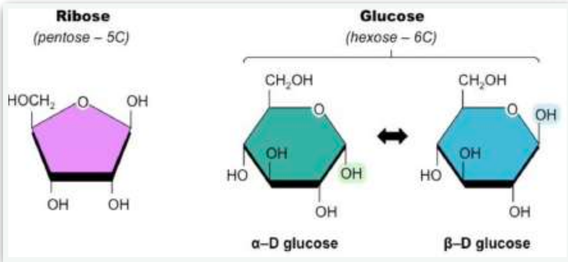
Chapter 2 —> Molecular Biology

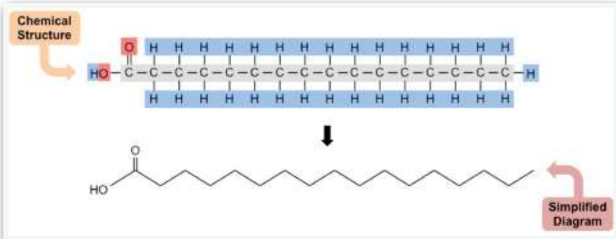
2.1 Molecules to Metabolism

Carbohydrates:



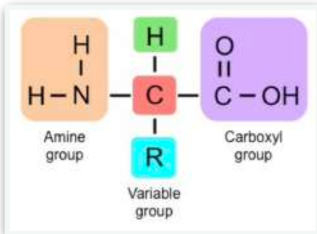
- Contain carbon, hydrogen, oxygen —> CH_2O
- Organic compounds consisting of one or more simple sugars
- Principally function as a source of energy and a recognition molecule

Lipids:



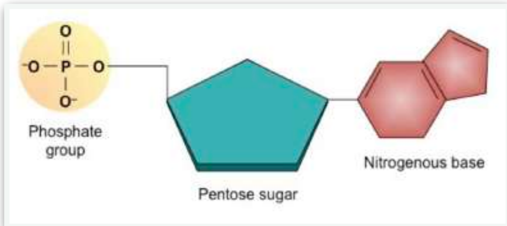
- Contain C,H,O
- Insoluble in water and soluble in non-polar solvents
- Triglycerides, phospholipids, steroids
- May be utilised as a long-term energy storage molecule or signalling molecule

Proteins:



- Contain C,H,O,N and sometimes sulphur
- Large organic compounds made by amino acids
- Hormones, enzymes, gas transport
- Major regulatory molecules involved in catalysis

Nucleic acids:



- Contain C, H, O, N and phosphorus
- Made by nucleotides —> base, sugar and phosphate
- Genetic material of all cells and determines the inherited features of an organism

Metabolic reactions:

- Metabolism —> the web of all enzyme-catalysed reactions that occur within a cell or organism —> provide a source of energy for cellular processes and enables synthesis of new materials
- Condensation makes bonds —> water in —> anabolic reactions
- Hydrolysis breaks bonds —> water out —> catabolic reactions —> Dehydration reaction —> catabolic reaction
- Both require enzymes

Falsifying vitalism —> Synthesis of Urea:

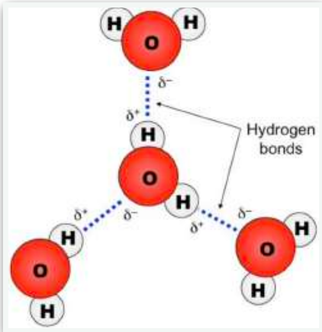
- Vitalism thought that organic molecules could only be synthesised by living systems
- Frederick Wöhler —> 1828 —> synthesised Urea with ammonium cyanite
- This demonstrated that organic molecules are not fundamentally different to inorganic ones

2.2 Water

Bonds:

- H_2O —> having more protons, the oxygen attracts the electrons more strongly
- The oxygen end is slightly negative and the hydrogen end is slightly positive
- This make H_2O molecules become polar
- H_2O molecules can associate via weak hydrogen bonds

Properties:



Cohesion:
- Due to the polarity of water
- Although hydrogen bonds are weak, the being many gives a large force
- Water molecules are strongly cohesive

Adhesion:
- Due to the polarity of water
- H_2O molecules tend to stick to other charged or polar molecules
- Capillary action is caused by the combination of adhesive forces

Thermal:
- It takes a lot of energy to change temperature in water
- Used as a coolant in organisms
- 4200 J to raise temperature of 1g by 1°C —> specific heat capacity
- High heat of vaporisation
- High heat of fusion

Solvent:
- The polar attraction of large quantities of water molecules can interrupt intra-molecular forces and so dissociating the atoms —> is able to dissolve polar and ionic substances

Hydrophilic:
- All substances that dissolve in water
- Substances chemically attracted to water

Hydrophobic:
- If do not have charges and are non-polar
- Lipids are hydrophobic

Transport in the blood:
- Glucose —> polar hence soluble —> carried by blood plasma
- Amino acids —> amine group (polar) —> carried by blood plasma
- Oxygen —> carried by haemoglobin as non-polar
- Lipids —> large and non-polar —> carried in lipoprotein complexes

Methane VS water:
- Non-polar (low specific heat capacity) —> methane
- Polar (high specific heat capacity) —> water

2.3 Carbohydrate and lipids

Carbohydrates:

Monosaccharides:

- Glucose —> $C_6H_{12}O_6$ —> sugar that fuels respiration
- Galactose —> $C_6H_{12}O_6$ —> less sweet —> common in milk and some times in cereals
- Fructose —> $C_6H_{12}O_6$ —> sweets carbohydrate —> common in milk and honey
- Ribose —> $C_6H_{12}O_6$ —>backbone of RNA/DNA when deoxyribose

Disaccharides (1 glycosidic bond):

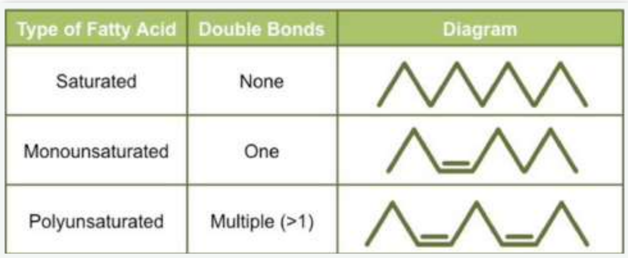
- Maltose —> $C_{12}H_{22}O_{12}$ —> glucose + glucose —> honey …
- Lactose —> $C_{12}H_{22}O_{12}$ —> glucose + galactose —> milk …
- Sucrose —> $C_{12}H_{22}O_{12}$ —> glucose + fructose —> table sugar …

Polysaccharides (Oligosaccharide 3 to 20 monosaccharides):

- Cellulose —> beta-glucose —> straight chain —> 1 - 4 —> indigestible for most animals
  —> structural polysaccharide that is found in the cell wall of plants
  —> very high tensile strength
- Starch —> alpha-glucose —> curved chain —> 1 - 6
  —> an energy storage polysaccharide found in plants
  —> size of molecule not fixed
  —> amylose —> forms a helix —> 300 - 3000 glucose units
  —> amylopectin —> globular shape —> 2000 - 200000 units
- Glycogen —> $(C_6H_{12}O_6)_n$ —> usually 30000 units —> alpha-glucose —> compact
  —> stored in the liver and in some muscles in human
  —> useful as energy and storage

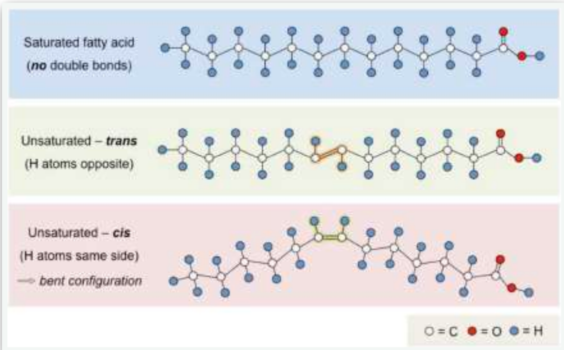
Fatty acids:

Types of fatty acids:



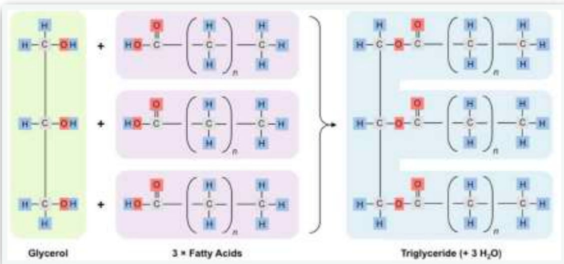
Type of Fatty Acid	Double Bonds	Diagram
Saturated	None	
Monounsaturated	One	
Polyunsaturated	Multiple (>1)	

Cis / trans isomer:



Tryglicerids:

- The largest class of lipids and function primarily as long-term energy storage molecules
- Animals store them as fats; plants store them as oils
- Can be either saturated or unsaturated depending on the composition of the fatty acid chains



Energy storage:

Carbohydrate (Glycogen)		Lipid (Triglyceride)
Short-term energy storage	**Storage**	Long-term energy storage
More effect on osmotic pressure	**Osmolality**	Less effect on osmotic pressure
More readily digested – used for aerobic or anaerobic respiration	**Digestion**	Less easily digested – can only be used for aerobic respiration
Stores half as much ATP per gram (~1760kJ per 100g)	**ATP Yield**	Stores twice as much ATP per gram (~4000kJ per 100g)
Water soluble as monomers / dimers – easier to transport	**Solubility**	Not water soluble (hydrophobic) – more difficult to transport

-1 gram of lipid is 6 times more energetic than glycogen

Blood cholesterol levels:

- Low density lipoproteins —> carry cholesterol from the liver to the rest of the body —> increased by saturated fats and trans fats
- High density lipoproteins —> scavenge excess cholesterol and carry it back to liver for disposal —> decreased by trans fats and increased by cis fats
- High cholesterol levels in the blood —> hardening and narrowing of arteries (atherosclerosis)
- Accumulation of fat within the arterial walls lead to the development of plaques and restricted blood flow —> coronary heart disease

BMI; Body Mass Index:

- Not a diagnostic tool
- Used as a screening tool to identify possible weight problems
- BMI = mass in kg / (height in m)^2

2.4 Proteins

Condensation:

- Proteins are comprised of long chains of recurring monomers called amino acids
- A ribosome condenses two amino acids into a dipeptide
- Peptide bonds —> types of covalent bonds
- Ribosomes —> where polypeptides are synthesised
- 20 types of amino acids which are universal to all living organisms
- DNA —> mRNA —> polypeptide
- From DNA to mRNA —> transcription
- From mRNA to polypeptide —> translation

Protein structure:

- Primary —> the order of the amino acids of which the protein is made
  —> controls all subsequent levels of structure due to the chemical properties
- Secondary —> alpha helix —> folds into a spiral / beta-pleated sheet —> directionally-oriented strand conformation / Random coil —> when no secondary structure exists
- Tertiary —> the overall three-dimensional configuration of the protein
- Quaternary —> interaction between multiple polypeptides
  —> haemoglobin is composed of four polypeptide chains (two alpha and two beta)

Fibrous and Globular proteins:

	Fibrous	Globular
Shape	Long and narrow	Round / spherical
Purpose	Structural	Functional
Acid Sequence	Repetitive amino acid sequence	Irregular amino acid sequence
Durability	Less sensitive to changes in pH, temperature, etc.	More sensitive to changes in pH, temperature, etc.
Examples	Collagen, myosin, fibrin, actin, keratin, elastin	Enzymes, haemoglobin, insulin, immunoglobulin
Solubility	(Generally) insoluble in water	(Generally) soluble in water

Gene —> Polypeptide:

- A gene sequence is converted into a polypeptide sequence via two processes:
- 1 —> Transcription —> making mRNA transcript based on a DNA template
- 2 —> Translation —> using the instructions of the mRNA transcript to link amino acids

Functions:

- Collagen —> gives tensile strength to cells
- Insulin —> pancreas —> triggers a reduction in blood glucose
- Glucagon —> pancreas —> triggers an increase in blood glucose
- Immunoglobulin —> antibodies
- Haemoglobin —> responsible for transport of oxygen
- Rhodopsin —> pigment responsible for the detection of light
- Actin and myosin —> muscle contraction
- Rubisco —> enzyme involved in the light independent stage of photosyntheses

Proteome:

- The totality of proteins expressed within a cell, tissue or organism at a certain time
- Influenced by the genome (genes) and environment
- Unique to every individual

Denaturation:

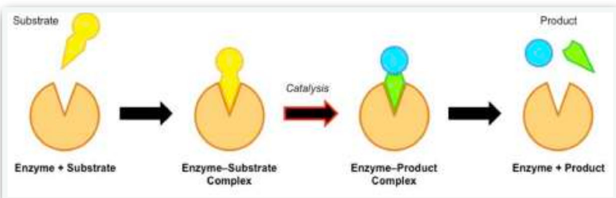
- Irreversible process which causes a structural change in a protein
- Caused usually by heat or pH changes
- Bonds and interactions are disrupted or broken

2.5 Enzymes

- A globular protein that increases the rate of biochemical reaction by lowering the activation energy threshold
- Reactions typically occur in aqueous solutions —> substances moving randomly

Components:

- Substrate —> reactant in biochemical reaction
- Enzyme —> catalyst
- Active site —> region where substrate bind; specific to substrate

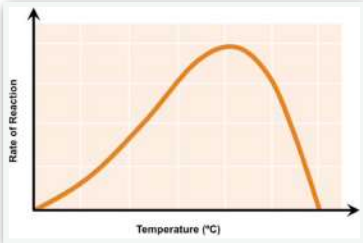


Lock-and-Key + Induced fit models:

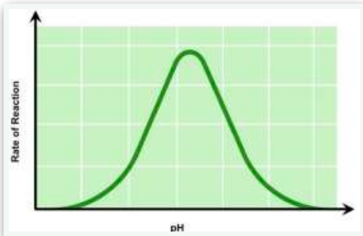
- Lock and key —> Active site matches —> structurally —> 3d structure specific
  —> chemically —> attraction needed
- Induced fit model —> the enzyme's active site is not a completely rigid fit for the substrate
  —> active site will undergo a conformational change (broad specificity)

Enzymatic activity:

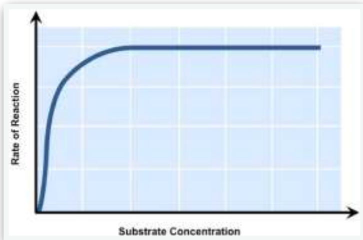
Temperature:
- Higher E_K —> more collisions
- Higher temperature —> higher activity
- Lower temperature —> insufficient thermal energy
- To high temperature —> denaturation



PH:
- Altering pH —> could change shape of molecule
- Different enzymes —> different pH



Substrate concentration:
- Increasing substrate concentration —> more reactions
- Increased chance for substrate to collide with enzymes
- Optimum concentration —> maximum efficiency
- Plateau reached after a certain point



Enzyme immobilisation:

- Concentration can be increased as enzyme not dissolved
- Enzymes can be recycles as easy to separate from mixture
- Enzymes can be removed at precise times
- Enzymes are more stable —> denature less quickly

2.6 Structure of DNA and RNA

Nucleic acids:

- Are the genetic material of the cell and are composed of recurring monomeric units called nucleotides
- Three principal components: —> 5-carbon pentose sugar , phosphate group , nitrogenous bases
- Two types of nucleic acids present in cells —> DNA and RNA
- DNA is more stable and is a double stranded form that stores the genetic blueprint for cells
- RNA is a more versatile single stranded form that transfers the genetic information for decoding

Structure:

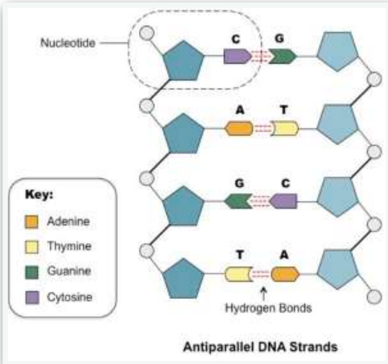
- DNA is a double-helix (two strands) —> antiparallel
- Each strand is made of single units called nucleotides
- Bases join strands by hydrogen bonds
- C pairs with G —> 3 hydrogen bonds

	DNA	RNA
Pentose sugar	Deoxyribose	Ribose
Base Composition	Adenine (A) Guanine (G) Cytosine (C) **Thymine (T)**	Adenine (A) Guanine (G) Cytosine (C) **Uracil (U)**
Number of strands	Double stranded (forms a double helix)	Single stranded

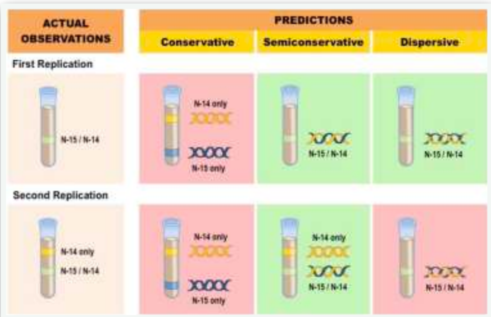
- T pairs with A —> 2 hydrogen bonds
- Uracil replaces thymine in RNA
- Phosphodiester bonds
- The sequence of bases make ups the genetic code
- DNA strands pair via complementary base pairing

Watson and crick:

- building models allowed them to visualise the molecule
- Triple-helix rejected —> so double-helix
- Nitrogenous bases were not initially configure correctly and hence did not demonstrate complementarity
- To allow base pairing strands must be anti-parallel
- Their model also suggested possible mechanisms for replication and that information was encoded in triplets of bases
- Rosalind Franklin —> X-ray crystallography data confirmed the arrangement in a double-helix



2.7 DNA replication, transcription and translation



DNA replication:

-Is a semi-conservative process —> one strand will be from the original template molecule, one strand will be newly synthesised
-Each new strand formed will be identical to the original strand separated from the template
-Meselson-Stahl experiment —> used radioactive isotopes of nitrogen to validate the process

DNA helicase:

- Used to unwind and unzip the DNA (is an enzyme)
- Separates the two strands by breaking the hydrogen bonds
- ATP used helicase
- Two separated strands become parent strands for replication

DNA polymerase:

- Creates complementary strands from the parent strands
- Catalyses the covalent phosphodiester bonds
- Moves in opposite directions on each strand

DNA replication:

- Adenine, Guanine —> Purines
- Thymine, Cytosine —> Pyrimidines
- DNA replication —> semi-conservative process

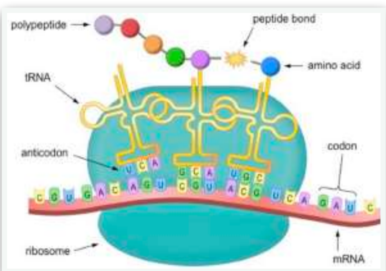
Polymerase Chain Reaction:

- Used to amplify large quantities of a specific sequence of DNA —> over 1 billion copies
- Used to copy a segment of DNA, not whole genome
- For DNA profiling, recombination, species identification, …
- 3 steps —> denaturation —> DNA heated to separate in two strands (90°C)
  —> Annealing —> DNA primers attach to opposite end of strands in cooler temp. (55°C)
  —> Elongation —> sample heated to optimal temp for Taq DNA polymerase (75°C)
- Taq DNA polymerase —> enzyme isolated form the thermophilic bacterium Thermus aquaticus

Transcription and translation:

Transcription:
- Occurs in the nucleus and is the process by which an RNA sequence is produced from a DNA template —> copies gene sequence into mRNA
- RNA polymerase separates the DNA strands and synthesises a complementary RNA copy
- Once the RNA sequence has been synthesised, RNA polymerase detaches from the DNA molecule and the double helix reforms
- Antisense —> the strand that is transcribed (it is complementary to the RNA sequence)
- Sense —> the strand that is not transcribed (is identical to the RNA sequence)

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

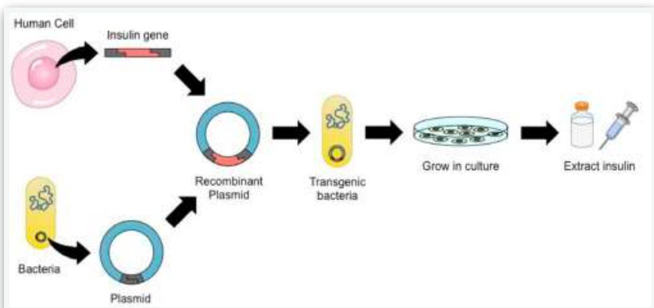


-tRNA —> carries a specific amino acid
-Ribosome —> catalyse the formation of peptide bonds in adjacent amino acids (condensation)
  —> small subunit binds to the mRNA
  —> large subunit binds to the tRNA
  —> protein-making machinery (ribose) —> reads mRNA to translate it in amino acid

The genetic Code:

- The set of rules by which information in the mRNA is converted into proteins by living cells
- Every living organism uses the same code so genetic information is transferable between species
- 1 amino acid per codon (triplet of bases)
- The order of the codons in the mRNA sequence determines the order of amino acids in the chain
- 64 different codon combinations (4^3)
- 20 possible amino acids
- Different codons can translate for the same amino acid —> degenerate
- All amino acids start with AUG and terminate with a stop codon
- Stop codon causes the release of the polypeptide
- tRNA carries the amino acid

Insulin production via Recombinant Gene transfer:



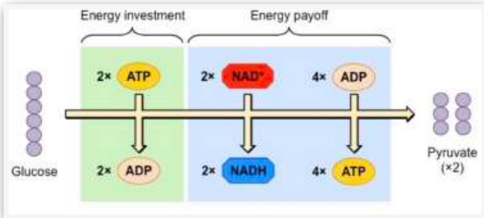
2.8 Cell respiration

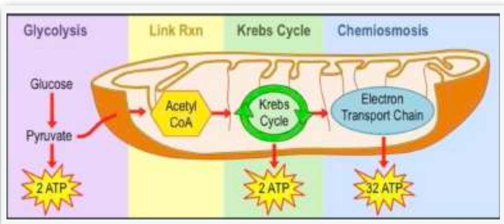
Cell respiration:

- The controlled release of energy from organic compounds to produce ATP
- Anaerobic respiration —> the partial breakdown of glucose in the cytosol for small yield of ATP
- Aerobic respiration —> utilises oxygen to completely break down glucose in the mitochondria for a larger ATP Yield
- ATP —> one molecule of ATP contains three covalently linked phosphate groups

Anaerobic respiration:

- Proceeds in the absence of oxygen and does not result in the production of any further ATP mol.
- Pyruvate —> in animals —> converted into lactic acid
  —> in plants converted in ethanol or CO_2
- Muscle contraction requires the expenditure of high amounts of energy and thus requires high levels of ATP, so the body will break down glucose anaerobically



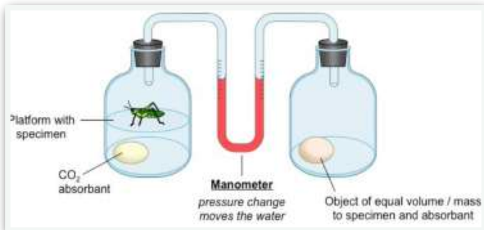


Aerobic respiration:

-Requires the presence of oxygen and takes place in the mitochondrion
-Pyruvate is broken down into carbon dioxide and water —> large amount of ATP (34 / 36 mole.)
-Link reaction, citric acid cycle and electron transport chain

Respirometer:

- Device that determines an organism's respiration rate measuring the exchange of O_2 and CO_2
- Factors which may affect reparation rates are temperature, hydration, light, age and activity level



2.9 Photosynthesis

Equation:

$$6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

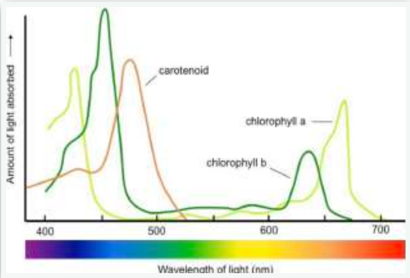
Carbon dioxide + Water → Glucose + Oxygen + Water

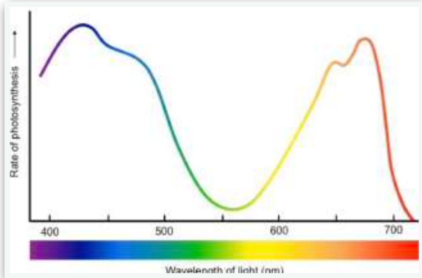
- The reverse of cell respiration
- The process by which cells synthesise organic compounds from inorganic molecules with light
- Photosynthetic organisms use light energy to create ATP —> used by the organism or to synthesise organic compounds such as starch and cellulose
- Photolysis —> the splitting of water molecules

Chlorophyll:

- A green pigment found in photosynthetic organisms that is responsible for light absorption
- Absorbs light most strongly in the blue portion and then in the red portion, while reflect green

- Absorption spectrum —> indicates the wavelengths of light absorbed by each pigment
- Action spectrum —> the overall rate of photosynthesis x wavelength of light





Photosynthetic reactions:

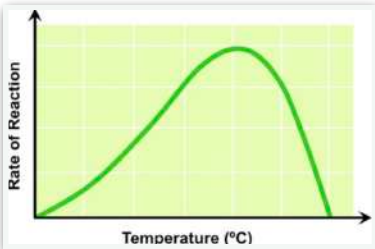
- Light dependent reactions —> convert light energy from the sun into chemical energy (ATP)
- Light independent reactions —> use the chemical energy to synthesise organic compounds

Chromatographs:

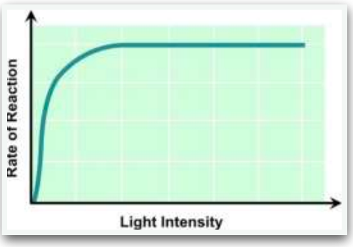
- An experimental technique by which mixtures can be separated
- Paper chromatography —> uses paper (cellulose) as the stationary bed
- Thin layer chromatography —> thin layer of adsorbent which runs faster and separates better

Limiting Factors:

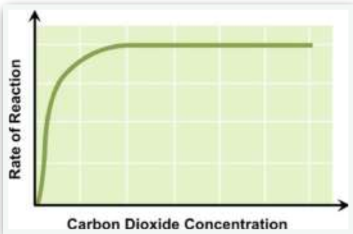
Temperature:
- Photosynthesis is controlled by enzymes which are sensitive to temperature fluctuations
- Above a certain temperature the rate of photosynthesis decreases as enzymes begin to denature



Light intensity:



CO_2 concentration:



Measuring:

- CO_2 uptake —> measured as an increase in surrounding pH
- Oxygen production —> submerging the plant and counting bubbles
- Glucose production —> change in plant's dry biomass
- Starch —> staining with iodine solution and using a colorimeter

Extra:

Types of bonding:

- Intramolecular bonds —> Atoms may join together by gaining and losing electrons
  —> Ionic bonds —> occur between metals and non-metals
  —> creates a strong electrostatic attraction between the two
  —> Covalent bonds —> occurs between two non-metals
  —> carbon can form four covalent bonds as 4 missing electrons
  —> weaker bonds compared to ionic bonds
- Intermolecular bonds —> Atoms from one molecule may attract atoms from another molecule
  —> these bonds are much weaker than intramolecular bonds
  —> hydrogen bonds are a very common type

Calcium	Important for bones and teeth Involved in synaptic transfer
Iron	Found in red blood cells Involved in oxygen transport
Sodium	Involved in impulse generation in the nervous system
Phosphorus	Found in nucleic acids and phospholipids (membranes)
Sulphur	Found in certain amino acids Important for disulphide bonds

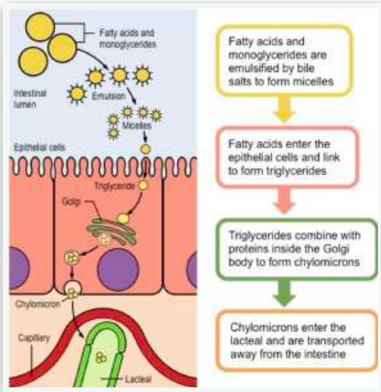
Trace elements:

-Chemical elements required by living things other than carbon, hydrogen, oxygen and nitrogen

Functions of lipids:

- Storage of energy
- Hormonal roles
- Insulation
- Protection
- Structural components of cells

Lipid absorp. and transport:

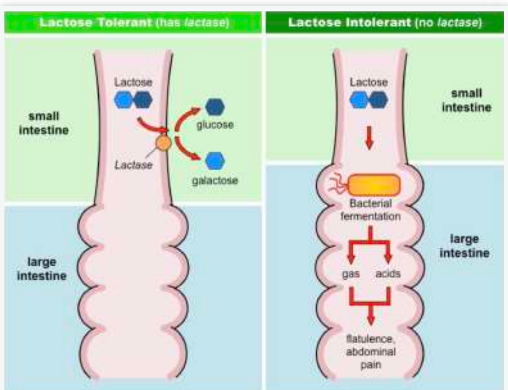


pH scale (power of Hydrogen):

Types of enzymes:

Enzyme Class	Reaction Catalyzed	Example
Hydrolase	Hydrolysis (catabolic)	Lipase, protease
Isomerase	Rearrangement of atoms within a molecule	Phosphohexoisomerase
Lyase	Splitting chemicals into smaller parts without using water (catabolic)	Decarboxylases, aldolases
Oxidoreductase	Transfers electrons or hydrogen atoms from one molecule to another	Dehydrogenases, oxidases
Synthetases	Joining of two molecules by the formation of new bonds (anabolic)	DNA ligase, DNA polymerase
Transferase	Moving a functional group from one molecule to another	Kinases, transaminase

Lactose intolerance:



Central Dogma:

-Explains the flow of genetic information within a cell —> DNA codes for RNA via the process of transcription (occurs within the nucleus) —> RNA codes for protein via the process of translation (occurs at the ribosomes)
-This flow was considered uni-directional until 1970 when it was discovered that retroviruses could copy DNA from an

RNA sequence —> possess an enzyme (*reverse transcriptase*) that allows for reverse transcription to occur
- Reverse transcription is now used in scientific studies to establish gene expression profiles

Degeneracy:

- More than one codon may code for a single amino acid
- Possible because the genetic code has 20 amino acids but has 64 different codon combinations

Point mutations:

- Point mutations are changes to one base in the DNA code and may involve either:

- The substitution of a base (e.g. A**T**G becomes A**C**G)
- The insertion of a base (e.g. ATG becomes AT**C**G)
- The deletion of a base (e.g. A**T**G becomes AG)
- The inversion of bases (e.g. A**TG** becomes A**GT**)

- Base substitutions may create either silent, missense or nonsense mutations, while insertions and deletions cause frameshift mutations

Uses of ATP:

- **B**iosynthesis of macromolecules (e.g. polymer assembly)
- **A**ctive transport (e.g. endocytosis / exocytosis)
- **N**erve transmission
- **G**rowth and repair (e.g. mitotic division)
- **M**ovement (e.g. muscle contraction)
- **E**mission of light (e.g. bioluminescence)

Aerobic vs Anaerobic:

	Anaerobic	Aerobic
Reactants	Glucose	Glucose **and** oxygen
Combustion	Incomplete	Complete
Energy Yield	Low (2 ATP)	High (36 – 38 ATP)
Products	**Animals:** Lactic acid **Yeast:** Ethanol + CO_2	CO_2 and H_2O
Location	Cytoplasm	Cytoplasm **and** mitochondrion
Stages	Glycolysis Fermentation	Glycolysis Link reaction Krebs cycle Electron transport chain