

- Species are the smallest classification units, defined as a group of organisms capable of producing fertile offspring.

For example:

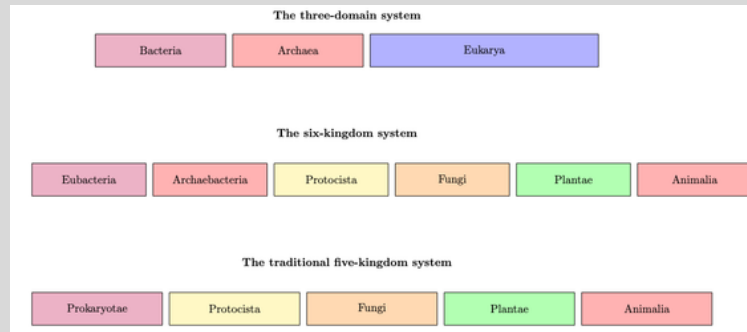
- Donkeys and horses can breed, but their offspring (e.g., mules) are infertile due to an odd number of chromosomes, meaning mules are not a species.

BINOMIAL NOMENCLATURE

- Developed by Carl Linnaeus, binomial nomenclature is the globally accepted system for naming organisms.
- Each species is given a scientific name with two parts:
 1. Genus name (first word, capitalized).
 2. Species name (second word, lowercase).
- Example: *Turdus merula* (blackbird), *Turdus philomelos* (song thrush), and *Turdus pilaris* (fieldfare).
- Rules for scientific names:
 - Names are usually italicized (or underlined if handwritten).
 - The first letter of the genus is uppercase, and the species name is in lowercase.
- Binomial names help to avoid confusion and reflect evolutionary relationships between organisms.

1BIOL-5

BIODIVERSITY AND CLASSIFICATION



Historically, organisms were classified into just two kingdoms: Plantae and Animalia. As more was discovered about organisms, a more complex system was needed. In the 1960s, Robert Whittaker introduced the five-kingdom system, based on Linnaean principles.

THE FIVE KINGDOMS ARE:

1. Prokaryotae (bacteria)
 - Unicellular, no nucleus or membrane-bound organelles.
 - Example: Escherichia coli, Staphylococcus aureus.
2. Protocista
 - Mostly unicellular with membrane-bound organelles.
 - Some species contain chloroplasts for photosynthesis.
 - Example: Paramecium, Amoeba.
3. Fungi
 - Unicellular or multicellular, with chitin cell walls.
 - Nutrients acquired through absorption (saprophytic).
 - Example: Mushrooms, moulds, yeast.
4. Plantae
 - Multicellular organisms, cell walls made of cellulose.
 - Photosynthetic (autotrophic), store food as starch.
 - Example: Roses, oak trees, grasses.
5. Animalia
 - Multicellular, no cell walls or chloroplasts.
 - Heterotrophic feeders, ingesting food.
 - Example: Mammals, birds, insects.

ARCHAEBACTERIA

- Archaeobacteria, also called ancient bacteria, are prokaryotes that thrive in extreme environments such as:
 - Hot thermal vents
 - Anaerobic conditions
 - Highly acidic environments
 - Example: Methanogens live in anaerobic environments, such as sewage treatment plants, and produce methane.
- Archaeobacteria lack peptidoglycan in their cell walls, differentiating them from Eubacteria.

EUBACTERIA

- Eubacteria, or true bacteria, are also prokaryotes but are found in all environments. They include most bacteria we are familiar with.
- Eubacteria have peptidoglycan in their cell walls.

DIFFERENCES BETWEEN ARCHAEABACTERIA AND EUBACTERIA

- Although both groups are prokaryotes, chemical differences in their cell wall structure (presence or absence of peptidoglycan) place them in different domains.
- While some scientists still use the five-kingdom system, the discovery of these differences has led most scientists to adopt the three-domain, six-kingdom system.

RECENT CHANGES TO CLASSIFICATION SYSTEMS

Originally, classification systems were based on observable features. With the advancement of genetics, scientists now study DNA and protein structures to determine evolutionary relationships.

- An example is haemoglobin, which shows similarities between humans, chimpanzees, and gorillas, indicating a common ancestor.

Modern classification now incorporates the Three Domain System, introduced by Carl Woese in 1977, which is based on differences in rRNA sequences. The three domains are:

1. Archaea:
 - 70s ribosomes
 - RNA polymerase has between 8-10 proteins
2. Bacteria:
 - 70s ribosomes
 - RNA polymerase has 5 proteins
3. Eukarya:
 - RNA polymerase has 12 proteins



PHYLOGENY

- Phylogeny refers to the evolutionary relationships between organisms.
- Phylogenetics is the study of the evolutionary history of groups of organisms, revealing how closely related different species are and their common ancestors.
- While classification can occur without considering phylogeny, modern classification aims to incorporate an organism's evolutionary history.

PHYLOGENETIC TREES

- A phylogenetic tree (or evolutionary tree) is a branched diagram representing the evolutionary relationships between species.
- The base of the tree represents the earliest species, while the tips of the branches show the most recent species.

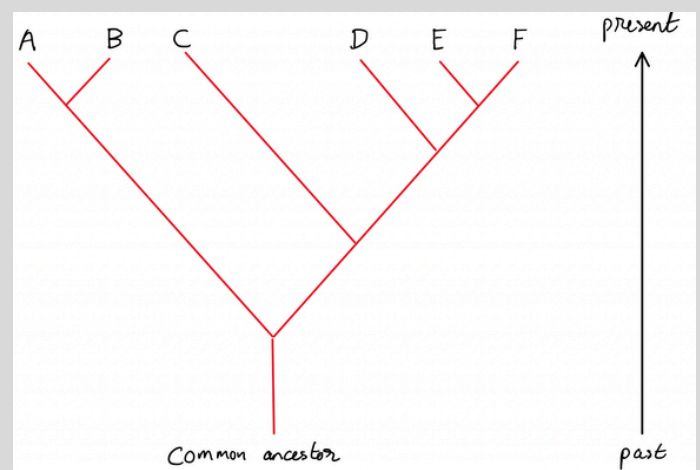
Phylogenetic trees are constructed using evidence from:

- Physical characteristics
- Genetic makeup
- Fossils that provide insight into evolutionary links.

INTERPRETING

PHYLOGENIC TREES:

- Tips represent groups of descendants
- Points of branching represents where evolution occurred
- Descendants from the same node are sister groups
- The closer two species are to each other, the closer the evolutionary relationship is



ADVANTAGES OF PHYLOGENETIC CLASSIFICATION

Phylogeny provides insight into the evolutionary relationships between organisms, which can lead to changes in traditional classification.

- Example: Dolphins share many characteristics with fish, but phylogenetic evidence confirms they are mammals.
- Continuous tree: Phylogeny produces a continuous, branching tree rather than requiring discrete taxonomic groups. Scientists are not forced to place organisms into rigid categories.
- Avoids misleading equivalence: The hierarchical structure of Linnaean classification can imply that groups at the same rank are equivalent, which is not always the case.
- For example:
- Felidae (cats) and Orchidaceae (orchids) are both families, but they have different evolutionary histories and levels of diversity.
 - Orchids have existed for over 100 million years, while cats have been around for about 30 million years.
 - Orchids also exhibit more diversity than cats, with around 20,000 species compared to approximately 35 cat species.



EVOLUTION AND NATURAL SELECTION

Evolution is the theory that species change over time through the process of natural selection.

- Natural selection: Organisms with traits that are better suited to their environment are more likely to survive and reproduce, passing these traits to the next generation. Over time, this leads to the development of more advantageous phenotypes.
- The mechanism behind the transmission of traits is genetics, where advantageous traits are passed through genes in DNA.

DEVELOPING THE THEORY OF EVOLUTION

- Charles Darwin is credited with developing the theory of evolution. His ideas were influenced by the scientific work of others, including Charles Lyell, whose book *Principles of Geology* argued that fossils provide evidence of life from millions of years ago.
- Darwin's observations of finches in the Galapagos Islands provided key evidence for his theory:
- He observed that finches on different islands had different beak shapes, which were adapted to the food sources available on each island. This suggested that finches had evolved based on their environment.
- Darwin's theory was controversial at the time because it conflicted with the Christian belief that God created all life in its current form

While Charles Darwin was developing his theory, another scientist, Alfred Wallace, independently developed a similar theory of evolution while studying in Borneo.

EVIDENCE FOR EVOLUTION

Scientists use various sources to study evolution, including:

Palaeontology:

- Fossils provide a record of life on Earth and show how organisms have changed over time.

Evidence from the Fossil Record:

1. Simple organisms (e.g., bacteria and algae) are found in the oldest rocks, while more complex organisms (e.g., vertebrates) appear in younger rocks. This supports the theory that simple life forms evolved into more complex organisms over time.
2. The sequence of fossils matches their ecological relationships. For example, plant fossils appear before animal fossils, reflecting that animals rely on plants for survival.
3. By studying anatomical similarities in fossils, scientists can trace the evolutionary relationships between species. For example, zebras and horses (genus *Equus*) are closely related to rhinoceroses, with evidence linking them to a common ancestor (*Hyracotherium*).
4. Fossils allow the investigation of relationships between extinct and extant organisms.

Limitations of the Fossil Record

- The fossil record is incomplete. Many organisms, especially soft-bodied organisms, do not fossilize well, and some fossils may be destroyed by geological activity (e.g., volcanic eruptions or earthquakes).

Comparative Anatomy: Examines similarities and differences in the anatomy of species, such as homologous structures, which indicate common ancestry.

HOMOLOGOUS STRUCTURES

- A homologous structure is an anatomical feature that appears superficially different in various species but shares the same underlying structure. An example is the pentadactyl limb in vertebrates.
- Although vertebrate limbs are used for different functions (e.g., running, flying, swimming), the basic bone structure is similar. This indicates that all vertebrates evolved from a common ancestor, and their limbs have evolved to perform different functions through divergent evolution.

Divergent evolution occurs when species with a common ancestor evolve to adapt to different environments or ecological niches. This process leads to the development of species with unique adaptations, while retaining homologous structures.

1BIOL-5

BIODIVERSITY AND CLASSIFICATION



COMPARATIVE BIOCHEMISTRY

- Comparative biochemistry studies the similarities and differences in the proteins and other molecules that control life processes (e.g., DNA, proteins like cytochrome c, and ribosomal RNA). Some molecules are highly conserved across species meaning they undergo few changes over time.

NEUTRAL EVOLUTION

The neutral theory of molecular evolution suggests that most variability in molecules occurs in regions that do not affect their function.

- These changes are termed neutral substitutions and occur at a regular rate, unaffected by natural selection.

MOLECULAR COMPARISONS

- To determine how closely related two species are, scientists compare molecular sequences:
- DNA base sequences or amino acid sequences in proteins are compared.
- The number of differences between sequences is plotted against the rate of neutral substitutions to estimate the time when two species shared a common ancestor.
- Closely related species have more similar sequences, while distantly related species show more differences.
- Ribosomal RNA (rRNA) evolves slowly and is used with fossil evidence to determine relationships between ancient species.



TYPES OF VARIATION

- Interspecific variation refers to the differences between members of different species.
- Intraspecific variation refers to the differences between individuals within the same species.
- Example: In humans, individuals vary in height, build, hair color, and intelligence.

CAUSES OF VARIATION:

1. Genetic variation: Differences in an organism's genetic material (e.g., DNA) inherited from its parents lead to genetic variation.
2. Environmental variation: Differences caused by the environment in which the organism lives.

GENETIC CAUSES OF VARIATION:

1. Alleles: Different forms of a gene, called alleles, lead to variation. For example, the gene for human blood groups has three alleles: A, B, and O.
2. Mutations: Changes to the DNA sequence can result in altered proteins, leading to changes in physical or metabolic traits. Mutations in gametes can be passed to offspring, contributing to genetic variation.
3. Meiosis: During the formation of gametes (sex cells), independent assortment and crossing over shuffle genetic material, resulting in variation.
4. Sexual reproduction: Offspring inherit a unique combination of alleles from two parents, increasing variation compared to asexual reproduction.
5. Chance: During sexual reproduction, the combination of gametes occurs by random fertilization, contributing to genetic diversity.

Points 3, 4, and 5 highlight that sexual reproduction produces greater variation than asexual reproduction, where genetic diversity only increases through mutation.

ENVIRONMENTAL CAUSES OF VARIATION

- Environmental variation is caused by external factors affecting an organism's phenotype.
- For example, two plants of the same species growing in different light conditions will vary in size. A plant with greater sunlight exposure will grow larger than one in the shade, as plants cannot move to seek better conditions.
- Some characteristics are determined purely by environmental factors. For example, scars result from injury or disease and are not inherited.
- Hydrangeas provide an example of environmental variation, as they produce blue flowers in acidic soil and pink flowers in alkaline soil.

COMBINED GENETIC AND ENVIRONMENTAL CAUSES

- Most characteristics result from a combination of genetic and environmental factors. For example:
 - Height: If you inherit genes for tall height but have a poor diet, your growth may be stunted, showing both genetic and environmental influence.
 - Skin color: Skin color is determined by the amount of melanin, a genetically inherited trait. However, exposure to sunlight increases melanin production, causing the skin to darken as an environmental response.
- The difficulty in determining whether a trait is caused by genetics or environment is known as the nature vs. nurture debate.
- Characteristics such as intelligence are influenced by both factors, and no definitive conclusion has been reached on their relative contributions.

DISCONTINUOUS VARIATION

- Discontinuous variation (or discrete variation) occurs when a characteristic has distinct, non-overlapping categories.
- There are no intermediate values.
- Example: Sex (male or female) and blood groups (A, B, AB, or O).
- Genetic factors exclusively determine discontinuous variation, and it is often controlled by a single gene.

Visual representation: Discontinuous variation is usually shown in a bar chart or pie chart.

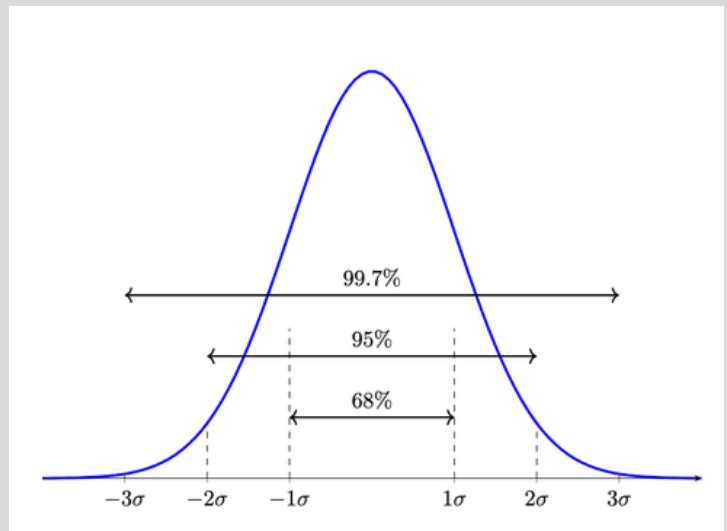
CONTINUOUS VARIATION

- Continuous variation occurs when a characteristic can take any value within a range. It involves a gradual change between extremes, known as a continuum.
- Example: Height and mass in plants and animals.
- Continuous variation is influenced by multiple genes (polygenes) and often involves environmental factors.

Visual representation: Data for continuous variation is collected in a frequency table and plotted as a histogram. A curve is typically drawn to show the trend.

CHARACTERISTICS OF A NORMAL DISTRIBUTION

- The mean, mode, and median are all equal.
- The distribution forms a bell-shaped curve, which is symmetrical about the mean.
- 50% of values are less than the mean, and 50% are greater than the mean.
- Most values cluster around the mean, with fewer values at the extremes.



STANDARD DEVIATION

- Standard deviation is a measure of how spread out the data is.
- A larger standard deviation indicates a greater spread of data, meaning more variation in the characteristic being measured.
- A smaller standard deviation means the data points are more clustered around the mean, indicating less variation.
- In a normal distribution, standard deviation helps to describe the spread of values around the mean.



STUDENT'S T-TEST

- The Student's t-test is used to compare the mean values of two sets of data.
- The data must be normally distributed for the test to be valid.
- Sufficient data should be collected to calculate a reliable mean.
- The test allows for different sample sizes to be used.

If the t-test returns a value that has an absolute value of <0.05 , there is sufficient evidence to reject the null hypothesis

- thus we can conclude that the differences in means are *statistically significant*

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{\sigma_1}{n_1} + \frac{\sigma_2}{n_2}}}$$

$\bar{X}_1, \bar{X}_2$ = mean of populations 1 and 2

σ_1, σ_2 = standard deviation of populations 1 and 2

n_1, n_2 = total number of values in samples 1 and 2

CORRELATION COEFFICIENT

- Correlation occurs when two sets of data show a relationship.
- No correlation: There is no relationship between the two data sets.
- Positive correlation: As one set of data increases, the other set of data also increases.
- Negative correlation: As one set of data increases, the other set of data decreases.

SPEARMAN'S RANK CORRELATION COEFFICIENT

$$\rho = 1 - \frac{6\Sigma d^2}{n(n^2 - 1)}$$

The value returned by Spearman's Rank must fall <0.05 for the correlation to be statistically significant.

ρ = correlation coefficient Σ = the sum (total) of
 d = difference in ranks n = number of pairs of data

1BIOL-6

BIODIVERSITY AND CLASSIFICATION



- Anatomical adaptations: Physical features (internal or external).
- Behavioural adaptations: The way an organism behaves, which can be inherited or learned.
- Physiological adaptations: Internal processes that take place inside the organism.

ANATOMICAL ADAPTATIONS

Some examples include:

- Body covering: Features like hair, scales, or feathers help organisms survive.
- Camouflage: An organism's outer coloration allows it to blend into its environment, making it harder for predators to detect it.
- Teeth: The shape and type of teeth are adapted to the organism's diet.
- Mimicry: Some animals mimic the appearance of others to deter predators.

Plant anatomical adaptations:

Are typically adapted towards minimising transpiratory losses through the use of:

- Curled leaves: Minimize the surface area exposed to the air and protect moist tissues from wind, reducing water loss.
- Hairs on the inside of leaves: Trap moist air close to the leaf, reducing the diffusion gradient and slowing transpiration.
- Sunken stomata: Stomata are positioned in pits, which reduces the chance of water evaporation.
- Thick waxy cuticle: Covers the leaves and stems, further reducing water loss through evaporation.

BEHAVIOURAL ADAPTATIONS

-are actions performed by organisms to increase their chances of survival and reproduction.

- Behavioural adaptations fall under 2 categories: Innate (instinctive) and learned behaviour
- Innate: inherited via genes
- Learned behaviour: learned via experience or from other organisms and not inherited

A behavioural adaptation may be a function of both innate and learned behaviours.

Examples include:

- Survival behaviours: Actions that increase an organism's chance of survival.
- Example: An opossum plays dead when threatened, while a rabbit freezes to avoid detection by predators.
- Courtship behaviours: Behaviours used to attract a mate, increasing the organism's chance of reproduction.
- Example: Scorpions perform a dance to attract a partner.
- Seasonal behaviours: Adaptations that allow organisms to cope with environmental changes.
- Migration: Animals move to a more favourable environment (better climate or food source) and return when conditions improve.
- Hibernation: Periods of inactivity where body temperature, heart rate, and breathing slow to conserve energy, reducing the need for food.
- Example: Brown bears hibernate in winter.

PHYSIOLOGICAL ADAPTATIONS

-are internal processes that help organisms survive in their environments. Examples include:

Poison production:

- Many reptiles produce venom to kill prey.
- Some plants produce poisons in their leaves to deter herbivores.

Antibiotic production:

- Some bacteria produce antibiotics to kill other bacterial species in their surroundings.

Water holding:

- The water-holding frog (*Cyclorana platycephala*) stores water in its body, allowing it to survive in deserts for over a year without water access.
- Cacti and other desert plants store large amounts of water in their tissues.

1BIOL-6

BIODIVERSITY AND CLASSIFICATION



ANALOGOUS STRUCTURES

Analogous structures are features that perform the same function but have different structural and genetic origins.

- For example, the tail fins of a whale and a fish perform the same role in water, but their structures are very different.
- Analogous anatomy demonstrates convergent evolution

Convergent evolution occurs when unrelated species evolve to share similar traits due to selection pressures or similar environmental challenges.

For instance:

- Marsupials in Australia and placental mammals in the Americas resemble each other due to their adaptations to similar environments, despite evolving independently.
- Aloe and agave plants appear similar as they both evolved to survive in deserts. However, aloe evolved in Africa (“old world”), while agave evolved in North America (“new world”).



NATURAL SELECTION

Natural selection is the process by which organisms best adapted to their environment are more likely to survive and reproduce.

- This increases the frequency of their advantageous characteristics in the population.
- The process is influenced by selection pressures, which affect survival and reproductive success.

STEPS IN NATURAL SELECTION:

1. Genetic variation exists within a species due to different alleles (e.g., through mutation).
2. Organisms with advantageous characteristics are better adapted to selection pressures (e.g., predation, competition, disease) and are more likely to survive and reproduce. This is called survival of the fittest.
3. These organisms pass their advantageous alleles to their offspring, while less adapted organisms are less likely to pass on their genes.
4. Over time, the frequency of advantageous alleles increases in the gene pool as the process is repeated across generations.
5. After many generations, this can lead to the evolution of a new species.

MODERN EXAMPLES OF EVOLUTION:

Antibiotic-Resistant Bacteria

- *Staphylococcus aureus* (MRSA) evolved resistance to methicillin.
- Mutation in *S. aureus* provided resistance to the antibiotic.
- When exposed to methicillin, resistant bacteria survived and reproduced.
- The resistant allele frequency increased in the population.

Peppered Moths

- *Biston betularia* experienced environmental changes during the industrial revolution.
- Before, pale moths camouflaged with light-colored tree bark, giving them a survival advantage.
- Post-industrial revolution, tree bark darkened due to soot, favoring dark moths.
- Dark moths increased in frequency due to better camouflage and survival.
- Post Clean Air Act, air quality improved, tree bark lightened, and pale moths increased again.

Sheep Blowflies

- *Lucilia cuprina* developed resistance to diazinon (an organophosphate pesticide).
- Within 6 years, flies with resistant alleles survived and reproduced.
- Research revealed pre-adaptation—resistance alleles existed before diazinon use.
- Resistance spread rapidly in response to environmental selection pressure.

Flavobacterium

- *Flavobacterium* evolved to digest nylon 6 (a human-made material) due to mutations.
- This bacterium produces nylonase enzymes, allowing it to survive in factory waste.
- Evolution resulted from gene duplication and frameshift mutations.



THE IMPORTANCE OF BIODIVERSITY:

- Biodiversity ensures a balanced ecosystem where species depend on each other.
- Examples: Trees provide homes for animals; animals aid in plant growth by consuming plants and producing waste, which microorganisms decompose into fertile soil.
- Reduced biodiversity harms these interconnections, disrupting the balance.
- Biodiversity provides essential resources like food, oxygen, and nutrients.
- Human activities, like farming and land clearing, reduce biodiversity.

MEASURING BIODIVERSITY:

- Biodiversity varies by region, with tropical regions (e.g., Amazon rainforest) being the most biodiverse.
- UK's temperate climate has moderate biodiversity, while arctic and desert regions have the least.
- Measuring biodiversity helps establish a baseline to assess environmental changes.
- Environmental Impact Assessments (EIA) help predict how new projects affect biodiversity.

BIODIVERSITY IS STUDIED AT THREE LEVELS:

- Habitat biodiversity – variety of habitats in an ecosystem.
- Species biodiversity – the number of species in an area.
- Genetic biodiversity – the genetic variation within species.

Habitat Biodiversity:

- Habitat biodiversity refers to the variety of different habitats in an area.
- Each habitat supports multiple species, and more diverse habitats lead to higher species biodiversity.
- Examples: The UK has diverse habitats (meadows, woodlands, streams), leading to high biodiversity. In contrast, Antarctica has low habitat biodiversity due to its ice-covered environment.

Species Biodiversity:

- Species richness – number of different species in an area.
- Species evenness – compares population sizes of species in a community.
- Areas can have similar species richness but differ in species evenness. For example, a cornfield with mostly corn may seem less balanced than a meadow with evenly distributed species.

Genetic Biodiversity:

- Genetic biodiversity is the variety of genes within a species.
- Higher genetic diversity allows for better adaptation and resistance to disease.
- Example: Different alleles in dog breeds lead to variations in traits like coat color and length.

1BIOL-6

BIODIVERSITY AND CLASSIFICATION



SAMPLING:

- involves measuring a subset of individuals to estimate characteristics (e.g., abundance) of a population.
- Used to estimate the number of organisms (abundance) or measure a specific characteristic (e.g., height).
- Results are used to generalize data about the entire population or habitat.

Random Sampling:

- Random sampling means selecting individuals purely by chance, ensuring equal selection probability.

Steps:

1. Grid setup: Mark a grid using tape measures at right angles.
2. Random coordinate generation: Use random numbers for x and y coordinates.
3. Sample collection: Collect samples at the random coordinates.

NON-RANDOM SAMPLING:

- Non-random sampling: Used when random sampling isn't feasible. Includes:

Opportunistic:

- Weakest method, uses readily available organisms but may not be representative.

Stratified Sampling:

- Population divided into strata based on characteristics (e.g., male/female).
- A random sample is taken from each stratum proportional to its size.

Systematic Sampling:

- Sampling different areas of a habitat to study changes across a gradient (e.g., distance from the sea).
- Uses line transect (sampling along a line) or belt transect (samples taken between two parallel lines).

Sampling Bias:

Bias may occur when the selection process is influenced (deliberate or accidental).

- For example, choosing a site with more flowers.
- Reduce bias by using random sampling, removing human involvement.

Chance:

- Chance organisms selected may not represent the whole population (e.g., collecting the longest worms by coincidence).
- Minimize chance by increasing the sample size to improve reliability.

TECHNIQUES FOR SAMPLING ANIMALS:

Pooter:

- Used to collect small insects.
- Insects are drawn into the holding chamber through suction via a mouthpiece.

Sweep nets:

- Used for collecting insects in long grass areas.

Pitfall traps:

- Catch small, crawling invertebrates (e.g., beetles, spiders, slugs).
- A hole is dug in the ground, and the trap is left overnight for nocturnal species.

Tree beating:

- Used to collect invertebrates from trees or bushes.
- A large white cloth is placed under the tree, and the tree is beaten to dislodge animals onto the sheet.

Kick sampling:

- Collects organisms living in a river.
- The river bed is disturbed by kicking, and a net downstream captures organisms released into the water.

SAMPLING PLANTS

Quadrats are used to sample plants or slow-moving animals (e.g., limpets, barnacles, mussels, sea anemones).

Point Quadrat: A frame with a horizontal bar.

- Pins are pushed through the bar at intervals to touch the ground. The species each pin touches is recorded.

Frame Quadrat: A square frame divided into a grid. The type and number of species within each section are recorded.

- To ensure a representative sample:
- Use random sampling methods to avoid bias.
- Place quadrats systematically along a line or belt transect to study variations in organism distribution across an area.



MEASURING SPECIES RICHNESS

- Species richness is a measure of the number of different species living in a specific area.
- Methods involve:
 - Using various sampling techniques to identify species.
 - Compiling a list of all identified species to calculate the total number.
- Identification Keys:
 - Help scientists classify organisms based on identifiable characteristics.
 - Keys may include images or a series of questions to help in identification.

MEASURING SPECIES EVENNESS

- Species evenness refers to the relative abundance of different species in a given area.
- Example: If 50 organisms are found under a log, with various proportions, the evenness is calculated based on how evenly distributed each species is.
 - If evenly distributed, the community is described as “even.”
 - If dominated by one species, it would be considered “uneven.”

USING FRAME QUADRATS

- Frame quadrats are used to sample plant populations in a habitat.

Methods include:

- Density: Counting individual plants in a set area (1m²) to calculate per square meter.
- Frequency: Estimating the number of squares within a quadrat in which a species occurs.
- Percentage Cover: Estimating the area a particular plant species covers within the quadrat.

Quadrat Sampling Tips:

- Larger sample sizes increase reliability.
- Calculate average values from quadrat data to estimate overall species abundance in a habitat.

MEASURING ABIOTIC FACTORS

- Abiotic factors are non-living conditions that affect living organisms.

Examples include:

- Wind Speed: Measured with an anemometer.
- Light Intensity: Measured with a light meter.
- Humidity, pH, Temperature: Measured with specific sensors like humidity probes and pH meters.

Advantages of Using Sensors:

- Can detect rapid changes.
- Minimize human error.
- Achieve high precision.
- Data can be stored and analyzed electronically.



MEASURING BIODIVERSITY:

1. Species Richness: Count the number of species present in the area (species richness).
2. Species Evenness: Take into account how evenly the individuals are distributed among the species (species evenness).

WHY USE SIMPSON'S INDEX OF DIVERSITY?

By combining species richness and evenness, Simpson's Index provides a more accurate reflection of the diversity in an area.

SIMPSON'S INDEX OF DIVERSITY FORMULA:

$$D = 1 - \sum \left(\frac{n}{N} \right)^2$$

$$\sum = \text{sum of (total)}$$

N = the total number of organisms of all species

n = the total number of organisms of a particular species

Interpretation:

- D value range: 0 to 1.
- 0: No diversity.
- 1: Infinite diversity.
- The closer to 1, the more diverse the habitat.

LOW BIODIVERSITY:

- Relatively few successful species
- Stressful or extreme environment with few ecological niches
- Few species, often with very specific adaptations for the environment
- Simple food webs
- Major effects on the ecosystem when the environment changes

HIGH BIODIVERSITY:

- Large number of successful species
- Benign/not stressful environment with more ecological niches
- Many species, often with fewer specific adaptations for the environment
- Complex food webs
- Relatively small effects on the ecosystem when the environment changes



THE IMPORTANCE OF GENETIC BIODIVERSITY

- Genetic biodiversity refers to the variety of alleles present in a population of a species.
- Within species, individuals generally share the same genes, but alleles (different versions of genes) provide variation.
- A higher number of alleles leads to greater genetic diversity.
- Populations with higher genetic diversity are more likely to:
 - Adapt to environmental changes.
 - Survive new threats such as disease.
 - Reproduce, ensuring the survival of the species.

FACTORS THAT INCREASE GENETIC BIODIVERSITY:

- Mutations in DNA can create new alleles.
- Gene flow: Interbreeding between populations introduces new alleles.

FACTORS THAT DECREASE GENETIC BIODIVERSITY:

- Selective breeding (artificial selection): Breeding only individuals with specific traits, reducing diversity.
- Captive breeding programs: Limited genetic diversity due to a small breeding population.
- Rare breeds: Once popular breeds decline, leaving fewer breeding individuals, lowering genetic diversity.
- Artificial cloning: Produces genetically identical offspring, reducing variation.
- Natural selection: Favors alleles that improve survival, leading to the loss of other alleles over time.
- Genetic bottlenecks: Occur when a population drastically reduces, leaving fewer alleles.
- Founder effect: When a small group of individuals establishes a new population, with limited alleles.
- Genetic drift: Random changes in allele frequency, more pronounced in smaller populations.

MEASURING GENETIC DIVERSITY

- Polymorphic genes have more than one allele.
- Monomorphic genes have only one allele, providing no variation.

The proportion of polymorphic loci can be calculated using the formula:

$$\text{Proportion of polymorphic gene loci} = \frac{\text{number of polymorphic loci}}{\text{total number of loci}}$$

locus: the position of an allele on a chromosome

The greater the proportion of polymorphic loci, the higher the genetic biodiversity.



HUMAN INFLUENCE ON BIODIVERSITY

- Human population growth disrupts ecosystems by increasing demand for space, housing, and food production.
- Major causes:
 - Deforestation: Permanent removal of forests for logging, roads, and agriculture.
 - Agriculture: Clearing land for farming, often using monoculture (single crops).
 - Climate change: Rising levels of carbon dioxide and pollutants due to burning fossil fuels, leading to global temperature increases.

DEFORESTATION

Impacts:

- Direct reduction in the number of trees.
- Lower species diversity if specific trees are felled.
- Habitat destruction for animal species, reducing food sources and causing migration.
- Limited reforestation leads to reduced biodiversity restoration.

AGRICULTURE

- Farmers select high-yielding species, reducing species diversity.

Techniques that reduce biodiversity:

- Deforestation to increase farming land.
- Removal of hedgerows: destroys habitats for small animals.
- Pesticides and herbicides: kill pests and plants, lowering species diversity.
- Monoculture: supports only one species, further reducing biodiversity.

CLIMATE CHANGE

Key findings from the IPCC (2007):

- Global temperature has risen 0.13°C per decade for the past 50 years.
- Sea levels rose by 1.8 mm per year from 1961 to 2003.
- Arctic temperatures increased at twice the global average rate in the last 100 years.
- Melting glaciers and ice caps contributed to sea level rise.
- Long-term trends show changes in precipitation patterns since 1900.

GLOBAL WARMING IMPACT ON BIODIVERSITY

- Polar ice cap melting: threatens species in the Arctic.
- Rising sea levels: reduces habitats for freshwater plants and animals.
- Increased temperatures and droughts: harm plant species, leading to dominance of xerophytes.
- Insect population shifts: disrupt plant pollination and spread diseases.

1BIOL-6

BIODIVERSITY AND CLASSIFICATION



AESTHETIC REASONS:

- Different plants and animals enrich our environment, providing enjoyment through nature (e.g., walking in woodlands, beaches).
- The natural world inspires artists, musicians, and writers, enhancing cultural life.
- Studies show that patients recover faster from stress and injury in natural settings.

ECONOMIC REASONS:

- Biodiversity supports long-term productivity by preventing soil erosion and desertification (e.g., deforestation leads to loss of arable land).
- Sustainable use of resources like timber is essential for maintaining economic viability in industries reliant on natural materials.
- High biodiversity provides opportunities for discovering economically valuable species (e.g., medicinal plants).
- Monocultures deplete soil nutrients, increasing reliance on pesticides and fertilizers, making ecosystems fragile.
- High biodiversity protects crops against abiotic stresses and disease (e.g., Irish potato famine was caused by lack of genetic diversity in crops).

ECOLOGICAL REASONS:

- All organisms are interconnected; removal of one species can affect many others (e.g., decomposers maintain nutrient cycles).
- Keystone species maintain the structure of ecosystems and biodiversity; their removal can lead to drastic ecological changes.

HUMAN ACTIVITY VS. BIODIVERSITY

- Human intervention in ecosystems (e.g., farming, grazing, planting hedges) can positively impact biodiversity by maintaining habitats.
- Land management practices, such as controlled burning or grazing, promote biodiversity (e.g., grazing allows rare species to thrive in managed habitats).



IMPORTANCE OF BIODIVERSITY CONSERVATION:

- Conservation: Preservation and careful management of the environment and natural resources.
- Biodiversity: Maintains ecosystem stability and species survival, safeguarding genetic diversity.

CONSERVATION METHODS:

1. In situ conservation:
 - Takes place in the natural habitat.
 - Protects species' genetic diversity and promotes interaction with other species.
 - Cheaper and allows evolutionary adaptation.
2. Ex situ conservation:
 - Takes place outside the natural habitat (e.g., zoos, seed banks).
 - Usually implemented alongside in situ methods to ensure survival.

SPECIES CLASSIFICATION FOR CONSERVATION:

- Extinct: No individuals of the species exist.
- Extinct in the wild: Species only survive in captivity.
- Endangered: Species are at risk of extinction.
- Vulnerable: Species likely to become endangered soon.

IN SITU CONSERVATION METHODS:

- Wildlife reserves: Actively managed areas with controlled grazing, restricted access, poaching control, feeding, species reintroduction, and invasive species removal.
- Succession control: Prevent natural succession through controlled grazing to maintain certain habitats, like heathlands.

ACTIVE MANAGEMENT IN WILDLIFE RESERVES:

- Controlled grazing: Allows species recovery by limiting livestock grazing periods.
- Restricting human access: Prevents disturbance during sensitive periods, such as breeding seasons.
- Controlling poaching: Implements fines and security measures to protect species.
- Feeding animals: Supports species survival until reproductive maturity.
- Species reintroduction: Reintroduces species to areas where they became extinct.
- Culling/removing invasive species: Removes species that disrupt native ecosystems.
- Halting succession: Prevents early colonizing species from altering habitats, such as transitioning from heathland to woodland.

MARINE CONSERVATION ZONES

- Marine reserves protect species-rich areas (e.g., coral reefs).
- Purpose: Create safe refuge zones within marine areas, not just prevent fishing.



EX SITU CONSERVATION

- Definition: Involves removing organisms from their natural habitat for protection and survival.

Botanic Gardens

- Provide optimal resources (e.g., nutrients, watering) for plant growth.
- House 35,000 plant species in over 1,500 gardens worldwide.
- Help conserve wild relatives of crop species, offering genetic resources (e.g., pest/disease resistance).

Seed Banks

- Store genetic material (e.g., seeds), preserved at low temperatures (-20°C).
- Ensure seeds remain viable, serving as a backup against extinction (e.g., Svalbard 'Doomsday Vault').
- Store 800,000 species; long-term goal: 3 million types.
- Limitations: Some seeds (e.g., tropical rainforest trees) don't survive drying and freezing.

Captive Breeding Programs

- Produce species in controlled environments (zoos, aquariums).
- Example: National Marine Aquarium for sea horses.
- Aim: Create stable, healthy populations for reintroduction into the wild (e.g., Arabian Oryx).

Challenges in Captive Breeding

1. Disease Resistance: Loss of immunity to local diseases.
2. Behavior: Learned behavior for survival in the wild is difficult.
3. Genetic Races: Differences between captive and wild populations, leading to potential interbreeding issues.
4. Habitat: Restoring and ensuring suitable natural habitats for reintroduction.

CONSERVATION AGREEMENTS:

- International Cooperation is crucial for preserving biodiversity across borders.
- Animals don't respect boundaries, so cross-border protection is vital to ensure their survival.

International Union for the Conservation of Nature (IUCN):

- Intergovernmental organization working on global conservation efforts.
- Publishes the Red List yearly to indicate the conservation status of threatened species.
- Encourages nations to collaborate on protecting species.

Specific International Agreements:

1. Convention on International Trade in Endangered Species (CITES):

- Regulates international trade of wild plants and animals.
- Protects over 35,000 species from over-exploitation by controlling cross-border trade.

2. The Rio Convention (1992 Earth Summit):

- Brought together 172 nations to address environmental concerns.
- Includes key agreements like:
 - Convention on Biological Diversity (CBD): Requires countries to create national strategies for sustainable development, maintaining biodiversity.
 - UN Framework Convention on Climate Change (UNFCCC): Stabilizes greenhouse gas concentrations.
 - UN Convention to Combat Desertification (UNCCD): Prevents land degradation and combats drought through international cooperation.

Countryside Stewardship Scheme (UK):

- Focuses on local conservation efforts.
- Operated from 1991–2014, supporting farmers and land managers to enhance and conserve the landscape.
- Specific aims:
 - Sustain the beauty and diversity of landscapes.
 - Create and extend wildlife habitats.
 - Conserve historic and archaeological sites.
 - Improve countryside enjoyment opportunities

This scheme has been replaced by the Environmental Stewardship Scheme, which works similarly.

COMMUNICABLE DISEASES

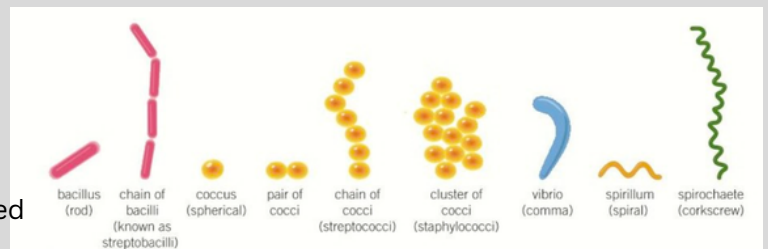
- Pathogens: Infectious organisms such as bacteria, viruses, fungi, and protoctista.
- Transmission: Can be passed between organisms (in animals, typically from individual to individual; in plants, from plant to plant).
- Vectors: Agents like water and insects that carry pathogens between hosts.
- Global Impact: Communicable diseases cause 13 million deaths annually (23% of all deaths).

TYPES OF PATHOGENS

Bacteria:

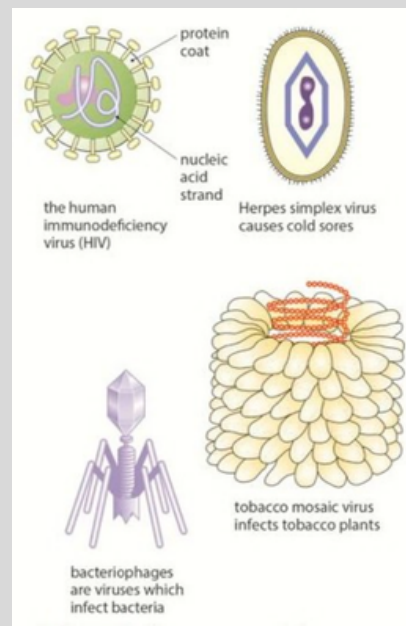
- Characteristics:
 - Prokaryotic cells (no membrane-bound nucleus or organelles).
 - Differ from eukaryotic organisms in structure.
- Classifications:
 - Shape: Rod-shaped (bacilli), spherical (cocci), comma-shaped (vibrios), spiral (spirilla), corkscrew (spirochaetes).
 - Cell Walls:
 - Gram-positive: Appear purple-blue under a microscope (e.g., MRSA).
 - Gram-negative: Appear red (e.g., E. coli).

Cell wall differences affect how bacteria respond to antibiotics.



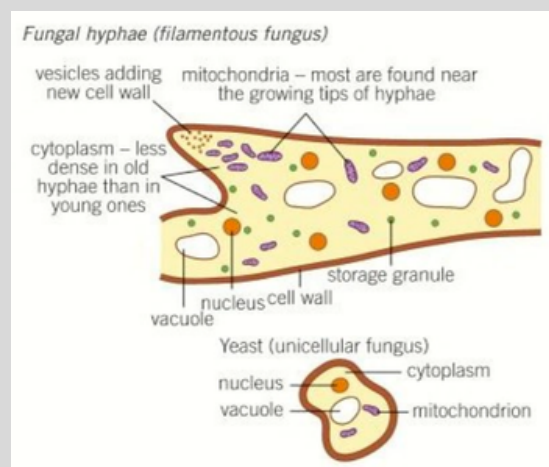
Viruses

- Non-living infectious agents: Viruses are not classified as living organisms.
- Size: 0.02–0.3 μm in diameter (about 50 times smaller than bacteria).
- Structure: Consists of genetic material (DNA or RNA) surrounded by a protein coat.
- Reproduction: Invades host cells, takes over the host's biochemistry, and reproduces more viruses.
- Pathogenicity: All naturally occurring viruses are pathogens, causing diseases in every type of organism.
- Bacteriophages: Viruses that attack bacteria. Used in research to treat some diseases.
- Parasites: Viruses are considered ultimate parasites as they rely completely on a host cell for reproduction and survival.



Fungi

- Primarily problematic in plants but can affect animals.
- Eukaryotic, multicellular organisms (e.g., yeast causing human diseases).
- Fungi digest food extracellularly and absorb nutrients, cannot photosynthesize.
- Pathogenic fungi can destroy crops, leading to significant agricultural losses.
- Spread through spores, making them capable of traveling long distances.



MODES OF ACTION OF PATHOGENS:

DAMAGING THE HOST TISSUES DIRECTLY

Viruses:

- Take over cell metabolism by inserting viral genetic material into the host's DNA.
- New viruses form inside the host cell, eventually causing the cell to burst and release viruses to infect other cells.

Protista:

- Enter host cells, digest them, and use the cell contents to reproduce.
- Protists like those causing malaria damage cells without altering their genetic material.

Fungi:

- Digest and destroy living cells.
- The body's response to the damage caused by fungi often results in symptoms of disease.

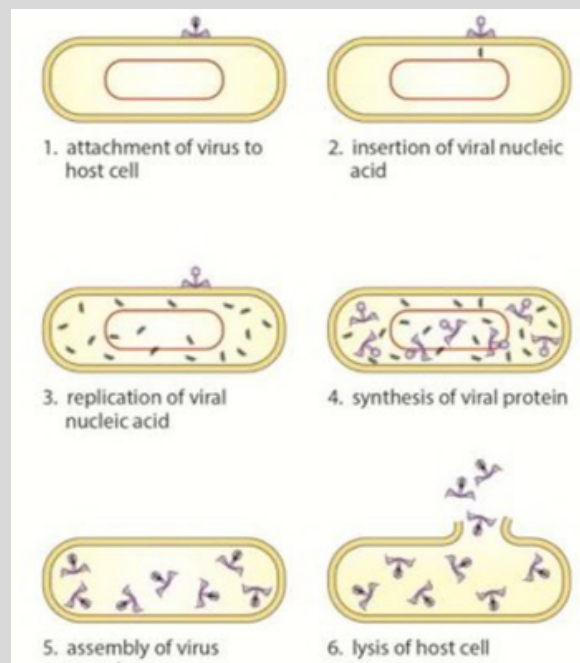
PRODUCING TOXINS THAT DAMAGE HOST TISSUES

Bacteria:

- Produce toxins that poison or damage host cells, leading to disease.
- Toxins may break down cell membranes, inactivate enzymes, or interfere with genetic material, disrupting normal cell functions.

Fungi:

- Some produce toxins that also harm host cells and contribute to disease.



PLANT DISEASES AND THEIR EFFECTS ON PLANTS:

1. Ring rot:

- Pathogen: Gram-positive bacterium *Clavibacter michiganensis*.
- Host plants: Potatoes, tomatoes, aubergines.
- Effect: Destroys leaves, tubers, fruit. Can wipe out up to 80% of the crop.
- No cure: Infected fields cannot grow potatoes for at least two years.

2. Tobacco mosaic virus (TMV):

- Pathogen: TMV virus.
- Host plants: Tobacco and over 150 species, including tomatoes, peppers, and cucumbers.
- Effect: Damages leaves, flowers, and fruit, reducing yield and causing crop loss.
- Management: No cure, but resistant crop strains available.

3. Potato blight (Late blight):

- Pathogen: Fungus-like protist *Phytophthora infestans*.
- Host plants: Potatoes, tomatoes.
- Effect: Hyphae destroy leaves, tubers, and fruit, leading to significant financial loss.
- Management: No cure, but resistant strains and chemical treatments help reduce infection.

4. Black sigatoka:

- Pathogen: Fungus *Mycosphaerella fijiensis*.
- Host plant: Bananas.
- Effect: Destroys leaves, causes a 50% yield reduction.
- Management: No cure, but fungicide treatment and resistant strains help manage the disease.

ANIMAL DISEASES

Tuberculosis (TB):

- Bacterial infection caused by *Mycobacterium tuberculosis* and *M. bovis*.
- Affects humans and animals like cows, pigs, badgers, and deer.
- Destroys lung tissue and weakens the immune system.
- 2012 Statistics: 8.6 million cases worldwide; 1.3 million deaths.
- Strong association with HIV/AIDS due to immunocompromisation
- TB is curable with antibiotics and preventable through improved living conditions and vaccination.

Bacterial Meningitis:

- Infection of brain membranes (*Streptococcus pneumoniae* or *Neisseria meningitidis*).
- Rapidly spreads, leading to septicaemia (blood poisoning) and death.
- Symptoms include a red rash, and immediate treatment is essential.
- Treatment: Antibiotics if caught early; vaccines prevent some forms.

HIV/AIDS:

- Virus (HIV) targets T helper cells, compromising the immune system.
- Transmission: Through bodily fluids (e.g., unprotected sex, shared needles).
- Affects both humans and some primates.
- 2012 Statistics: 35 million living with HIV; 1.6 million deaths.
- No cure, but antiretroviral drugs can slow the progression.

Influenza (Flu):

- Viral infection (*Orthomyxoviridae* spp.) affecting mammals and birds.
- Kills cells in the respiratory system, leading to secondary infections.
- Strain A is the most virulent (e.g., A(H1N1), A(H3N2)).
- Frequent mutations make annual vaccinations essential.
- There is no permanent cure.



MALARIA:

- Cause: Plasmodium (a protist) transmitted by Anopheles mosquitoes (vector).
- Life cycle: Requires two hosts (humans and mosquitoes); reproduces in the mosquito.
- Transmission: Female mosquito takes blood meals to nourish eggs, passing the parasite to humans.
- Effect on the body: Parasite invades red blood cells, liver, and brain.
- Prevalence: Affects ~200 million people annually; over 600,000 deaths.
- Control: No vaccine; focus on vector control using insecticides, removing breeding sites, and using protective measures like mosquito nets.

RINGWORM:

- Cause: Fungal infection in mammals (e.g., cattle, dogs, humans), commonly by Trichophyton verrucosum in cattle.
- Symptoms: Circular, grey-white, crusty, itchy patches on the skin.
- Treatment: Antifungal creams are effective.

ATHLETE'S FOOT:

- Cause: Fungal infection in humans caused by *Tinia pedis* (a form of ringworm).
- Symptoms: Cracking, scaling, and itching between toes; moist areas between skin are affected.
- Treatment: Antifungal creams are effective.



TRANSMISSION OF PATHOGENS BETWEEN ANIMALS

Understanding how diseases spread between individuals helps in finding ways to prevent transmission. There are two main types of transmission: direct and indirect.

DIRECT TRANSMISSION:

- Direct contact (contagious diseases):
Kissing or contact with body fluids (e.g., bacterial meningitis), skin-to-skin contact (e.g., ringworm, athlete's foot), or microorganisms from feces (e.g., diarrheal diseases).
- Inoculation:
Through breaks in the skin (e.g., sex with HIV/AIDS), animal bites (e.g., rabies), or punctures (e.g., sharing needles).
- Ingestion:
Consuming contaminated food or water (e.g., amoebic dysentery).

INDIRECT TRANSMISSION:

- Fomites: Inanimate objects like bedding, socks, or cosmetics that can transfer pathogens (e.g., Staphylococcus infections).
- Droplet infection (inhalation): Pathogens in saliva or mucus expelled while talking, coughing, or sneezing (e.g., influenza, tuberculosis).
- Vectors: Animals like mosquitoes transmitting malaria, rat fleas spreading the plague, or rabies from foxes and bats. Water can also act as a vector (e.g., diarrheal diseases).

TRANSMISSION BETWEEN ANIMALS AND HUMANS:

- Diseases such as bird flu (H1N1) or brucellosis can pass from animals to humans. Avoiding close contact with animals and practicing good hygiene reduces this risk. People can act as vectors of animal diseases (e.g., foot-and-mouth disease).

Factors affecting the transmission of communicable diseases in animals:

- Overcrowded conditions, poor nutrition, and compromised immune systems (e.g., AIDS).
- Poor waste disposal providing breeding sites for vectors.
- Climate change, which introduces new vectors and diseases.
- Socioeconomic factors like lack of healthcare workers and infrastructure.

TRANSMISSION OF PATHOGENS BETWEEN PLANTS

Direct transmission:

- Pathogens are passed directly between plants via direct contact. Examples include ring rot, TMV, potato blight, and black sigatoka.

Indirect transmission:

Soil contamination:

- Infected plants leave pathogens in the soil, which can infect subsequent crops (e.g., black sigatoka, ring rot).

Vectors:

- Wind: Spores can be carried by the wind (e.g., black sigatoka, *P. infestans*).
- Water: Spores swimming in water can infect leaves (e.g., *P. infestans*).
- Animals: Insects and birds can carry pathogens from plant to plant.
- Humans: Pathogens are transmitted through contaminated hands, tools, and farming practices (e.g., TMV).

Factors affecting the transmission of communicable diseases in plants:

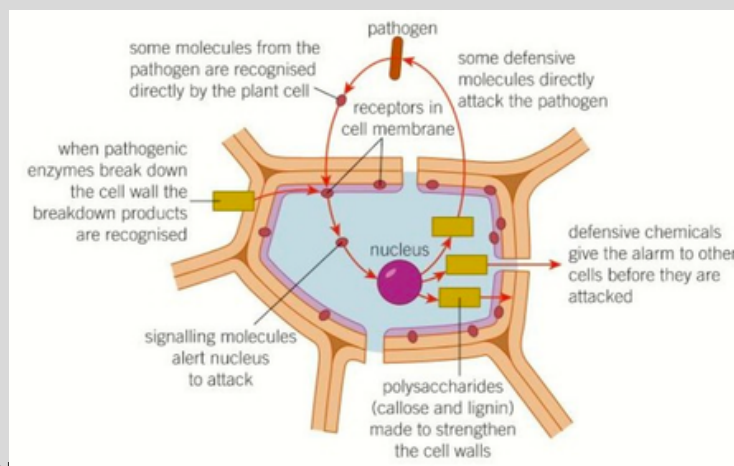
- Planting crops susceptible to disease, overcrowding, poor nutrition, damp/warm conditions, and climate change (e.g., increased rainfall promoting disease spread).

PHYSICAL DEFENCES:

- Plants develop barriers like the waxy cuticle, bark, and cellulose cell walls to prevent pathogens from entering.
- Diseased tissue is sealed off and sacrificed since plants do not heal it, allowing them to replace damaged parts through continuous growth at the meristems.

RECOGNISING AN ATTACK:

- Receptors in plant cells detect pathogen molecules or chemicals from the plant cell wall when attacked.
- This triggers the release of signalling molecules that activate genes in the nucleus, leading to cellular responses.
- Responses include the production of defensive chemicals, sending alarm signals to other cells, and strengthening the cell walls.



CALLOSE PRODUCTION:

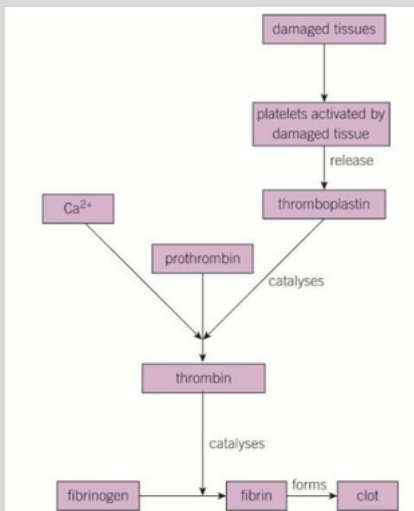
- Callose is a polysaccharide produced in response to attack, containing β -1,3 and β -1,6 linkages between glucose.
- Within minutes of an attack, callose is deposited between cell walls and membranes around the infection site to block pathogen entry.
- Additional callose and lignin are produced to thicken and strengthen barriers.
- Callose also blocks sieve plates in the phloem, halting the pathogen's spread.
- Callose in the plasmodesmata seals off infected cells from neighboring cells.

CHEMICAL DEFENCES:

- Insect repellents (e.g., pine resin, citronella).
- Insecticides (e.g., pyrethrins from chrysanthemums, caffeine as an insect neurotoxin).
- Antibacterial compounds, such as phenols and defensins, disrupt bacterial cell membranes.
- Antifungal compounds, like phenols, caffeine, and chitinases (break down chitin in fungal cell walls).
- Anti-oomycetes, such as glucanases, break down glucans found in oomycetes.
- General toxins, like cyanogenic compounds, release cyanide to defend against various pathogens.

NON-SPECIFIC DEFENCES (PHYSICAL BARRIERS)

- Skin: Acts as a physical barrier, with healthy microorganisms competing against pathogens for space. Sebum inhibits pathogen growth.
- Mucous Membranes: Line tracts like the gas exchange system, trapping microorganisms. Mucus contains lysozymes and phagocytes to break down pathogens.
- Lysozymes: Found in tears and urine, breaking down bacterial cell walls.
- Acid in Stomach: Kills pathogens ingested with food.
- Expulsive Reflexes: Coughs and sneezes eject pathogens from the gas exchange system.



BLOOD CLOTTING AND WOUND REPAIR

- Thromboplastin: Enzyme that triggers a blood clotting cascade, forming a clot to seal wounds and prevent pathogen entry.
- Serotonin: Constricts blood vessels, reducing blood flow to the wound area.
- Scab Formation: Scab forms over a clot to keep pathogens out, while epithelial cells grow underneath, healing the wound. Collagen strengthens the new tissue. Once the epidermis reaches normal thickness, the scab sloughs off.

INFLAMMATORY RESPONSE

- Definition: A localized response to pathogens, damage, or irritants. Inflammation is characterized by pain, heat, redness, and swelling.
- Mast Cells: Activated in damaged tissue and release two key chemicals: Histamines:
 - Cause blood vessels to dilate, leading to localized heat and redness.
 - Increase blood vessel permeability, allowing plasma to escape into tissues, causing swelling (oedema) and pain.
- Cytokines:
 - Attract white blood cells (phagocytes) to the site, where they engulf and destroy pathogens through phagocytosis.

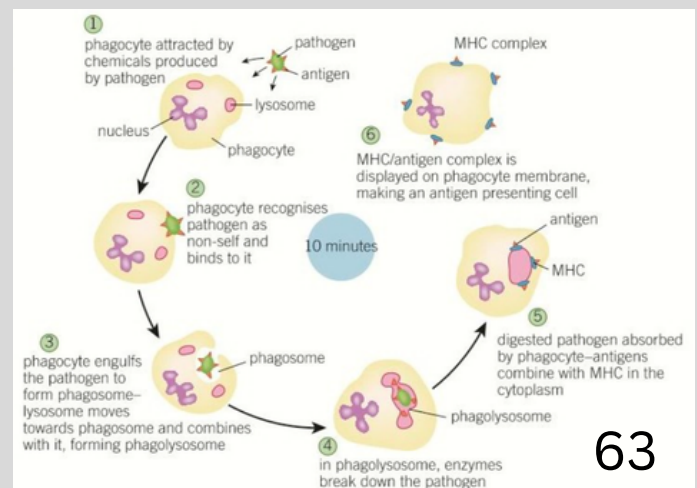
NON-SPECIFIC DEFENCES:

Fevers:

- Normal body temperature (~37°C) maintained by the hypothalamus.
- Cytokines stimulate the hypothalamus to raise body temperature to inhibit pathogen reproduction.
- Higher temperatures: Make the immune system work faster.

Phagocytosis:

- Phagocytes: Specialised white blood cells (neutrophils and macrophages) that engulf pathogens.
- Stages of Phagocytosis:
 1. Pathogens produce chemicals to attract phagocytes.
 2. Phagocytes recognise non-self proteins on the pathogen.
 3. Phagocytes engulf the pathogen, forming a phagosome.
 4. Phagosome fuses with lysosome to form a phagolysosome.
 5. Enzymes from the lysosome digest and destroy the pathogen.





PHAGOCYTOSIS PROCESS AND ROLE OF MACROPHAGES

- Neutrophils: Engulf and destroy bacteria in under 10 minutes.
- Macrophages: Take longer but engage in a more complex process.
- After digesting the pathogen, macrophages present antigens from the pathogen's surface membrane.
- Antigens bind to major histocompatibility complex (MHC) glycoproteins.
- The macrophage becomes an antigen-presenting cell (APC), which stimulates other immune cells for a specific immune response.

Counting Blood Cells

- Involves observing blood smears under a microscope, often stained to highlight lymphocytes' nuclei.
- Counting different lymphocyte types helps identify whether the immune response is non-specific or specific.

HELPFUL CHEMICALS IN IMMUNE RESPONSE

Cytokines:

- Produced by phagocytes after engulfing a pathogen.
- Function as cell-signaling molecules, alerting other phagocytes of an attack.
- Stimulate the immune system and increase body temperature (fever response).

Opsonins:

- Bind to pathogens to "tag" them for phagocytes.
- Phagocytes have receptors on their membrane to bind opsonins, making it easier to engulf the pathogen.
- Immunoglobulin G (IgG) and Immunoglobulin M (IgM) are examples of opsonins, with IgM being the strongest.

ANTIGENS AND IMMUNE RESPONSE

Antigens: Molecules on cell surfaces that distinguish between self and non-self cells.

Antibodies: Polypeptides produced in response to antigens, which help defend the body.

The specific immune system (active/acquired immunity) responds more slowly than non-specific defences but reacts quicker to repeat infections.

ANTIBODIES (IMMUNOGLOBULINS)

Antibodies: Y-shaped glycoproteins that bind to specific antigens.

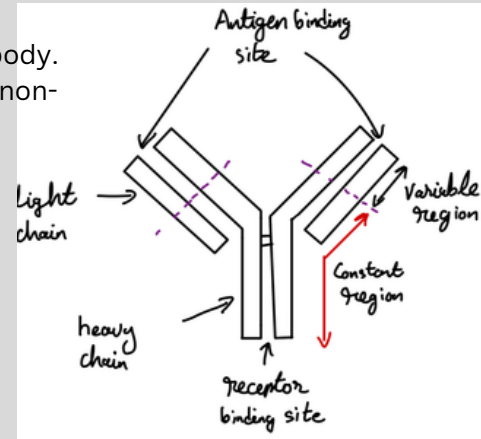
Made up of:

Two heavy chains and two light chains, held by disulfide bridges.

Variable region: Binding site, specific for each antibody (110 amino acids).

Constant region: Same for all antibodies.

Antibodies form an antigen-antibody complex when they bind to antigens.



HOW ANTIBODIES DEFEND THE BODY

• **Opsonization:** Antigen-antibody complex acts as an opsonin, making pathogens easier to engulf by phagocytes.

• **Neutralization:** Prevent pathogens from entering host cells by blocking their binding.

• **Agglutination:** Causes pathogens to clump together (agglutinate), making it easier for phagocytes to engulf them.

• **Anti-toxins:** Bind to toxins produced by pathogens, neutralizing them.

LYMPHOCYTES AND THE IMMUNE RESPONSE

• **Lymphocytes:** White blood cells that are central to the specific immune response.

• B lymphocytes mature in the Bone marrow.

• T lymphocytes mature in the Thymus gland.

TYPES OF T LYMPHOCYTES:

T helper cells:

• Have CD4 receptors that bind to antigens on APCs (antigen-presenting cells).

• Produce interleukins (a type of cytokine) that stimulate:

• B cell activity and antibody production.

• Production of other T cells.

• Attraction of macrophages to engulf pathogens.

T killer cells:

• Destroy pathogens carrying antigens by producing perforin, which makes the cell membrane permeable.

• T memory cells:

• Provide long-term immunological memory.

• Respond rapidly by cloning T killer cells upon re-exposure to the antigen.

T regulator cells:

• Suppress the immune response after a pathogen has been eliminated.

• Prevent autoimmune responses by ensuring the body recognizes self-antigens.

• Interleukins play a role in this regulation.

TYPES OF B LYMPHOCYTES:

Plasma cells:

• Produce and release antibodies into circulation.

• Active for a few days but produce around 2000 antibodies per second.

B effector cells:

• Divide to form plasma cell clones.

B memory cells:

• Provide long-term immunological memory.

• Rapidly respond when a pathogen carrying the specific antigen is encountered again.

CELL-MEDIATED IMMUNITY

- T lymphocytes respond to cells altered by virus infection, antigen processing, or mutation (e.g., cancer cells), and transplanted tissue.
- This immune response is essential for fighting viruses and early cancers.

1. NON-SPECIFIC DEFENSE:

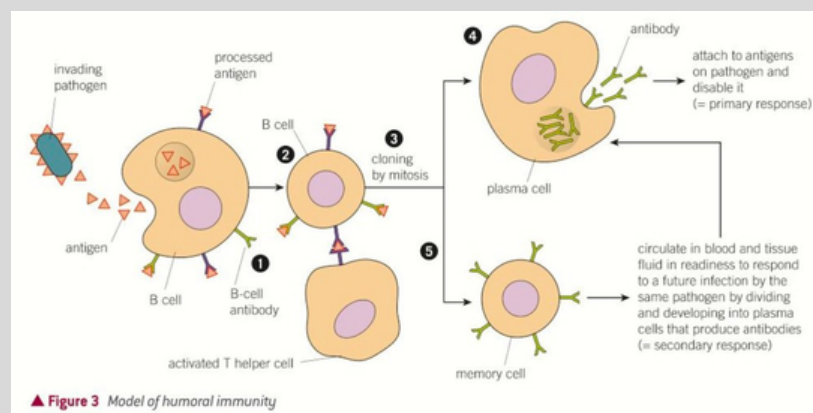
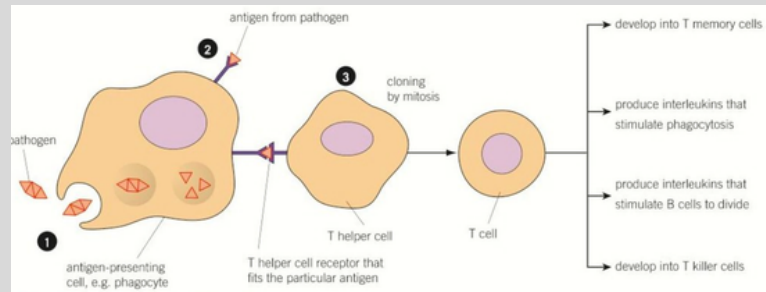
- Macrophages perform phagocytosis, engulfing and digesting pathogens.
- They process antigens and present them on their surface, forming antigen-presenting cells (APCs).

2. ACTIVATION OF T HELPER CELLS:

- T helper cells have receptors that recognize specific antigens on APCs.
- They activate and release interleukins, causing T cells to divide rapidly by mitosis, forming clones.

3. FUNCTIONS OF CLONED T CELLS:

- T memory cells: Provide a faster response to future invasions by the same pathogen.
- Produce interleukins that:
- Stimulate phagocytosis.
- Stimulate B cell division.
- T killer cells: Destroy infected cells.



▲ Figure 3 Model of humoral immunity

HUMORAL IMMUNITY

- Humoral immunity targets antigens found outside cells, such as bacteria, fungi, and antigens presented by APCs.
- It relies on B lymphocytes that have specific antibodies (IgM or IgG) on their surface. When an antigen enters the body, a B cell with the complementary antibody binds, engulfs, and presents it as an APC.

1. ACTIVATION OF B CELLS:

- T helper cells bind to the B cell APC. This is called clonal selection, where the B cell with the correct antibody is selected.

- Interleukins produced by the activated T helper cells stimulate B cell activation.

2. CLONAL EXPANSION:

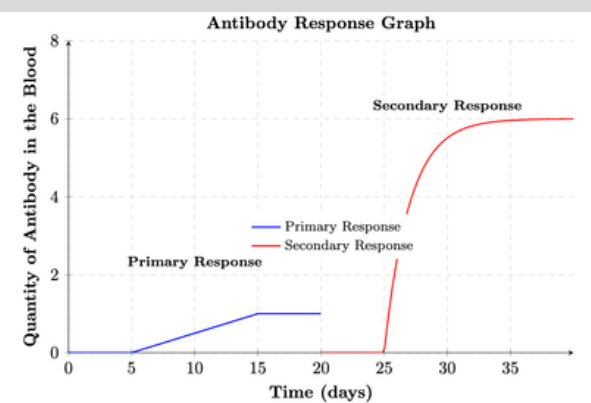
- The activated B cell divides by mitosis to form clones of plasma cells and memory B cells. This is clonal expansion.

3. PRIMARY IMMUNE RESPONSE:

- Plasma cells produce antibodies that bind to the antigens on pathogens acting as opsonins or agglutinins.
- This process can take days to weeks, leading to the primary immune response. Symptoms arise during this time because pathogens divide freely before the immune response is fully active.

4. SECONDARY IMMUNE RESPONSE:

- Some cloned B cells develop into B memory cells.
- Upon reinfection by the same pathogen, these memory cells divide rapidly, producing antibodies and eliminating the pathogen quickly, resulting in a secondary immune response, which prevents the onset of symptoms.





AUTOIMMUNE DISEASES

- The immune system mistakenly attacks healthy “self” cells, resulting in autoimmune diseases.
- Causes are not fully understood, but there may be a genetic tendency. Sometimes, T regulator cells fail to function properly, or the immune system responds abnormally to mild pathogens or normal body microorganisms.
- There are about 80 known autoimmune diseases, causing chronic inflammation or destruction of healthy tissue.
- Immunosuppressant drugs can help manage these conditions but weaken the body’s defenses against other diseases.

EXAMPLES OF AUTOIMMUNE DISEASES:

1. Type 1 Diabetes:
 - Affects: Insulin-secreting cells of the pancreas.
 - Treatment: Insulin injections, pancreas transplants, immunosuppressant drugs.
2. Rheumatoid Arthritis:
 - Affects: Joints (especially hands, wrists, ankles, feet).
 - Treatment: No cure, anti-inflammatory drugs, steroids, immunosuppressants, pain relief.
3. Lupus:
 - Affects: Often affects skin and joints, can attack any organ (e.g., kidneys, liver, lungs, brain).
 - Treatment: No cure, anti-inflammatory drugs, steroids, immunosuppressants.



NATURAL IMMUNITY:

is acquired through natural processes in the body, without medical intervention.

1. NATURAL ACTIVE IMMUNITY:

- When the body encounters a pathogen for the first time, the immune system activates, producing antibodies and destroying the antigen.
- The immune system creates T and B memory cells, allowing for a faster and stronger response if the pathogen is encountered again.
- This is termed natural active immunity because the body itself produces antibodies and memory cells after exposure to the antigen.

2. NATURAL PASSIVE IMMUNITY:

- A newborn baby has an immature immune system and relies on protection from the mother.
- Antibodies are transferred from the mother to the baby through the placenta during pregnancy and through colostrum (the first milk) after birth.
- These maternal antibodies provide immunity until the baby's immune system starts producing its own antibodies.
- This is known as natural passive immunity, as the baby receives antibodies without directly producing them.

ARTIFICIAL IMMUNITY:

-Some diseases can be fatal before the body produces sufficient antibodies. Artificial immunity provides protection without exposure to live pathogens.

1. ARTIFICIAL PASSIVE IMMUNITY:

- Antibodies from another individual (often an animal) are injected into a person's bloodstream, providing temporary immunity.
- Example: Tetanus injections contain antibodies from horses to prevent the disease but do not provide long-term immunity.
- Example: Rabies treatments use a series of injections to provide this form of temporary immunity.

2. ARTIFICIAL ACTIVE IMMUNITY (VACCINATION):

- In artificial active immunity, the body is stimulated to produce its own antibodies by exposure to a safe form of the antigen through vaccination.
- Vaccines do not contain live pathogens but instead use safe antigens to avoid causing the disease.

Vaccines may include:

- Killed or inactivated bacteria/viruses (e.g., whooping cough).
- Attenuated (weakened) strains (e.g., rubella, polio).
- Toxins altered and detoxified (e.g., diphtheria, tetanus).
- Isolated antigens (e.g., influenza).
- Genetically engineered antigens (e.g., hepatitis B).

Process:

1. The antigen is made safe and injected into the blood.
2. The body's primary immune response is triggered, producing antibodies and memory cells.
3. If exposed to the live pathogen later, the body's secondary immune response rapidly destroys it, preventing symptoms.
4. Immunity may last years or a lifetime, and boosters can extend the period of protection.



ARTIFICIAL IMMUNITY

• Some diseases can be fatal before the immune system produces enough antibodies. Artificial immunity provides protection without exposure to live pathogens.

1. ARTIFICIAL PASSIVE IMMUNITY:

- Antibodies are obtained from another individual (often an animal) and injected into the bloodstream, providing temporary immunity.
- Example: Tetanus injections use antibodies from horses to prevent the disease temporarily.
- Example: Rabies treatment involves a series of injections that offer temporary protection.

2. ARTIFICIAL ACTIVE IMMUNITY (VACCINATION):

- Vaccines stimulate the immune system to produce its own antibodies by introducing a safe form of the antigen.
- The antigen is not the live pathogen, preventing the risk of causing the disease.

Types of vaccines:

- Killed or inactivated bacteria/viruses (e.g., whooping cough).
- Attenuated (weakened) strains (e.g., rubella, polio).
- Detoxified toxins (e.g., diphtheria, tetanus).
- Isolated antigens (e.g., influenza).
- Genetically engineered antigens (e.g., hepatitis B).

VACCINATION PROCESS:

1. The pathogen is made safe and injected into the blood.
2. The immune system triggers a primary immune response, producing antibodies and memory cells.
3. If exposed to the live pathogen later, a secondary immune response destroys it rapidly.
4. Immunity may last years or a lifetime. Boosters may be required to extend the duration of protection.

VACCINES AND THE PREVENTION OF EPIDEMICS

- Vaccines provide long-term immunity and help prevent epidemics.
- An epidemic occurs when a communicable disease spreads rapidly among many people at a local or national level.
- A pandemic is when the disease spreads across several countries or continents.

HOW VACCINES PREVENT EPIDEMICS:

- At the start of an epidemic, mass vaccination can stop the pathogen from spreading widely.
- Vaccines may need to be updated regularly to remain effective in preventing epidemics.
- When enough people are vaccinated, it creates herd immunity, protecting those who cannot be vaccinated by reducing the chances of an outbreak.

COMMUNICABLE DISEASES WITHOUT VACCINES

Some communicable diseases cannot yet be prevented by vaccination. Examples include:

- Malaria: Caused by the Plasmodium protist, which hides inside erythrocytes, evading the immune system. It can also reshuffle its antigens within an infected individual.
- HIV (Human Immunodeficiency Virus): Causes AIDS by entering macrophages and T helper cells, disabling the immune system itself.

Despite ongoing research, no vaccines have been developed for these diseases, which affect millions of people worldwide each year.



MEDICINES AND THE MANAGEMENT OF DISEASE

- Medicines treat both communicable and non-communicable diseases, alleviating symptoms or curing them.
- Common medicines include painkillers, anti-inflammatories, and anti-acid medicines (for indigestion).
- Cures include chemotherapy for cancer, antibiotics to kill bacteria, and antifungals for fungal pathogens.

SOURCES OF MEDICINES:

- Penicillin: The first widely used antibiotic, discovered by Alexander Fleming from the mould *Penicillium chrysogenum*. Initially tested on *Staphylococcus* cultures, it later became a critical treatment for bacterial infections, thanks to industrial development by Howard Florey and Ernst Chain.
- Today's medicines come from various sources. Computer programs help design drugs by modeling key molecules in pathogens, allowing the identification of potential drug targets. This includes searching through chemical libraries for compounds that can act against pathogens or cancer cells.
- The genomes of pathogens and cancer-linked genes are analyzed to create novel drugs that target specific vulnerabilities.

COMMON MEDICINAL DRUGS FROM LIVING ORGANISMS:

1. Penicillin: Sourced from mould; an effective antibiotic against bacterial diseases.
2. Docetaxel/Paclitaxel: Derived from yew trees, used in breast cancer treatment.
3. Aspirin: Based on compounds from willow bark; used as a painkiller, anti-coagulant, and anti-inflammatory.
4. Prialt: Derived from cone snail venom; a powerful painkiller, 1000 times more effective than morphine.
5. Vancomycin: Sourced from a soil fungus; one of the most powerful antibiotics.
6. Digoxin: Based on digitoxin from foxgloves; treats heart conditions such as atrial fibrillation.

BIODIVERSITY AND DRUG DISCOVERY

- Biodiversity is rapidly being lost due to habitat destruction, deforestation, and human activity.
- The loss of species could mean the loss of potential life-saving drugs, as only a fraction of life on Earth has been analyzed for medicinal potential.
- Preserving biodiversity is essential as plants, animals, and microorganisms could hold the key to future medicines.

PHARMACOGENETICS:

- Personalized medicine tailors drugs to an individual's genetics and disease profile.
- The human genome is now easily analyzed, helping to understand the genetic basis of diseases.
- Pharmacogenomics is the study of how drugs interact with a person's genetic material.
- Example: About 30% of breast cancer cases involve the HER2 gene, which can be treated with drugs like trastuzumab (Herceptin) and lapatinib. Analyzing patient tumors can reduce breast cancer deaths by up to 50%.

SYNTHETIC BIOLOGY:

- Synthetic biology uses genetic engineering to produce drugs using bacteria as biological factories.
- Mammals have been genetically modified to produce therapeutic proteins in their milk.
- Nanotechnology is another area, using tiny particles to deliver drugs directly to cells in pathogens or tumors.

THE ANTIBIOTIC DILEMMA:

- In the early 20th century, antibiotics like penicillin greatly reduced childhood deaths from communicable diseases.
- Selective toxicity means antibiotics can kill bacteria without harming human cells.
- Many different antibiotics target a wide range of bacteria, including streptomycin, amoxicillin, tetracyclines, and vancomycin.
- Antibiotics are often prescribed for minor infections, but bacterial resistance is becoming a major issue.

THE DEVELOPMENT OF ANTIBIOTIC RESISTANCE:

- Bacterial resistance develops when bacteria mutate, allowing them to survive and reproduce even in the presence of antibiotics.
- Bacteria reproduce rapidly, and resistant strains can multiply quickly.
- The overuse of antibiotics in humans and animals has accelerated this problem, making more bacteria resistant to all available antibiotics.



ROUTINE USE OF ANTIBIOTICS IN ANIMALS:

- In some countries, antibiotics are added to animal feed to prevent disease and maintain profits. However, this accelerates the natural selection of antibiotic-resistant strains.
- In the UK, it is illegal to routinely give animals antibiotics, but the overprescription of antibiotics in humans remains a major cause of antibiotic resistance.

MRSA AND C. DIFFICILE

Antibiotic-resistant bacteria are a major issue in hospitals and care homes, especially among older people where antibiotics are frequently used.

MRSA (METHICILLIN-RESISTANT STAPHYLOCOCCUS AUREUS):

- Carried by up to 30% of the population on the skin or in the nose.
- Can cause boils, abscesses, and potentially fatal septicaemia.
- Initially treated with methicillin, but mutations have led to methicillin-resistant strains.

C. DIFFICILE (CLOSTRIDIUM DIFFICILE):

- Present in the guts of about 5% of the population.
- Produces toxins that damage the intestines, causing diarrhea, bleeding, and potentially death.
- Not typically harmful to healthy individuals but becomes a problem when antibiotics kill off helpful gut bacteria, allowing it to reproduce rapidly.

REDUCING ANTIBIOTIC-RESISTANT INFECTIONS:

To reduce antibiotic resistance, measures include:

- Minimizing antibiotic use and ensuring that all prescribed courses of antibiotics are completed to prevent resistant strains from developing.
- Good hygiene in hospitals and care homes to prevent the spread of infections, including resistant strains.

SOLVING THE PROBLEM OF ANTIBIOTIC RESISTANCE

The rise of antibiotic-resistant bacteria is one of the biggest health challenges today, with concerns that bacterial infections could once again become a major cause of death. Despite ongoing research, bacterial resistance is building faster than new antibiotics can be developed.

EFFORTS TO DISCOVER NEW ANTIBIOTICS INCLUDE EXPLORING SOURCES LIKE:

- Soil microorganisms
- Crocodile blood
- Fish slime
- Honey
- Ocean depths

EXAMPLES OF CHANGES IN THE INTERNAL AND EXTERNAL ENVIRONMENT

Internal environment	External environment
Blood glucose concentration	Humidity
Internal temperature	External temperature
Water potential	Light intensity
Cell pH	New or sudden sound

WHAT IS HOMEOSTASIS

- Homeostasis = maintenance of a constant internal environment

FUNCTIONS OF CELL SIGNALLING

- Transfer signals locally (synapses)
- Transfer signals across large distances (hormones)

TYPES OF NEURON

- Sensory neurons--> transmit impulses from a sensory receptor cell to a relay neuron, motor neuron, or brain, one dendron and one axon
- Relay neuron- transmit impulses between neuron's--> eg between sensory neurons and motor neurone, many axons and dendrons
- Motor neurons--> these neurons transmit impulses from a relay neuron or sensory neuron to an effector (eg. muscle or gland), one long axon and many short dendrites

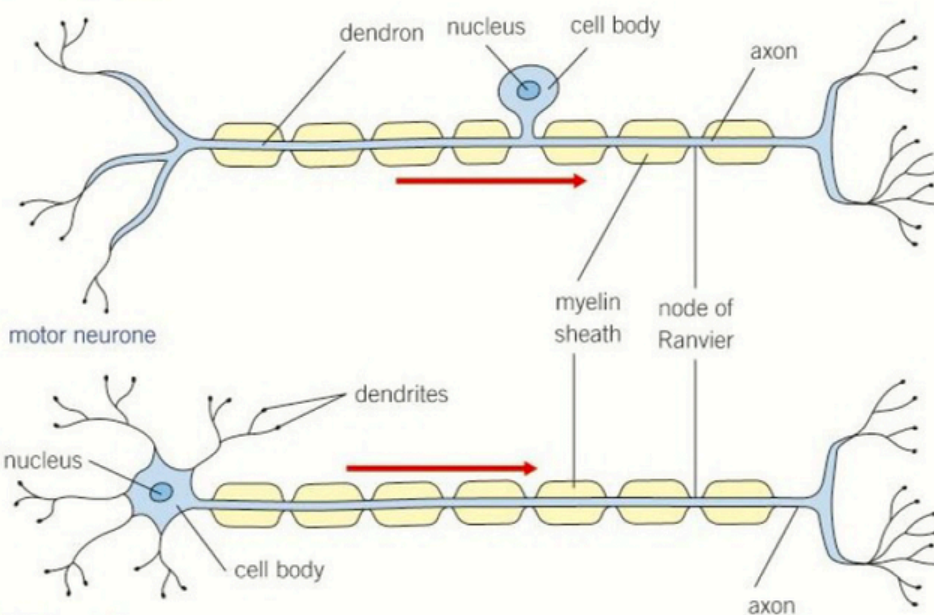
NEURONS

- **Neuron**- specialised nerve cell that transmits electrical impulses

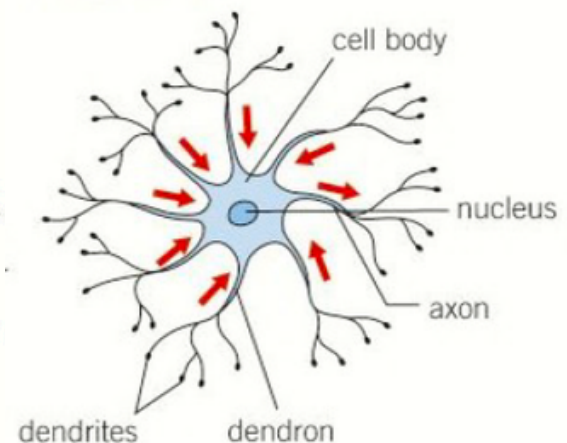
STRUCTURE OF A NEURON

- **Cell body**- contains nucleus surrounded by cytoplasm, abundant mitochondria and endoplasmic reticulum (produces neurotransmitter)
- **Dendrons**- short extensions which come from cell body--> divide into smaller and smaller branches known as dendrites--> transmits electrical impulses towards the cell body
- **Axons**- transmits impulses away from cell body

sensory neurone



relay neurone



MYELINATED NEURONS

- Axons of some neurons are enclosed in a **myelin sheath**--> contains many layers of plasma membrane of Schwann cells (PNS)--> 20 layers
- Wrapped with oligodendrocyte cell membrane in CNS
- Myelinated neurons transmit at 100 metres per second whereas non-myelinated neurons only transmit at 1 m/s



WHY IS THIS?

- Nodes of Ranvier present between each adjacent Schwann cell--> creates gap
- As myelin is insulatory--> impulse has to jump between these gaps/node to node as it travels along the neuron
- Allows fast transmission of the impulse

FEATURES OF SENSORY RECEPTORS

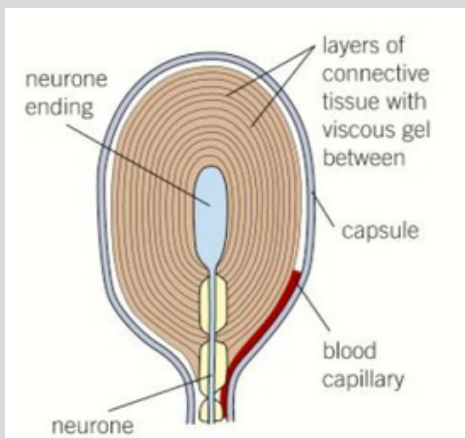
- Specific to a single type of stimulus
- Act as a transducer--> convert a stimulus into a nerve impulse
- Converts a stimulus into an electrical impulse/nerve signal

Types of sensory receptor

Type of sensory receptor	Stimulus	Example of receptor	Example of sense organ
Mechanoreceptor	Pressure and movement	Pacian corpuscle (detects pressure)	Skin
Chemoreceptor	Chemicals	Olfactory receptor (detects smells)	Nose
Thermoreceptor	Heat	End-bulbs of Krause	Tongue
Photoreceptors	Light	Cone cell (detects different light wavelengths)	Eye

WHAT ARE PACINIAN CORPUSCLES?

- Sensory receptors detecting mechanical pressure
- Located deep in skin and most abundant in the fingers and soles of the feet
- Found within joints--> allow you to know which joints are changing direction when moving



HOW DOES A PACINIAN CORPUSCLE CARRY OUT TRANSDUCTION OF A STIMULUS

- At resting state, stretch mediated sodium ion channels (type of sodium channel that change permeability to sodium when stretched) in membrane are too narrow to allow sodium in--> inside of cell is negative compared to outside--> **negative resting potential**
- When pressure applied to pacinian corpuscle, it changes shape and the membrane surrounding the neuron stretches
- When membrane stretches, the sodium ion channels present in the membrane widen--> sodium ions able to diffuse in
- Influx of positive sodium ions changes the potential of the membrane--> becomes depolarised--> generator potential
- Generator potential creates an action potential that passes along sensory nerve

HOW DOES A PACINIAN CORPUSCLE CARRY OUT TRANSDUCTION OF A STIMULUS

- 3 Na ions are actively pumped out and 2 K ions are actively pumped in by Na-K ATPase
- More sodium ions outside compared to inside and more potassium ions on the inside compared to outside
- Most voltage gated sodium ion channels (VGNaCs which open in response to depolarisation) are closed so sodium cannot move in, potassium channels open so potassium moves out
- Overall--> more positive ions outside of cell compared to inside--> so inside is negative compared to outside--> **resting potential is about -70mV (we always compare inside of cell to outside when determining membrane potential)**

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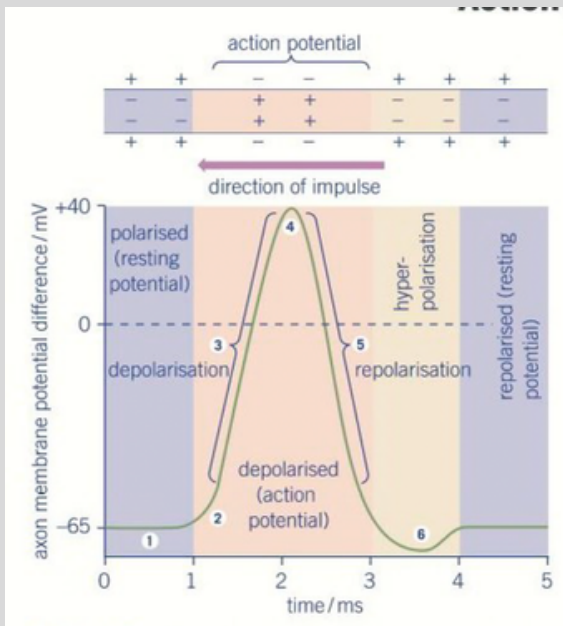
REFRACTORY PERIOD

- VGNaICs inactivate after 1 ms
- Stay inactivated for 2ms
- Means that further APs cannot be stimulated during this time

PROPAGATION OF ACTION POTENTIAL

- Opening of VGNaICs causes positive feedback opening of VGNaICs adjacent/little further to them
- Causes depolarisation of the section after
- In section before, the VGNaICs close and VGKICs open so repolarisation happens

ACTION POTENTIAL



- 1) -65mV--> Resting potential--> some potassium ion channels are open (mainly ones that are not voltage gated) but all the sodium ion channels are closed
- 2) Energy of the stimulus causes opening of some VGNaICs--> membrane more permeable to sodium--> sodium ions move in--> membrane potential starts increasing
- 3) Opening of some VGNaICs causes more VGNaICs to open--> positive feedback
- 4) When the membrane potential reaches +40mV--> VGNaICs inactivate and VGKICs open (delayed type ion channels)
- 5) Potassium diffuse out--> resulting in repolarisation (membrane becomes negative)
- 6) Hyperpolarisation--> goes below -65mV, potassium channels delayed to close--> potassium keeps moving out--> making the inside of cell even more negative than resting potential (-80mV). Na-K ATPase pump restores the resting membrane potential.

PROPAGATION OF ACTION POTENTIAL

- Opening of VGNaICs causes positive feedback opening of VGNaICs adjacent/little further to them
- Causes depolarisation of the section after
- In section before, the VGNaICs close and VGKICs open so repolarisation happens

PURPOSE OF REFRACTORY PERIOD

- Prevents further propagation of APs backwards as well as forwards
- Makes sure APs are unidirectional
- Makes sure that APs occur as discrete impulses

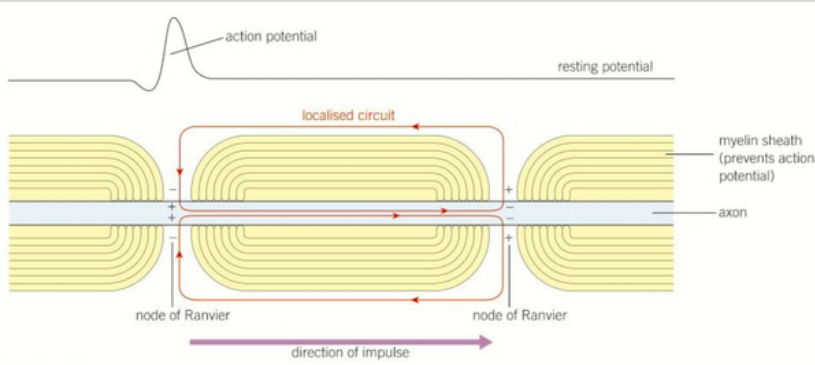
SALTATORY CONDUCTION

- In myelinated axons--> saltatory conduction
- Nodes of Ranvier in myelinated axons, and where there is myelin--> electrical impulses cannot be generated
- Faster
- Energy efficient--> fewer places have to be repolarised by the Na-K ATPase (only nodes of Ranvier)

FACTORS AFFECTING SPEED OF IMPULSE TRANSMISSION

- Axon diameter--> bigger the axon diameter--> faster the impulse is transmitted--> less membrane resistance
- Temperature--> increase temperature--> kinetic energy of the ions is greater--> ions move faster

SALTATORY CONDUCTION



SYNAPSE STRUCTURE

- **Synaptic cleft**- gap separating the axon of one neurone from dendrite of next neurone--> 20-30 nm across
- **Postsynaptic neurone**- neurone receiving transmitter
- **Synaptic knob**- swollen end of presynaptic neurone--> contains many mitochondria and large amounts of endoplasmic reticulum to produce neurotransmitters
- **Synaptic vesicles**- vesicles that have neurotransmitters--> fuse with presynaptic membrane and release contents into synaptic cleft
- **Neurotransmitter receptors**- receptor molecules which the neurotransmitter binds in the postsynaptic membrane

WHAT HAPPENS TO NEUROTRANSMITTER AFTER IT IS RELEASED?

- Broken down by enzymes in the synaptic cleft
- So that a continual response is not produced
- Eg. acetylcholinesterase breaks down acetylcholine

ROLE OF SYNAPSES

- Makes impulses unidirectional--> as neurotransmitter receptors are only at postsynaptic membrane
- Allow an impulse from one neurone to be transmitted to a number of neurons at multiple synapses--> single stimulus creates lots of simultaneous responses--> divergence
- Convergence--> multiple neurons feed into the same synapse

WHAT IS SUMMATION (CONTINUED)

- **Temporal summation**- occurs when a single presynaptic neurone releases neurotransmitter as a result of an action potential several times over a short period--> neurotransmitter accumulates and reaches threshold

ALL-OR-NOTHING PRINCIPLE

- There is a threshold for AP to occur/response
- If too few VGNaCs open--> positive feedback opening of other VGNaCs doesn't happen
- So depolarisation doesn't reach threshold

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- There is a threshold for AP to occur/response
- If too few VGNaCs open--> positive feedback opening of other VGNaCs doesn't happen
- So depolarisation doesn't reach threshold

TYPES OF NEUROTRANSMITTER

- **Excitatory**- depolarise the postsynaptic neurone--> eg. acetylcholine
- **Inhibitory**- hyperpolarise the postsynaptic membrane--> drawing membrane potential further away from threshold (makes it more negative)--> eg. is GABA which is found in synapses of the brain

HOW AN IMPULSE IS TRANSMITTED ACROSS A SYNAPSE

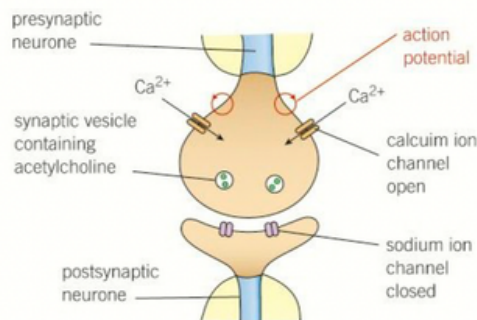
- Action potential reaches the end of the presynaptic neurone
- Depolarisation of the presynaptic membrane results in opening of calcium channels
- Calcium channels diffuse into presynaptic knob
- Increase in calcium concentration causes synaptic vesicles with neurotransmitter to fuse with presynaptic membrane--> neurotransmitter is then released into the synaptic cleft by exocytosis
- Neurotransmitter diffuses to postsynaptic membrane receptors down concentration gradient (fast as short distance) and binds
- This causes opening of sodium channels
- Sodium ions diffuse into postsynaptic neurone
- Results in an action potential and the impulse is propagated along the postsynaptic neurone

WHAT IS SUMMATION?

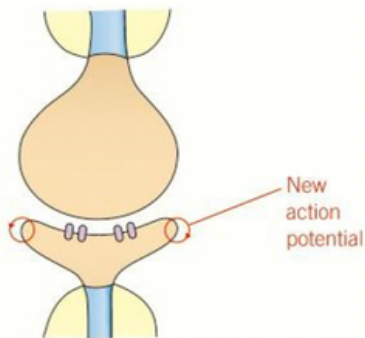
- **Summation**- if the amount of neurotransmitter builds up sufficiently to reach threshold then an action potential will be triggered--> two types: spatial and temporal
- **Spatial summation**: when multiple presynaptic neurons connect to one postsynaptic neurone--> accumulation of neurotransmitter so that threshold is reached

CHOLINERGIC TRANSMISSION ACROSS A SYNAPTIC CLEFT

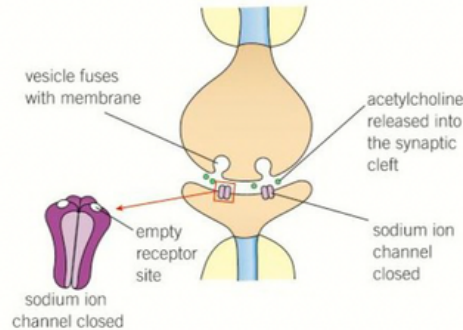
- 1** The arrival of an action potential at the end of the presynaptic neurone causes calcium ion channels to open and calcium ions (Ca^{2+}) enter the synaptic knob.



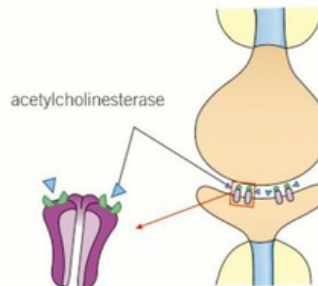
- 4** The influx of sodium ions generates a new action potential in the postsynaptic neurone.



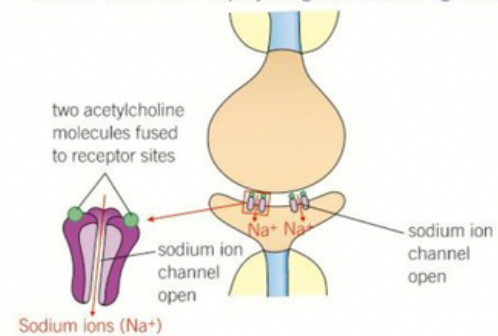
- 2** The influx of calcium ions into the presynaptic neurone causes synaptic vesicles to fuse with the presynaptic membrane, so releasing acetylcholine into the synaptic cleft.



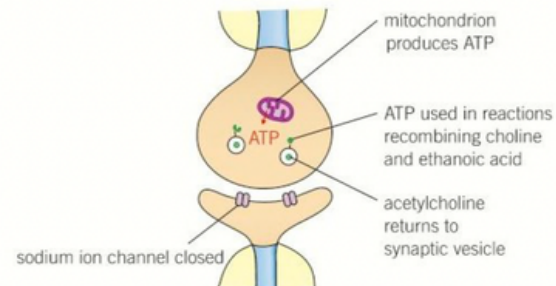
- 5** Acetylcholinesterase hydrolyses acetylcholine into choline and ethanoic acid (acetyl), which diffuse back across the synaptic cleft into the presynaptic neurone (= recycling). In addition to recycling the choline and ethanoic acid, the breakdown of acetylcholine also prevents it from continuously generating a new action potential in the postsynaptic neurone.



- 3** Acetylcholine molecules fuse with receptor sites on the sodium ion channel in the membrane of the postsynaptic neurone. This causes the sodium ion channels to open, allowing sodium ions (Na^+) to diffuse in rapidly along a concentration gradient.



- 6** ATP released by mitochondria is used to recombine choline and ethanoic acid into acetylcholine. This is stored in synaptic vesicles for future use. Sodium ion channels close in the absence of acetylcholine in the receptor sites.





STRUCTURAL ORGANISATION OF THE NERVOUS SYSTEM

- **Central nervous system**- brain and spinal cord
- **Peripheral nervous system**- all neurons that connect the CNS to the rest of the body: sensory and motor neurons

FUNCTIONAL ORGANISATION OF THE NERVOUS SYSTEM

- **Somatic nervous system**- under conscious control
- **Autonomic nervous system**- under subconscious control/involuntary--> eg. control of heart rate, **further divided** into **parasympathetic** and **sympathetic nervous systems**

SYMPATHETIC/PARASYMPATHETIC NERVOUS SYSTEM

- Sympathetic--> fight or flight--> eg. increased sweating during intense activity
- Parasympathetic--> rest and digest--> decrease in heart rate after exercise

Structure	Sympathetic stimulation	Parasympathetic stimulation
salivary glands	saliva production reduced	saliva production increased
lung	bronchial muscle relaxed	bronchial muscle contracted
kidney	decreased urine secretion	increased urine secretion
stomach	peristalsis reduced	gastric juice secreted
small intestine	peristalsis reduced	digestion increased

Components of the autonomic and somatic motor systems

Neurotransmitter	Effector Organ	Effect
Acetylcholine	Skeletal Muscle	Stimulatory
Noradrenaline	Smooth muscle, glands, cardiac muscle	Stimulatory/Inhibitory (depending on effector)
Acetylcholine	Smooth muscle glands, cardiac muscle	Stimulatory/Inhibitory (depending on effector)



GROSS STRUCTURE OF THE BRAIN

- **Cerebrum**- controls voluntary actions, such as learning, memory, personality and conscious thought
- **Cerebellum**- controls unconscious functions such as posture, balance, and non-voluntary movement
- **Medulla oblongata**- used for autonomic control, eg ventilation/breathing rate and heart rate
- **Hypothalamus**- thermoregulatory and osmoregulatory centre
- **Pituitary gland**- stores and releases hormones that regulate many body functions

CEREBELLUM FUNCTIONS

- Involved in control of movement, body posture and balance--> **coordinates movement**

INFORMATION FLOW IN THE CEREBELLUM

- Receives information from vestibular organs (balance organs in ear) and muscles/tendons
- Relays this to motor areas of cerebral cortex (motor cortex)

HYPOTHALAMUS

Functions

- Controls complex patterns of behaviour: sleep, feeding, aggression
- Monitoring the composition of blood plasma, eg. the concentration of water and blood glucose so has a rich blood supply
- Producing hormones--> endocrine gland
- **Location**: Two centres: one for parasympathetic and one for sympathetic control (make up the autonomic nervous system)

PITUITARY GLAND

- **Location**: base of hypothalamus and is the size of a pea
- **Function**:
 - Two sections: **adenohypophysis (anterior pituitary)**, **neurohypophysis (posterior pituitary)**
 - **Hypophysis =>** pituitary and **anterior/posterior =>** front, back--> so the pituitary gland is divided into a front and back section
- **Adenohypophysis**- produce FSH, LH, ACTH (adrenocorticotropin hormone), prolactin, TSH, GH (growth hormone), MSH (melanocyte-stimulating hormone)

CEREBRUM FEATURES

- **Receives sensory information**--> interprets it with respect to information stored from previous experiences, sends impulses along motor neurons to effectors to produce a response
- **Convolved**--> increases SA and capacity for complex activity, left hemisphere controls the right side of the body and right hemisphere controls left side
- **Cerebral cortex**- outer layer of the cerebral hemispheres, 2-4mm thick, reasoning and decision making happen in the prefrontal and frontal lobes
- **Sensory homunculus**- body part is made in proportion to the number of sensory inputs received from it--> hands and lips made very large as they are very sensitive

FLOW OF INFORMATION IN THE CEREBRUM

- Sensory receptors--> sensory area of cerebral hemisphere--> Association areas (analysed and acted upon)
- Size of sensory area allocated is in proportion to the relative number of receptor cells present in the body part
- Size of motor area allocated is in proportion to the relative number of motor endings in it
- At **base of brain**--> impulses from each side of the body cross--> eg. left hemisphere receives information from right side of body

MEDULLA OBLONGATA

Function

- Controls reflex activities such as ventilation
- Also involved in swallowing, peristalsis and coughing

Location

- Brainstem

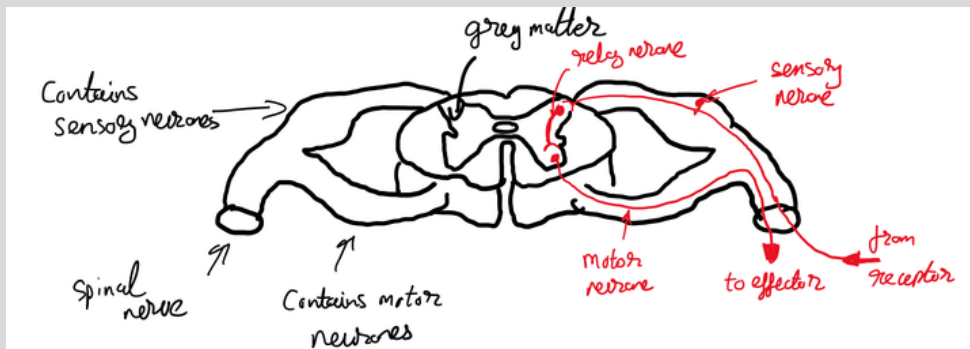
WHAT IS A REFLEX?

- **Reflex**- involuntary response to a sensory stimulus
- **Spinal reflex**- impulse only travels as high as the spinal cord and does not go to the brain
- **Cranial reflex**- impulse travels to the brain

HOW DOES A REFLEX ARC HAPPEN?

- **Receptor**- detects stimulus and creates an action potential to the sensory neuron
- **Sensory neurone**- carries impulse to spinal cord
- **Relay neurone**- connects the sensory neurone to the motor neurone within the spinal cord or brain
- **Motor neurone**- carries impulse to the effector (eg. muscles and glands) to carry out the appropriate response
- **Effector**- produces response

STRUCTURE OF THE SPINAL CORD



THE KNEE-JERK REFLEX (SPINAL REFLEX)

- Leg tapped just below patella
- Stretches patella tendon which acts as a stimulus
- Initiates a reflex arc that causes quadriceps (knee extensor) contracts
- Simultaneously, the antagonistic knee flexor muscle (hamstrings) relax
- Together they produce leg extension

USES OF THE KNEE-JERK REFLEX

- Absence of reflex indicates nervous problems
- Multiple oscillations of the leg (clonus) indicates cerebella disease

HOW DOES THE BLINKING REFLEX HAPPEN

- Stimulus (eg. dust in eye) triggers impulse along 5th cranial nerve (sensory neurone)
- Passes through relay neurone in lower brainstem
- Sent along branches of 7th cranial nerve (motor neurone) to perform motor response to close eyelid
- Blinking/corneal reflex is a **consensual reflex**--> both eyelids are closed in response to the stimulus

WHEN DOES THE BLINKING REFLEX HAPPEN

- Occurs when cornea is stimulated (eg. when it is touched)
- Protects eye
- Also happens when sounds greater than 40-60 dB are heard

USES OF THE CORNEAL REFLEX

- Assess if unconscious patient is dead (clinically dead if brainstem not active)
- If there is no corneal reflex--> brainstem non-functional--> so clinically not alive

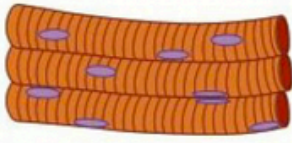
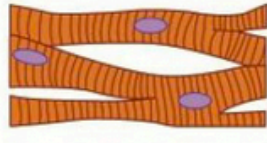
USES OF THE CORNEAL REFLEX

- **Involuntary**- brain not involved so not overloaded with information
- **Not learnt**- present at birth so provide immediate protection
- **Fast**- reflex is short and involves one/two synapses (slowest part of nerve transmission)
- **Everyday actions**- many reflexes are used in day to day life (eg. those that keep us upright, digestion control)

TYPES OF MUSCLE

- **Skeletal Muscle**
- **Cardiac muscle** (myogenic--> contracts without nervous stimulus)
- **Smooth muscle**

COMPARISONS BETWEEN DIFFERENT MUSCLE TYPES

Type of muscle	Skeletal	Cardiac	Involuntary
Fibre appearance	striated	specialised striated	non-striated
Control	conscious (voluntary)	involuntary	involuntary
Arrangement	regularly arranged so muscle contracts in one direction	cells branch and interconnect resulting in simultaneous contraction	no regular arrangement – different cells can contract in different directions
Contraction speed	rapid	intermediate	slow
Length of contraction	short	intermediate	can remain contracted for a relatively long time
Structure	 Muscles showing cross striations are known as striated or striped muscles. Fibres are tubular and multinucleated.	 Cardiac muscle does show striations but they are much fainter than those in skeletal muscle. Fibres are branched and uninucleated.	 Muscles showing no cross striations are called non-striated or unstriated muscles. Fibres are spindle shaped and uninucleated.

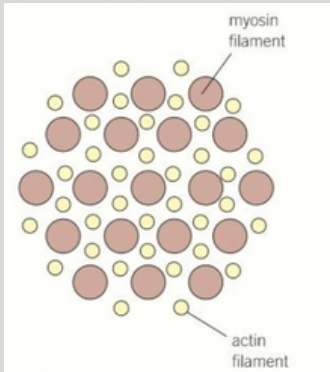
STRUCTURE OF SKELETAL MUSCLE

- **Sarcolemma**- plasma membrane of skeletal muscle cells, encloses the bundles of muscle fibres
- Nuclei longer than normal cells (as they are formed from individual embryonic muscle cells fusing together)
- **Sarcoplasm**- shared cytoplasm within a muscle fibre
- **T tubules (transverse tubules)**- folded, invaginated part of a sarcolemma which helps spread electrical impulses throughout the whole sarcoplasm
- **Sarcoplasmic reticulum**- modified endoplasmic reticulum that extends throughout the muscle fibre, contains calcium ions needed for muscle contraction
- **Lots of mitochondria**--> produce ATP for muscle contraction

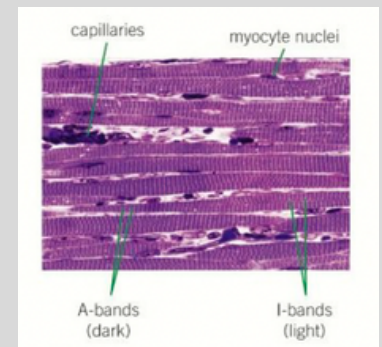
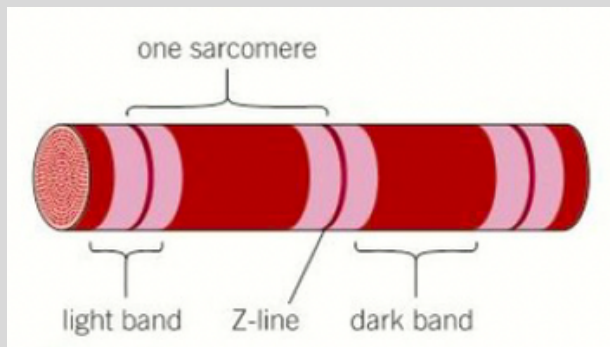
CONTRACTILE APPARATUS OF SKELETAL MUSCLE

- Each muscle fibre is made of many **myofibrils**--> long cylindrical organelles made of protein
- Collectively powerful as they are lined up in parallel to provide maximum force when they all contract together
- Made up of 2 protein filaments: **actin** (thinner filament, two strands twisted around each other) and **myosin** (thicker filament, long rod-shaped fibres with bulbous heads that project to one side)

STRUCTURE OF A MYOFIBRIL



- **Light bands-** actin and myosin do not overlap so appear light (also called isotropic/I-bands)
- **Dark bands-** actin and myosin overlap, appear dark due to the presence of thick myosin (also called anisotropic/A-bands)
- **Z-line-** found at the centre of each light band, distance between adjacent Z-lines is called a sarcomere which is the functional unit of a myofibril--> when **muscle contracts, sarcomere shortens**
- **H-zone-** lighter region at the centre of each dark band--> only myosin present here, when muscle contracts the H-zone decreases

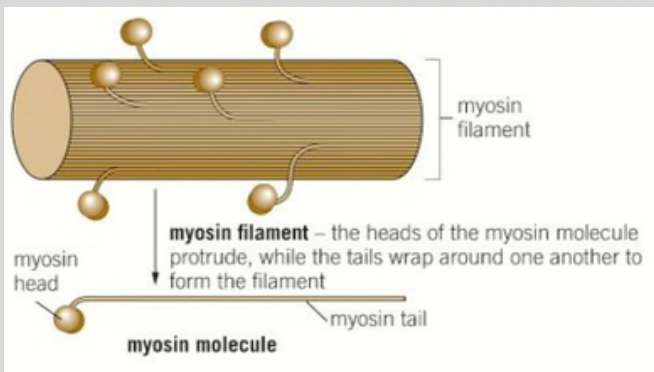


Source: OCR A-level BIOLOGY by Ann Bullock

HISTOLOGICAL FEATURES OBSERVED DURING MUSCLE CONTRACTION

- Light band becomes narrower
- Z lines move closer together--> shortens sarcomere
- H-zone becomes narrower
- Dark band remains the same width

STRUCTURE OF MYOSIN



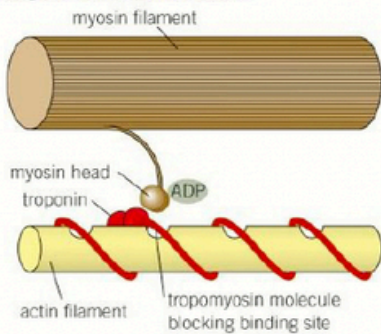
- Have globular heads with hinges--> allow them to slide back and forwards
- Head has ATP and actin binding site
- Tails are aligned end-to-end to form the myosin filament

STRUCTURE OF ACTIN

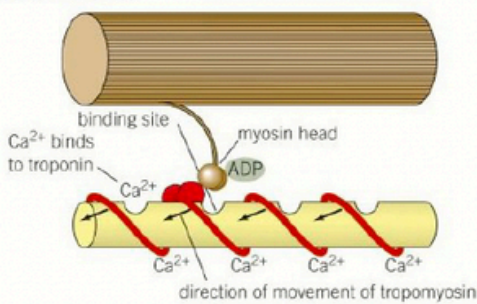
- Actin has binding sites for myosin heads--> **actin-myosin binding sites**
- These binding sites physically blocked by **tropomyosin**, which is held in place by troponin
- When muscle is relaxed--> binding sites blocked, so myosin head cannot bind to actin
- When muscle contracting--> myosin head forms bonds with actin filaments (**actin-myosin cross bridges**) which pulls actin along myosin

ACTIN-MYOSIN CROSS BRIDGE CYCLING

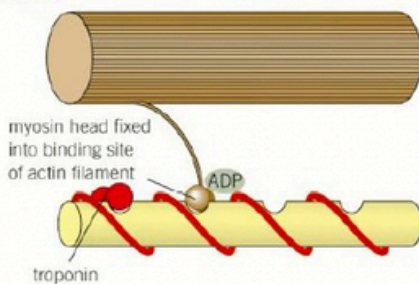
1 Tropomyosin molecule prevents myosin head from attaching to the binding site on the actin molecule.



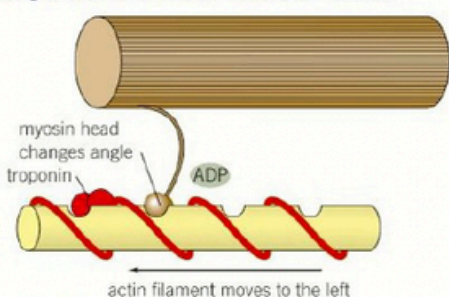
2 Calcium ions released from the endoplasmic reticulum cause the tropomyosin molecule to pull away from the binding sites on the actin molecule.



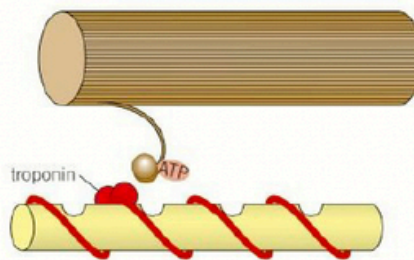
3 Myosin head now attaches to the binding site on the actin filament.



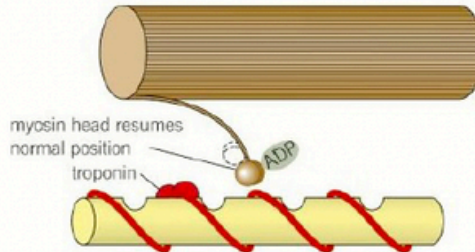
4 Head of myosin changes angle, moving the actin filament along as it does so. The ADP molecule is released.



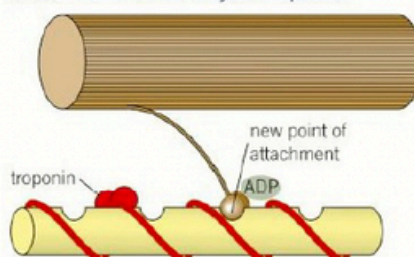
5 ATP molecule fixes to myosin head, causing it to detach from the actin filament.



6 Hydrolysis of ATP to ADP by myosin provides the energy for the myosin head to resume its normal position.



7 Head of myosin reattaches to a binding site further along the actin filament and the cycle is repeated.



SOME DEFINITIONS...

- **NMJ**- neuromuscular junction, where a motor neuron and a skeletal muscle fibre meet
- **Motor unit**- all muscle fibres supplied by a single motor neuron--> lots recruited if large force needed, only few recruited if small force needed



WHY HAVE AN NMJ

- Lots of NMJs along length of muscle
- Make contractions fast--> as a wave of conduction would have to travel across the muscle to stimulate the individual fibres to contract



TRANSMISSION ACROSS AN NMJ

- Action potential reaches NMJ
- Stimulates calcium channels in presynaptic neurone to open
- Calcium ions diffuse into synaptic knob from synapse down concentration gradient
- Stimulate fusion of synaptic vesicles with presynaptic membrane
- Acetylcholine exocytosed into the synapse--> binds to receptors on post-synaptic membrane--> depolarisation
- Acetylcholine broken down into choline and ethanoic acid by acetylcholinesterase
- Choline and ethanoic acid diffuse back into neurone where they are recombined to acetylcholine using ATP hydrolysis for energy (from mitochondria)

WHAT IS THE ENERGY SOURCE FOR MUSCLE CONTRACTION AND HOW IS IT PRODUCED?

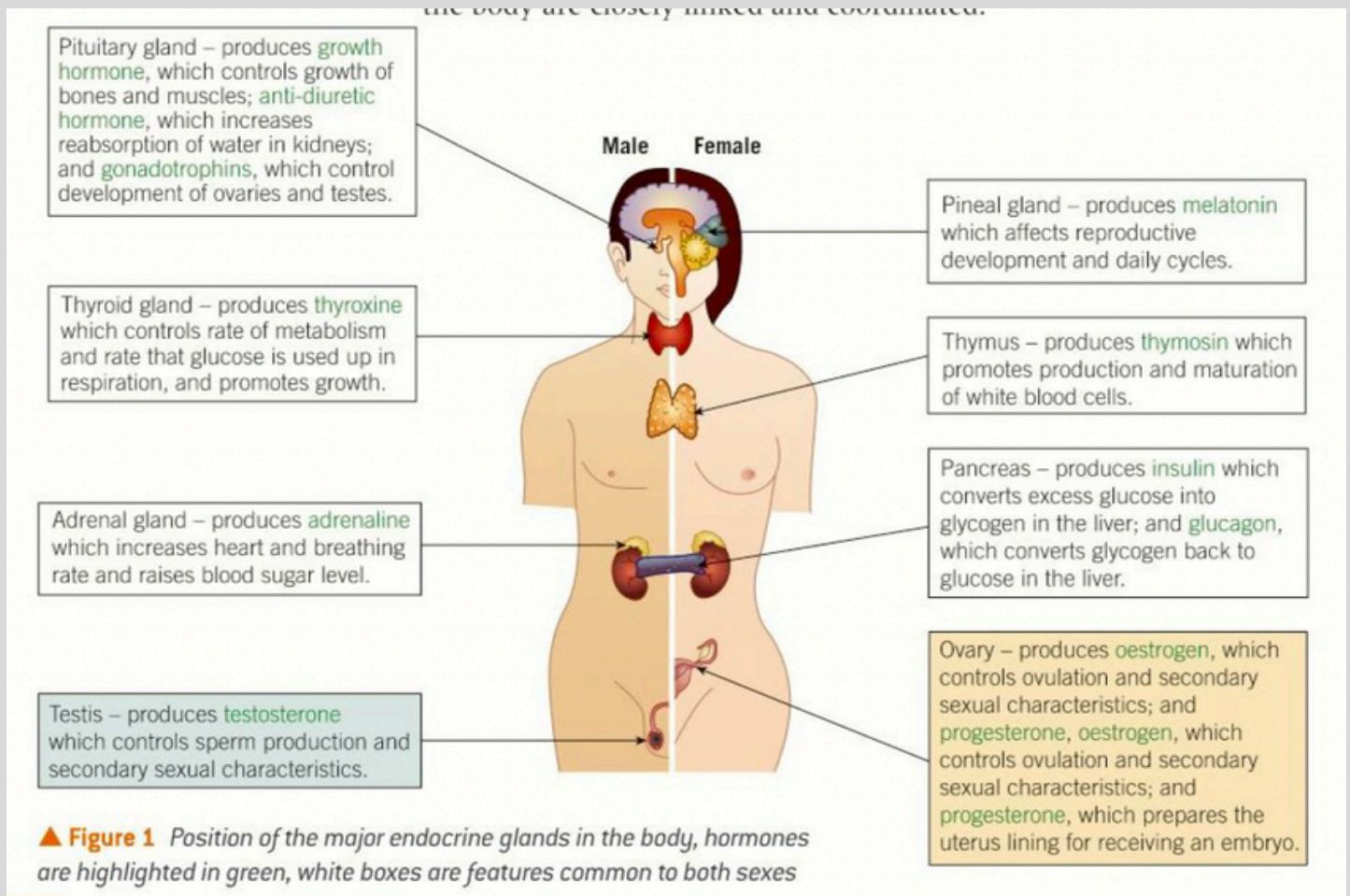
- Energy is provided by the hydrolysis of ATP to ADP and an inorganic phosphate group

How is it produced (3 main ways):

- **Aerobic Respiration**
- **Anaerobic Respiration**
- **Creatine Phosphate** (store of phosphate) which is immediately combined with ADP to form ATP, used for short bursts of vigorous exercise, replenished using phosphate from ATP when the muscle relaxes

THE ENDOCRINE SYSTEM

- The endocrine system is made up of many glands (**endocrine glands**)
- An endocrine gland** is a group of cells which are specialised to secrete hormones (secreted directly into the bloodstream)



HORMONES

- Hormones are chemical messengers that are secreted and bind to target cells by diffusing out of blood
- Target cells**--> specific to hormones, produces a response by cell signalling cascades (binding of a hormone to a receptor results in intracellular activities which produce a response)

TYPES OF HORMONES:

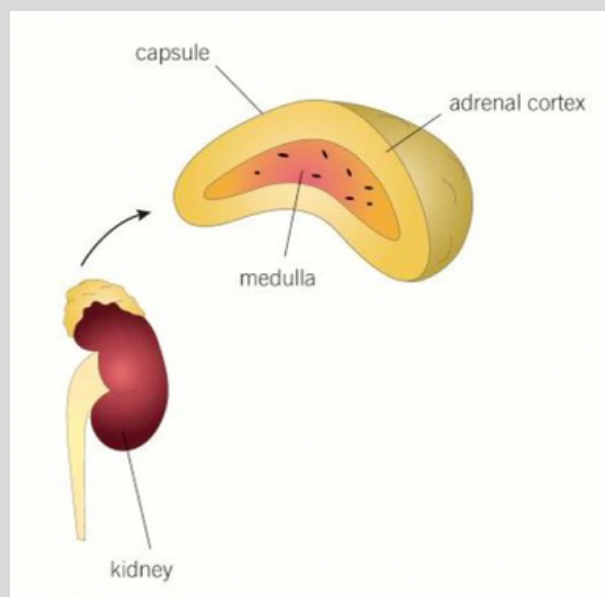
- Steroid hormones:** lipid soluble--> pass through plasma membrane (mixes readily with the lipid in membrane) and bind to intracellular steroid receptors (in cytoplasm or attached to the nucleus)--> hormone-receptor complex acts as a transcription factor which stimulates or inhibits the transcription of a gene
- Non-steroid hormones:** Hydrophilic so do not pass directly through lipid membrane--> bind to specific receptors on the cell surface membrane of target cell--> triggers intracellular cascade by second messenger chemicals (substances inside of the cell) which produces a response

HORMONAL SYSTEM VS NERVOUS SYSTEM

Hormonal system	Nervous system
communication is by chemicals called hormones	communication is by nerve impulses
transmission is by the blood system	transmission is by neurones
transmission is usually relatively slow	transmission is very rapid
hormones travel to all parts of the body, but only target organs respond	nerve impulses travel to specific parts of the body
response is widespread	response is localised
response is slow	response is rapid
response is often long-lasting	response is short-lived
effect may be permanent and irreversible	effect is temporary and reversible

ADRENAL GLANDS

- **Structure:** adrenal cortex and adrenal medulla--> **adrenal cortex:** outer region, produces hormones that are essential to life (cortisol- regulates metabolism, aldosterone- regulates blood pressure), **adrenal medulla:** inner region of the glands, produces non-essential hormones (adrenaline)



3 TYPES OF HORMONE PRODUCE BY THE ADRENAL CORTEX

- **Glucocorticoids:** Eg **cortisol**--> regulates metabolism, blood pressure, cardiovascular response to stress. Eg corticosterone--> works with cortisol to regulate the immune response and suppress inflammation, release is mediated by the **hypothalamus**
- **Mineralocorticoids:** Eg **aldosterone**--> regulates blood pressure by maintaining a balance between sodium and water concentrations, release is mediated by the **kidney**
- **Androgens:** Eg testosterone and oestrogen

SPECIFIC HORMONES RELEASED BY THE ADRENAL MEDULLA

- **Adrenaline:** increases heart rate, increases blood glucose
- **Noradrenaline:** increases heart rate, widens the pupils, widens bronchi, narrows blood pressure in non-essential organs (stomach)

PANCREAS FUNCTION

- **Exocrine function:** produces and releases enzymes into duodenum
- **Endocrine function:** produces and releases hormones into the blood

EXOCRINE FUNCTION OF THE PANCREAS

Produces 3 enzymes

- **Amylases:** break down starch--> glucose (eg pancreatic amylase)
- **Proteases:** breaks down proteins--> amino acids
- **Lipases:** break down lipids--> fatty acids and glycerol, eg pancreatic lipase

ENDOCRINE FUNCTION OF THE PANCREAS

- **Islets of Langerhans:** produce **insulin** and **glucagon**, small regions of endocrine tissue within exocrine tissue

HISTOLOGY OF THE PANCREAS

Structure	Appearance	Shape	Type of tissue	Function
islets of Langerhans	lightly stained	large, spherical clusters	endocrine pancreas	produce and secrete hormones
pancreatic acini (singular – acinus)	darker stained	small, berry-like clusters	exocrine pancreas	produce and secrete digestive enzymes

ISLETS OF LANGERHANS

- Alpha cells: larger, more numerous, produce and secrete glucagon
- Beta cells: smaller, fewer in number, produce and secrete insulin

BLOOD GLUCOSE CONCENTRATION

- Insulin and glucagon work antagonistically to maintain blood glucose concentration at 90mg per cm³ of blood
- Insulin reduces blood glucose concentration and glucagon increases blood glucose concentration

HOW TO INCREASE BLOOD GLUCOSE CONCENTRATION

- **Diet:** eating carbohydrate rich foods (pasta is high in starch which is broken down into glucose)
- **Glycogenolysis:** glycogen stored in the liver and muscle cells is broken down into glucose
- **Gluconeogenesis:** glucose produced from non-carbohydrate sources (liver able to make glucose)

HOW TO DECREASE BLOOD GLUCOSE CONCENTRATION

- **Respiration:** uses up glucose
- **Glycogenesis:** excess glucose is used to produce glycogen--> stored in muscle and liver--> stimulated by **insulin**

HOW DOES INSULIN DECREASE BLOOD GLUCOSE CONCENTRATION

- Increases rate of glucose absorption by cells (eg skeletal muscle cells)
- Increasing respiratory rate of cells--> increases need for glucose and causes a higher uptake of glucose from blood
- Increasing the rate of glycogenesis--> insulin stimulates liver to remove glucose from blood by turning glucose--> glycogen and storing it liver and muscle
- Increasing rate of glucose--> fat production
- Inhibiting the release of glucagon from alpha cells of islets of Langerhans

1BIOL-10

HOMEOSTASIS - HORMONAL COMMUNICATION



HOW ARE BLOOD GLUCOSE LEVELS DETECTED? WHAT HAPPENS WHEN INSULIN BINDS TO TARGET CELL RECEPTOR?

- Beta cells of islets of Langerhans detect levels of insulin in the blood

ROLE OF GLUCAGON

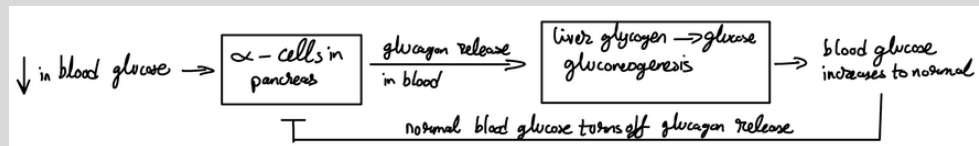
- IMPORTANT:** glucagon receptors are ONLY present in liver and fat cells

How does glucagon increase blood glucose concentration?

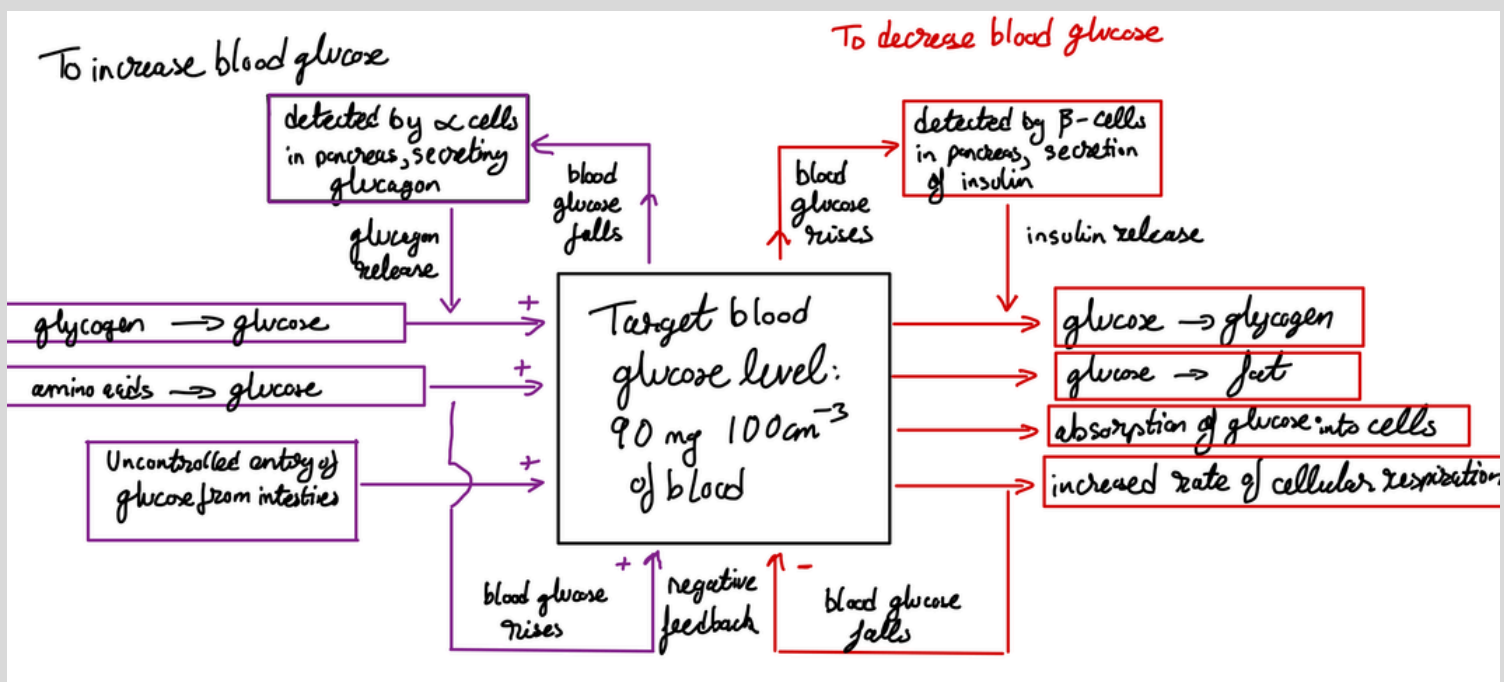
- Glycogenolysis**
- Reducing the amount of glucose absorbed by the liver cells
- Increasing gluconeogenesis

- Changes the specific 3D tertiary structure of the insulin glycoprotein receptor
- Stimulates second messenger intracellular signalling cascade that increases the transcription and translation of glucose channels
- More glucose channels inserted into membrane
- Increased absorption of glucose via facilitated diffusion into cells
- IMPORTANT:** Insulin receptors are present in most body cells

SUMMARY OF THE NEGATIVE FEEDBACK REGULATION OF GLUCOSE

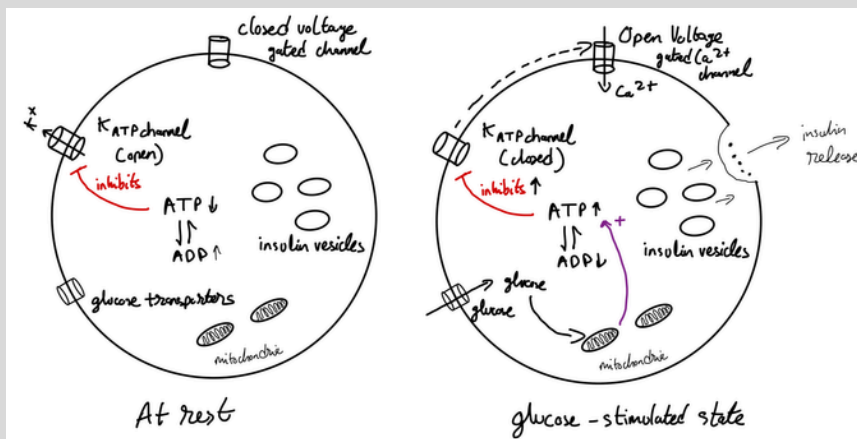


ANTAGONISTIC NATURE OF INSULIN AND GLUCAGON



HOW IS THE SECRETION OF INSULIN CONTROLLED?

- At normal blood glucose levels--> potassium channels in plasma membrane of beta cells are open and potassium ions diffuse out of cell--> inside of cell has a resting membrane potential of -70mV
- As blood glucose levels increase--> glucose enters cell by a glucose transporter
- Glucose is metabolised inside the mitochondria--> resulting in the production of ATP
- ATP binds to potassium channels--> closes them--> these are known as ATP-sensitive potassium channels
- So potassium ions no longer diffuse out--> membrane potential increases to -30 mV and membrane is depolarised
- Depolarisation causes voltage-gated calcium channels to open
- Calcium ions diffuse in and stimulate secretory vesicles containing insulin to fuse with the inside of the plasma membrane and release the insulin via exocytosis



WHAT HAPPENS WHEN THE CONTROL OF BLOOD GLUCOSE GOES WRONG?

- Diabetes mellitus results if blood glucose concentrations are not maintained at a constant level

COMMON SYMPTOMS OF DIABETES

- High blood glucose concentration
- Glucose present in urine
- Excessive need to urinate (polyuria)
- Excessive thirst (polydipsia)
- Constant hunger
- Weight loss
- Blurred vision
- Tiredness

DIABETES AS A VICIOUS CYCLE

- Hyperglycaemia (high blood glucose concentration) due to lack of insulin or desensitisation to insulin
- Reduced absorption into cells--> glucose remains in blood
- Liver cells perceive this as low cellular glucose concentration--> releasing glucagon--> further increasing blood glucose concentrations
- Worsens hyperglycaemia--> leads to inflammation and oxidative stress

TYPE 1 DIABETES

- Beta cells of islets of Langerhans unable to produce insulin
- May be due to autoimmunity (body's immune system destroys the beta cells)
- Develops in childhood and symptoms appear quickly

TYPE 2 DIABETES

- Cannot effectively use insulin and control their blood sugar levels
- Either due to beta cells not producing enough insulin or the person's body has become desensitised to insulin
- 90% of people with diabetes have type 2 diabetes
- **Risk factors:** excess body weight, physical inactivity, overeating of carbohydrates
- Symptoms are less severe and develop slowly later in life (age of 40)



DIABETES TREATMENT- TYPE 1

- Regular insulin injections--> **insulin-dependent diabetes**
- To determine if they need insulin--> do **finger-prick test**

DIABETES TREATMENT- HOW IS INSULIN PRODUCED IN VITRO?

- Structure of human insulin identified in 1955--> now made by genetically modified bacteria

Advantages:

- Human insulin is produced from a pure form--> less likely to cause allergic reactions
- Insulin produced in much higher quantities
- Production costs are much cheaper
- Concerns over using animal insulin in humans are overcome

DIABETES TREATMENT- TYPE 1

- Regular insulin injections--> **insulin-dependent diabetes**
- To determine if they need insulin--> do **finger-prick test**

DIABETES TREATMENT- TYPE 2

- Regulate person's carbohydrate intake/exercise levels
- Overweight people encouraged to lose weight
- **Drugs:** sulphonylureas (promote insulin secretion), metformin(inhibits liver gluconeogenesis and increases peripheral insulin sensitivity)

DIABETES TREATMENT- STEM CELLS

Why stem cell treatment needed:

- Only 8% of pancreatic beta cell injection successful--> immunosuppressive drugs given increase their metabolic demand and exhaust their ability to produce insulin
- Pancreas transplants--> 80% success BUT few donors

Advantages:

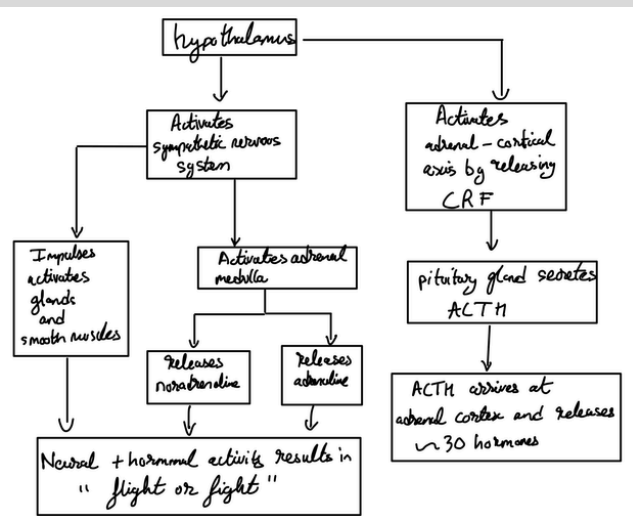
- Donor availability not an issue
- Reduced rejection if embryonic stem cells used, stem cells can also be made by somatic cell nuclear transfer (**SCNT**)
- People have to no longer inject themselves with insulin

WHAT IS THE FIGHT OR FLIGHT RESPONSE?

- When a potentially dangerous situation is detected--> body automatically triggers series of physical responses
- Prepare to fight or run away (flight)

FIGHT OR FLIGHT PHYSIOLOGICAL RESPONSES

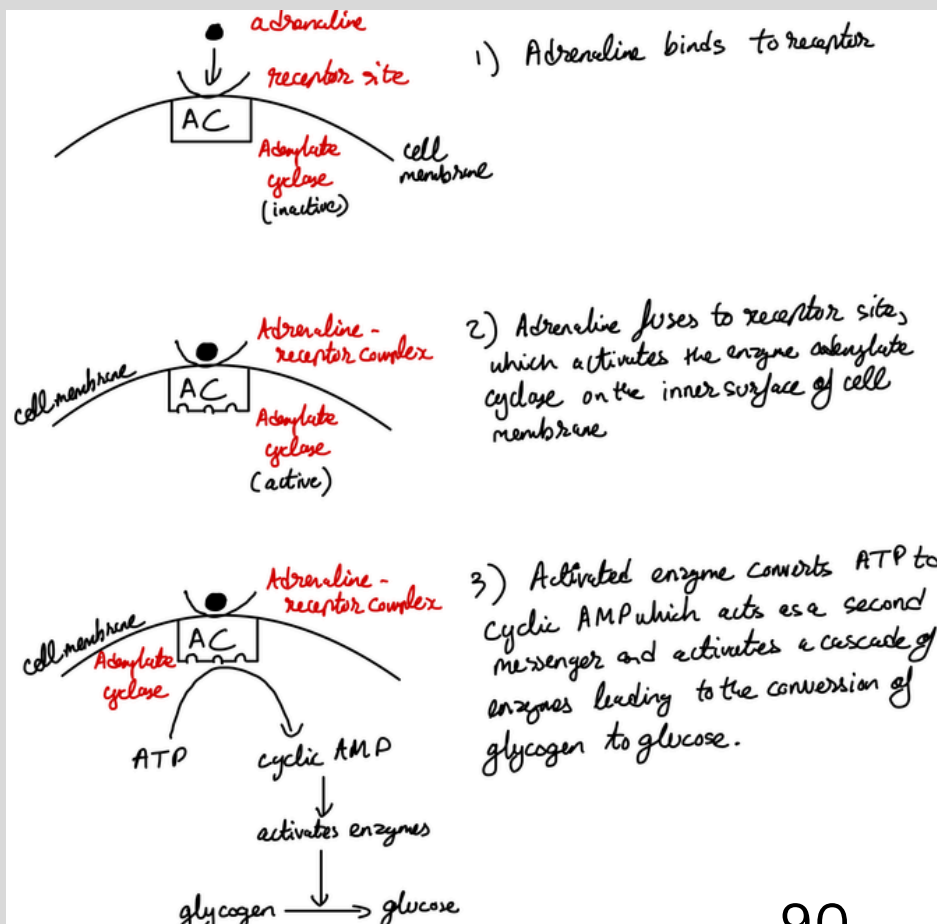
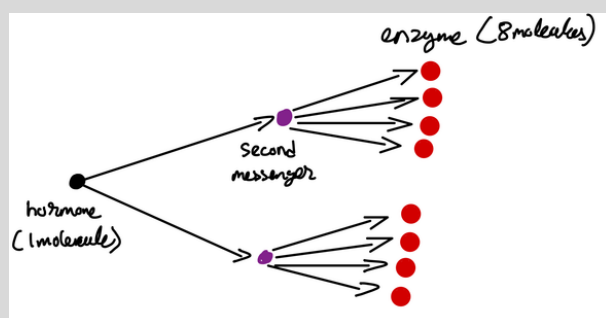
Physical response	Purpose
heart rate increases	to pump more oxygenated blood around the body
pupils dilate	to take in as much light as possible for better vision
arterioles in skin constrict	more blood to major muscle groups, brain, heart, and muscles of ventilation
blood glucose level increases	increase respiration to provide energy for muscle contraction
smooth muscle of airways relaxes	to allow more oxygen into lungs
non-essential systems (like digestion) shut down	to focus resources on emergency functions
difficulty focusing on small tasks	brain solely focused only on where threat is coming from



ACTION OF ADRENALINE- THE MAIN HORMONE IN FIGHT OR FLIGHT

SECOND MESSENGER MODEL

- Intracellular actions of adrenaline is an example of a second messenger model
- Adrenaline is the first messenger and cAMP is the second messenger
- Main advantage:** provides amplification (shown below)



HOW IS HEART RATE CONTROLLED

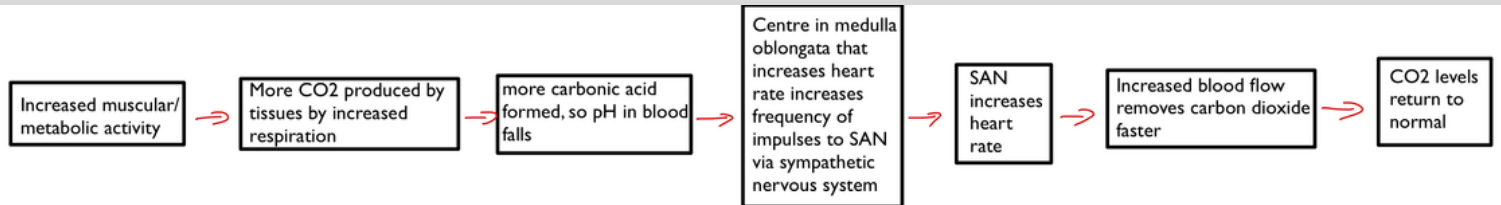
- Controlled involuntarily by the autonomic nervous system--> **medulla oblongata**
- Two centres in the medulla: sympathetic centre which increases heart rate (**accelerans nerve**), parasympathetic centre which decreases the heart rate (**vagus nerve**)

How do we detect the heart rate

- Two types of receptors in blood vessels provide information about heart rate: **baroreceptors and chemoreceptors**
- Baroreceptors:** detect changes in blood pressure, present in aorta, vena cava and carotid arteries
- Chemoreceptors:** detect changes in the level of particular chemicals in blood such as carbon dioxide (by detecting change in pH--> if CO₂ increases then pH decreases), present in aorta, carotid artery, and medulla

BARORECEPTORS

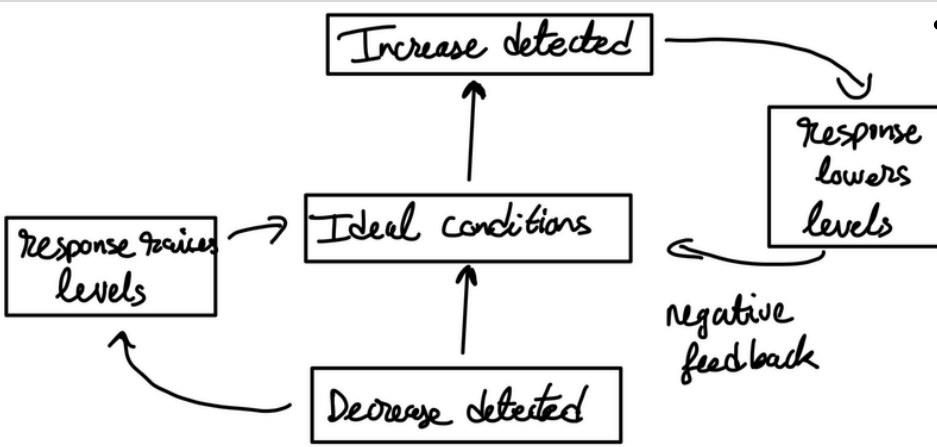
- If pressure too high--> detected by baroreceptors in aorta, vena cava and carotid arteries--> sends impulses to medulla--> impulses to SAN to decrease heart rate along parasympathetic vagus nerve
- If pressure too low--> opposite to the above happens--> impulse from medulla to SAN via sympathetic accelerans nerve





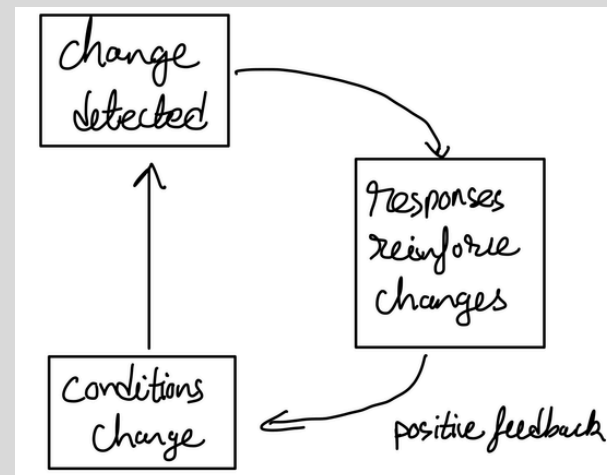
WHAT IS HOMEOSTASIS?

- **Homeostasis:** maintenance of a dynamic equilibrium with small fluctuations over a narrow range of conditions
- Mainly uses **negative feedback systems**



IF THERE IS NEGATIVE FEEDBACK, IS THERE POSITIVE FEEDBACK?

- Yes
- Eg: blood clotting cascade--> activation of some platelets to form clot--> activates multiple other platelets thus reinforcing the change
- Eg: during childbirth, head of baby presses against cervix--> oxytocin (hormone) produced--> oxytocin stimulates uterine contractions--> pushing the head of baby even harder against cervix stimulating release of more oxytocin





WHY DO ORGANISMS BECOME COOL/HOT

Due to:

- Exothermic chemical reactions
- Latent heat of evaporation--> objects cool down as water evaporates from a surface
- Radiation--> transmission of electromagnetic waves to and from the air, water, or ground
- Convection--> warm air rises and cool air sinks
- Conduction--> heating as a result of the collision of molecules

ENDOTHERMS

- Mammals and birds
- Rely on metabolic processes to warm up
- Stable body temperature regardless of environment
- Metabolic rate 5x higher than ectotherms



HOW IS TEMPERATURE DETECTED IN ENDOTHERMS?

- Hypothalamus acts as a thermostat by 'measuring' the temperature of the blood passing through it
- Sends signals to maintain it at 37 degrees celcius

HOW DO ENDOTHERMS COOL DOWN?

- **Vasodilation:** arterioles near surface of skin dilate when temperature rises--> this happens as the arterio-venous shunts (connection between arteries and veins) constrict--> skin cools as heat moves out by radiation
- **Increased sweating:** sweat has water which evaporates from skin--> heat lost as radiation
- **Hairs flattens:** Erector pilli muscles relax--> hair flattens--> avoids trapping a layer of insulating air

HOW DO ENDOTHERMS WARM UP?

- **Vasoconstriction:** Arterioles near surface of skin constrict as the artery-venous shunts dilate--> little radiation of heat out
- **Decreased sweating:** less evaporation of water--> reduced heat loss, BUT some evaporation from lungs
- **Raising body hairs:** Erector pilli contracts--> traps layer of insulating air
- **Shivering:** Rapid, involuntary contraction and relaxation of muscles--> generates heat from metabolism

ECTOTHERMS

- Use surroundings to warm their bodies
- Body temperature dependent on environment
- Ectotherms living in water do not need to thermoregulate as the specific heat capacity of water is high

HOW DO ECTOTHERMS THERMOREGULATE



Behavioural Responses:

- **Move their body to increase exposure to the sun:** lizards bask in sun to get warm to hunt prey, locusts and butterflies spread their wings to maximise surface area of sun exposure
- **Press bodies against warm ground:** gain heat by conduction
- **Exothermic metabolism:** galapagos iguanas contract their muscle to increase metabolism and body temperature
- **Cooling down:** get away from sun, reduce movement so metabolism and muscle contraction reduced

Physiological Responses

- **Coloured skin:** lizards in cooler environments have darker colours as they absorb more radiation--> warmer
- **Alter heart rate:** increase or decrease metabolic rate

ENDOTHERM ANATOMICAL ADAPTATIONS

- **Small ears-->** minimise SA:V ratio
- **Thick layer of fat:** insulation--> blubber

CONTROLLING THERMOREGULATION

- **Two control centres:** heat loss centre, heat gain centre
- **Heat loss centre:** activated when the temperature of the blood flowing through hypothalamus increases--> sends impulses through autonomic motor neurons to effectors in skin and muscles--> stimulates responses that lower temperature
- **Heat gain centre:** activated when the temperature of blood flowing through hypothalamus decreases--> sends impulse via autonomic nervous system to effectors in skin and muscles--> stimulates responses that increases core body temperature

MAIN METABOLIC WASTE PRODUCTS IN MAMMALS

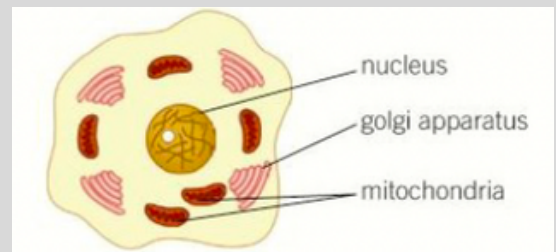
- **Carbon dioxide**
- **Bile pigments**--> formed from breakdown of haemoglobin from old RBCs in the liver--> these colour the faeces
- **Nitrogenous waste products (urea)**--> formed from the breakdown of excess amino acids by the liver

BLOOD FLOW TO AND FROM LIVER

- **Hepatic artery**--> supplies liver with oxygenated blood
- **Hepatic vein**--> returns deoxygenated blood back to heart
- **Hepatic portal vein**--> carries blood with products of digestion from intestines to liver--> starting point for many metabolic reactions--> up to 75% of blood flowing into liver comes from hepatic portal vein

STRUCTURE OF THE LIVER

- **Hepatocytes (shown below):** liver cells, have large nuclei, prominent Golgi, lots of mitochondria (metabolically active), divide and replicate (so liver is capable of regeneration)
- **Sinusoids:** where blood from hepatic artery and vein are mixed, contain Kupffer cells (liver macrophages that protect against disease)
- **Bile:** Hepatocytes secrete bile into canaliculi, drains into ductules which take it to gall bladder



FUNCTIONS OF THE LIVER

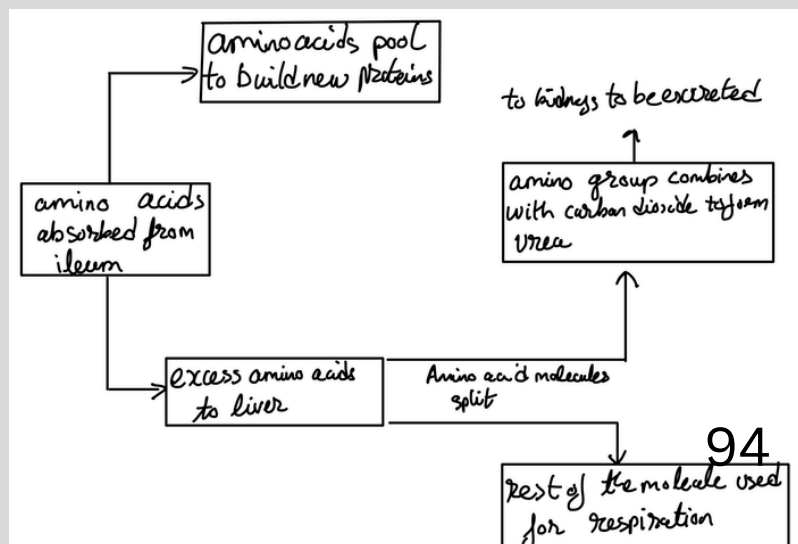
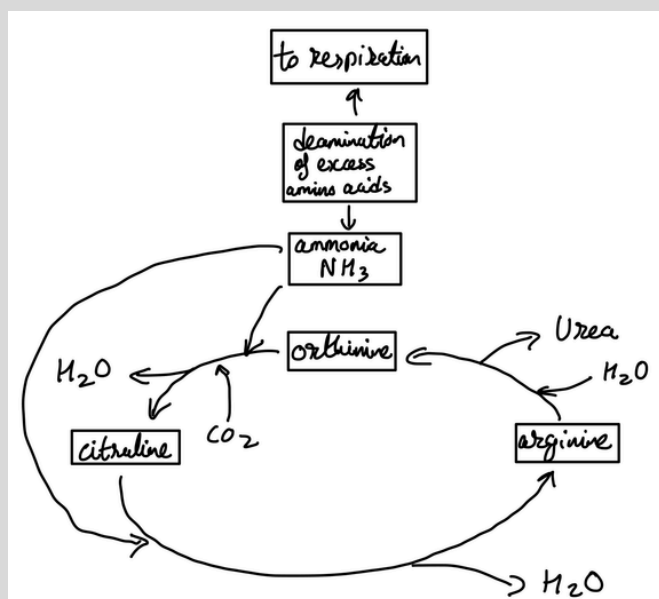
- Carbohydrate metabolism
- Deamination of excess amino acids
- Detoxification

CARBOHYDRATE METABOLISM

- When glucose levels increase--> insulin secreted--> stimulates conversion of glucose--> glycogen which is stored in liver and muscle
- When glucose levels fall--> glucagon secreted--> glycogen broken down to glucose

DEAMINATION OF AMINO ACIDS

- Deamination is the removal of an amine group from excess amino acids--> converted to ammonia--> converted to urea (not high enough concentration to be toxic) by the **ornithine cycle**
- Remainder of amino acid fed into cellular respiration or converted into lipids for storage





DETOXIFICATION

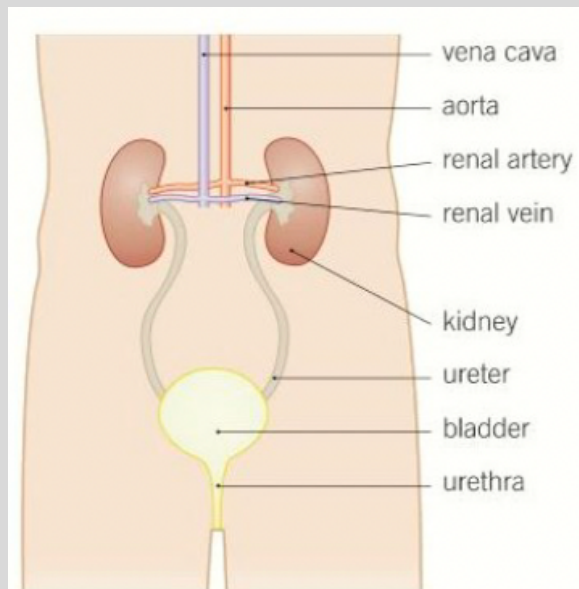
- Eg: breakdown of **hydrogen peroxide by catalase enzyme** (splits hydrogen peroxide into water and oxygen)
- Eg: ethanol detoxification--> alcohol dehydrogenase breaks down ethanol--> ethanal --> converted to ethanoate which is used to make fatty acids or in respiration

LIVER CIRRHOSIS

- Normal liver tissue replaced by fibrous scar tissue
- Causes can be genetic, diseases such as hepatitis C, and alcoholism (most common)
- **Alcoholic liver disease has 3 stages-->** alcoholic fatty liver, alcoholic hepatitis, liver cirrhosis
- **First**, big fat-filled vesicles displace nuclei and the liver gets larger
- Hepatocytes and sinusoids get narrowed and liver becomes irreversibly damaged
- Hepatocytes become replaced with fibrous tissue
- Hepatocytes no longer divide and replace so liver shrinks and ability to detoxify decreases

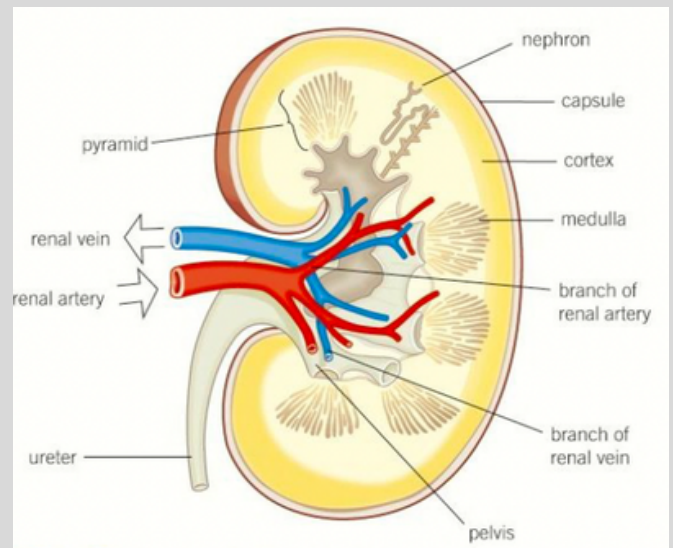
ANATOMY OF THE KIDNEYS

- **Blood supply:** renal artery (branch of abdominal aorta), renal vein (carries blood away from kidneys to inferior vena cava)
- **Renal plasma/blood flow rate** => $90-120\text{cm}^3$
- Made up of **nephrons** that are filtering units
- Waste liquid produced by the kidneys is urine
- Urine passes down kidneys by ureters into bladder
- Urine passes out of body from bladder via urethra



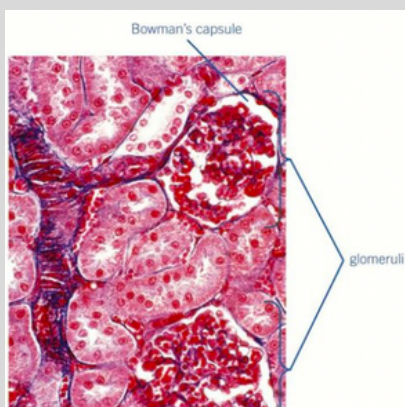
KIDNEY STRUCTURE

- **Cortex:** dark outer layer, blood filtering takes place here, very dense capillary network carrying blood from renal artery to nephrons
- **Medulla:** lighter in colour--> contains tubules of nephrons that form the pyramids of kidney and the collecting ducts
- **Pelvis:** central chamber which collects urine before it passes down the ureter

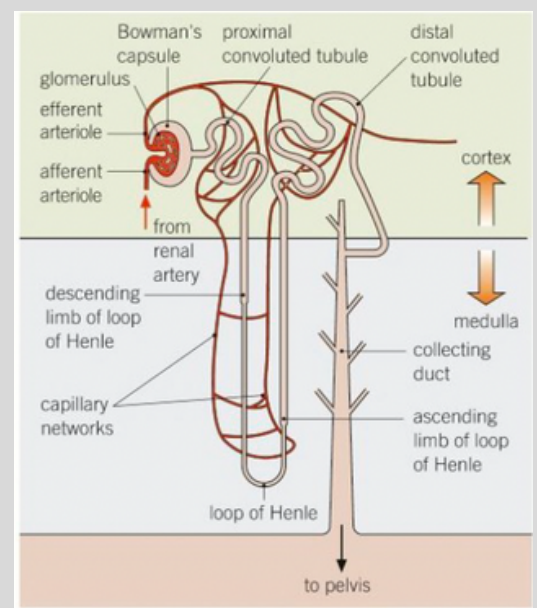


STRUCTURE OF THE NEPHRON

- **Bowman's capsule:** cup shaped structure containing the glomerulus (large bundle of capillaries)--> more blood goes into glomerulus than leaves it due to ultrafiltration
- **Proximal convoluted tubule:** first, coiled region of the tubule after the Bowman's capsule, in cortex of kidney--> reabsorption takes place
- **Loop of Henle:** divided into descending (thinner) and ascending (thicker) parts
- **Distal convoluted tubule:** further reabsorption, permeability of the walls change depending on ADH (anti-diuretic hormone) concentration
- **Collecting duct:** More reabsorption



Light micrograph of a section through a human kidney
SOURCE: OCR A LEVEL BIOLOGY
TEXTBOOK BY ANN FULLICK



FUNCTIONS OF THE NEPHRONS

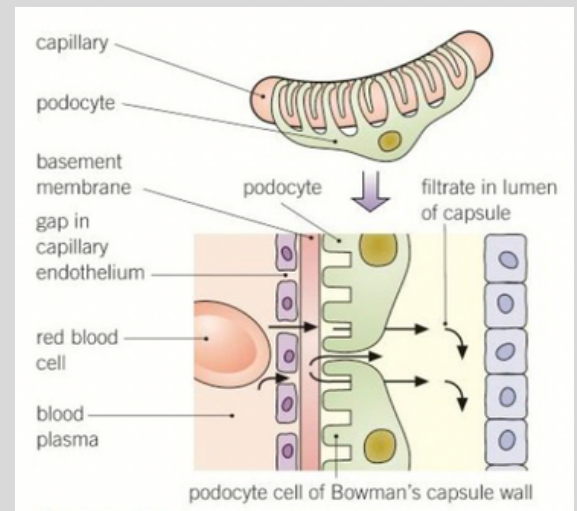
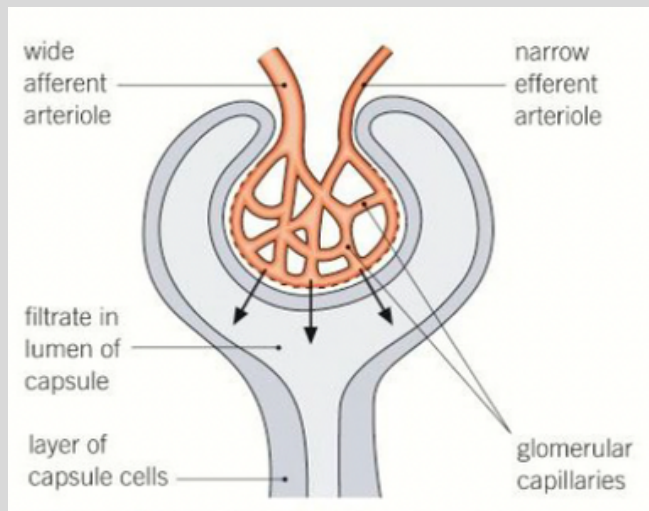
2 main functions

- **Ultrafiltration**
- **Reabsorption**

IMPORTANT: glomerular filtration rate is the volume of blood that is filtered through the kidneys in a given time

ULTRAFILTRATION

- Afferent arteriole of glomerulus (arteriole coming in) wider than efferent arteriole (arteriole going out- efferent just means 'going out' and afferent means 'going in')--> creating high blood pressure
- Forces most plasma contents through gaps in capillary endothelium and then basement membrane but RBCs and plasma proteins remain in blood (as they are too big)--> **first filter** (fenestrations and basement membrane)
- **Second filter** (podocytes which have pedicles- extensions) that wrap around capillaries makes sure that any cells/plasma proteins that did pass through first filter doesn't pass into the tubule itself
- So filtrate entering capsule contains glucose, salt, urea



WHERE DOES REABSORPTION HAPPEN

- PCT (proximal convoluted tubule), Loop of Henle, Distal Convoluted Tubule (DCT), Collecting Duct

REABSORPTION- PCT

- All glucose, amino acids, vitamins, and hormones are moved from filtrate back into blood by active transport
- 85% of NaCl and H₂O is reabsorbed
- **Adaptations for absorption:** microvilli (increase SA: V ratio), mitochondria (provides ATP needed in active transport systems)
- Once substances removed from nephron--> they move into surrounding capillaries which have constant flow of blood--> maintains concentration gradient for absorption
- Filtrate reaching the loop of Henle at the end of the proximal convoluted tubule is isotonic with the tissue fluid surrounding it



REABSORPTION- LOOP OF HENLE

- Filtrate entering descending loop of henle (from PCT ending to hairpin) is isotonic with blood. Water moves out into surrounding fluid by osmosis down concentration gradient. Descending limb is not permeable to sodium or chloride ions so the concentration of solutes is very high at the bottom of the descending limb (hypertonic to blood)
- Active transport of sodium and chloride ions from ascending limb into surrounding fluid leads to the creation of the water potential gradient allowing water to move out of the descending limb in the previous step
- First section of ascending limb is very permeable to sodium and chloride--> so they move out down concentration gradient. Second part of ascending limb is impermeable to water and actively transports sodium and chloride out into the surrounding space--> so the concentration inside the tubule is very dilute
- But there is high concentration of sodium and chloride in the medulla so enables urine to be more concentrated than the blood--> **key part of the countercurrent multiplier system**

REABSORPTION- DISTAL CONVOLUTED TUBULE

- Areas where the permeability of the walls of tubules varies with level of ADH
- Cells lining DCT have lots of mitochondria--> adapted for active transport
- If blood has low sodium--> sodium actively pumped out of the DCT and Cl⁻ follows down an electrochemical gradient
- Water also leaves DCT if it is an area where it is permeable to water--> further concentrates the urine
- Plays a role in balancing the pH of the blood

REABSORPTION- COLLECTING DUCT

- Water moves out of the collecting duct by diffusion down a concentration gradient as it passes through the renal medulla
- Urine becomes more concentrated and the sodium ion levels in surrounding fluid increases through the medulla, from cortex to pelvis
- So water can be removed from the collecting duct along its length--> produces hypertonic urine when the body needs to conserve water
- ADH levels effects the permeability of the collecting duct--> if there is high ADH levels--> more water reabsorbed and vice versa (as ADH stands for anti-diuretic hormone which means 'hormone that causes less urination')

MECHANISM OF ADH ACTION

- ADH binds to G-protein coupled (second messenger) vasopressin receptors on the collecting duct
- Increases intracellular cAMP which has **3 effects:**
 - Vesicles in cells lining collecting duct fuse with cell surface membrane on the side of the cell in contact with the tissue fluid of medulla
 - Membranes of these vesicles contain aquaporins (water protein channels) and are inserted into the cell surface membrane
 - Increasing the permeability of the collecting duct to water
 - This provides a route for water to move out of the tubule cells into the tissue fluid of the medulla and blood capillaries by osmosis down water potential gradient
 - Produces low volume, concentrated urine
 - This is a negative feedback control system (opposite happens when water levels in the body are high)--> water levels are detected by osmoreceptors in the hypothalamus, which detect the concentration of inorganic ions in the blood



CAUSES OF KIDNEY FAILURE

- Kidney infections--> structure of podocytes and tubules are damaged/destroyed
- Increased blood pressure--> damages the epithelial cells and basement membrane of Bowman's Capsule
- Genetic disease--> polycystic kidney disease where healthy kidney tissue is replaced by fluid-filled cysts

CONSEQUENCES OF KIDNEY DISEASE

- **Proteinuria**- protein in kidneys as basement membrane or podocytes of Bowmans capsule are damaged--> no longer act as filters and plasma proteins are able to pass into the filtrate and into urine
- **Hematuria**- blood in urine

DIAGNOSIS OF KIDNEY DISEASE

- To quantify such disease--> GFR (glomerular filtration rate) used
- Values compared against standard metrics for healthy individuals--> standardised according to gender and age
- Levels of creatinine measured in the blood (creatinine is a breakdown product of muscles and is freely filtered by the kidneys)--> used to give **eGFR (estimated glomerular filtration rate)**
- If creatinine levels are too high--> kidney disease as it is not effectively being cleared
- **NORMAL GFR PATTERNS WITH AGE/GENDER:** GFR decreases steadily with age even if you are healthy, men have more muscle mass so more creatinine levels in blood

RENAL DIALYSIS

Haemodialysis

- Dialysis machine used
- Arterial blood leaves patient's arm and flows into dialysis machine--> flows between partially permeable dialysis membranes
- Membranes mimic the basement membrane, on the other side of the membrane is the dialysis fluid which has a carefully controlled composition of fluid
- **Dialysis fluid** contains **normal plasma levels of glucose** (no net movement of glucose out of blood), **normal plasma levels of mineral ions** (excess mineral ions from blood move into fluid down concentration gradient), **no urea** (urea leaves the blood)
- Blood and dialysis fluid move in opposite directions--> countercurrent exchange

CONSEQUENCES OF KIDNEY FAILURE

- **No electrolyte balance**- body cannot excrete sodium, potassium, and chloride ions
- **Accumulation of urea in blood**- toxic
- **High blood pressure**- kidney adjusts blood volume to regulate blood pressure by regulating the amount of water in blood--> no kidneys--> no regulation
- **Weakened bones**- calcium/phosphorous balance in blood is lost
- **Pain/stiffness in joints**- abnormal proteins build up in the blood
- **Anaemia**- kidneys are involved in the production of a hormone called erythropoietin that stimulates the formation of RBCs--> when kidneys fail--> reduces the production of RBCs--> tiredness and lethargy

QUANTIFYING KIDNEY DISEASE AND TREATING KIDNEY DISEASE

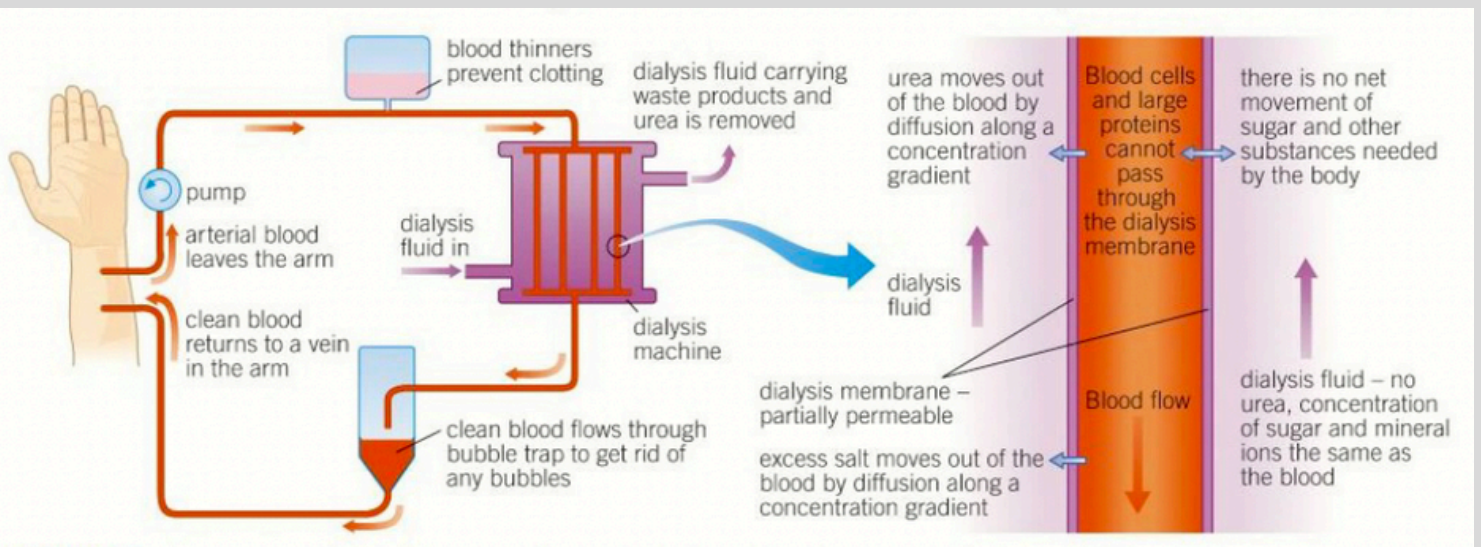
- **Moderate/severe chronic:** GFR<60 for 3 months
- **Two treatment types:** Renal dialysis, Transplant

RENAL DIALYSIS

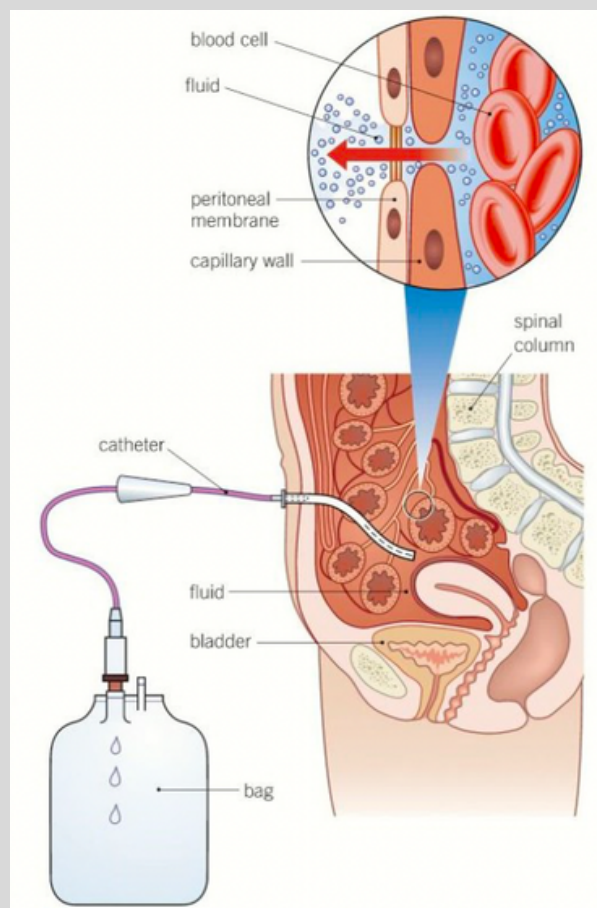
Peritoneal Dialysis

- Done inside body
- Uses the peritoneal membrane in abdomen as the dialysis membrane
- Dialysis fluid introduced into abdomen using catheter and left for few hours for mineral ions and urea levels to balance out
- Fluid drained and discarded

HAEMODIALYSIS



HAEMODIALYSIS



KIDNEY TRANSPLANTATION

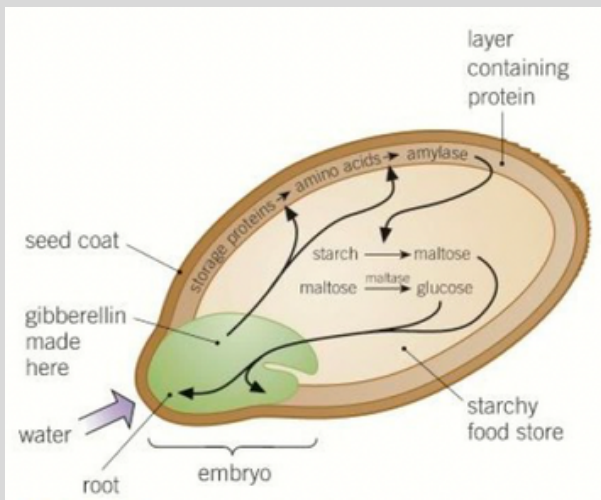
- Diseases kidney replaced by healthy kidneys
- Blood vessels are joined and the ureter is inserted into the bladder
- **Problems:** rejection by host immune system, greater demand than supply from donors
- **Solutions:** tissue/HLA matching, immunosuppressants (more prone to common disease)

PLANT HORMONES AND THEIR FUNCTIONS

Hormone	Some of their known roles in plants
Auxins	Control cell elongation, prevent leaf fall (abscission), maintain apical dominance, involved in tropisms, stimulate the release of ethene, involved in fruit ripening
Gibberellin	Cause stem elongation, trigger the mobilization of food stores in a seed at germination, stimulate pollen tube growth in fertilization
Ethene	Causes fruit ripening, promotes abscission in deciduous trees
ABA (abscisic acid)	Maintains dormancy of seeds and buds, stimulates cold protective responses, for example, antifreeze production, stimulates stomatal closing

EXPERIMENTAL EVIDENCE

- Mutant seeds which do not have the gene to make gibberellins do not germinate--> if gibberellins applied externally--> germinate
- If gibberellin biosynthesis inhibitors are applied to seeds--> they do not germinate as they cannot make the gibberellins needed for them to break dormancy--> if gibberellin inhibition is removed, or gibberellins are applied externally then germination happens



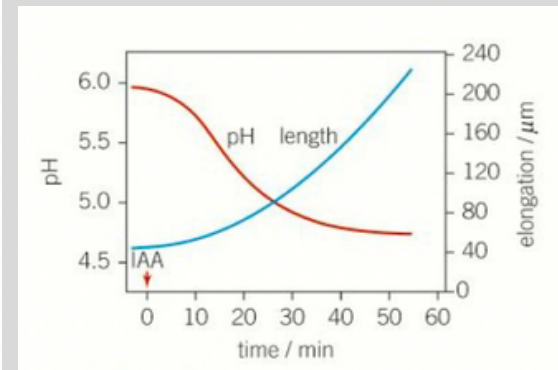
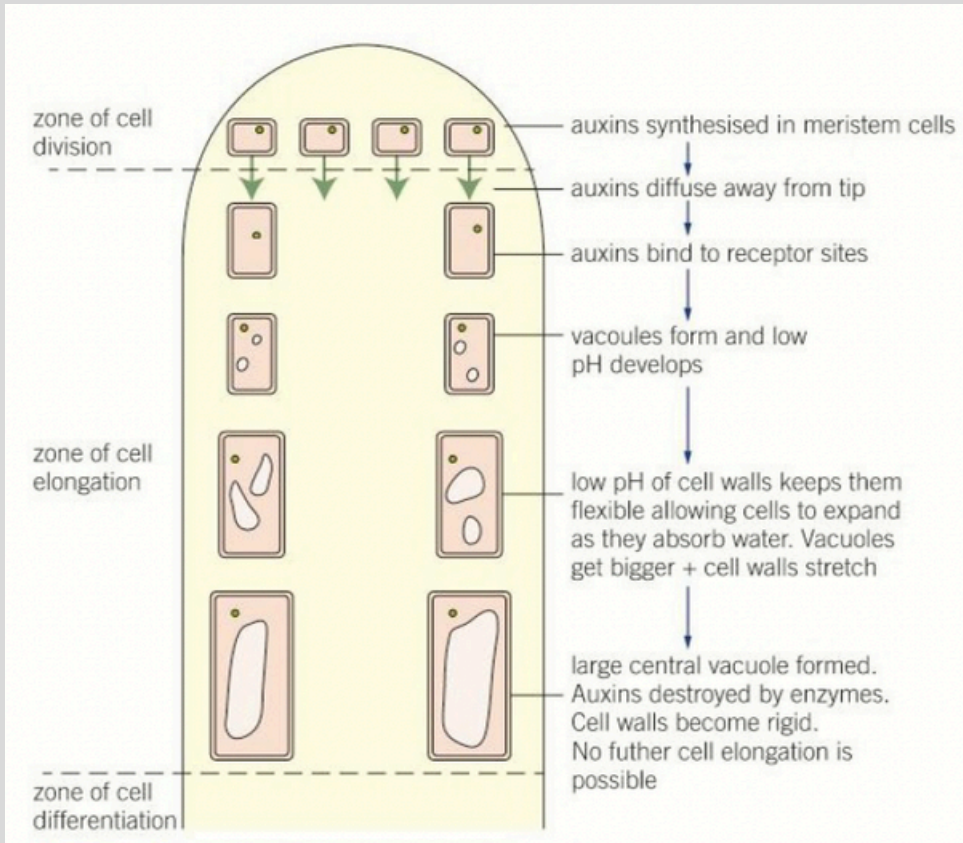
PLANT HORMONES AND SEED GERMINATION

- When seed absorbs water--> embryo is activated and starts to produce gibberellins
- This stimulates the production of enzymes that break down the food stores in the seed
- Food store is located in the cotyledons in dicots and endosperm in monocots
- Embryo uses food sources to produce ATP for production of macromolecules so it can grow and break out of the seed coat
- Gibberellins switch on genes which code for amylases and proteases (digestive enzymes needed for germination)
- ABA (another hormone) acts as an antagonist to gibberellins
- Relative levels of ABA and gibberellins determine when a seed will germinate

CONTROL OF PLANT GROWTH AFTER GERMINATION

- **Auxins (Indoleacetic acid or IAA)** are growth stimulants produced in plants
- Made in cells at the tip of the roots and shoots, and in the meristems
- Auxins move down the stem and up the root both in the transport tissue and from cell to cell
- Magnitude of the effects auxin has depends on its concentration and any interactions it has with other hormones
- Auxins stimulate growth of the apical shoot--> bind to specific receptors on plant cell membrane--> causes fall in pH to 5--> optimum pH for enzymes needed to keep the walls flexible and plastic--> as cells mature, auxin is destroyed so pH rises and plasticity decreases--> wall fixed in shape and cannot grow

SUMMARY OF THE EFFECTS OF AUXIN ON APICAL GROWTH



EFFECTS OF HIGH CONCENTRATIONS OF AUXIN

- Suppress the growth of lateral shoots--> **apical dominance**
- Lateral shoots are inhibited by the auxins that moves back down the stem and growth in the main shoot is stimulated by the auxin produced at the tip
- Further down shoot--> auxin concentration is lower so lateral shoots grow well
- **EVIDENCE:** if apical shoot is removed, auxin-producing cells are removed and so lateral shoots grow and shoots don't, if auxin applied artificially to cut apical shoot--> apical dominance is reasserted and lateral shoot growth is suppressed

EFFECTS OF LOW CONCENTRATIONS OF AUXIN

- Low concentrations of auxins promote root growth--> **up to a given concentration of auxin** the more auxin that reaches the roots the more they grow
- Removing the apical shoot (site of auxin production, along with root tips) reduces auxin concentration reaching root tips so growth is slowed
- Replacing auxin artificially at the cut shoot restores growth
- High auxin concentrations inhibit growth

GIBBERELLINS

- Gibberellins important in: elongation of plant stems during growth, affect the length of the internodes (region between the leaves on a stem)
- No gibberellins--> plant stems are shorter--> reduces waste and makes plants less vulnerable to damage by weather and harvesting (**commercial benefits**)



LEAF SHEDDING IN DECIDUOUS PLANTS AS A RESPONSE TO ABIOTIC STRESS

Daylight Sensitivity

- Photoperiodism--> plants sensitive to a lack of light in their environment
- Sensitivity of plants to day length results from light sensitive pigment- **phytochrome** (two forms: Pr and Pfr)
- Each form absorbs a different type of light and the ratio of Pr and Pfr changes depending on light levels

Abcission/leaf fall

- Fall in light levels--> fall in auxins--> leaves produce ethene (another hormone)
- At the base of the leaf stalk is a region called the abscission zone, made up of two layers of cells sensitive to ethene
- Ethene initiates gene switching in these cells--> resulting in the production of new enzymes
- These enzymes digest and weaken the cell walls in the outer layer of the abscission zone, which is known as the **separation zone**
- Vascular bundles which carry nutrients and water to leaves become sealed off
- Fatty material is deposited in the cells on the stem side of separation layer--> forming a protective scar when the leaf falls--> prevents pathogen entry
- Cells which are deep in the separation zone respond to hormonal cues by retaining water and swelling, putting more strain on the already weakened outer layer
- This process is finished by further decreasing temperatures, and the leaf falls, leaving a neat, waterproof scar

HOW DO PLANTS PREVENT FREEZING

- Solutes in cytoplasm and vacuole lower freezing point
- Production of antifreeze molecules (carbohydrates, amino acids, proteins)

STOMATAL CONTROL

- Stomatal opening and closing is under control of the hormone ABA
- Stomata is opened and closed to conserve water, minimise heat loss etc
- ABA released by roots when water content of soil low (early warning system for leaves)
- Transported up plant to leaves where it binds to receptors on plasma membrane of stomatal guard cells
- Where it changes the ionic balance inside guard cells--> water moves out of guard cells by osmosis down water potential gradient--> reducing turgor causing stomatal opening

PHYSICAL DEFENCES TO HERBIVORY

- Thorns, barbs, spikes, spiny leaves, fibrous and inedible tissue, hairy leaves stings,

CHEMICAL DEFENCES TO HERBIVORY

- **Tanins:** phenol, bitter taste, toxic to insects (bind and inactivates digestive enzymes)
- **Alkaloids:** bitter nitrogenous compound, metabolic poison, toxic to fungi and insects, caffeine and nicotine
- **Terpenoids:** toxic to insects and fungi, pyrethrin is an example which acts as a neurotoxin and is produced by chrysanthemums, citronella produced by lemon grass repels insects

WHAT ARE PHEROMONES

- Chemical made by an organism which affects the social behaviour of other members of the same species





HOW ARE PHEROMONES USED FOR DEFENCE?

- **Eg: maple trees** produce a pheromone that is absorbed by leaves on other branches if attacked by insects--> leaves on other branches make calls (chemical) which helps protect them if attacked
- Plants communicate via roots to warn other plants of a coming attack

VOCs (VOLATILE ORGANIC COMPOUNDS)

VOCs produced when plant detects chemicals in the saliva of insects that attack them--> communicate between themselves, examples?

- When cabbages attacked by caterpillars, they produce a chemical which attracts a wasp which lays its eggs in the caterpillars which are then eaten alive--> protects plant
- Signal from plant also deters any other female caterpillars from laying their eggs
- When apple trees attacked by spider mites--> produce VOCs which attract predatory mites that destroy the apple tree pests
- Some types of wheat seedling produce VOCs when they have been attacked by aphids and these repel other aphids from the plant
- VOCs produced also acts as a pheromone so that neighbouring plants begin to produce the VOC before they start getting attacked

FOLDING IN RESPONSE TO TOUCH

- **Mimosa pudica** collapses if the leaves are touched--> frightens large herbivores and dislodges small insects which have landed on the leaves
- Leaf falls in a few seconds and recovers over 10-12 minutes as a result of potassium ion movement into specific cells, which is followed by water movement by osmosis down water potential gradient

TROPISM DEFINITIONS

- **Phototropism**- growth of plants in response to light which comes from one direction only
- **Geotropism**- response to gravity
- **Chemotropism**- response to chemicals
- **Thigmotropism**- response to touch

WHY ARE TROPISMS NEEDED

- **Phototropism** important so that plants grow up towards sun to maximise light absorption for photosynthesis
- **Geotropism** important so plant grows down into soil which provides minerals, water and support

HOW ARE TROPISMS RESEARCHED AND WHY

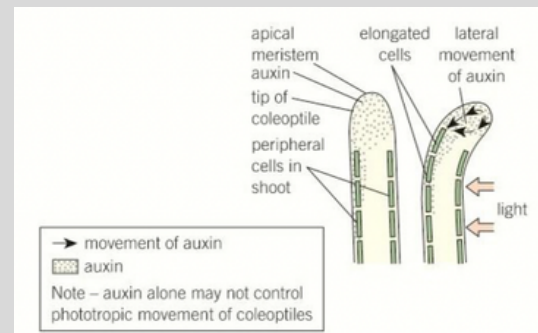
- Research is done on **germinating seeds and young seedlings**
- As they are easy to work with and manipulate, grow rapidly and changes show quickly
- Seedlings of monocotyledonous plants are most commonly used

PHOTOTROPISM

Expt no.	Method	Result	Explanation
1	unilateral light plant shoot	shoot bends towards light	The shoot is positively phototropic. Bending occurs behind the tip.
2	shoot tip removed light tip discarded	no response	The tip must either detect the stimulus or produce the messenger (or both) as its removal prevents any response.
3	lightproof cover is placed over intact tip of shoot light	no response	The light stimulus must be detected by the tip.
4	thin, impermeable barrier of mica light	movement of chemical down shaded side bends towards the light	Mica on the illuminated side of the shoot allows the hormone to pass only down the shaded side where it increases growth and causes bending.
5	mica inserted on shaded side light	movement of chemical down shaded side is prevented by mica no response	
6	tip removed, gelatin block inserted and tip replaced light gelatin block	movement of chemical down shaded side bends towards the light	As gelatin allows chemicals to pass through it, but not electrical messages, the bending which occurs must be due to a chemical passing from the tip.

EFFECT OF UNILATERAL LIGHT

- Side of a shoot exposed to light contains less auxin than the side which is not illuminated
- Appears that light causes the auxin to move laterally across shoot (to the side which is not illuminated)
- Stimulates cell elongation and growth on the dark side--> shoot tip bends towards light
- Once shoot is growing towards light--> unilateral stimulus is removed and lateral auxin movement stops
- Original theory** was that light destroys auxin--> **disproved** as the levels of auxin was measured to be the same whether they are kept in the dark or in unilateral illumination

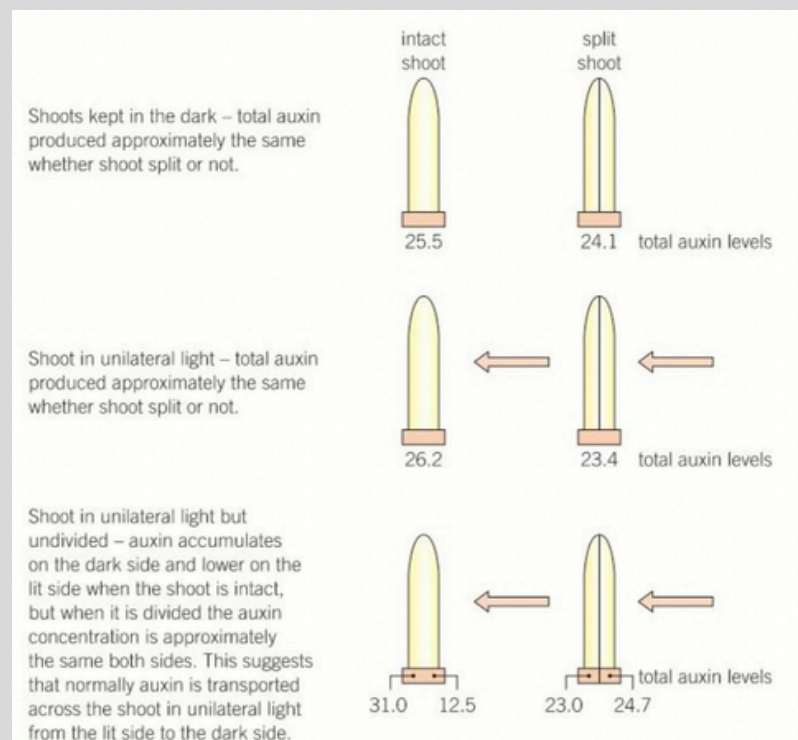


CHANGES OBSERVED WHEN PLANTS GROW IN THE DARK

- Plants grow faster in the dark to reach as high as possible to the light source
- As shoots that break through soil first will avoid competition with other seedlings for light
- Gibberellins are responsible for the extreme elongation of the internodes when a plant is grown in the dark
- Once plant is exposed to light--> growing slowed and resources used for: **leaf synthesis, strengthening stems, overall growth**

GEOTROPISMS

- Shoots--> negatively geotropic (grow away from force of gravity)
- Roots--> positively geotropic (grow towards force of gravity)
- Seen in the lab by placing plants on the sides in all round light or in the dark



▲ **Figure 3** Experiments such as these with maize coleoptiles help us to determine what happens to auxin levels within a shoot illuminated by unilateral light.



USE OF ETHENE

- Ethene used to control ripening of climacteric fruits (bananas, mangoes, tomatoes, avocados)--> ripen rapidly after picking whereas non-climacteric fruits (oranges, strawberries, watermelons) do not
- Effect seen when ripe banana put into a bag with a bunch of green bananas vs just a bag of green bananas
- Bag with green and ripe bananas show that the green bananas ripen faster compared to the other bag, with just the green bananas
- As the ethene produced from the ripe bananas cause rapid ripening of the green bananas
- Other factors, eg temperature, kept the same
- **Commercial use:** after picking, fruits cooled and stored, when ready for sale they are exposed to ethene

USE OF HORMONE ROOTING POWDERS

- Auxin applied to cut shoots--> stimulates production of new shoots--> able to propagate new plants from **plant cuttings** (small piece of the stem of a plant, usually with some leaves on)
- Horticulturists (plant science people) dip plant cuttings in rooting powder

USE OF HORMONES FOR WEEDS

- Many weeds are broad-leaved dicots, compared to the narrow-leaved monocots such as rice, maize and wheat
- Synthetic dicot auxin applied which is absorbed by the broad-leaved plants--> unsustainable/too much growth--> do not survive

OTHER USES OF PLANT HORMONES

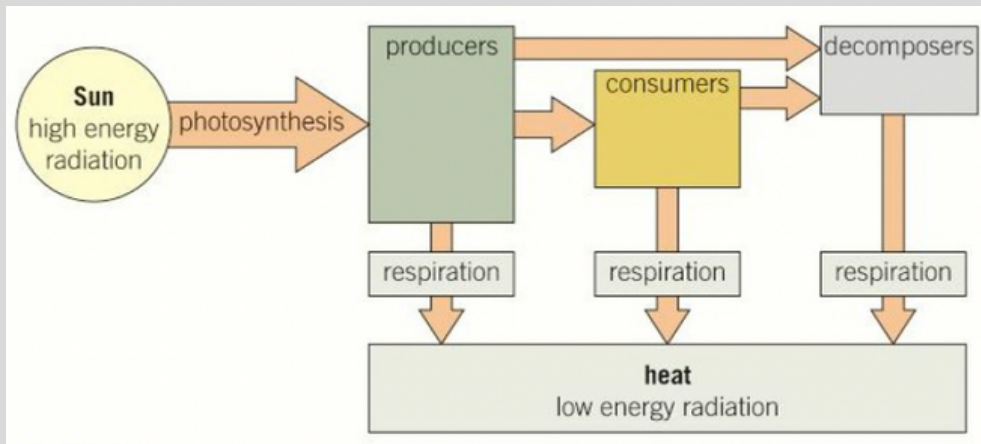
- Auxins used to produce seedless fruit
- Ethene used to promote fruit dropping in plants such as cotton, walnuts, and cherries
- Sytokinins used to prevent ageing of ripening fruit and products such as lettuces, and in micropropagation to control tissue development
- Gibberellins used to delay ripening and ageing in fruit, to improve the size and shape of fruits, and in beer brewing to make the malting process faster

2BIOL-1

ENERGY CYCLES, PHOTOSYNTHESIS, RESPIRATION

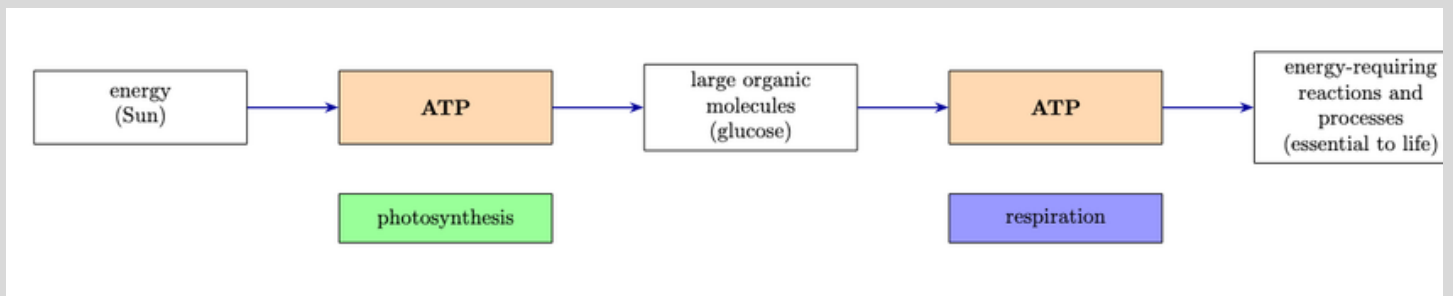


ENERGY FLOW THROUGH AN ECOSYSTEM



- BUT WHAT IS THE FORM OF THIS ENERGY?

ROLE OF ATP IN ENERGY FLOW



CHEMIOSMOSIS

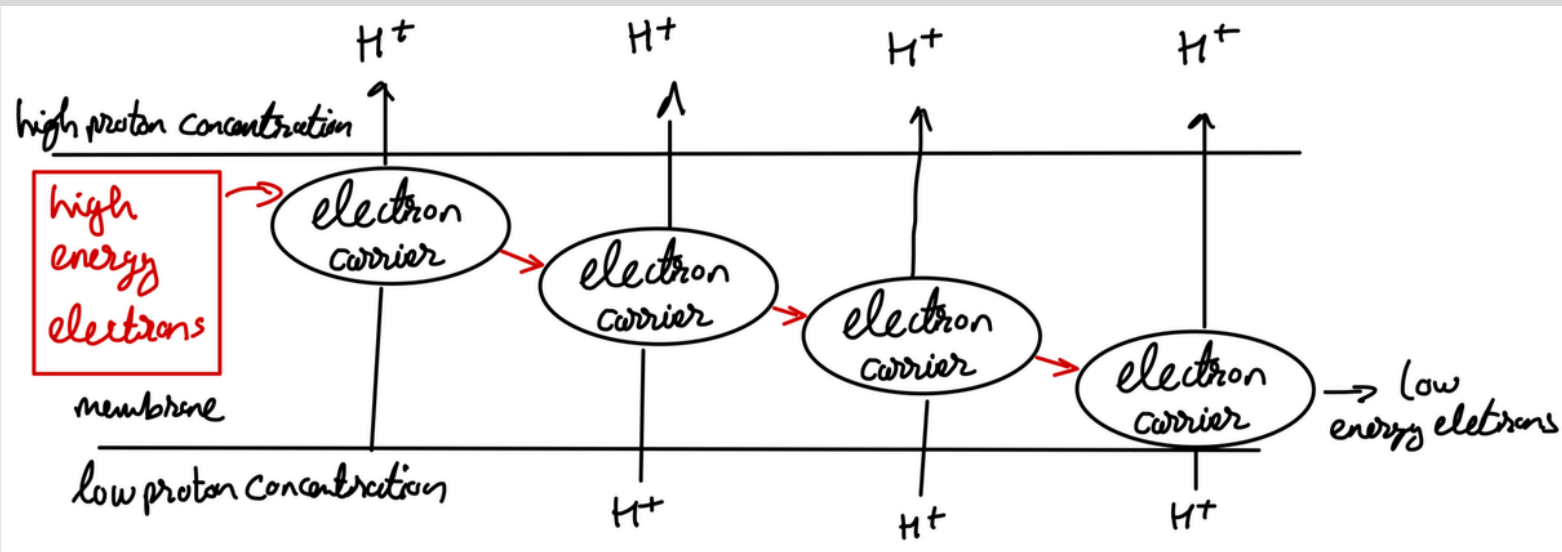
- **Chemiosmosis:** process by which ATP is produced in both photosynthesis and respiration
- Involves diffusion of protons from a region of high concentration to a region of low concentration through a partially permeable membrane
- Movement of protons as they flow down their concentration gradient releases energy--> used to form ATP from ADP and Pi
- **MOST IMPORTANT PART:** proton gradient needs to be established first--> energy for this comes from excited electrons (raising of electrons to higher energy levels)

ELECTRON EXCITATION- 2 WAYS

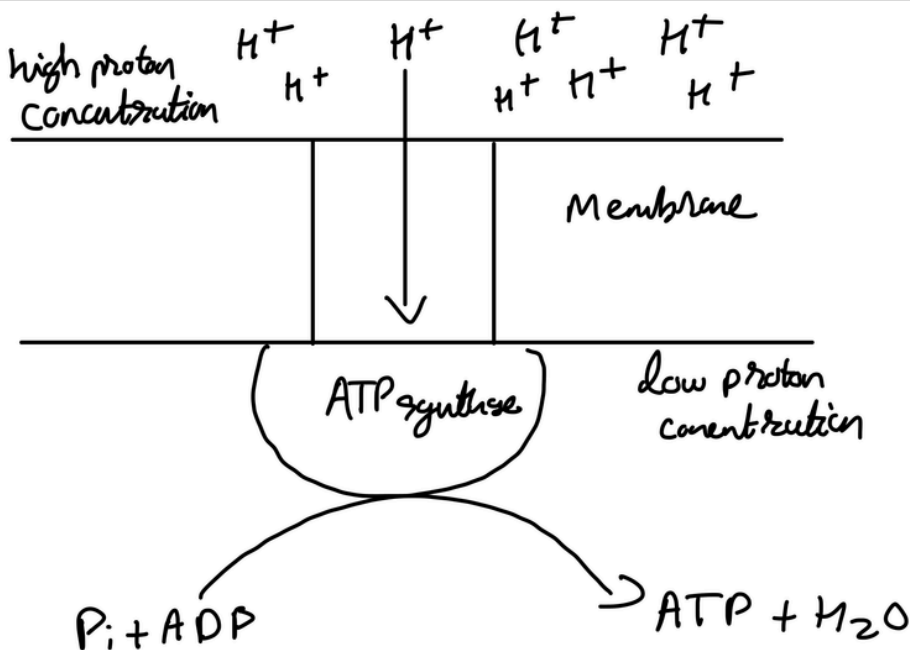
- Electrons present in chlorophyll are excited by absorbing light from the sun
- High energy electrons are released when chemical bonds are broken in respiratory molecules (eg glucose)
- Excited electrons go into the electron transport chain which generates the energy needed to create the proton gradient

ELECTRON TRANSPORT CHAIN

- Electron transport chain has a series of electron carriers--> each with progressively lower energy levels
- As the electrons move from one carrier to another--> they release some energy--> used to actively pump protons across the membrane--> proton gradient established
- Maintenance of the proton gradient is due to the impermeability of the membrane to protons



- As the membrane is impermeable to protons--> the only way protons can move back across down electrochemical gradient is through hydrophilic membrane channels which are linked to ATP synthase
- ATP synthase is an enzyme--> catalyses the formation of ATP from ADP and P_i as protons move across the channel



- In photosynthesis--> ATP used to synthesise glucose and other organic molecules
- In respiration--> ATP provides energy to drive metabolic processes essential to life

ELECTRON TRANSPORT CHAIN

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- As the electrons move from one carrier to another--> they release some energy--> used to actively pump protons across the membrane--> proton gradient established
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AUTOTROPHIC VS HETEROTROPHIC

- **Autotrophic:** Organisms that can photosynthesise
- **Heterotrophic:** Organisms that obtain complex organic molecules by eating each other

STRUCTURE AND FUNCTION OF CHLOROPLASTS

- **Thylakoids:** flattened discs of membranes
- **Grana:** Joined by membranous channels called lamellae
- Thylakoids and grana give an increased surface area for the absorption of light by **chlorophyll** which is the green pigment in chloroplasts
- **Stroma:** fluid enclosed in the chloroplast is the stroma and is the site of chemical reactions that form complex organic molecules

CHLOROPHYLL

- Absorbs red and blue light and reflects green
- Two forms of chlorophyll: chlorophyll a and b--> absorb different wavelengths of light
- **Antennae complex:** light absorbing pigments (chlorophyll b, xanthophylls, carotenoids) are embedded in the thylakoid membrane of the chloroplast--> forms the light harvesting system
- Chlorophyll a is located in the reaction centres (stroma)--> where the reactions of photosynthesis takes place

PHOTOSYNTHESIS STAGES

2 stages:

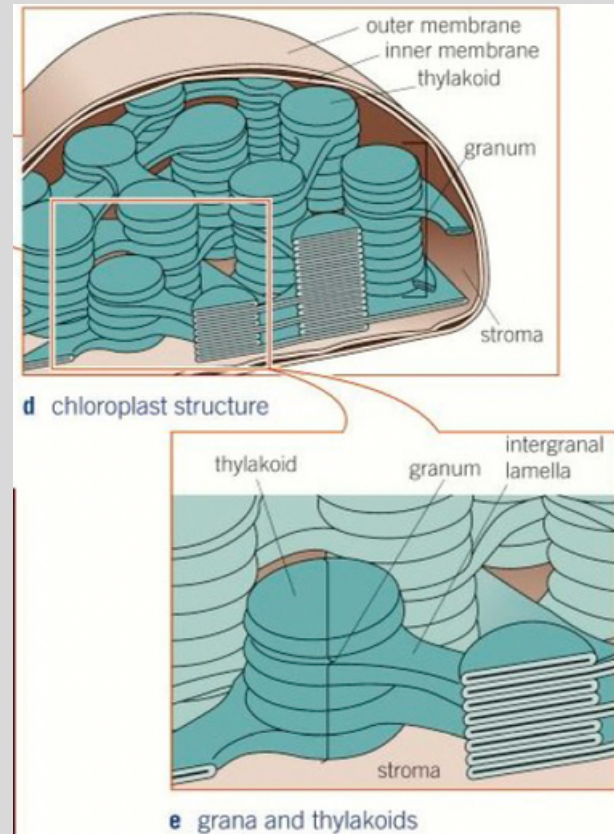
- **Light dependent stage**
- **Light independent stage**



LIGHT DEPENDENT STAGE

Non-cyclic photophosphorylation

- Areas called photosystems are the main reaction centres, and this stage involves PSI and PSII (photosystem I and II)
- PSII is involved in non-cyclic photophosphorylation first and then PSI
- Reaction centre of PSI absorbs light at a higher wavelength (700nm) than PSII (680nm)
- Absorbed light excites electrons at the photosystems
- Excited electrons are released from reaction centre of PSII and go to the electron transport chain--> producing ATP via chemiosmosis
- Electrons that are released are replaced by the breakdown of water molecules using energy from the sun (photolysis)
- Excited electrons are then released from PSI--> pass to a different electron transport chain--> produce ATP via chemiosmosis
- Electrons released from PSII are used to replace the electrons released from PSI
- Electrons leaving the electron transport chain of PSI and protons (from photolysis of water) are accepted by the coenzyme NADP to form reduced NADP--> provides reducing power/hydrogen to produce organic molecules

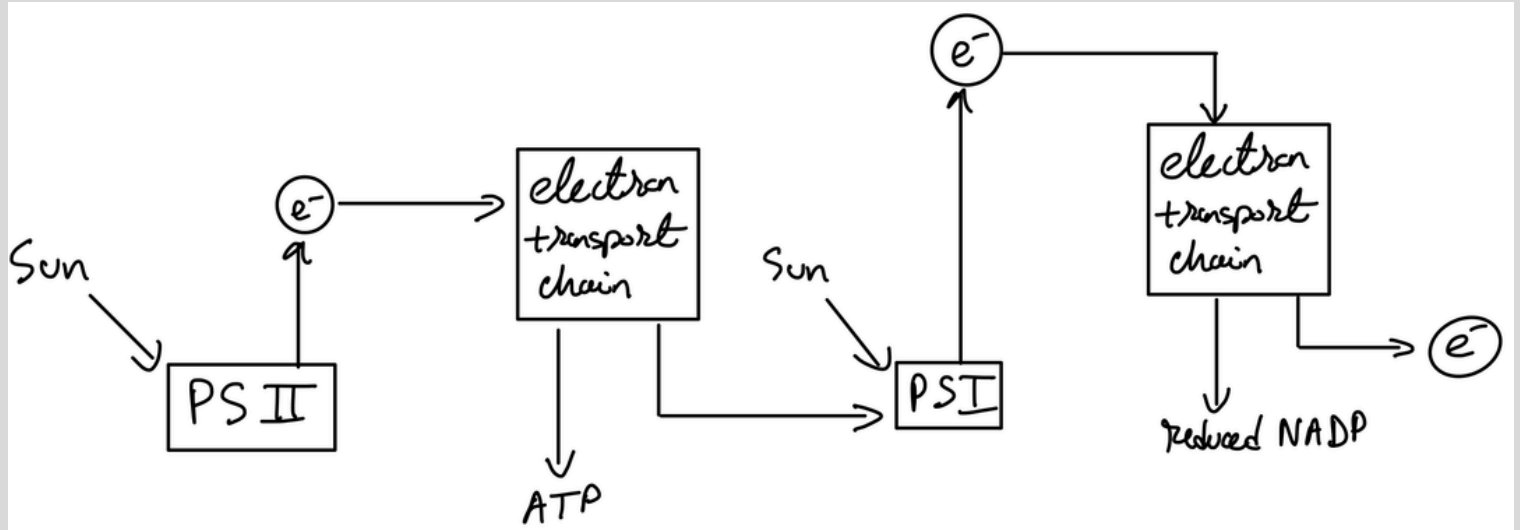


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ENERGY CYCLES,
PHOTOSYNTHESIS, RESPIRATION

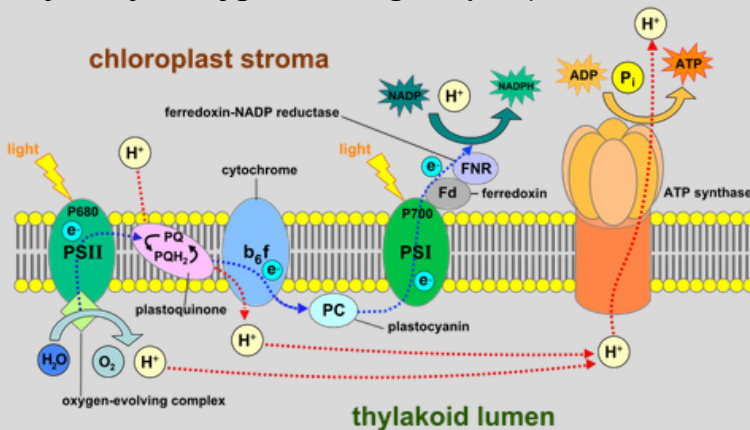
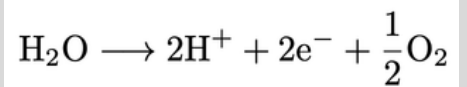


THE Z-SCHEME--> DIAGRAM SUMMARISING THE ELECTRON TRANSPORT CHAINS IN PHOTOSYNTHESIS



PHOTOLYSIS

- **Photolysis:** splitting of water into oxygen, protons and electrons using energy from sunlight
- Electrons released replace the electrons lost from the reaction centre of PSII
- Catalysed by an **oxygen-evolving complex** present in PSII



- Oxygen released as a by-product
- Protons are released into the lumen of the thylakoids--> increasing the proton concentration across the membrane
- As they move back across the membrane down a concentration/electrochemical gradient--> ATP is formed by chemiosmosis
- Once Hydrogen is returned to the stroma--> combines with NADP and an electron from PSI to form reduced NADP (used in light-independent reaction)

CYCLIC PHOTOPHOSPHORYLATION

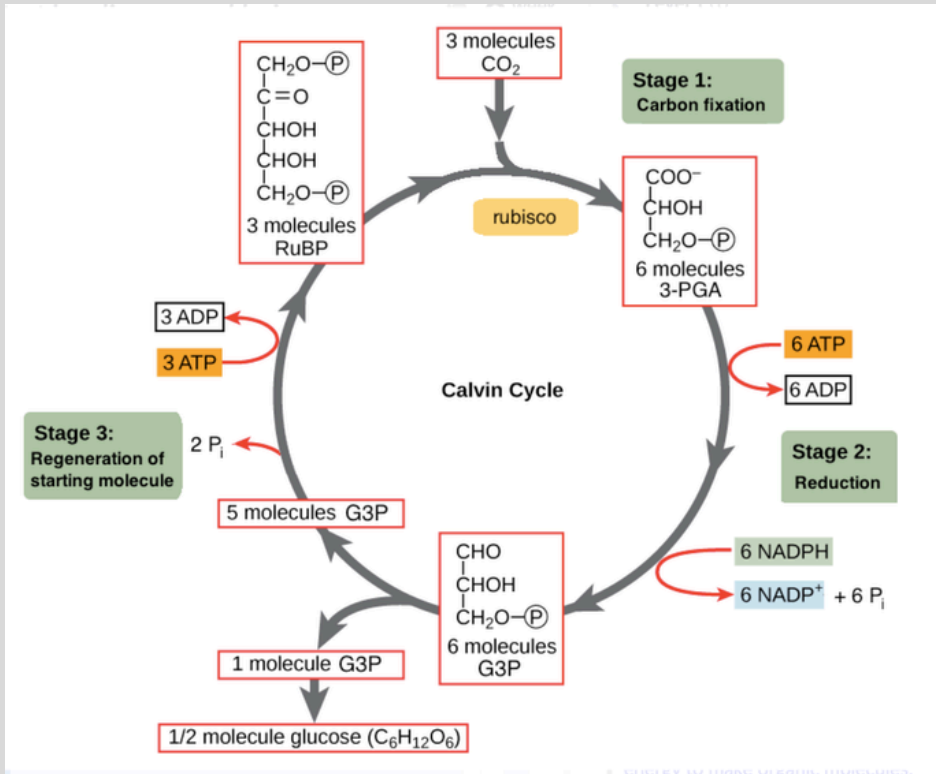
- Electrons leaving the electron transport chain after PSI can be returned to PSI, so is not used to form reduced NADP
- **Cyclic** as PSI still leads to ATP being produced without any electrons being supplied from PSII

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ENERGY CYCLES, PHOTOSYNTHESIS, RESPIRATION



LIGHT-INDEPENDENT STAGE

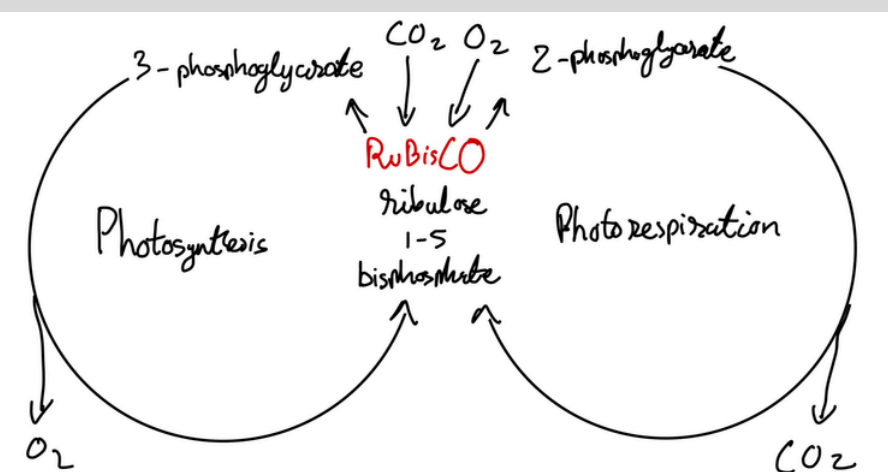


- CO_2 enters the intercellular spaces within the spongy mesophyll of leaves by diffusion through stomata
- Combines with **ribulose biphosphate (RuBP)** → **fixation** (as the carbon is incorporated into RuBP)
- Catalysed by the enzyme **RuBisCO (ribulose biphosphate carboxylase)** → unstable 6C (carbon) molecule is formed
- 6C compound breaks down to form 2 molecules of **GP (glycerate-3-phosphate)**
- Each GP molecule is converted to another 3 C molecule (**triose phosphate-TP**) using a hydrogen atom from reduced NADP and energy released from the hydrolysis of ATP
- **Majority of TP** is recycled to regenerate RuBP so the Calvin cycle is able to continue

REGENERATION OF RuBP

- 5/6 TP molecules used to regenerate RuBP
- 10 TP molecules are then used to make 6 RubP molecules (for 6 turns of the cycle)
- As 6 turns needed to produce 1 glucose molecule

WHAT IS PHOTORESPIRATION?



- When humidity is low, temperature is high → plants lose water by transpiration through open stomata → so they close
- Closing means that they cannot obtain CO_2
- So when CO_2 very low → respiration continues but photosynthesis rate falls → increased O_2 levels
- Oxygen is a competitive inhibitor of RuBisCO → produces the toxic product **2-phosphoglycolate** → reducing the efficiency of photosynthesis

2BIOL-1

ENERGY CYCLES, PHOTOSYNTHESIS, RESPIRATION



LIMITING FACTORS OF PHOTOSYNTHESIS

- **Light intensity:** as light intensity increases, ATP and reduced NADP are produced at a higher rate
- **Carbon Dioxide:** increasing CO₂ concentration increases the rate of carbon fixation in the Calvin cycle so TP production is higher
- **Temperature:** rate of enzyme activity increases as temperature increases until proteins denature, rate of photorespiration also increases above 25 degrees Celsius so photosynthesis made less efficient

EFFECT OF TEMPERATURE ON CALVIN CYCLE

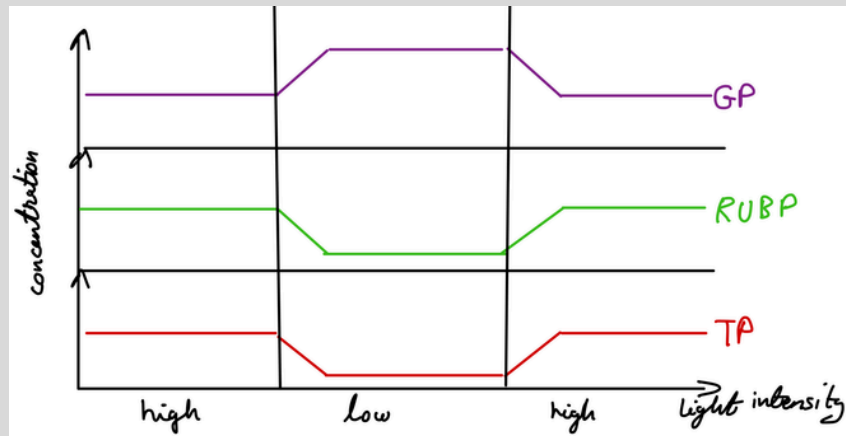
- Low temperature--> low kinetic energy of molecules--> fewer collisions and successful collisions--> reduced rate of reaction
- Decrease temperature--> lower concentrations of GP, TP and RuBP

EFFECT OF CO₂ ON CALVIN CYCLE

- Low CO₂--> low GP--> low TP
- Concentration of RuBP increases as it gets regenerated from the available TP but is not used to fix CO₂

EFFECT OF REDUCING LIGHT INTENSITY ON CALVIN CYCLE

- Reducing light intensity reduces the rate of the light-dependent stage of photosynthesis
- Reducing amount of ATP and reduced NADP produced
- Reduced NADP and ATP needed to convert GP to TP--> so GP accumulates and increases, whereas TP levels decrease
- TP used to regenerate RuBP--> less TP means that RuBP levels decrease

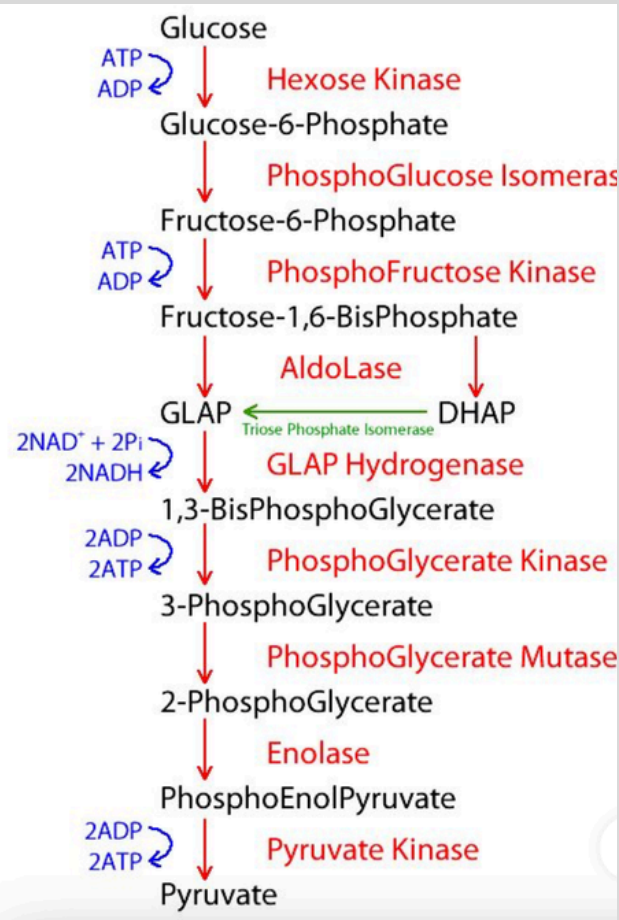


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ENERGY CYCLES, PHOTOSYNTHESIS, RESPIRATION



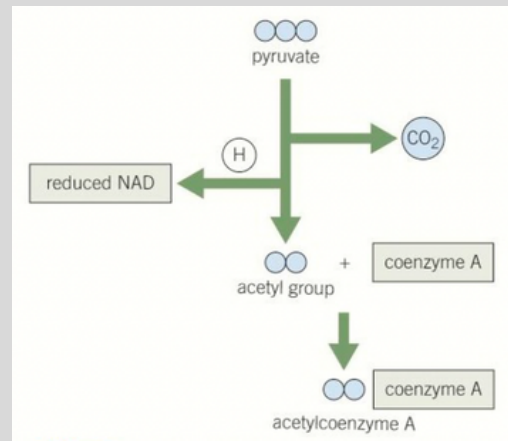
GLYCOLYSIS (1)



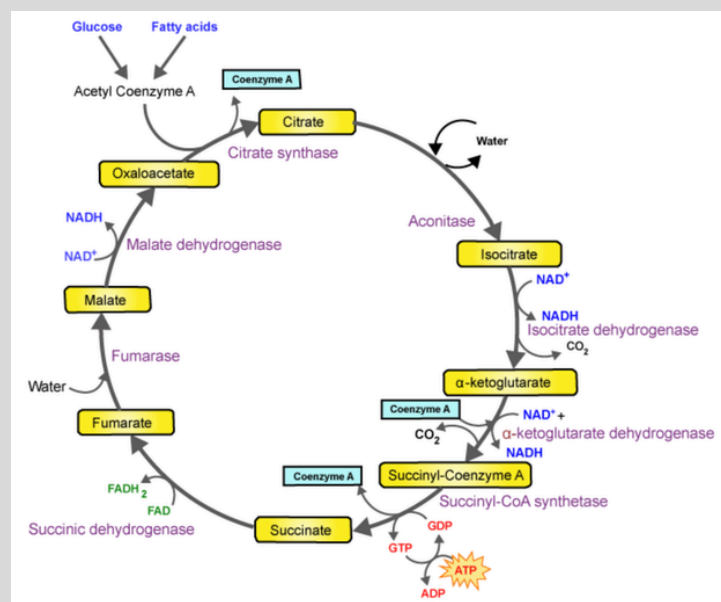
- **Fructose-1,6-Bisphosphate = Hexose Bisphosphate**
- In the process of producing pyruvate from hexose bisphosphate--> **dehydrogenation and formation of ATP** happens--> **NAD** coenzymes accept these hydrogens--> they are reduced, forming two reduced NAD molecules

LINK REACTION (2)

- Happens in the **mitochondrial matrix** as pyruvate enters it by active transport
- CO₂ is removed from pyruvate (**decarboxylation**) along with hydrogen (**oxidation**)--> hydrogen accepted by NAD forming reduced NAD
- Acetyl group that remains is bound by coenzyme A forming acetyl-CoA which delivers the acetyl group to the Krebs cycle



KREBS CYCLE (3)



- Happens in the mitochondrial matrix
- Hydrogen atoms released are accepted by NAD and FAD (flavin adenine dinucleotide)

NEED FOR COENZYMES IN RESPIRATION

- Used to transfer protons, electrons, and functional groups between enzyme catalysed reactions

DIFFERENCES BETWEEN NAD AND FAD

- NAD in all parts of respiration but FAD only accepts H in Krebs cycle
- NAD accepts one H and FAD accepts 2 H
- Reduced NAD is oxidised at start of ETC (electron transport chain) whereas reduced FAD is oxidised further along
- Reduced NAD results in 3 ATP being produced whereas reduced FAD results in 2

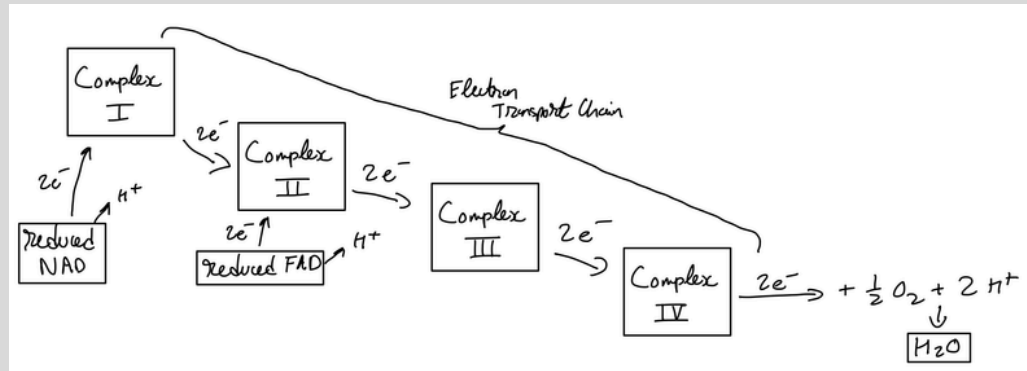
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ENERGY CYCLES, PHOTOSYNTHESIS, RESPIRATION



OXIDATIVE PHOSPHORYLATION

- Hydrogen atoms that have been collected by the coenzymes NAD and FAD go to the ETC present in the membranes of mitochondrial cristae
- H atoms break down into protons and electrons and the high energy electrons are used in the synthesis of ATP by chemiosmosis
- Energy is released by redox reactions as electrons reduce and oxidise the electron carriers as they are flowing along the electron transport chain (ETC)
- This energy used to actively pump out protons to create a proton gradient
- At end of ETC electrons combine with H ions and oxygen to form water
- Oxygen acts as the terminal electron acceptor



SUBSTRATE-LEVEL PHOSPHORYLATION VS OXIDATIVE PHOSPHORYLATION

- Production of ATP by using transfer of a phosphate group from a short-lived, reactive intermediate such as creatine phosphate
- Different to oxidative phosphorylation as it couples the flow of protons through ATP synthase to the phosphorylation of ADP to form ATP

WHAT HAPPENS IF OXYGEN IS NOT AVAILABLE

- A less efficient form of respiration that produces 2 molecules of ATP per glucose molecule (anaerobic respiration--> fermentation) happens--> compared to the 38 molecules of ATP produced per glucose molecule



FIRST- ORGANISM CLASSIFICATION DEPENDING ON OXYGEN USE

- Obligate Anaerobes:** cannot survive in the presence of oxygen, almost all are prokaryotes, eg Clostridium
- Facultative Anaerobes:** synthesises ATP by aerobic respiration if oxygen is present--> able to switch to anaerobic respiration in absence of oxygen
- Obligate Aerobes:** only synthesises ATP in the presence of oxygen (mammals)

FERMENTATION

- Fermentation:** Form of anaerobic respiration by which complex organic molecules are broken down into simpler ones, in the absence of oxygen or an ETC (no oxygen to act as terminal acceptor)
- Organic compounds not fully broken down--> produces less ATP
- Small amount of ATP synthesised by substrate-level phosphorylation
- Eg: **alcohol fermentation**--> yeast, produces ethanol and CO2
- Eg: **lactate fermentation**--> animal cells, produces lactate
- Reduced NAD and FAD are no longer able to be oxidised as the electron transport chain has stopped--> so electrons have no where to go
- NAD and FAD cannot be regenerated--> glycolysis and Krebs cycle stops

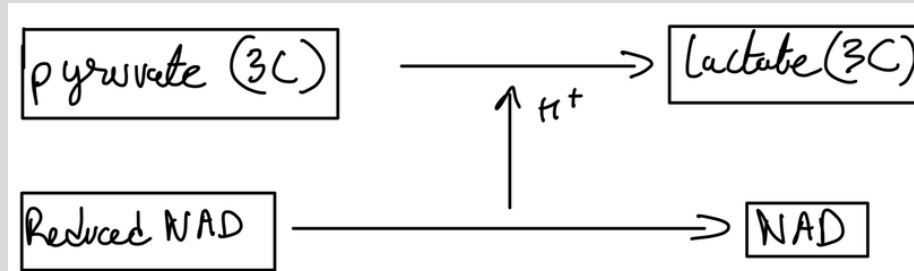
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ENERGY CYCLES, PHOTOSYNTHESIS, RESPIRATION



LACTATE FERMENTATION IN MAMMALS

- Catalysed by **lactate dehydrogenase**
- **Regenerates NAD** which is able to be used in **glycolysis** to produce 4 molecules of ATP
- Lactate produced is converted back to glucose in the liver but oxygen needed to complete the process--> **oxygen debt created**



Why lactate fermentation is not sustainable:

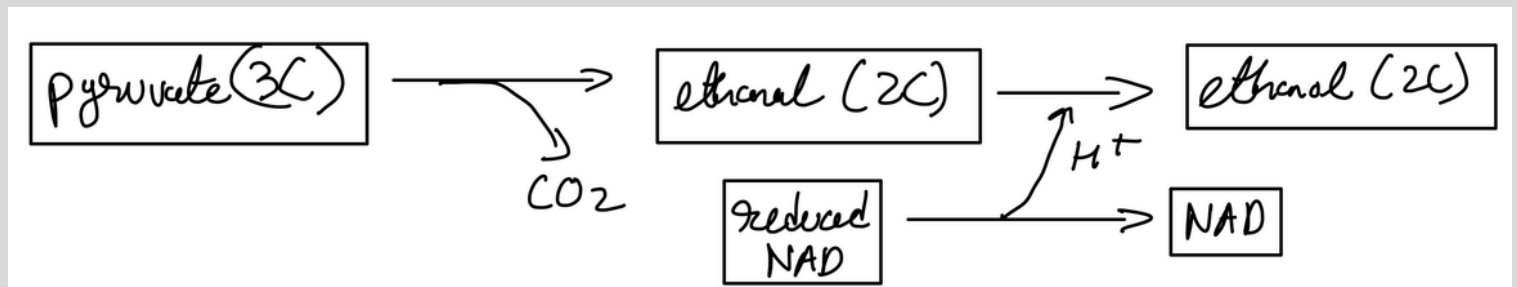
- Reduced ATP produced (only by glycolysis) not enough to sustain vital

processes

- Proteins denature due to accumulation of lactate which lowers pH

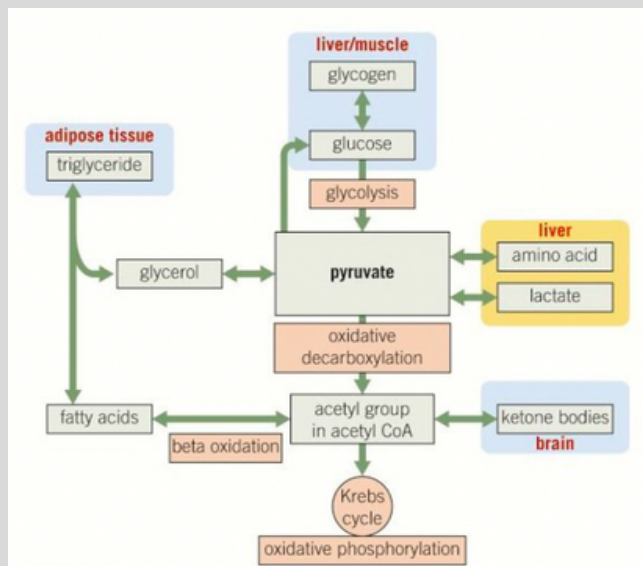
ALCOHOLIC FERMENTATION

- Non-reversible (compare this to lactate fermentation which is reversible)
- Regenerates NAD, so it can be used in glycolysis to produce some ATP needed to continue vital metabolic processes
- Able to continue indefinitely



USE OF DIFFERENT RESPIRATORY SUBSTRATES

- Other materials than carbohydrates can be used as respiratory substrates



RESPIRATORY QUOTIENT (RQ)

$$RQ = \frac{\text{CO}_2 \text{ produced}}{\text{O}_2 \text{ consumed}}$$

- Glucose has an RQ of 1--> takes 6 oxygen molecules to completely respire one molecule of glucose--> produces 6 molecules of CO₂
- Carbohydrates- 1.0
- Protein- 0.9
- Lipids- 0.7
- During normal activity--> RQ 0.9--> all molecules are being used (mostly carbohydrates)
- Anaerobic respiration RQ > 1



WHAT ARE GENE MUTATIONS?

- **Mutations:** change in sequence of bases in DNA
- Due to substitution, deletion, or insertion of one or more nucleotides within a gene
- **Point mutation:** if only one nucleotide is affected
- Change in base sequence means that the sequence of amino acids/primary structure is changed
- Degeneracy of the genetic code--> mutated codon can still code for the same amino acid
- **Frameshift mutations:** insertion or deletion of a nucleotide(s), shifts the reading frame of the sequences (read in codons/triplets), changes all amino acids after mutation (degeneracy means some may not be changed)

EFFECTS OF DIFFERENT MUTATIONS

- **No effect:** functioning protein still produced
- **Damaging:** due to non-functional protein
- **Beneficial:** new protein results in a new and useful characteristic in the phenotype (eg mutation in receptor corresponding to HIV surface protein means that HIV cannot bind to host cells)

CAUSES OF MUTATIONS

- Mutations occur **spontaneously**, but the rate of mutations are increased by **mutagens** (a chemical, physical, or biological agent which causes mutations)
- Eg of mutagens:

Type of Mutagen	Examples	Effects on DNA
Physical mutagens	Ionizing radiations such as X-rays	Break one or both DNA strands—some breaks can be repaired but mutations can occur in the process
Chemical mutagens	Deaminating agents	Chemically alter bases in DNA such as converting cytosine to uracil in DNA, changing the base sequence
	Alkylating agents	Methyl or ethyl groups are attached to bases resulting in the incorrect pairing of bases during replication
Biological agents	Base analogs	Incorporated into DNA in place of the usual base during replication, changing the base sequence
	Viruses	Viral DNA may insert itself into a genome, changing the base sequence

ADVANTAGEOUS MUTATIONS, A KEY EXAMPLE

- Ability to digest lactose by producing the enzyme lactase
- Most people lose the ability after suckling
- Advantageous as in the early days it helps with survival and preventing osteoporosis

ADVANTAGEOUS MUTATIONS, A KEY EXAMPLE

- **Deletion:** section of a chromosome breaks off and is lost within the cell
- **Duplication:** sections get duplicated on a chromosome
- **Translocation:** section of one chromosome breaks off and joins another non-homologous chromosome
- **Inversion:** a section of chromosome breaks off, is reverse, and then joins back into the chromosome

REGULATION OF GENES

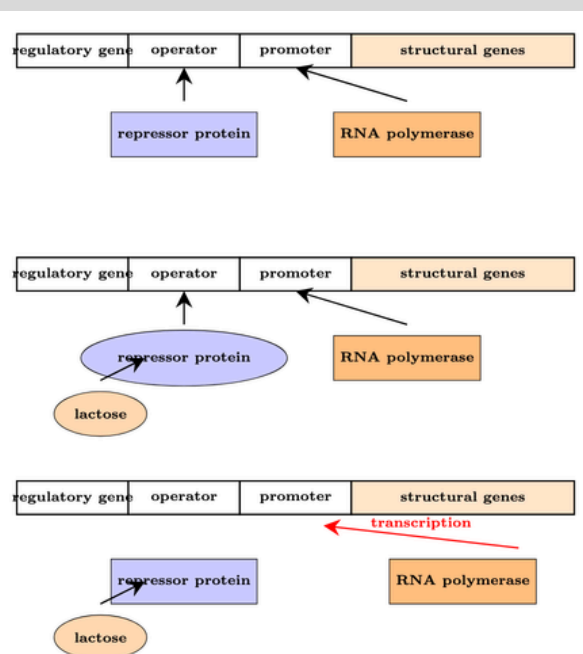
- Genes can be turned 'off' and 'on' depending on if they are useful or not--> but some genes are always required, for examples those that produce enzymes needed in metabolic processes--> **housekeeping genes**
- **Tissue-specific genes:** only required at specific times to produce a specific response--> only switched on when needed

HOW ARE THESE GENES REGULATED?

- **Transcription-** genes can be turned on or off
- **Post-transcriptional-** mRNA can be modified which regulates translation and the types of protein produced
- **Translational-** translation is able to be stopped or started
- **Post-translational-** proteins are able to be modified after synthesis which changes their function

LAC OPERON

- **Operon:** group of genes that are under control of the same regulatory mechanism, expressed at the same time
- More common in prokaryotes than eukaryotes
- If glucose is not readily available for prokaryotes--> then they use lactose--> **switch on the lac operon**
- **Lac operon:** group of 3 **structural genes** (lacZ, lacY, lacA) that code for beta-galactosidase (lacZ), lactose permease (lacY), transacetylase (lacA)
- **A regulatory repressor gene** (lacI) is present before the operon starts--> prevents the transcription of the structural genes in the absence of lactose



TRANSCRIPTIONAL CONTROL

Chromatin Remodelling

- DNA is tightly wound around histones and packed together forming chromatin
- **Heterochromatin** is the form which is very tightly wound--> chromosomes visible during cell division
- **Euchromatin** is the form which is loosely wound and is present during interphase
- Transcription not viable when chromatin is in the heterochromatin phase as RNA polymerase cannot access the genes--> but is possible in euchromatin phase

Histone modification

- **Acetylation** (combining a negatively charged acetyl group to DNA) makes them more negative
- Repels more--> coils less tightly--> allows access to RNA polymerase to genes
- **Methylation** causes genes to be more hydrophobic so they bind more tightly--> more tightly coiled--> less accessible--> reduced transcription

EPIGENETICS: control of gene expression by the modification of DNA

MORE ON THE REPRESSOR PROTEIN

- **When lactose is absent:** repressor protein is present and binds to operator region--> prevents RNA polymerase from binding and transcribing the structural genes
- **When lactose is present:** repressor protein binds to lactose--> does not bind to operator region due to specific change in 3D tertiary structure after lactose binding--> RNA polymerase able to transcribe the genes

THERES MORE TO IT....

- When glucose enters the cell--> decreases the levels of cyclic AMP (cAMP)
- Less cAMP binds to a protein called CRP (cAMP receptor protein)
- Transcription of lac structural genes only possible when: CRP with cAMP bound present, when repressor bound to lactose
- First condition not met when glucose present--> lac genes not transcribed



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MORE WAYS OF CONTROLLING GENE EXPRESSION

RNA Processing- Transcriptional control

- Pre-mRNA is the product of transcription and is a precursor--> turned into mature mRNA
- Cap is added to the 5 prime end and a tail is also added (long chain of adenine nucleotides) to the 3 prime end
- Both of these stabilise mRNA and delay degradation in the cytoplasm
- Cap helps the mRNA bind to ribosome
- Also, splicing happens where introns (non coding DNA) is removed and only exons remain

RNA Editing- Transcriptional Control

- mRNA nucleotides can be added, deleted or substituted--> same effect as a mutation where the protein coded for is changed

Translational control

- mRNA degradation time--> more resistant to breakdown mRNA is--> longer it lasts in cytoplasm and the more proteins that are coded
- inhibitory proteins bind to mRNA to prevent it from binding to ribosomes--> no protein synthesis
- Activation of initiation factors which allow mRNA to bind to ribosomes

Protein Kinases

- Protein kinases phosphorylate proteins and nucleic acids
- Activates some and inhibits some

Post-translational control

- Non-protein groups (carbohydrate, lipid, phosphates) get combined onto proteins
- Modification of amino acids and disulfide bridge formation
- Folding/shortening of proteins
- Modification by cAMP (eg in the **lac operon**)

ROLE OF GENE EXPRESSION IN THE CONTROL OF GROWTH

- Gene expression has to be controlled to modify growth and development
- **Morphogenesis**- regulation of the pattern of anatomical development
- Morphogenesis is controlled by specific genes called **homeobox genes**

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- Morphogenesis is controlled by specific genes called **homeobox genes**

WHAT ARE HOMEBOX GENES

- **Homeobox genes**: group of regulatory genes which all contain a **homeobox** (section of DNA 180 base pairs long coding for a part of the protein 60 amino acids long, highly conserved in plants, animals and fungi)
- Highly conserved--> very similar
- The part of the protein that a homeobox codes for is called a **homeodomain**. which binds to DNA and switches other genes off and on
- Important homeobox gene: **Pax6**--> when mutated it causes a form of blindness (due to underdevelopment of retina) in humans, mice and other organisms--> suggest that it is involved in the development of the eye

WHAT ARE HOX GENES

- **HOX genes** are one group of homeobox genes that are only in animals
- Responsible for positioning of body parts
- Found in clusters--> mammals have 4 clusters on different chromosomes
- Order in which the genes appear along a chromosome is the order in which their effects are expressed in the organism



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SO, WHAT IS THE BODY PLAN OF LIVING ORGANISMS

- Body plans are represented as cross sections through organisms--> **diploblastic organisms** have 2 layers, **triploblastic organisms** have 3 layers
- **Somites**: segments in the embryo which gives rise to individual vertebrae and associated structures
- Somites directed to develop in a particular way depending on their position in the sequence

BODY PLAN FEATURES- SYMMETRY

- **Radial symmetry**: seen in diploblastic animals--> no left or right, only top and bottom
- **Bilateral symmetry**: seen in most animals, have both a left and right and a top and bottom
- **Assymetry**: seen in sponges which have no lines of symmetry

CONSTRUCTING THE BODY PLAN

- **Mitosis and apoptosis** are important when making an organism--> cells need to form where they are needed and be destroyed to shape an organism

FACTORS AFFECTING THE EXPRESSION OF SUCH REGULATORY GENES

- **Stress**: change in temperature/light (external), change in hormone concentrations (internal)
- Drugs (eg thalidomide)



CHLOROSIS- PLANT VARIATION

- **Chlorosis:** when leaves of plants look pale or yellow as the plants do not produce enough chlorophyll
- Reduced chlorophyll--> reduced rate of photosynthesis--> less glucose made

Causes

- **Lack of light:** plants turn of chlorophyll production to conserve resources
- **Mineral deficiencies:** eg: lack of iron or magnesium--> iron is needed as a cofactor by some of the enzymes that make chlorophyll, magnesium is found at the heart of the chlorophyll molecule--> if these molecules are not present--> chlorophyll cannot be made
- **Virus infections:** when infected with a virus--> affects plant cell metabolism--> cant produce chlorophyll--> leaves become yellow

ANIMAL BODY MASS- ANIMAL VARIATION

- Body mass varies between individual animals--> determined by both genetic and environmental factors
- Some cases--> obesity can be due to genetics--> eg leptin mutations, mutation on chromosome 7

SO, HOW DOES THIS GENETIC VARIATION ARISE?

- **Meiosis, Random fusion of gametes**

Some definitions

- **Genotype:** combination of alleles an organism inherits for a characteristic, genetic make-up of an organism in respect of a specific gene
- **Phenotype:** observable characteristics of an organism, changes are **not passed onto offspring**
- **Dominant allele:** version of a gene that is always expressed if it is present in an organism
- **Recessive allele:** two copies of this allele is needed for it to be expressed in the phenotype
- **Homozygous:** have two identical alleles for a characteristic--> eg homozygous dominant (have two alleles for the dominant phenotype), homozygous recessive (have two alleles for the recessive phenotype)
- **Heterozygous:** have two different alleles for a characteristic--> allele for the dominant characteristic is expressed

CONTINUOUS AND DISCONTINUOUS VARIATION

	Continuous Variation	Discontinuous Variation
Definition	characteristic that can take any value within a range	characteristic that can only appear in specific (discrete) values
Cause of variation	genetic and environmental	mostly genetic
Genetic Control	polygenetic--> controlled by multiple different genes	one or two genes
Examples	leaf surface area, animal mass, skin colour	blood group, albanism, round and wrinkled pea shape



WHAT IS A GENETIC CROSS AND HOW DO WE DO IT

- A **genetic cross** shows how genes are passed on from one generation to the next
- A genetic cross usually shows the inheritance of a single gene only--> **monogenic inheritance**
- First shown by **Gregor Mendel** and his work on **peas**--> **mendelian inheritance**

How to perform a genetic cross

- 1) Write the phenotype of both parents
- 2) Write the genotype of both parents--> assign a letter code to represent the alleles of the genes--> capital letter used to show dominant allele and lower case letter used to show recessive allele
- 3) Write the gametes of each parent--> conventionally we circle each letter
- 4) Use a punnet square to show the results of random fusion of gametes during fertilisation--> label the gametes on the edges of the square
- 5) Write the proportion of each genotype produced (written in the form of a percentage)
- 6) Write the phenotypes as the possible genotypes (written in the form of a fraction/percentage or number)

[INSERT DIAGRAM OF HOMOZYGOUS AND HETEROZYGOUS GENETIC CROSS]

WHAT IS CODOMINANCE?

- **Codominance:** occurs when two different alleles occur for a gene--> both are equally dominant so both are expressed in the phenotype
- Eg: snapdragon flowers--> allele that codes for red flowers codes for enzyme that catalyses the formation of a red pigment from colourless precursor, allele that codes for white flowers codes for an altered enzymes which cant catalyse the conversion of the colourless pigment to the red pigment
- If both expressed--> pink flowers produced

[INSERT DIAGRAM FOR PINK FLOWERS]

SEX DETERMINATION

- Humans have 23 pairs of chromosomes--> 22 autosomes (normal body chromosomes where both members of the pair are the same), the other chromosome is the sex chromosome
- XX--> female, XY--> male
- Y chromosome is very small--> determines the 'maleness' due to a small region called the SRY (**sex-determining region of Y**)
- Sperm carries either X or Y chromosome BUT egg always has X--> so cannot get YY



MULTIPLE ALLELES

- If a person has more than 2 versions of a gene (eg blood group- O, A, B--> **they have multiple alleles**)
- **Blood group**--> immunoglobulin gene (gene I) codes for the production of different antigens present on the surface of RBCs
- 3 alleles for this gene (Ia, Ib, Io) as mentioned above: A codes for antigen A, B for antigen B and O for production of neither antigen
- Ia and Ib are codominant BUT Io is recessive to both of the other alleles
- Different combinations of these alleles result in the 4 blood groups: blood group A (Ia, Ia or Ia, Io), blood group B (Ib, Ib or Ib, Io), blood group AB (Ia,Ib), blood group O (Io, Io)

SEX LINKAGE

- **Sex linkage:** some characteristics are determined by genes carried on the sex chromosomes--> these are sex linked
- As males have XY (and Y is very small)--> they have a higher probability of getting recessive disorders as there are a number of genes in the X chromosome that males only have one copy of
- In females there could be a dominant copy in the other X chromosome--> cancelling out the effects
- **Eg: colour blindness is X-linked recessive disorder** which is more common in males than females, so is **haemophilia**



HAEMOPHILLIA

- Sex-linked recessive genetic disorder
- Blood clots very slowly due to factor VIII (clotting factor) not being coded for by genes
- If a male inherits the recessive allele on the X chromosome--> they cannot have dominant copy on Y so they get the disorder
- **Carriers:** females who carry one copy of the recessive allele (on one X chromosome) and one copy of the dominant allele (on the other X chromosome)--> they do not actually have the disease but can pass it on to children
- [INSERT GENETIC CROSS DIAGRAM FOR HAEMOPHILLIA]

HAEMOPHILLIA

- **Observed** results most often differ from the **expected** results--> need to do statistical test to see if differences are significant or due to chance
- **Chi-squared test**--> measures the size of the difference between the observed results and expected results
- Chi squared test is used to test a **null hypothesis** (always used to say that there is no significant difference between observed and expected results--> results are due to chance)
- Large chi squared values mean that there is a significant difference between observed vs expected results--> not due to chance
- **Degrees of freedom:** number of categories there are (how many comparisons are being made(n) -1)
- **Critical value:** value at p=0.05 or 5% significance--> if the chi squared value is greater than this then **we do not have sufficient evidence to reject the null hypothesis, no significant difference between observed and expected**
- If chi squared value smaller--> opposite is true

The chi-squared formula is:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

Where:

- χ^2 = the test statistic
- $\sum$ = the sum of
- O = observed frequencies
- E = expected frequencies

DIHYBRID INHERITANCE

- Previously monohybrid inheritance was discussed--> the inheritance of a single gene
- **Dihybrid inheritance** is the inheritance of two genes, and is shown by a **dihybrid cross**
- 4 alleles (2 for each characteristic) are shown at each stage
- EgL inheritance of seed phenotype in pea plants--> can be yellow or green in colour, and round and wrinkled

[INSERT DIAGRAM FOR DIHYBRID CROSS- PG 529]

AUTOSOMAL LINKAGE

- **Autosomal linkage:** when the linked genes are found on a pair of chromosomes other than the sex chromosomes
- **Linked genes** are inherited as one unit--> no independent assortment during meiosis unless the alleles are separated by chiasmata--> inherited together
- Autosomal linkage is one reason why expected ratios of genotypes and phenotypes may not be produced--> **recombinant offspring** have different combinations of alleles compared to parents, and is due to crossing over
- Able to measure **recombination frequency:**

$$\text{Recombination frequency} = \frac{\text{number of recombinant offspring}}{\text{total number of offspring}}$$

EPISTASIS

- **Epistasis:** interaction of genes at different loci, when the allele for one gene masks the expression of an allele of another gene
- A gene that is affected by another gene is said to be **hypostatic** and a gene that affects the expression of another gene is said to be **epistatic**



DOMINANT AND RECESSIVE EPISTASIS

- If the presence of 2 recessive alleles led to a lack of enzyme/protein production for example (doesn't have to be a lack of protein production)--> **recessive epistasis**
- If there is a dominant allele which affects the expression of other genes--> **dominant epistasis**
- **Eg:** labrador colours--> one gene codes for the production of pigment (has alleles B and b) and the other codes for where the pigment is deposited (E and e)

FACTORS AFFECTING EVOLUTION

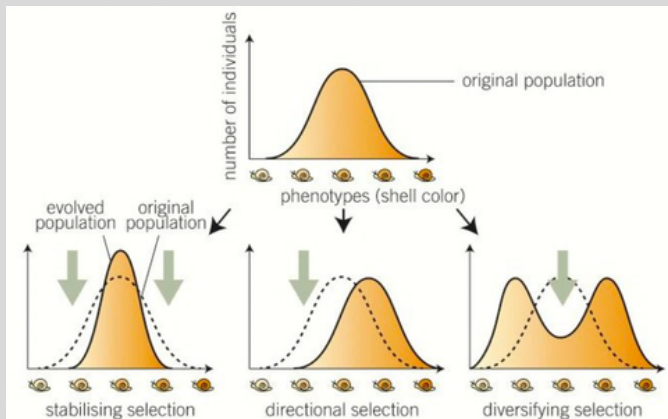
- **What is evolution:** change in inherited characteristics of a group of organisms over time, due to changes in the frequency of different alleles within a population

Factors:

- Rate of mutation
- Sexual selection selects alleles which improve mating success
- Immigration and emigration results in changes of allele frequency within a population
- **Genetic drift**--> happens in small populations where the frequency of a new allele increases much faster compared to in a larger population as the **gene pool** is smaller (total number of genes in the population)
- **Natural selection**--> only the best alleles survive and are passed onto offspring

FOUNDER EFFECT

- **What is the founder effect:** when small populations arise new colonies are able to be formed by a few isolated individuals--> extreme example of genetic drift
- Smaller populations have smaller gene pools and has less genetic variation
- **Amish people**--> have high frequency of the normally rare genetic disorder **Ellis-van Crevid syndrome**--> have polydactyly (extra fingers or toes), hole between the two atria of the heart



LIMITING FACTORS AFFECTING POPULATION SIZE

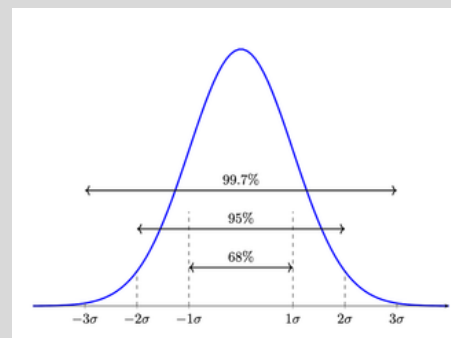
- **Limiting factors:** factors which limit or decrease the size of a population:
- **Density-dependent factors**--> dependent on population size and include competition, predation, parasitism, communicable disease
- **Density-independent factors**--> affect populations of all sizes in the same way (climate change, seasonal change, human activities)



WHAT HAPPENS WHEN POPULATION SIZE GETS TOO SMALL

- **Genetic bottleneck**--> when the populations get too small and lasts for at least one generation, genetic diversity and the gene pool is greatly reduced, however, a beneficial mutation will have a greater impact--> increase the speed of development of species

TYPES OF SELECTION



Stabilising selection: babies with very low birth weights more prone to infection and babies with very high birthweight have a difficult delivery--> so average is selected for

Directional selection: occurs when there is change in the environment and the most common phenotype is no longer the most successful--> organisms which have the more extreme phenotypes are positively selected--> allele frequency shifts towards the extreme phenotypes and evolution occurs--> eg. peppered moths seen during the industrial revolution

Disruptive selection: extremes are selected for and the normal is selected against--> opposite to stabilising selection where the average is selected



SPECIATION

- **Speciation:** formation of new species through evolution--> this new organism cannot no longer interbreed to produce fertile offspring with organisms of its previous species

Speciation Process:

- Members of one population become isolated--> no longer able to reproduce/interbreed with other organisms of the same species
- Alleles within both groups undergo random mutations, and if the two environments of the two populations are different--> different alleles are advantageous and are selected for and against
- Accumulation of such mutations and change in allele frequencies over many generations--> lead to changes in the phenotype
- Members of the different populations become so different that they are no longer able to interbreed and reproduce with each other when they come together--> reproductively isolated and are a different species

PROBLEMS CAUSED BY INBREEDING

- Inbreeding, as mentioned before, is the breeding between closely related members
- Increases the frequency of recessive alleles--> increases the frequency of genetic disorders such as **cystic fibrosis**
- Closely related so more likely that offspring inherits two recessive alleles

WHAT ARE GENE BANKS

- **Gene banks:** store biological samples, such as sperm or eggs
- Used to increase genetic diversity in a process called outbreeding--> breeding unrelated/distantly related varieties is a form of outbreeding--> reduces frequency of homozygous recessives--> increases the potential to adapt to environmental change
- **Seed banks:** samples of seeds from both wild type and other domestic species too

ALLOPATRIC SPECIATION

- Two populations become geographically isolated by a physical barrier such as river/sea
- Environments are different so **different selection pressures**--> different alleles are advantageous and are selected for and against
- Separation of a small group results in founder effect--> genetic drift enhancing the differences between the populations

SYMPATRIC SPECIATION

- Happens less frequently than allopatric speciation
- Occurs within populations that share the same habitat
- More common in plants than animals
- Occurs when members of 2 different species interbreed and form fertile offspring--> have a different number of chromosomes from parent--> cannot interbreed with members of the species

ARTIFICIAL SELECTION

- Populations are **polymorphic** (show more than one distinct phenotype) for most features--> a **wild type allele** is the normal form of an allele and the mutated versions are called **mutants**
- **Artificial selection**--> selection for breeding of plants or animals with desired characteristics by farmers or breeders
- Offspring are **inbred** (bred with close relatives) and this is repeated until the frequency of desired alleles increases so much that speciation eventually results

THE HUMAN GENOME

- **Genome:** all the genetic material an organism has--> DNA in the nucleus and the mitochondria combined for eukaryotes
- **Introns:** large non coding regions of DNA
- **Satellite DNA:** regions within introns which consists of repeating bases, examples include telomeres and centromeres
- **Minisatellite:** sequence of 20-50 base pairs that are repeated from 50 to several hundred times
- Occur at more than 1000 locations in the human genome so are known as **variable number tandem repeats (VNTRs)**
- **Microsatellite:** region of 2-4 bases repeated only 5-15 times--> known as **short tandem repeats (STRs)**
- Discovered by a technique called **DNA profiling**--> used in identification of people and family relationships



PRODUCING A DNA PROFILE

- Extract DNA--> **PCR (polymerase chain reaction)** technique can be used to amplify if small amount of DNA obtained
- Digest the sample--> **restriction endonuclease** enzymes are used to cut the sample DNA into small fragments at **restriction sites** (specific to specific restriction endonucleases)
- Separate the DNA fragments--> cut fragments of DNA separated by **gel electrophoresis (see practical guide)**
- Hybridisation--> radioactive/flourescent DNA probes (short fragments of DNA/RNA that bind to desired complementary base pairs on the DNA fragments by hydrogen bonding) under specific temperature, pH
- Excess probes washed off
- X ray images taken of the paper (if radioactive probes added), if flourescent probes added then paper placed under UV light so probes flouresce

POLYMERASE CHAIN REACTION (PCR)

Strand seperation

- Temperature increased to 90-95 degrees celcius for 30 seconds--> denatures the DNA by breaking the hydrogen bonds between complementary base pairs

Primer annealing

- Temperature is decreased to 55-60 degrees celcius
- Primers bind (anneal) to the ends of the DNA strands--> primers are needed to start of the DNA replication process in the next step

DNA synthesis

- Temperature increased to 72-75 degrees celcius for at least 1 minute
- This temperature is the optimum for the enzyme DNA polymerase (**Taq polymerase is used-** a heat resistant polymerase) isolated from thermophillic bacteria)
- DNA polymerases catalyses the formation of phosphodiester bonds between adjacent DNA nucleotides- so adds to the primer--> elongating and replicating the DNA
- Double stranded DNA identical to the parent molecule is produced

USES OF DNA PROFILING

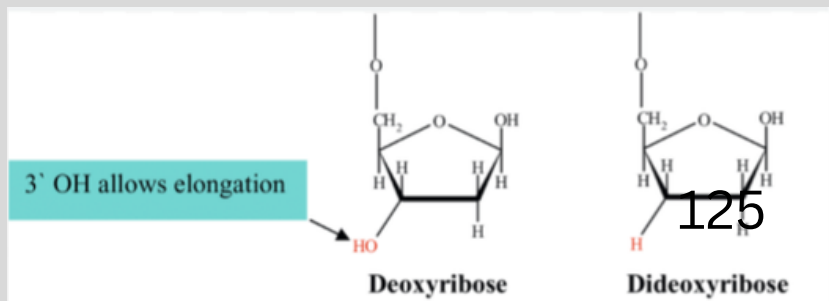
- Forensics--> obtain DNA from scene and compare DNA profile to stored databases
- Paternity proof
- Identification of individuals at risk of certain diseases (as specific alleles can be profiled and identified)

DEVELOPING DNA PROFILING

- **DNA sequencing** allows determination of the precise order of nucleotides within a DNA molecule--> developed by Frederik Sanger--> called **Sanger sequencing**

Key thing for Sanger DNA sequencing:

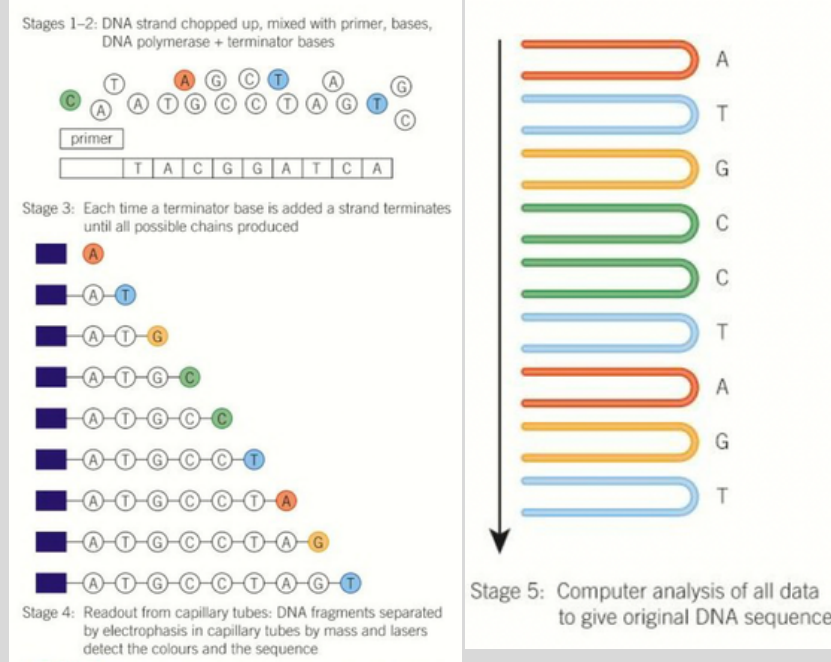
- Involved terminator bases for all 4 bases (A, T, C, G)
- Terminator bases have the prefix **di-deoxy** as they have two H atoms on the 'bottom' compared to deoxy which has one OH group and 1 H atom (shown below)
- Terminator bases stop the elongation by DNA polymerase





SANGER SEQUENCING- THE METHOD

- DNA for sequencing is mixed with a primer, DNA polymerase, an excess of normal nucleotides, terminators
- Mixture placed in thermocycler (machine used for PCR)
- At 60 degrees celcius--> DNA polymerase makes new DNA strands by combining nucleotides with the complementary base to a single-stranded template of DNA
- Where the terminator bases are added--> elongation stopped--> repeating this for many cycles means that at every possible base in the DNA fragments there is a terminator base--> sequenced using gel electrophoresis--> fluorescent markers on the terminator base allow identification of the final base by lasers which detect different colours
- Order of bases in the gel shows the sequence of the new, complementary bases--> used to identify the original sequence of bases as complementary bases are known



NEXT-GENERATION SEQUENCING

- Sequencing reaction takes place in a flow cell (plastic slide)
- Lots of fragments of DNA are attached to the slide and replicated in vitro by PCR to form clusters of identical DNA fragments
- Uses coloured terminator base to stop the reaction--> image then taken
- Lots of clusters being sequenced at the same time--> **massively parallel sequencing**
- Efficient and fast--> used in genome projects

COMPUTATIONAL BIOLOGY AND BIOINFORMATICS

- **Bioinformatics:** development of software and computing tools needed to organise and analyse raw biological data
- Able to build theoretical models of biological systems--> eg able to model how a drug will act inside the body
- **Genomics:** field which applies DNA sequencing and computational biology to analyse the structure and function of genomes
- **DNA Barcoding:** identifying specific sections of the genome that are common to all species but differ between them--> allows them to be compared
- **Example of DNA barcoding:** for animals, a 648 base pair section of mitochondrial DNA, which codes for the enzyme cytochrome c oxidase (involved in cellular respiration)--> small so able to be sequence but large enough to give clear differences between species
- Bioinformatics also used to study evolutionary relationships

GENOMICS AND PROTEOMICS

- **Proteomics:** sequencing the proteome of an organism (all the proteins in an organism)

Why the proteome is so large:

- After splicing of the pre-mRNA to remove introns, the remaining exons can be combined in any order by the spliceosome--> different sequence of amino acids and primary structure made--> different proteins can be produced from the same exons by combining them in a different order
- Proteins modified after translation--> produce different functional proteins

SYNTHETICS

- **Synthetic biology:** emerging area of research that can broadly be described as the design and construction of novel artificial biological pathways, organisms or devices, or the redesign of existing natural biological systems (**Definition by the Royal Society**)

TECHNIQUES USED IN SYNTHETIC BIOLOGY

- **Genetic engineering**
- **Biologics use in industry:** eg, using immobilised enzymes and production of drugs from micro-organisms
- **Synthesis of new genes:** replacing faulty genes (cystic fibrosis gene) with healthy ones
- **Synthesis of entire new organisms:** eg--> able to synthesise entire genomes of bacterium and produce new ones

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WHAT IS GENETIC ENGINEERING

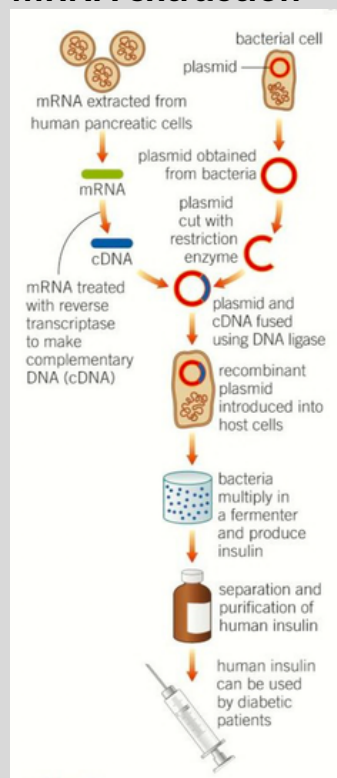
- Manipulating an organism's genome to produce a desired effect
- **GMO:** genetically modified organism

HOW TO ISOLATE A DESIRED GENE (1)

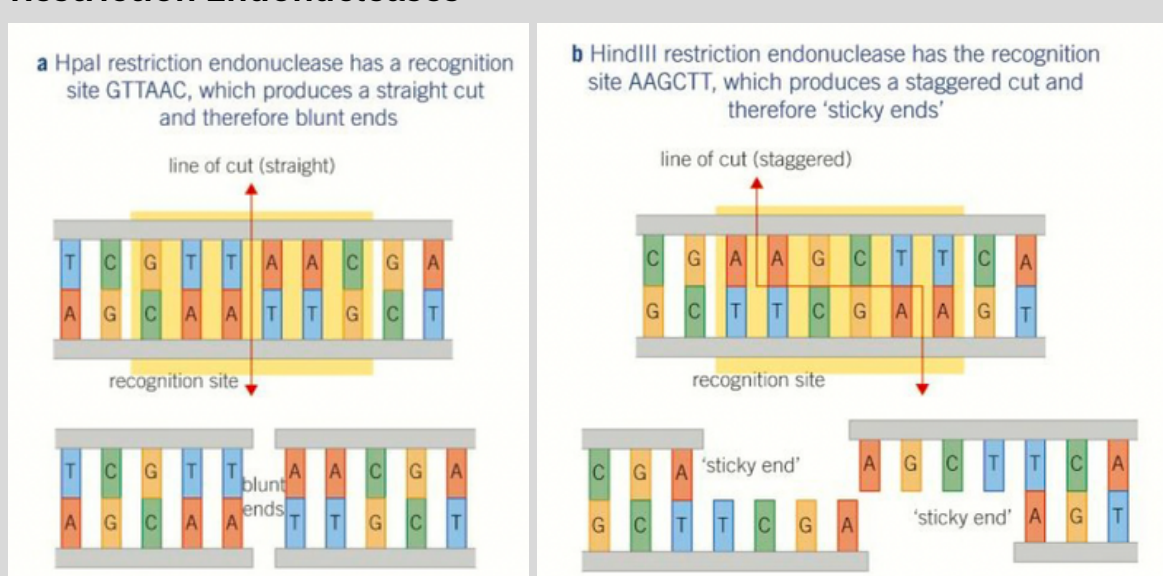
In order to produce a desired effect, the desired gene must be isolated--> two ways:

- **mRNA extraction**
- **Use of restriction endonucleases**

mRNA extraction



Restriction Endonucleases



- **Restriction Endonucleases** are able to cut the two strands unevenly--> leaving **sticky ends**, or cut it evenly leaving **blunt ends**
- Sticky ended DNA fragments are the most useful as it is easier for the desired gene can be combined



WHAT HAPPENS AFTER DNA ISOLATION (2)

- **Isolated DNA** is inserted into a vector that carries it into the host cell
- Bacterial plasmids are the most common vector (**plasmid**- extrachromosomal circular DNA which carries antibiotic resistance genes, able to replicate independently)
- Same restriction endonuclease used to isolate DNA is used to cut open the plasmid at a **fluorescent marker gene** (if desired gene is inserted successfully then fluorescent marker gene won't function and bacteria won't fluoresce)--> sticky ends of plasmid is complementary to the sticky ends of the isolated gene--> fuse by hydrogen bonding between complementary base pairs
- Marker gene also able to be gene for antibiotic resistance

TRANSFERRING THE VECTOR

- **Transformation:** process where the recombinant DNA is transferred to the host cell

METHODS:

- 1) Culturing bacterial cells and plasmids in a calcium rich solution, increasing the temperature--> bacterial membrane becomes more permeable so plasmids enter
- 2) **Electroporation**--> applying a controlled electric current which makes bacterial membrane porous--> allows plasmid entry--> current has to be carefully controlled to avoid permanent membrane damage
- 3) **Electrofusion**--> application of small electric currents to two different cells causes cell fusion and production of a hybrid cell containing genetic material from both cells--> **used to produce genetically modified plants, monoclonal antibodies**

ENGINEERING IN DIFFERENT ORGANISMS

ENGINEERING PROKARYOTES

- Bacteria engineered to produce desired products such as hormones, antibiotics etc

ENGINEERING PLANTS

- Uses **Agrobacterium Tumefaciens**--> bacterium causes tumours in healthy plants
- Desired gene (eg for herbicide resistance) is placed in the **Ti plasmid** with a marker gene--> carried into plant cell DNA
- Transgenic plant cell forms a **callus**--> mass of GM plant cells--> each is able to be grown into a new transgenic plant
- New transgenic plant cells also able to be produced by **transfusion** as mentioned earlier

ENGINEERING ANIMALS

- Harder than prokaryotes or plants as animal cell membranes are harder to alter

WHAT ARE DNA LIBRARIES AND HOW ARE THEY FORMED?

- **DNA Libraries:** store of DNA fragments previously made, stored in microorganisms for future use, some ethical concerns raised previously but now that they are successful not many ethical concerns raised



• Rapid gene technology advancements have led to significant progress in genetic engineering and biotechnology, but also ethical challenges.

AS SCIENTISTS, WHY SHOULD WE CONSIDER ETHICS ?

- Ethical considerations are essential to protect:
 - Human rights
 - Health and safety
 - Animal welfare
 - Environmental protection
- Ethical lapses:
 - Can cause harm and erode public trust.
 - May hinder the advancement of knowledge.
- Clear communication between scientists and the public is vital for trust-building and regulating research.

ETHICS SURROUNDING GENETIC MANIPULATION OF MICROORGANISMS:

- Microorganisms (especially bacteria) are genetically modified (GM) to produce substances like **insulin** and **vaccines** in large quantities.
- GM microorganisms are used in DNA libraries to store sequenced DNA from organisms. This allows further genetic engineering and **functional studies**.
- Thus, GM microorganisms play a crucial role in medical treatments, industrial processes, and the development of gene technology.
- Genetically engineered pathogens are rarely used due to concerns over health and safety for both **researchers** and the **public**.
- Genetic modification of pathogens is primarily for medical and epidemiological research, but it is **tightly regulated**.
- Ethical concerns arise over the use of genetically engineered pathogens for **biological warfare**, and this area is mostly prohibited except in **specialized military research**.

There is no little ethical debate regarding the use of microorganisms in genetic engineering, except for the use of pathogens in biological warfare

Insect resistance in GM soya beans:

- Soya beans are a major global crop with over 250 million tonnes produced annually, half being GM strains.
- Scientists inserted a gene to produce **Bt** protein, which is **toxic to pest insects and used as a pesticide**.
- Some strains are resistant to weed killers, allowing farmers to avoid pesticides, resulting in higher yields with less labor and lower costs.

Patenting and Technology Transfer:

Concerns:

- People in less economically developed countries may face barriers to using GM crops due to patents and technology transfer issues.
- Patents restrict others from using new technologies without payment, making GM seeds unaffordable for those who need drought or flood-resistant crops, high yields, and improved nutritional value.
- Farmers often rely on harvesting seeds for the next planting season, but patents may make this impossible.

Evidence:

- A company patented herbicide-resistant and pesticide-producing soya beans, limiting farmers to using seeds only in the year they are bought. This was upheld by the US Supreme Court in 2013.
- Positive efforts:
 - Organizations like IRRI are developing flood-resistant rice to support farmers in less developed countries without patent restrictions. For example, 'scuba' rice survives submersion for 2-3 weeks, providing up to 80% of maximum yield.



Genetically engineered characteristics and GM crop pros/cons

Pest resistance:

Pros: Reduces pesticide use, benefiting the environment and farmers, increases crop yield.

Cons: Non-pest insects and predators might be harmed, Pests may develop resistance to pesticides.

Disease resistance:

Pros: Reduces crop losses by resisting common plant diseases.

Cons: Genes may spread to wild populations, creating superweeds.

Herbicide resistance:

Pros: Herbicides reduce weeds and increase yield.

Cons: Overuse may reduce biodiversity and create superweeds.

Extended shelf-life:

Pros: Reduces food waste.

Cons: May lower commercial value

Growing conditions:

Pros: Crops can survive adverse conditions, like floods or droughts.

Nutritional value:

Pros: Increases nutritional levels, e.g., more vitamins.

Cons: Risk of allergies due to different proteins.

Medical uses:

Pros: GM plants can produce medicines and vaccines.

GM ANIMALS:

Challenges:

- It is harder to produce GM vertebrates, especially mammals.

- Techniques like microinjections (gold particles covered in DNA) and modified viruses are being used to insert new genes into animal DNA.

Goals:

- These techniques aim to transfer disease resistance between animals or modify the physiology of farmed animals.

Examples of GM animals:

- Swine fever-resistant pigs:

- In 2013, UK scientists inserted a gene from wild African pigs into European pig embryos, giving them immunity to African swine fever.

- Faster-growing salmon:

- In the USA, GM Atlantic salmon were given genes from faster-growing Chinook salmon, enabling them to grow to full size in half the time, making them an efficient food source.

PHARMING:

Definition: Using genetic engineering in animals to produce human medicines.

Two key aspects:

1) Creating animal models: Adding or removing genes to cause animals to develop diseases, serving as models for therapy development (e.g., knockout mice for cancer research).

2) Creating human proteins: introducing a human gene into animals (e.g., cow, sheep) to produce medically required proteins.

- The gene is expressed in the mammary glands of transgenic females, and milk from these animals contains the desired human protein, which can be harvested.

KEY QUESTIONS SURROUNDING THE ETHICS OF GENETIC ENGINEERING IN ANIMALS INCLUDE:

- Should animals be genetically engineered to model human diseases?
- Is it ethical to insert human genes into animals?
- Can genes from another species be safely inserted into animals without causing harm?
- Does genetically modifying animals reduce them to commodities?
- Is animal welfare compromised during the production of genetically engineered animals?



Examples of disease caused by faulty genes include: cystic fibrosis (CF), haemophilia, severe combined immunodeficiency (SCIDS)

Gene therapy: involves removing faulty alleles and replacing them with healthy equivalents.

2 different methods are possible: removing desired alleles from healthy cells or synthesise healthy alleles in a lab.

SOMATIC CELL GENE THERAPY:

- Definition: Replaces a mutant allele with a healthy allele in somatic cells.

Challenges: Issues include delivering the allele into the cell nucleus, maintaining gene expression, and using viral vectors.

Progress: Recent treatments for retinal disease, leukaemias, and immune diseases show promise.

Limitations: Therapy only affects treated somatic cells, which have a limited lifespan. The faulty allele can still be passed to offspring.

GERM LINE CELL GENE THERAPY:

- Definition: Involves inserting a healthy allele into germ cells (eggs or embryos) during IVF.

Outcome: The individual is born with the healthy allele and passes it to future generations.

Concerns:

- Human embryos are often excluded (currently illegal) from these treatments due to ethical and medical concerns.
- Issues include: the unknown long-term effects and potential violations of the human rights of unborn individuals, enabling people to choose desired characteristics in offspring (“designer babies”)



Asexual reproduction is a form of cloning.

- It results in offspring formed by mitosis, thus clones are usually genetically identical to the parent organism and to each other.

NATURAL CLONING:

- Vegetative propagation occurs in many flowering plants and results in a plant genetically identical to the parent.
- The new plant can grow from stems, leaves, buds, or roots of the parent, eventually becoming independent (e.g., strawberries and spider plants).

Examples of natural cloning:

Bulbs (e.g., daffodils):

- Swollen leaf bases store food from photosynthesis, and buds form new shoots.

Runners (e.g., strawberry, spider plant):

- A lateral stem grows from the parent plant, developing roots where it touches the ground.

Rhizomes (e.g., marram grass):

- A horizontal underground stem, swollen with stored food, forms new shoots.

Stem tubers (e.g., potato):

- The tip of an underground stem swells with stored food, producing buds that develop into new shoots (e.g., the “eyes” on a potato).

USING NATURAL CLONES IN HORTICULTURE:

Natural cloning is used by farmers and gardeners to produce new plants by:

- Splitting bulbs
- Removing young plants from runners
- Cutting up rhizomes

These methods produce plants with identical genetics to the parent.

Cuttings:

- Short sections of stems are planted in the ground or pots (e.g., sugar cane, pelargoniums).
- Rooting hormone encourages new roots, making the process faster than using seeds and ensuring quality plants.

Advantages of cloning in Horticulture:

- Faster planting to cropping time.
- Genetically identical offspring, which crop well.

Disadvantages of cloning in Horticulture:

- Lack of genetic variation, making plants vulnerable to diseases, pests, or climate change.

Important food crops propagated by cloning: Bananas, sugar cane, sweet potatoes, cassava, coffee, and tea



MICROPROPAGATION USING TISSUE CULTURE:

- Definition: A technique to produce large numbers of genetically identical plants from a single parent using tissue culture.
- Used when:
- When a plant doesn't readily produce seeds.
 - Doesn't respond well to natural cloning.
 - Is rare or difficult to breed.
 - Needs to be pathogen-free (e.g., strawberries, bananas, potatoes).

PRINCIPLES OF MICROPROPAGATION:

1. Sample collection:
 - Take a small tissue sample (e.g., from shoot tips or buds), in sterile conditions.
2. Sterilisation:
 - The tissue is sterilised using bleach, ethanol, or sodium dichloroisocyanurate. The sample becomes an explant.
3. Culture medium:
 - The explant is placed in a sterile medium with hormones (e.g., auxins, cytokinins) to stimulate mitosis, forming a mass of identical cells called a callus.
4. Division:
 - The callus is divided, and the cells are placed in a new medium with hormones to develop plantlets.
5. Planting:
 - Plantlets are transferred into compost to grow into small plants, and then planted to produce a crop.

Scaling up:

- Micropropagation is now done in bioreactors, creating artificial embryo plants for packaging in artificial seeds.

ARGUMENTS FOR MICROPROPAGATION:

- Rapid production of large numbers of plants with known genetic make-up.
- Disease-free plants produced by culturing meristem tissue.
- Enables viable plant production after genetic modification.
- Produces large numbers of seedless plants to meet consumer demand (e.g., bananas, grapes).
- Can grow plants that are infertile or difficult to grow from seed (e.g., orchids).
- Increases numbers of rare or endangered plants reliably.

ARGUMENTS AGAINST MICROPROPAGATION:

- Leads to monoculture, making plants susceptible to the same diseases or growing condition changes.
- Expensive and requires skilled workers.
- Explants and plantlets are vulnerable to infection during production.
- If the source material is infected with a virus, all clones will be infected.
- Significant loss of new plants can occur during the process.



Natural cloning in animals tends to occur in invertebrates than vertebrates.

CLONING IN INVERTEBRATES:

Forms:

- Starfish, flatworms, and sponges regenerate and produce genetically identical clones from fragments.
- Hydra form buds that develop into clones.
- Some insects reproduce offspring without mating (parthenogenesis), but high mutation rates suggest offspring may not be true clones.

CLONING IN VERTEBRATES:

- The main form of vertebrate cloning is monozygotic twins (identical twins).
- An early embryo splits into two, forming genetically identical embryos.
- Factors triggering this process are unknown.
- Frequency varies by species (e.g., rare in cattle, 3 in 1000 in humans).
- Despite being genetically identical, twins may look different due to uterine nutrition and position.

Amphibians and reptiles can produce offspring without males, but these offspring, while genetically derived from the mother, are not true clones.

ARTIFICIAL CLONING IN ANIMALS

Two main methods exist: artificial cloning and somatic cell nuclear transfer (SCNT)

- After fertilisation, the embryo divides into totipotent cells (capable of forming an entire animal).
- In natural twinning, the embryo splits into two to form identical offspring.
- In artificial twinning, the embryo is manually split into multiple parts, each developing into identical offspring. This is used in farming for desirable traits in cattle and sheep.

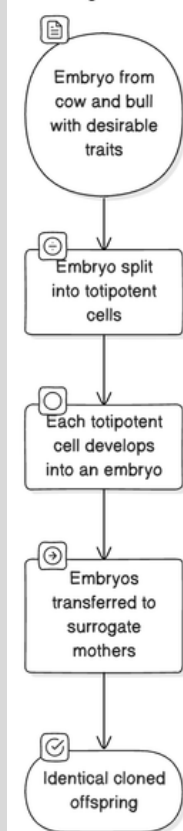
STAGES OF ARTIFICIAL TWINNING IN CATTLE:

1. A cow with desirable traits is super-ovulated with hormones (to release more mature ova)
2. Ova are fertilised naturally or through artificial insemination and flushed out of the uterus.
3. The fertilised eggs are split into smaller embryos on day six.
4. Split embryos are grown in the lab for several days.
5. Each embryo is implanted into a different surrogate mother.
6. Embryos develop into foetuses, producing multiple cloned animals.

ARTIFICIAL TWINNING IN PIGS:

- Same as above, except several cloned embryos are implanted into each mother pig because pigs naturally produce litters.
- This technology allows farmers to increase offspring from animals with the best genetic stock.
- Some embryos may be frozen for future use, allowing for evaluation of the stock's success.

Cloning Process





SOMATIC CELL NUCLEAR TRANSFER (SCNT):

- In SCNT, a nucleus from an adult somatic cell is transferred to an enucleated egg cell (an egg cell with its nucleus removed).
- An electric shock stimulates the cell to divide and form an embryo, which is a clone of the original adult.

Key Facts:

- First successful clone was Dolly the sheep in 1996.
- SCNT has since been used to clone species like mice, cows, horses, rabbits, cats, and dogs.
- The technique, though theoretically simple, faces many practical challenges and is not widely used.

SCNT Process:

1. Nucleus removal: The nucleus is removed from a somatic cell of the adult animal.
2. Enucleated egg: The nucleus is removed from a mature ovum (egg cell) harvested from another animal of the same species.
3. Fusion: The nucleus from the somatic cell is placed in the enucleated egg and electro-fusion is used to stimulate cell division.
4. The embryo begins to divide under the influence of the electric current.
5. Embryo transfer: The developing embryo is implanted into the uterus of a third animal (surrogate) to develop.
6. The resulting animal is a clone of the original, with nuclear DNA from the somatic cell and mitochondrial DNA from the egg.

PROBLEMS WITH SCNT: ARGUMENTS FOR ANIMAL CLONING: ARGUMENTS AGAINST ANIMAL CLONING:

- | | | |
|--|---|---|
| <ul style="list-style-type: none"> • Dolly the sheep developed arthritis and lung disease and was euthanized at six years old, a condition seen in much older sheep. • Concerns remain about premature aging in clones produced by SCNT. | <ul style="list-style-type: none"> • Artificial twinning allows high yielding farm animals to reproduce at a faster rate • SCNT enables the success of a sire (male animal) to be determined, and more identical animals can be produced from frozen clones. • SCNT replicates GM embryos for use in pharming to produce therapeutic proteins in genetically engineered farm animals. • SCNT allows cloning of specific animals, such as racehorses, pets (e.g., cats and dogs), or endangered/extinct species. | <ul style="list-style-type: none"> • SCNT is inefficient, requiring many eggs for a single clone. • Many cloned embryos fail, miscarry, or produce malformed offspring. • Cloned animals often have shortened lifespans, though cloned mice have lived normally for two years. • Despite being promising technology, SCNT has so far been unsuccessful in restoring populations of rare organisms and has not enabled an extinct species to be brought to life. |
|--|---|---|

ADVANCEMENTS IN SCNT:

- Japanese researchers produced 581 clones from one mouse across 25 generations.
- All clones had normal lifespans, reproduced naturally, and functioned normally.
- SCNT clones were successfully created from mice frozen for 16 years.



DEFINING BIOTECHNOLOGY:

- Biotechnology applies biological organisms or enzymes to processes for synthesis, breakdown, or transformation of materials for human benefit.
- It includes traditional processes (e.g., cheese, yogurt, wine) and modern DNA manipulation to produce genetically engineered microorganisms for synthesising drugs (e.g., insulin, antibiotics).
- Includes bioremediation—the use of biological systems to remove pollution.

ADVANTAGES TO USING MICROORGANISMS IN BIOTECHNOLOGY:

- No welfare issues—only optimal conditions for growth are needed.
- Large range of microorganisms capable of chemical syntheses or degradation.
- Genetic engineering allows for manipulation to carry out synthesis not naturally possible (e.g., insulin production).
- Short life cycle and rapid growth make mass production efficient.
- Nutrient needs are simple and cheap, and genetic manipulation allows microorganisms to use waste materials, reducing costs.
- Microorganisms grow under low temperature, with oxygen, food, and removal of waste gases, making bioprocesses cheaper than traditional industrial methods.
- Are self catalysing as they produce their own enzymes and do not need industrial conditions (high pressure, temperatures)

INDIRECT FOOD PRODUCTION:

- Microorganisms are widely used in biotechnology to produce food like bread, yogurt, and cheese.
- The microorganisms act indirectly on other food components (e.g., flour in bread, milk in yogurt and cheese).

ADVANTAGES:

- All the benefits of using microorganisms in biotechnology apply here:
- Efficient processes, low cost, and rapid production.

DISADVANTAGES:

- Non-ideal conditions (too hot/cold) prevent microorganism growth, making them inefficient.
- Ideal conditions for microorganisms may promote pathogen growth, requiring processes to be sterile.
- Some microorganisms in food production are genetically modified, raising ethical concerns, though this is less controversial than with animals or plants.

EXAMPLES OF MICROORGANISMS USED IN COMMERCIAL PROCESSES:

Baking: Yeasts used to make bread rise through production of carbon dioxide in respiration

Brewing: Yeasts: respire anaerobically to produce ethanol

Cheese-making: bacteria feed on lactose in milk, modifying the taste and texture. Also plays a role in inhibiting growth of bacteria that cause milk to spoil

Yoghurt-making: *Lactobacillus bulgaricus* and *Streptococcus thermophilus* (lactic acid) produce extracellular polymers that modify the texture of yogurt.



DIRECT FOOD PRODUCTION:

- Single-cell protein (SCP) involves directly producing edible protein from microorganisms.
- Quorn™ is a well-known SCP made from the fungus *Fusarium venenatum*.
- It is grown in fermenters using glucose syrup, then combined with egg white and compressed into meat substitutes.
- Quorn™ is popular due to its high protein and low fat content.

Other Attempts:

- Yeasts, algae, and bacteria can be used to grow proteins similar to animal proteins, but success is limited.
- Single-celled proteins are increasingly used to feed animals like fish and cattle.

Future Outlook:

- If protein shortages persist, foods made directly from microorganisms could become more common.

PRODUCING PENICILLIN:

- The first effective antibiotic, penicillin, was produced by the mould *Penicillium notatum*, but it had a low yield.
- Commercial production began after the discovery of *Penicillium chrysogenum*, which grows well in high oxygen and nutrient-rich conditions.

The process involves a semi-continuous batch process with two stages:

1. The fungus grows.
2. It produces penicillin, which is then extracted and purified.

Summary of modern Penicillin production:

- Small fermenters (40–200 dm³) are used to maintain high oxygenation levels.
- The mixture is continuously stirred to maintain oxygen levels.
- A rich nutrient medium is used.
- The medium is buffered to maintain a pH of around 6.5.
- Bioreactors are maintained at 25–27°C.

MAKING INSULIN:

- Insulin is essential for people with type 1 diabetes and some with type 2 diabetes to control blood sugar levels.
- Previously, insulin was extracted from the pancreas of animals (pigs or cattle), which led to erratic supply as it depended on the demand for meat.
- Problems included:
 - Allergic reactions to impure animal insulin.
 - Difficulty for some faith groups using pig products.
 - Peak activity of animal insulin occurred hours after injection, complicating meal planning.

Revolution of Genetic Engineering:

- In the 1970s, genetically engineered bacteria began producing human insulin.
- The bacteria are grown in fermenters, providing a constant supply of pure human insulin.

BIOREMEDIATION

-The use of microorganisms to break down pollutants in soil or water.

Approaches to Bioremediation:

1. Using natural organisms:

- Many microorganisms break down organic material (e.g., sewage or crude oil) into carbon dioxide and water.
- Example: In oil spills, nutrients are added to encourage microbial growth, and oil is dispersed to maximize surface area for microbial action.

2. Using GM organisms:

- Scientists are developing GM bacteria that can break down contaminants they would not naturally encounter (e.g., mercury in water).
- GM bacteria can be used in filters to remove toxic contaminants from contaminated sites.

Effectiveness:

- Bioremediation often occurs on-site, but material can also be removed for decontamination.
- In most cases, natural microorganisms outperform GM ones, though future improvements in genetic engineering may increase the effectiveness of bioremediation.

SAFETY IN CULTURING

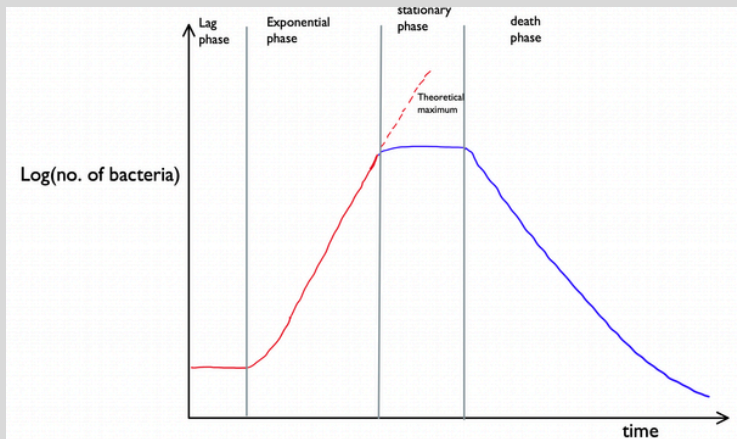
MICROORGANISMS:

- Health and safety procedures must be followed when culturing microorganisms, even if they seem harmless, because:
- There is always a risk of mutation making the strain pathogenic.
- There may be contamination from the environment with pathogenic microorganisms.

INOCULATING VIA NUTRIENT BROTH:

1. Prepare a bacterial suspension.
2. Mix with sterile nutrient broth in the flask.
3. Stopper with cotton wool to prevent contamination.
4. Incubate at a suitable temperature, shaking regularly for aeration.

BACTERIAL COLONY GROWTH CURVES:



THERE ARE FOUR DISTINCT STAGES IN BACTERIAL GROWTH:

1. Lag phase:
 - Bacteria adapt to their new environment, grow, and synthesize enzymes but do not yet reproduce at maximum rate.
2. Log (exponential) phase:
 - The rate of bacterial reproduction reaches its theoretical maximum.
3. Stationary phase:
 - Growth rate is zero—new cells from binary fission are balanced by the number of cells dying.
4. Decline (death) phase:
 - Reproduction nearly stops, and the death rate of cells increases.

REQUIREMENTS FOR CULTURING

MICROORGANISMS:

- Food sources through a sterile nutrient medium
- Correct conditions, including temperature, oxygen and pH
- Aseptic technique

INOCULATING USING AGAR:

1. Sterilise the inoculating loop by heating it in a Bunsen flame until red-hot.
 2. Dip the sterilised loop into the bacterial suspension and streak across the agar in a zig-zag pattern.
 3. Replace the lid of the Petri dish, securing it with tape but not fully sealing to allow oxygen in. (*prevents anaerobic growth*)
- Incubate at a suitable temperature.

Under ideal conditions, bacteria can grow at a rate of one division per 20 minutes.

- Equation for predicting the size of a colony:

$$N = N_0 \times 2^n$$

Where:

N is the total population

N₀ is the initial population size

n is the number of divisions

LIMITING FACTORS PREVENT THEORETICAL EXPONENTIAL GROWTH CURVE

Nutrient availability:

- As microorganisms multiply, nutrients are consumed, and eventually, the supply is insufficient for further growth unless replenished.

Oxygen levels:

- Increased population heightens demand for respiratory oxygen, leading to oxygen limitations.

Temperature:

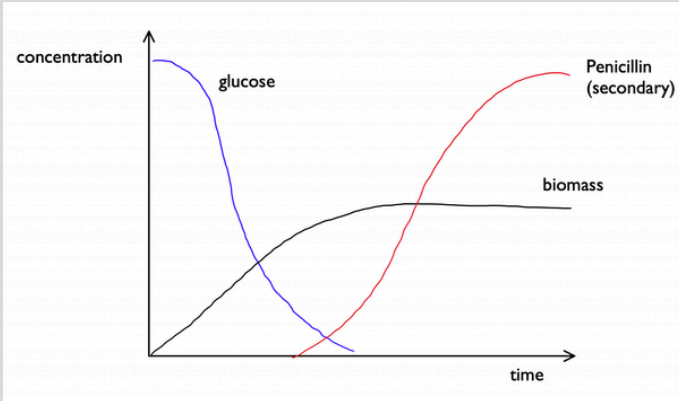
- Low temperatures slow down growth, while high temperatures speed it up. Excessive heat can denature enzymes and kill microorganisms.

Waste build-up:

- Accumulation of toxic waste products can inhibit growth and may poison or kill the culture.

pH changes:

- Carbon dioxide from bacterial respiration lowers the pH, reducing enzyme activity and inhibiting growth.



Primary and Secondary Metabolites:

Primary Metabolite: a desired metabolite that is produced as part of the essential growth and functioning of an organism.

examples: ethanol (anaerobic respiration)

Secondary Metabolite: a desired metabolite that is not essential to the growth or function of an organism and does not affect the survival or the organism.

examples: penicillin, pigments in plants

Types of Bioprocess:

Batch fermentation:

- Microorganisms are inoculated into a fixed volume of medium.
- As growth occurs, nutrients are used up, and both new biomass and waste build up.
- Growth reaches the stationary phase, during which microorganisms produce end products (e.g., antibiotics, enzymes).
- The process is stopped before the death phase, products are harvested, and the system is cleaned before starting a new batch.

Continuous fermentation:

- Microorganisms are inoculated into sterile nutrient medium.
- Sterile medium is added continually once growth reaches the exponential phase.
- The culture broth (medium, waste, microorganisms, and product) is continuously removed to maintain a constant volume.

All bioreactors produce a mixture of primary and secondary metabolites, waste products, and unused nutrient. Downstream processing is required to separate these.

Controlling Bioreactors:

Temperature:

- If too low, microorganisms grow slowly; if too high, enzymes denature. Bioreactors often use heating/cooling systems linked to temperature sensors for optimal conditions.

Nutrients and oxygen:

- Oxygen and nutrients are added as needed when probe readings show levels are dropping.

Mixing:

- Diffusion is not enough for large, thick cultures. Bioreactors use continuous stirring to ensure uniform distribution of oxygen, nutrients, and temperature.

Asepsis:

- To prevent contamination from air or workers, bioreactors are sealed and operate in aseptic units. For GM organisms, containment is legally required to avoid environmental release.



There are two main ways of using enzymes: using whole organisms, or isolated enzymes. Isolated enzymes can be intracellular or extracellular, and these can be free or immobilised.

ADVANTAGES OF USING ISOLATED ENZYMES IN INDUSTRY, RATHER THAN USING WHOLE ORGANISMS THAT PRODUCE THE ENZYME:

- Less wasteful: Whole microorganisms use substrate to grow and produce biomass, while isolated enzymes focus on product formation.
- More efficient: Isolated enzymes work at higher concentrations compared to when part of whole microorganisms.
- More specific: No unwanted enzymes are present, preventing wasteful side reactions.
- Maximised efficiency: Isolated enzymes can operate under ideal conditions, which may differ from what is needed for microorganism growth.
- Less downstream processing: Isolated enzymes produce pure products, avoiding complications from multiple by-products in whole microorganism cultures.

Industrial isolated enzymes are typically extracellular rather than intracellular.

ADVANTAGES OF USING EXTRACELLULAR ENZYMES:

- Easier to isolate: They are secreted by the microorganism, simplifying extraction.
- Fewer enzymes: Each microorganism produces fewer extracellular enzymes, making it easier to identify the desired enzyme compared to the hundreds of intracellular enzymes.
- More robust: Extracellular enzymes are more adaptable to variations in temperature and pH than intracellular enzymes.

USE CASES OF INTRACELLULAR ENZYMES:

- Despite the advantages of extracellular enzymes, intracellular enzymes are sometimes used due to the wider range of enzyme types, offering the ideal enzyme for specific processes.

Immobilised enzyme: an enzyme anchored to an inert support, and the substrates are passed over these enzymes. Products are recovered and the enzyme remains intact.

ADVANTAGES OF USING IMMOBILISED ENZYMES:

- Reusability: Immobilised enzymes can be reused, making them cheaper.
- Easily separated: Reactants and products are easily separated, reducing downstream processing costs.
- More reliable: Immobilised enzymes provide a stable microenvironment with greater process control.
- Temperature tolerance: They are less easily denatured by heat and work over a wider temperature range, reducing bioreactor costs.
- Ease of manipulation: Catalytic properties can be altered more easily than free enzymes. For example, immobilised glucose isomerase can be used for over 1000 hours continuously at 60–65°C, reducing running costs.

DISADVANTAGES OF USING IMMOBILISED ENZYMES:

- Reduced efficiency: Immobilising enzymes may reduce their activity rate.
- Higher initial costs: Immobilised enzymes are more expensive than free enzymes or microorganisms, but they do not require frequent replacement.
- Higher initial cost of bioreactors (an investment cost: will pay itself through saved costs)
- More technical issues, as immobilised enzymes are more complex and thus more opportunities for errors

An alternative to immobilising enzymes is immobilising microorganisms .

- This brings the same advantages of using immobilised, isolated enzymes but may avoid the cost of isolating enzymes
- However, this also means that the organisms have to be cultured under carefully controlled environments



METHODS OF IMMOBILISING ENZYMES:

1. Surface Immobilisation – Adsorption:

- Advantages: Simple, cheap, can be used for many processes, enzymes are accessible with unchanged activity.
- Disadvantages: Enzymes can be lost from the matrix easily.

2. Surface Immobilisation – Covalent/Ionic Bonding:

- Advantages: Strong enzyme binding, unlikely to lose enzymes, pH and substrate concentration have little effect.
- Disadvantages: Cost varies, active site modification may reduce enzyme effectiveness.

3. Entrapment in Matrix:

- Advantages: Applicable to many processes.
- Disadvantages: Can be expensive, difficult to entrap enzymes, slow diffusion to/from active site.

4. Entrapment in Membrane (Encapsulation):

- Advantages: Simple, minimal effect on enzyme activity, applicable to different processes.
- Disadvantages: Expensive, slow diffusion to/from active site.



DEFINING ECOSYSTEMS:

- An ecosystem consists of all living organisms interacting in a specific area and the physical factors in that region.
- Ecosystems vary in size, from small habitats (e.g., rock pools) to large ones (e.g., the biosphere).

FACTORS THAT AFFECT ECOSYSTEMS:

Biotic factors (living):

Refer to interactions between living organisms (or those that once lived).

- These interactions often involve competition within or between populations for resources.

Examples include the presence of organisms like shrews or hedgehogs, population size, and competition for food (e.g., insects).

Abiotic factors (non-living/physical):

Light:

- Photosynthesis is directly affected by light availability. More light generally leads to greater plant success.
- Plants adapt to different light levels by having larger leaves, developing pigments that require less light, or having reproductive systems that depend on optimal light levels.

Temperature:

- Temperature affects enzymes that control metabolic reactions. Plants grow faster in warmer temperatures.
- Seasonal temperature changes can cause migration and hibernation in animals and trigger leaf-fall or flowering in plants.

Water Availability:

- Lack of water causes stress and can lead to death in both plants and animals.
- Water keeps plant cells turgid, essential for photosynthesis. Some plants like cacti have evolved to handle water stress.

Oxygen Availability:

- In aquatic ecosystems, cold, fast-flowing water contains more oxygen.
- Waterlogged soil reduces available oxygen for plants, impacting their growth.

Edaphic (Soil) Factors:

- Clay: Fine particles, easily waterlogged, clumps when wet.
- Loam: Mixed-sized particles, retains water but does not waterlog.
- Sandy: Coarse particles, well-draining, prone to erosion.



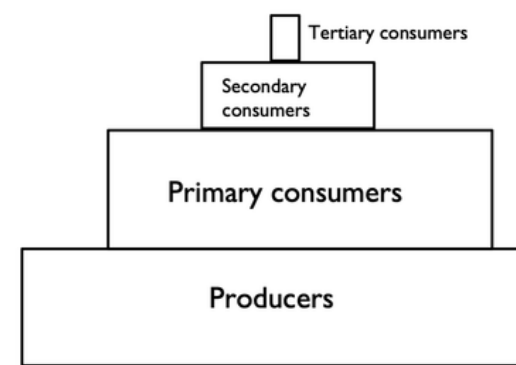
ENERGY IN ECOSYSTEMS:

- All organisms in an ecosystem need energy to survive.
- The Sun is the primary source of energy for almost all ecosystems.
- Through photosynthesis, the Sun's light energy is converted into chemical energy in plants and other photosynthetic organisms.
- This chemical energy is then transferred to non-photosynthetic organisms as food.

TROPHIC LEVELS:

Trophic level: Each stage in a food chain or food web representing the transfer of biomass and energy in an ecosystem.

- Producers: The first trophic level; organisms that convert light energy into chemical energy through photosynthesis.
- Consumers: The subsequent trophic levels, consisting of:
 - Primary consumers: Animals that eat producers (herbivores).
 - Secondary consumers: Animals that eat primary consumers.
 - Tertiary consumers: Animals that eat secondary consumers.
 - Quaternary consumers: Animals that eat tertiary consumers (if present).
- Decomposers: Organisms that break down dead material, recycling nutrients back into the ecosystem.



PYRAMID OF NUMBERS FOR AN ECOSYSTEM

MEASURING BIOMASS:

Biomass: The mass of living material in a given area or within organisms, important for understanding energy transfer in ecosystems.

To calculate biomass at each trophic level:

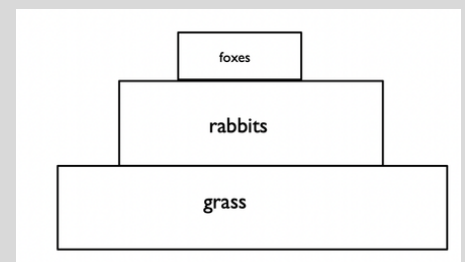
- Multiply the biomass per organism by the number of organisms in that trophic level.

Data is presented in a pyramid of biomass, showing biomass at a particular moment.

- Fresh mass: Measuring the mass of living organisms directly, but it is unreliable due to water content variation.
- Dry mass: Organisms are dried in an oven at 80°C until water is evaporated, and mass readings stabilize. Only a small sample is taken to represent the whole population.

Biomass is measured in:

- g/m² for land areas.
- g/m³ for water areas.



PYRAMIDS OF BIOMASS

EFFICIENCY OF BIOMASS AND ENERGY TRANSFER BETWEEN TROPHIC LEVELS

- Biomass decreases at each trophic level.
- Biomass is converted to energy content, but only a small proportion is transferred to the next level.
- Energy available at each trophic level is measured in $\text{kJ m}^{-2} \text{yr}^{-1}$.
- Ecological efficiency refers to the efficiency of biomass/energy transfer between trophic levels.

EFFICIENCY AT PRODUCER LEVEL

- Producers convert 1-3% of sunlight into biomass.
- 90% of sunlight is lost due to reflection, transmission, or unusable wavelengths.
- Other limiting factors: water availability and photosynthesis inefficiencies.

Gross production: Total energy converted by producers.

Net production: Energy available to the next trophic level:

Net production = Gross production - Respiratory losses

EFFICIENCY AT CONSUMER LEVELS

- Consumers convert about 10% of the biomass in their food into organic tissue.

Not all biomass is eaten (e.g., plant roots or animal bones).

- Energy is lost as metabolic heat during movement and respiration.
- Indigestible parts are egested as faeces.
- Energy loss through excretion (urine).
- Only 0.001% of the original energy from sunlight is converted into biomass at the tertiary consumer level.

ECOLOGICAL EFFICIENCY FORMULA:

$$\text{Ecological efficiency} = \left(\frac{\text{Energy or biomass available after the transfer}}{\text{Energy or biomass available before the transfer}} \right) \times 100$$

HUMAN CIVILISATION AND AGRICULTURE

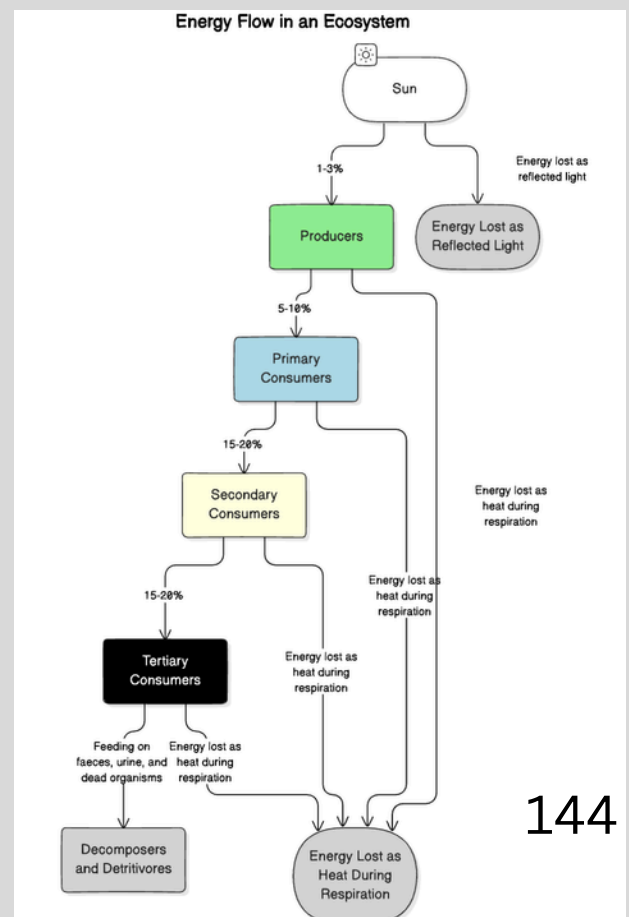
- Agriculture manipulates the environment to favour crops and animals for human consumption.
- Abiotic conditions are optimised (e.g., watering, warmth).
- Competition removed (e.g., pesticides) and predators excluded (e.g., fences).

In a natural ecosystem:

- Humans would occupy the second, third, or fourth trophic level.
- Energy losses occur at each level, reducing available biomass for consumption.

In agriculture food chains:

- Animals for consumption: Three trophic levels (producers, primary consumers—livestock, secondary consumers—humans).
- Plant cultivation: Two trophic levels (producers—crops, primary consumers—humans).
- Simpler food chains = less energy loss, maximizing biomass for human consumption.





ENERGY FLOW IN ECOSYSTEMS:

- Linear flow: Energy enters ecosystems from the Sun, and is transferred to organisms, eventually being lost as heat to the atmosphere.
- Nutrients cycle: Unlike energy, nutrients must be recycled as they are continuously used by organisms, without an external source to replenish them.

DECOMPOSITION:

Decomposition: A process breaking down compounds into smaller, usable molecules (e.g., nitrogen, carbon), returning them to the environment in inorganic forms.

Decomposers: Organisms (bacteria, fungi) that break down dead organic matter into inorganic nutrients.

- Use saprobial nutrition to secrete enzymes onto dead matter, breaking it into soluble molecules that are absorbed and returned to the ecosystem.

Detritivores: Organisms that consume detritus (e.g., woodlice, earthworms).

- They internally digest decaying material, speeding up decomposition and increasing surface area for decomposers.

RECYCLING NITROGEN

- Nitrogen is essential for making amino acids and nucleic acids in plants and animals.
- Animals obtain nitrogen from food; plants absorb nitrogen from their environment.
- Nitrogen gas (N_2), abundant in the atmosphere, cannot be used directly by plants.

Nitrogen-fixing bacteria convert atmospheric nitrogen into a usable form, like ammonia (NH_3), in a process called nitrogen fixation.

NITROGEN FIXATION

- Nitrogen-fixing bacteria like *Azotobacter* and *Rhizobium* contain the enzyme nitrogenase, which combines atmospheric nitrogen (N_2) with hydrogen (H_2) to form ammonia (NH_3), a form that plants can absorb and use. This process is known as nitrogen fixation.
- *Azotobacter* is an example of a free-living nitrogen-fixing bacterium.
- *Rhizobium* bacteria live inside root nodules of leguminous plants like peas, beans, and clover. The bacteria form a symbiotic mutualistic relationship with the plant:
 - The plant gains amino acids from *Rhizobium* through the fixation of nitrogen gas into ammonia.
 - The bacteria gain carbohydrates produced by the plant during photosynthesis, which they use as an energy source.
 - Other bacteria convert the ammonia produced during nitrogen fixation into organic compounds that can be absorbed by plants.

NITRIFICATION

- Nitrification: A two-step process in which ammonium (NH_4^+) is converted into nitrite (NO_2^-) and then nitrate (NO_3^-), which plants can absorb.

1. Nitrosomonas bacteria convert ammonium to nitrites. (NO_2^-)
2. Nitrobacter bacteria convert nitrites to nitrates (NO_2^- to NO_3^-)
 - Nitrates are soluble and move into plant roots via diffusion

Can only occur in well aerated soils.

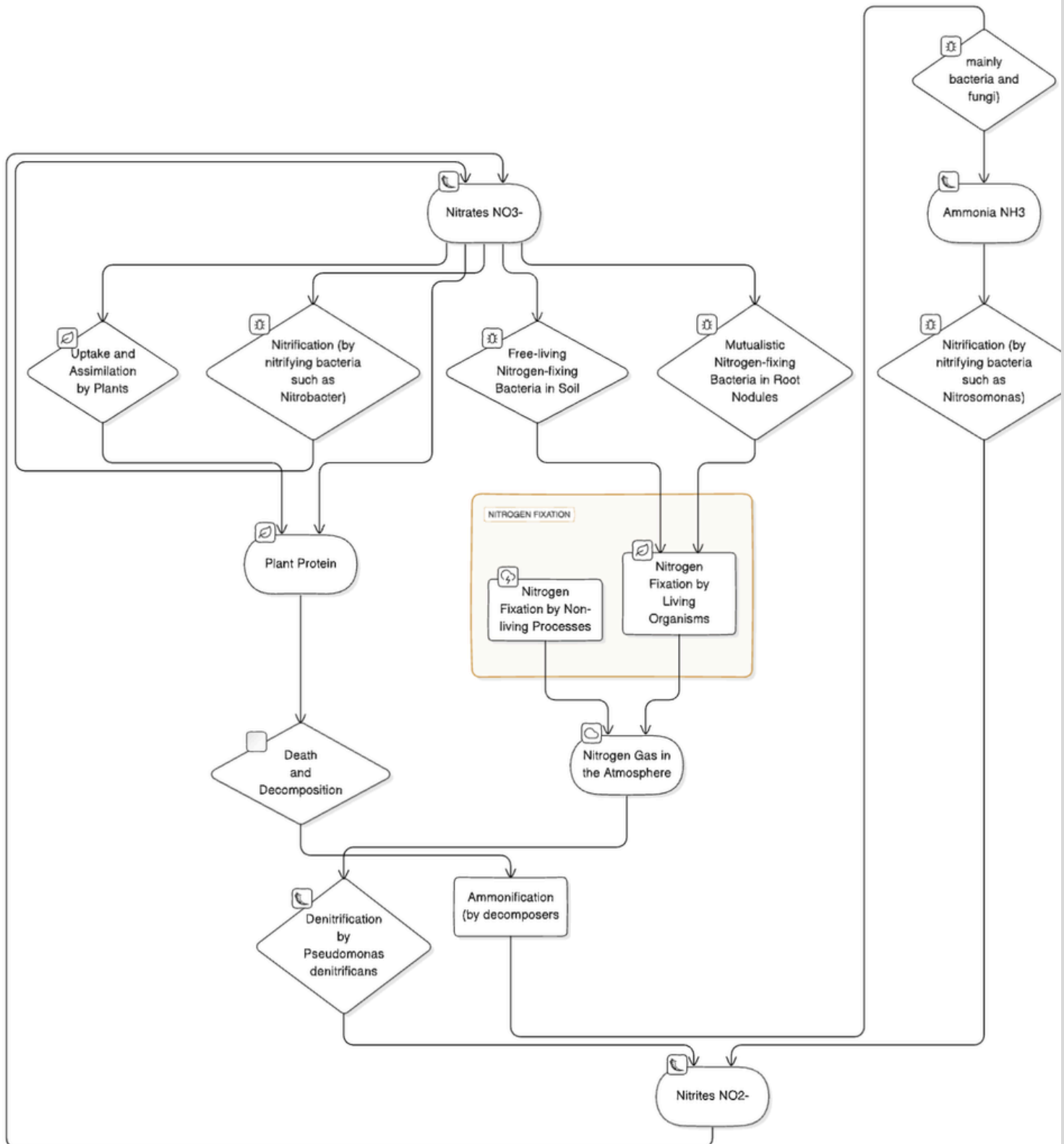
DENITRIFICATION

- Occurs in anaerobic conditions (e.g., waterlogged soils).
- Denitrifying bacteria convert nitrates into nitrogen gas.
- Bacteria use nitrates as an energy source for respiration, releasing nitrogen gas.

AMMONIFICATION

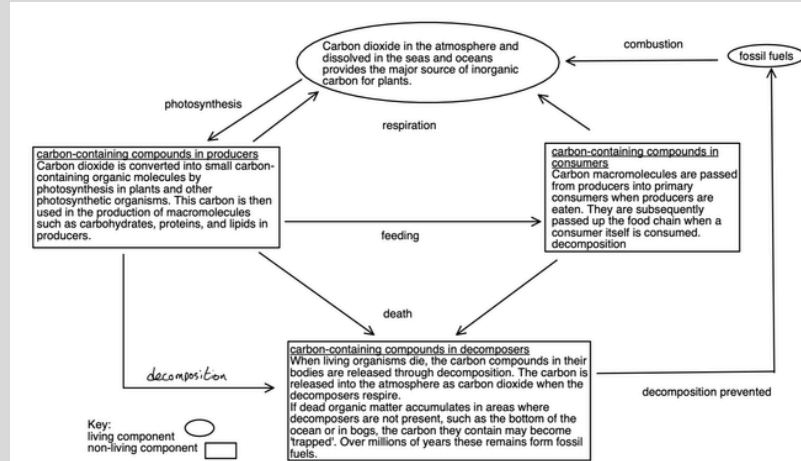
- Decomposers convert nitrogen-containing molecules (from dead organisms, feces, and urine) into ammonium compound

Nitrogen Cycle Flow Chart



CARBON CYCLE BREAKDOWN:

- Carbon dioxide in the atmosphere:
 - Main source of inorganic carbon for plants.
 - Dissolves in seas and oceans.
- Photosynthesis (Producers):
 - Plants and photosynthetic organisms convert CO_2 into organic molecules.
 - These molecules form macromolecules like carbohydrates, proteins, and lipids.
- Feeding (Consumers):
 - Carbon macromolecules pass to primary consumers when they eat producers.
 - These molecules move up the food chain.
- Decomposition (Decomposers):
 - When organisms die, decomposers break down carbon-containing compounds.
 - Decomposers respire, releasing carbon dioxide back into the atmosphere.
- Fossil Fuel Formation:
 - If decomposition is prevented (e.g., in ocean depths or bogs), carbon becomes trapped.
 - Over millions of years, trapped carbon forms fossil fuels.
- Combustion:
 - Burning fossil fuels releases stored carbon back into the atmosphere as CO_2 .



FLUCTUATIONS IN ATMOSPHERIC CARBON DIOXIDE

- Daytime: Photosynthesis (in light) removes CO_2 from the atmosphere.
- Nighttime: Respiration by organisms releases CO_2 into the atmosphere.
- CO_2 levels are higher at night due to the absence of photosynthesis.
- Seasonal variation:
 - Summer: Lower CO_2 levels due to higher rates of photosynthesis.
 - Winter: Higher CO_2 levels as photosynthesis slows down.

FACTORS INFLUENCING GLOBAL ATMOSPHERIC CARBON DIOXIDE INCREASE

- Combustion of Fossil Fuels:
 - Releases carbon stored for millions of years back into the atmosphere.
- Deforestation:
 - Reduces photosynthesizing biomass, leading to less CO_2 removal.
 - Burning of forests releases additional CO_2 .
- Greenhouse Effect:
 - Increased CO_2 traps more heat (thermal energy), contributing to global warming.
- Oceans and CO_2 :
 - CO_2 levels in oceans decrease as water temperature rises (less CO_2 is dissolved).
 - Global warming releases more CO_2 into the atmosphere, creating a positive feedback loop.

HISTORICAL FLUCTUATIONS IN CO_2 LEVELS:

- Millions of years of variation in CO_2 levels.
- Deep ice samples (e.g., from Antarctic glaciers) reveal historical atmospheric compositions.
- Air bubbles in glaciers show past CO_2 levels, reflecting atmospheric changes over time.



SUCCESSION IN ECOSYSTEMS

- Succession: The process by which ecosystems change over time.
- Example: Species diversity increases as you move inland from a beach.
- Caused by: Changes in abiotic factors leading to shifts in plant and animal species.

TWO TYPES OF SUCCESSION:

1. Primary Succession:

- Occurs on newly formed or exposed land (e.g., bare rock).
- No soil or organic material initially present.
- Examples:
 - Volcanoes depositing lava, forming new igneous rock.
 - Wind-blown sand forming new dunes.
 - Silt and mud deposited in river estuaries.
 - Retreating glaciers exposing bare rock.

2. Secondary Succession:

- Occurs on land where soil is present, but no plants or animals remain.
- Example: Bare earth after a forest fire.

PIONEER COMMUNITY

- Primary succession starts with the colonization of a bare environment by pioneer species (or pioneer colonizers).
- This marks the first seral stage.
- Pioneer species (e.g., algae and lichen) arrive through wind-blown spores or seeds, or are carried by birds or animals.

ADAPTATIONS OF PIONEER SPECIES:

- Produce large quantities of seeds/spores, easily dispersed by wind.
- Rapid germination of seeds.
- Can perform photosynthesis using available abiotic factors (light, air, rainfall).
- Tolerant of extreme environments.
- Can fix nitrogen from the atmosphere, enriching soil mineral content.

CLIMAX COMMUNITY

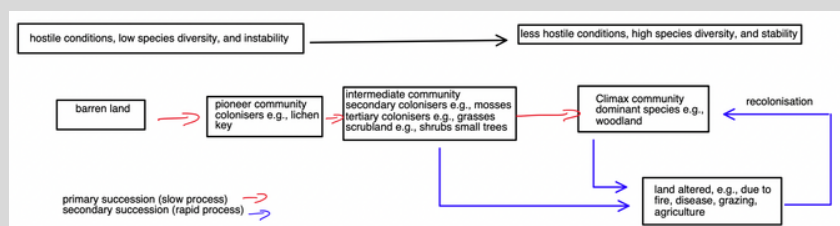
- The climax community is the final seral stage in succession, where the ecosystem reaches a stable state with minimal change over time.
- A few dominant species (both plants and animals) characterize this stage.
- The specific species making up the climax community depend on the climate:
 - Temperate climates: Large trees dominate due to mild temperatures and abundant water.
 - Sub-arctic climates: Herbs or shrubs dominate where temperatures are lower, and water is scarce.

BIODIVERSITY IN THE CLIMAX COMMUNITY

- While biodiversity increases during succession, the climax community often shows less diversity than mid-succession stages.
- Biodiversity peaks in mid-succession, then declines as dominant species outcompete others, leading to the elimination of pioneer species.

STAGES OF SUCCESSION

- Succession occurs in a series of steps, called seral stages (or seres).
- At each seral stage, key species modify the abiotic factors (especially soil).
- These changes make the environment more suitable for subsequent species to thrive.



INTERMEDIATE COMMUNITY

- Over time, weathering of bare rock produces particles, forming the basis of soil.
- Decomposition of pioneer species releases organic matter (humus) into the soil, enriching it with minerals like nitrates and giving it water-retaining capacity.
- Secondary colonisers (e.g., mosses) arrive via spores or seeds, taking advantage of the improved soil conditions.
- Tertiary colonisers (e.g., ferns) follow, adapting to further improved soil with features like waxy cuticles to reduce water loss.
- These species thrive even without abundant water, using soil moisture and minerals.

SOIL ENRICHMENT AND SPECIES DOMINANCE

- Decomposition of organisms contributes to deeper, nutrient-rich soil.
- Soil retains more water, supporting the growth of small plants (e.g., grasses) and eventually shrubs and small trees.
- At each seral stage, new species outcompete earlier ones, becoming the dominant species by mass in the ecosystem.



ANIMAL SUCCESSION

- Animals follow a similar progression to plants in succession.
- Primary consumers (e.g., insects, worms) are the first to arrive, consuming and sheltering in the available plant cover like mosses and lichens.
- Animal succession is slower than plant succession, especially in isolated areas (e.g., volcanic islands), as animals must move from neighboring areas.
- Secondary consumers appear after plant life has established and provided suitable food and habitats.
- Larger organisms (e.g., mammals, reptiles) arrive later when biotic conditions are favorable.

DEFLECTED SUCCESSION

- Human activities can interrupt natural succession, preventing the ecosystem from reaching the climax community.
- When halted artificially, the ecosystem forms a plagioclimax.
- Common causes of deflected succession:
 - Grazing and trampling of vegetation by domesticated animals, leaving grassland.
 - Removing vegetation for planting crops, with the crop becoming the final community.
 - Burning for forest clearance, which can increase biodiversity by creating space and nutrient-rich ash for new species like shrubs.



DISTRIBUTION OF ORGANISMS

- Refers to where organisms are located within an ecosystem.
- Organisms are usually found where abiotic (non-living) and biotic (living) factors are favorable.
- Distribution is often uneven because resources and pressure from predators vary across the ecosystem.

MEASURING DISTRIBUTION

- Line and belt transects are used to measure distribution:
- Line transect: A tape or line is laid out, and samples are taken at regular intervals.
- Belt transect: Two parallel lines are used, and samples are taken between them for more detailed information.
- Both are forms of systematic sampling (non-random) used to study how abiotic factors influence species distribution.
- Systematic sampling allows scientists to examine how environmental changes (e.g., moving inland from the sea) affect species distribution—useful for studying succession in sand dunes.

ABUNDANCE OF ORGANISMS

- Refers to the number of individuals of a species in an area at any given time.
- The number fluctuates due to:
- Immigration and births, which increase the population.
- Emigration and deaths, which decrease the population.

MEASURING ABUNDANCE

- Population: A group of similar organisms living in an area at a given time.
- Challenges: Populations are difficult to count accurately (e.g., elusive animals, time-consuming processes).
- Sampling techniques are used to estimate population sizes to avoid environmental damage and ensure practical data collection.
- Larger sample sizes reduce the chance of inaccurate results, and random sampling is important to minimize bias.

MEASURING PLANT ABUNDANCE

- Quadrats: Used to estimate the abundance of plants by placing them randomly in an area and counting the number of individuals within the quadrat.
- To estimate abundance, the following formula is used:

$$\text{Estimated number in population (m}^{-2}\text{)} = \frac{\text{Number of individuals in sample}}{\text{Area of sample (m}^2\text{)}}$$

SIMPSON'S INDEX OF DIVERSITY (D)

Used to mathematically calculate the biodiversity in a habitat.

$$D = \frac{N(N-1)}{\sum n(n-1)}$$

MEASURING ANIMAL ABUNDANCE

- Quadrats are ineffective for measuring animal abundance unless animals are very slow-moving (e.g., barnacles or mussels).
- The capture-mark-release-recapture method is commonly used to estimate population size.

STEPS FOR THE CAPTURE-MARK-RELEASE-RECAPTURE TECHNIQUE:

1. Capture as many individuals as possible in a sample area.
2. Mark or tag each individual.
3. Release the marked animals back into the sample area and allow time for them to redistribute.
4. Recapture as many individuals as possible from the same area.
5. Record the number of marked and unmarked individuals in the sample.
6. Use the Lincoln index to estimate the population size:

$$\text{Estimated population size} = \frac{\text{number of individuals in first sample} \times \text{number of individuals in second sample}}{\text{number of recaptured marked individuals}}$$

Where:

- D = diversity index
- N = total number of organisms in the ecosystem
- n = number of individuals of each species

Values of D range from 0 to 1:

- 0 represents no diversity.
- 1 represents infinite diversity.
- The higher the value of D, the more diverse the habitat.

SIGMOID POPULATION GROWTH

CURVE:

1. Phase 1 – Slow Growth:

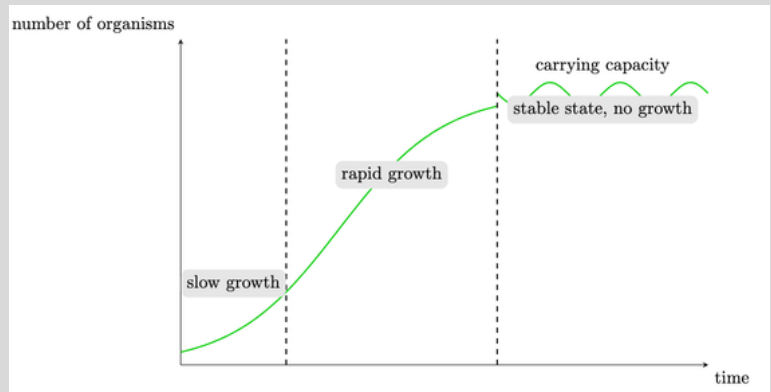
- A small number of individuals reproduce, gradually increasing the population size.
- The birth rate is higher than the death rate, causing the population to grow.

2. Phase 2 – Rapid Growth:

- The number of breeding individuals increases, leading to exponential population growth.
- No significant constraints limit the population's expansion.

3. Phase 3 – Stable State:

- Population growth is balanced by external constraints (e.g., predators, limited resources).
- Population size fluctuates slightly but remains stable overall.
- Birth and death rates are approximately equal.



LIMITING FACTORS

- In theory, populations could grow exponentially if resources were unlimited. However, this is rare in nature.
- Populations experience a brief period of exponential growth, but limiting factors prevent further growth or cause declines.

TYPES OF LIMITING FACTORS:

1. Abiotic Factors (non-living):

- Include temperature, light, pH, availability of water or oxygen, and humidity.

2. Biotic Factors (living):

- Include predators, disease, and competition for resources.

CARRYING CAPACITY

- The carrying capacity is the maximum population size that an environment can support.
- Population size fluctuates slightly around this level as the birth and death rates balance out.

MIGRATION

- Immigration: The movement of individuals into a population, resulting in an increase in population size.
- Emigration: The movement of individuals out of a population, resulting in a decrease in population size.

DENSITY-INDEPENDENT FACTORS

- Density-independent factors: These factors affect population size regardless of the population's density.
- Examples include earthquakes, fires, volcanic eruptions, and storms.
- These factors can significantly alter or even eliminate entire populations in a given area.



TYPES OF COMPETITION

Competition is a biotic limiting factor that occurs due to interactions between living organisms. There are two main types of competition:

1. Interspecific competition: Competition between different species.
2. Intraspecific competition: Competition between members of the same species.

INTERSPECIFIC COMPETITION

- Interspecific competition happens when two or more different species compete for the same resource (e.g., food, space).
- This reduces the availability of resources for both populations, leading to smaller population sizes.
-

If one species is better adapted to using the resource, the less adapted species will likely be outcompeted. Over time, the population of the less adapted species may decline or be eliminated entirely.

- This is known as the competitive exclusion principle, where one species is more efficient at resource utilization, ultimately excluding the other species from the habitat.

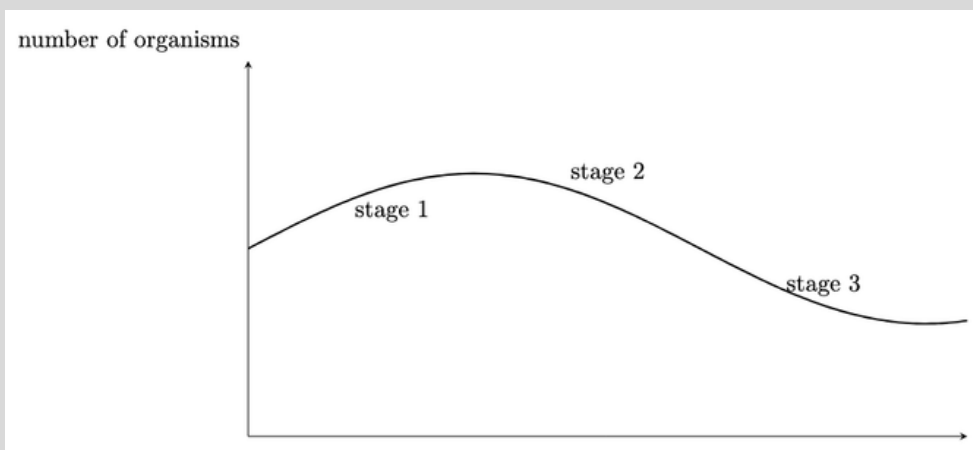
INTRASPECIFIC COMPETITION

- Intraspecific competition occurs when individuals of the same species compete for limited resources (e.g., food, space).
- The availability of these resources determines the population size. When resources are plentiful, the population increases, but competition causes fluctuations over time.

STAGES OF INTRASPECIFIC COMPETITION:

1. Stage 1:
 - Resources are plentiful, allowing all individuals to access enough to survive and reproduce.
 - This results in a population increase.
2. Stage 2:
 - As the population grows, the number of organisms sharing resources increases.
 - Resources become limited, causing some organisms to be unable to survive.
 - This leads to a decrease in population size.
3. Stage 3:
 - As the population decreases, there is less competition for resources.
 - More organisms can survive and reproduce, leading to population growth once again.

This cycle repeats as the population fluctuates due to competition.





PREDATION

- Predation is a biotic limiting factor where one organism (the predator) kills and consumes another organism (the prey).
- Example: Tigers preying on water buffalo or deer.
- Predation is a form of interspecific competition between predator and prey species.
- Both predators and prey have evolved adaptations:
- Predators may have adaptations such as speed, stealth, and enhanced senses for capturing prey.
- Prey have evolved defense mechanisms like camouflage, mimicry, or physical defenses (e.g., spines).

PREDATOR-PREY RELATIONSHIPS

- The populations of predators and prey are interlinked, causing fluctuations in population sizes as one affects the other.

Stages in Predator-Prey Relationships:

1. Stage 1:

- An increase in prey population provides more food for predators, causing the predator population to increase.

2. Stage 2:

- As predator numbers rise, they consume more prey, leading to a decline in prey population. The death rate of prey exceeds its birth rate.

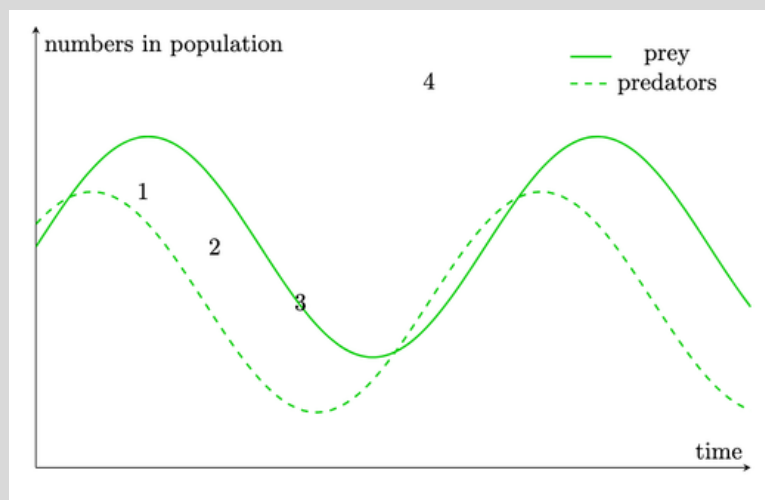
3. Stage 3:

- The reduced prey population cannot support the high predator numbers, leading to intraspecific competition among predators and a decrease in predator population.

4. Stage 4:

- Fewer predators result in less predation on the prey, allowing the prey population to recover. The cycle then repeats.

Other factors, such as the availability of food plants or seasonal abiotic changes, can also influence population size.





CONSERVATION

- Conservation refers to the active management of ecosystems to maintain biodiversity through sustainable practices.
- This includes maintaining genetic diversity within species, species diversity, and habitat diversity.
- Conservation aims for sustainable development, ensuring that natural resources are used without being depleted.
- Example: The Forest Stewardship Council promotes sustainable timber production.
- Conservation also involves reclamation, where damaged ecosystems are restored, such as through controlled burning or halting succession.

PRESERVATION

- Preservation involves protecting ecosystems from human activity, ensuring they remain in their original state.
- Preservation is typically applied to sensitive areas (e.g., caves or archaeological sites) where even small disturbances can cause significant damage.
- Human interference is usually prohibited, often by restricting access entirely.

IMPORTANCE OF CONSERVATION:

1. Economic:
 - Provides resources (e.g., timber, food, medicines) necessary for human survival and income generation.
 - Rainforest species can be used for medicines, clothing, and food production.
2. Social:
 - Promotes the enjoyment of natural beauty and supports health through activities like bird-watching, walking, and exercise in nature.
3. Ethical:
 - All organisms have a right to exist, and most contribute to ecosystem function.
 - Humans have a moral responsibility to protect biodiversity for future generations.



SUSTAINABLE USE OF RESOURCES

- The increasing global human population demands more resources, which puts pressure on ecosystems, reduces biodiversity, and depletes resources.
- Sustainable use of resources refers to managing the natural environment to ensure that renewable resources are not depleted. A sustainable resource is one that can be used without diminishing or running out.

AIMS OF SUSTAINABILITY:

1. Preserve the environment.
2. Ensure resources are available for future generations.
3. Allow all societies to live comfortably.
4. Support less economically developed countries (LEDs) by responsibly exploiting natural resources.
5. Balance resource consumption between more economically developed countries (MEDCs) and LEDs.

SUSTAINABLE TIMBER PRODUCTION

- Sustainable management of forests ensures the maintenance of biodiversity while meeting the economic needs of timber production.

Small-scale Timber Production:

- Coppicing: Cutting a tree trunk close to the ground to promote new shoot growth. This method maintains biodiversity by allowing light to reach the forest floor, preventing succession, and allowing other species to thrive.

Rotational Coppicing:

- In rotational coppicing, woodland is divided into sections, and each section is coppiced in rotation. Once all sections are coppiced, the process starts over. This ensures continuous timber supply without depleting the resource.

Pollarding:

- An alternative to coppicing, where the trunk is cut at a higher point, preventing animals from eating the new shoots.



PEAT BOGS

Peat bogs are regions of wet, spongy ground containing decomposing vegetation.

- They act as carbon sinks, storing carbon dioxide.
- However, when dried, peat can be used as a fuel, which releases carbon dioxide when burned, contributing to climate change.
- Peat is also valued for its use in agriculture. It improves soil structure and moisture retention while increasing acidity. However, commercial peat extraction poses a significant threat to these ecosystems.

PEATLAND ECOSYSTEM

- Peat forms in acidic, anaerobic conditions, inhibiting decomposition. This environment supports plants like sphagnum moss, cotton grass (*Eriophorum*), and heather (*Calluna vulgaris*). These plants have adapted to nutrient-poor, wet conditions.
- Peatlands support biodiversity, providing habitats for insects, birds, and predators. Many species rely on the lack of disturbance in these areas for breeding and feeding.

LOSS OF ECOSYSTEM

- In the UK, lowland raised bogs are rare and declining, with over 90% of their area lost due to activities like afforestation, peat extraction, and agricultural intensification.
- Maintaining the remaining areas is crucial for biodiversity, flood management, erosion control, and carbon storage.

KEY STEPS TO CONSERVING LOWLAND BOGS INCLUDE:

- Maintaining water levels: Ensuring peat and vegetation remain undisturbed and wet to prevent drying out.
- Ditch blocking: Used to raise the water table and restore natural water levels.
- Removal of seedling trees: Trees increase transpiration, reducing water levels. Removing seedlings helps maintain wet conditions.
- Controlled grazing: Helps to maintain biodiversity by promoting a diverse surface structure and species composition.

Organizations such as the Wildlife Trusts and RSPB are working to preserve and conserve these important ecosystems, balancing land use with biodiversity maintenance.



ENVIRONMENTALLY SENSITIVE ECOSYSTEMS

- Some ecosystems are more fragile and less resistant to change than others. These are called environmentally sensitive ecosystems.
- Example: Mass tourism can bring economic benefits but can also negatively affect ecosystems, such as causing biodiversity loss due to overdevelopment of coastlines.

IN MANY ENVIRONMENTALLY SENSITIVE AREAS, VARIOUS MANAGEMENT TECHNIQUES ARE APPLIED TO PROTECT BIODIVERSITY:

- Limiting tourist access to certain areas.
- Controlling livestock movement to prevent overgrazing.
- Anti-poaching measures to protect vulnerable species.
- Replanting forests and native vegetation to restore ecosystems.
- Limiting hunting by enforcing quotas and seasonal bans.