Topic 2: Molecular Biology

2.1 Molecules to metabolism

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

Molecular biology is the chemistry of living organisms

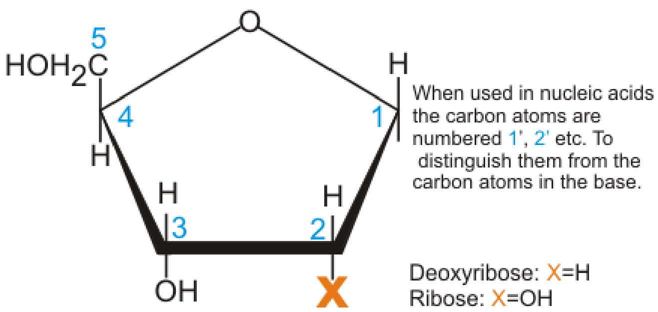
- “DNA makes RNA makes protein”.
- The information in this flow cannot be reversed and the protein generated cannot change the RNA or DNA
- There are many molecules important to living organisms including <u>water, carbohydrates, lipids, proteins and nucleic acids</u>
- Proteins are one of the most varied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

Carbon-based life

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

Carbohydrates

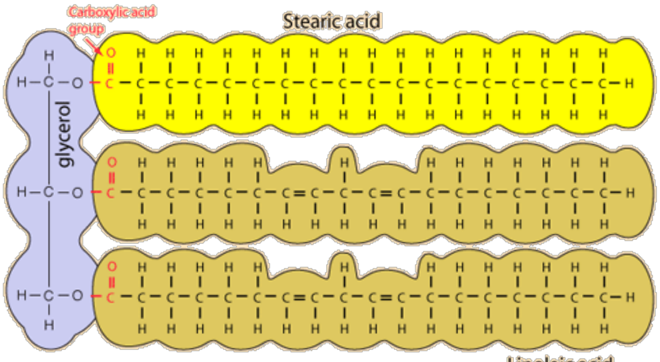
- Contain **carbon, hydrogen and oxygen**
- Organic compounds consisting of **one or more simple sugars**
- Monomers follow the general basic formula of **$(CH_2O)_n$**
- Monomers are commonly **ring shaped** molecules
- Many carbohydrates are used for <u>energy or structural purposes</u>
- Carbohydrates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



Deoxyribose & Ribose Sugars

Lipids

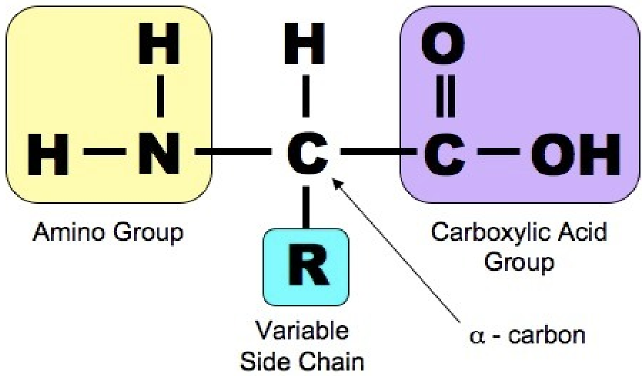
- Lipids are a **group of organic molecules** that are **<u>insoluble</u>** in **water** but **<u>soluble</u>** in **non-polar** organic solvents
- Common lipids include triglycerides (fats – solid at room temperature and oils – liquid at room temperature), phospholipids and steroids
- Some lipids function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



A lipid (a triglyceride)

Protein

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



Nucleic acid

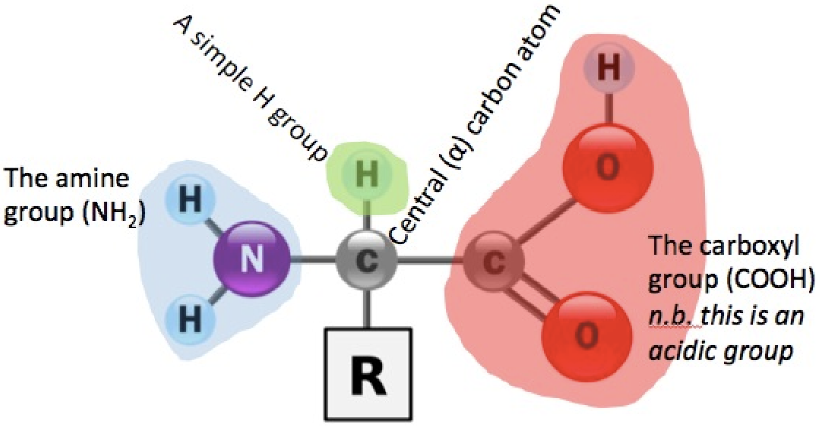
- Contain **carbon, hydrogen, oxygen, nitrogen and <u>phosphorus</u>**
- Chains of sub-units called **nucleotides**
- Nucleotides consist of **base, sugar and phosphate groups** covalently bonded together
- The bases of DNA are **A**denine, **T**hymine, **C**ytosine, and **G**uanine; In RNA, **U**racil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

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

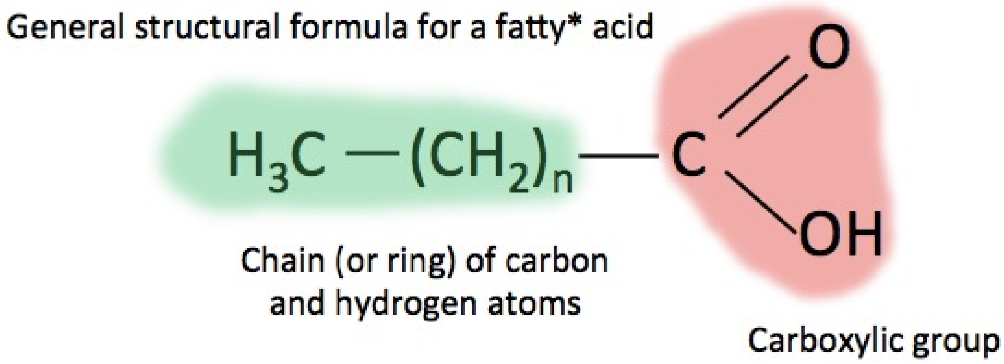
Identification of biochemical

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

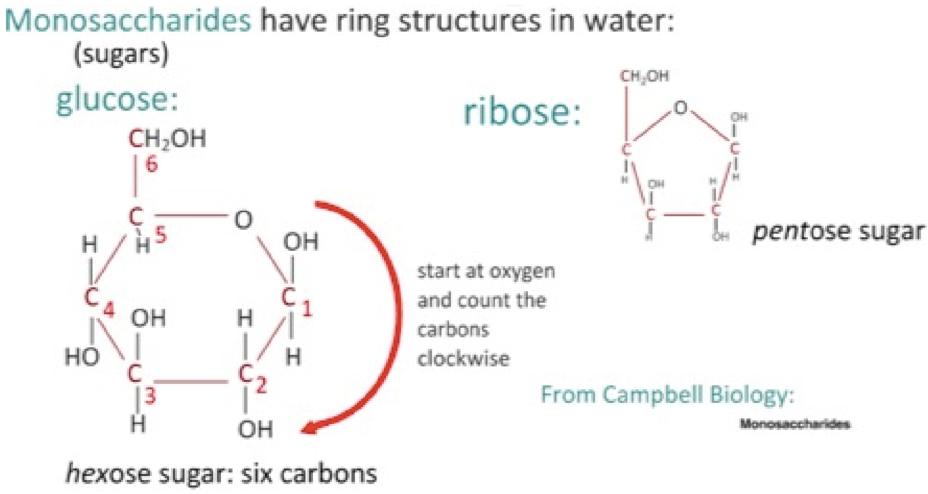
- **Amino acids**



- **Fatty acid**



- **Glucose**



Metabolism

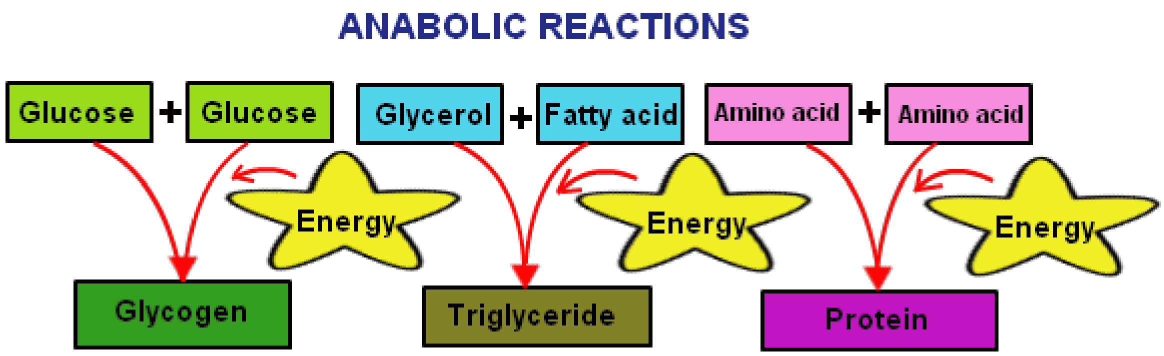
- Metabolism is the set of life-sustaining chemical reactions within the cells of living organisms.
- These reactions are catalyzed by enzymes and allow organisms to grow and reproduce, maintain their structures, and respond to their environments.
- Many of these reactions occur in the cytoplasm, but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

Anabolism & catabolism

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

Definition of anabolism

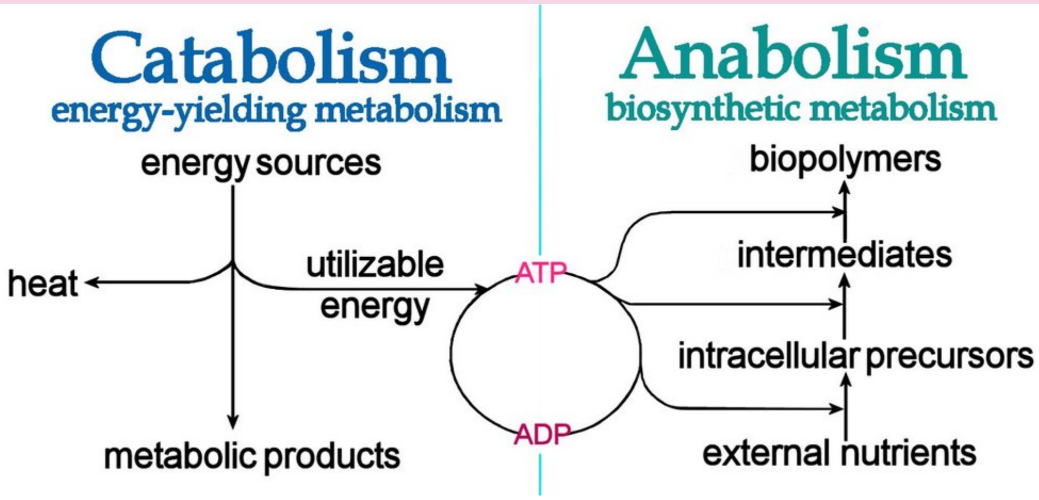
Anabolism is the synthesis of complex molecules from simpler molecules including the formation of macromolecules from monomers by condensation reactions.



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

Definition of catabolism

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



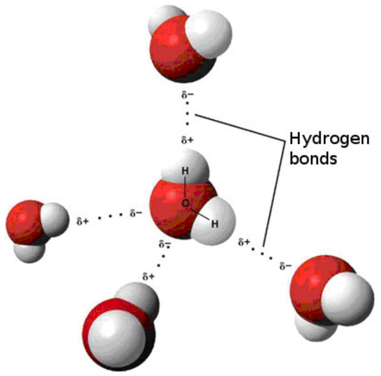
- **Condensation** makes bond, release water, take in heat, as an anabolism reaction, which is **endothermic**
- **Hydrolysis** breaks bond, give out heat, as a catabolism reaction, which is **exothermic**

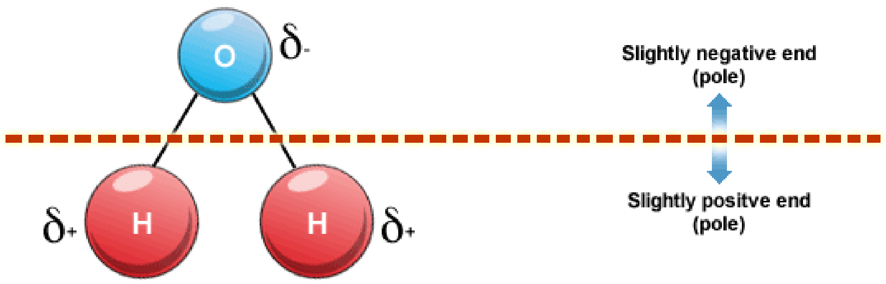
2.2 Water

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

The structure of water molecules

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





Cohesive properties

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

Definition of cohesion

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

Adhesive properties

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

Definition of adhesion

Any attraction between two unlike molecules is called adhesion.

Thermal properties

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

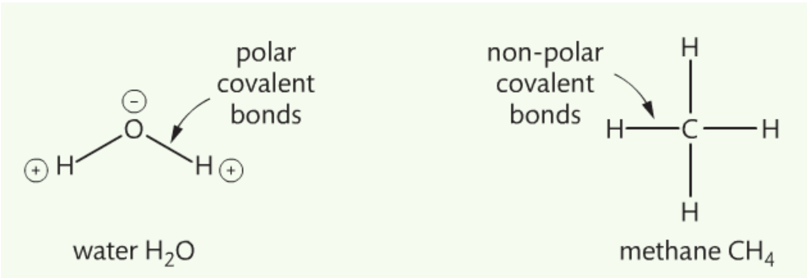
Solvent properties

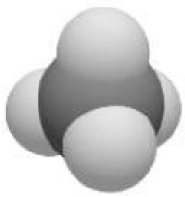
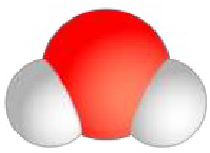
- Water is known as the "universal solvent" because of its ability to dissolve many substances because of its polarity.
- Water is able to dissolve other **polar molecules** such as many carbohydrates, proteins and DNA; and positively and negatively charged ions such as Na^+.
- This is essential because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

Hydrophilic & hydrophobic

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

Comparison of the thermal properties of water with those of methane



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

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

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

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

Polarity of different molecules

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

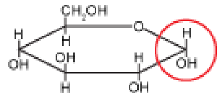
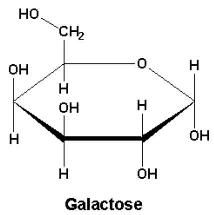
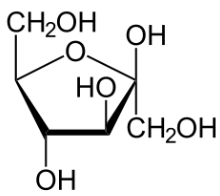
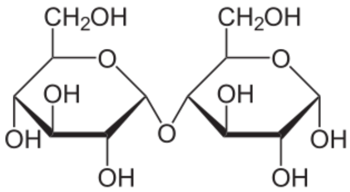
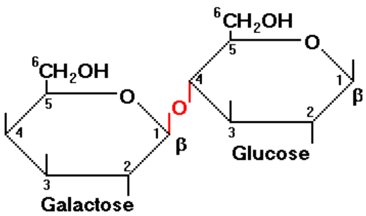
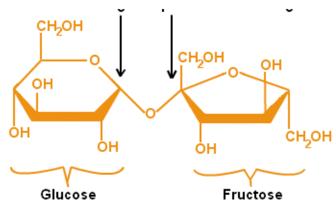
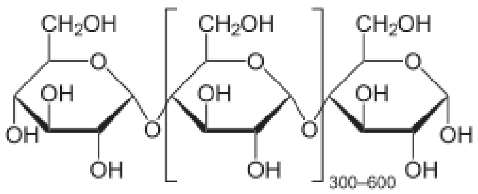
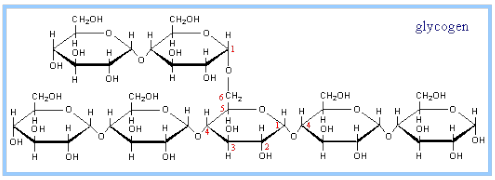
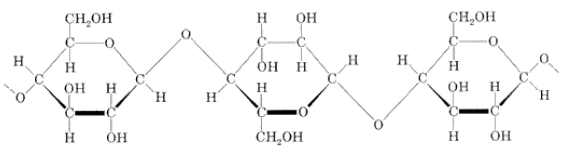
Water used as a coolant

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

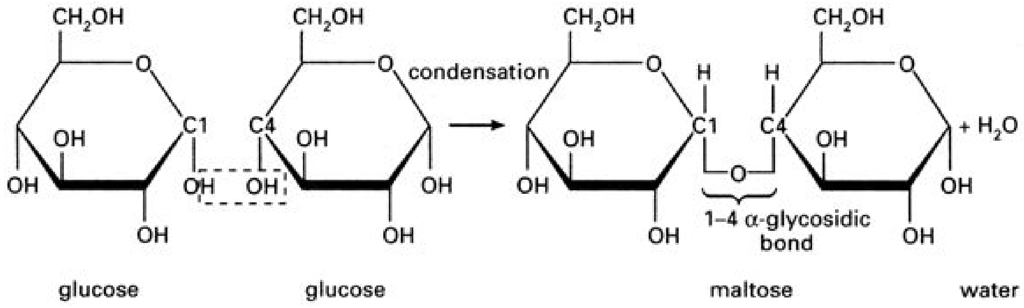
2.3 Carbohydrates and lipids

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

Monosaccharide: the building blocks of polysaccharides

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

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

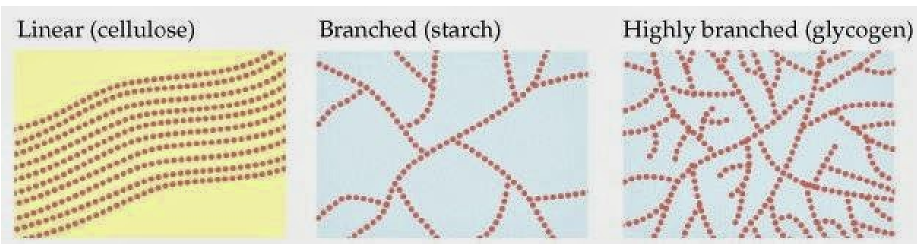


- When a plant or an animal needs to use energy stored in polysaccharide molecules, the opposite reaction to condensation takes place. This break down of larger polysaccharides into smaller monosaccharides through the addition of water is called hydrolysis (water split or separate).
- Starch and glycogen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

Structure of cellulose, starch and glycogen

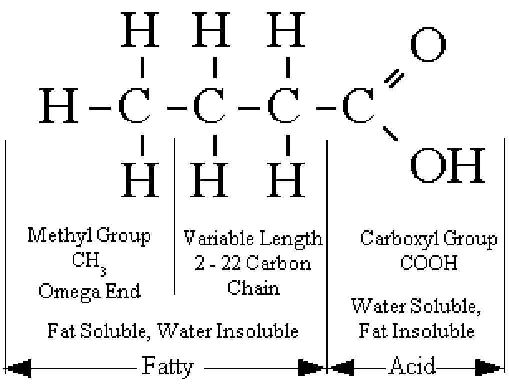
- Polysaccharides are long chains of monosaccharides held together with glycosidic linkages made by condensation reactions
- Starch, cellulose and glycogen are all polysaccharides that are made from long chains of glucose; however, they differ in their structure and the type of glucose, which leads to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

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



Fatty acid

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



Saturated fatty acid

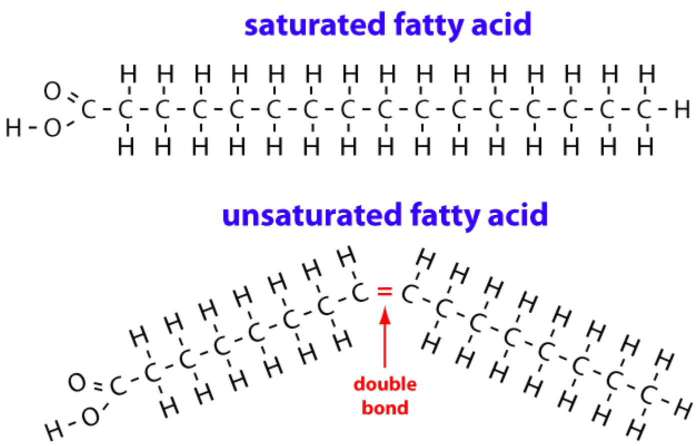
- Saturated fatty acid are called that because the carbons are carrying as many hydrogen atoms as they can, in other words they are saturated with hydrogen atoms.
- Found in animals products like butter, bacon and red meat
- Solid at room T
- No double bonds between the carbon atoms

Monounsaturated fatty acid

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

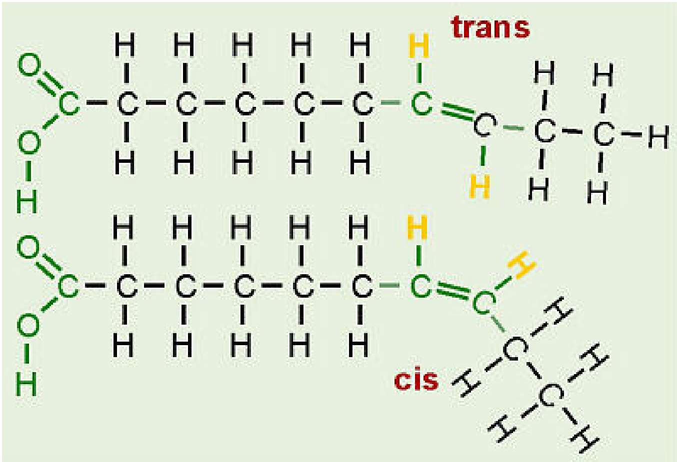
Polyunsaturated fatty acids

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



Hydrogenation: cis and trans fatty acids

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

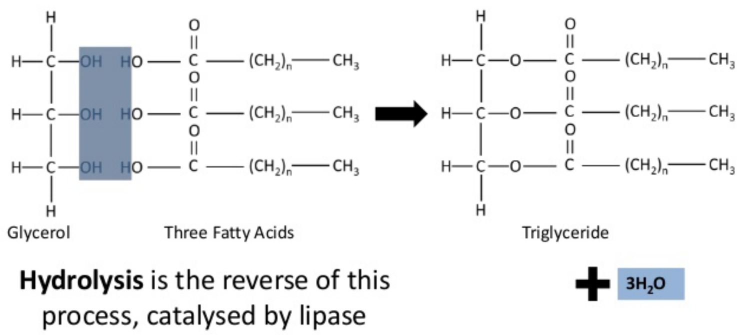


Properties	Cis Fatty acids	Trans Fatty acids
Health implications	Good	Detrimental; lowers good cholesterol and increases the level of bad cholesterol in the body.
Natural occurrence	Yes	Very less, hence produced artificially by partial hydrogenation of polyunsaturated fatty acids.
Orientation at double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

Condensation reactions result in the formation of triglyceride lipids

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

Condensation reaction between glycerol and fatty acids



Energy storage

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

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

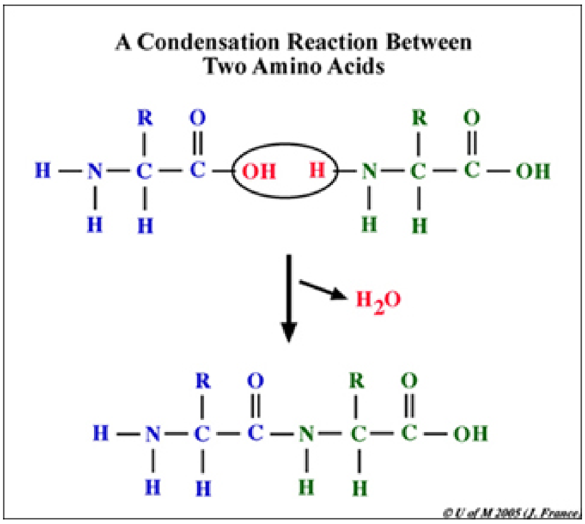
Glycogen	Lipids
Storage in liver	Storage in adipose cell
Can be transport by blood	Cannot be transported by blood
Easy to break down	More difficult to break down
Used in both anaerobic and aerobic respiration	Used only in aerobic respiration
Store less energy	Store 2 times more energy
High energy to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

2.4 Proteins

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

Formation of polypeptides

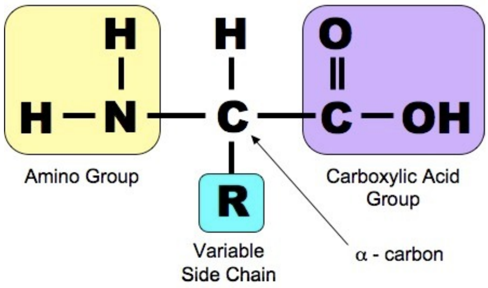
- Cells use the naturally occurring **<u>20</u>**amino acids to synthesize polypeptides.
- When polypeptides are **synthesized at ribosomes** under the control of genes, the reaction is a **condensation reaction**



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

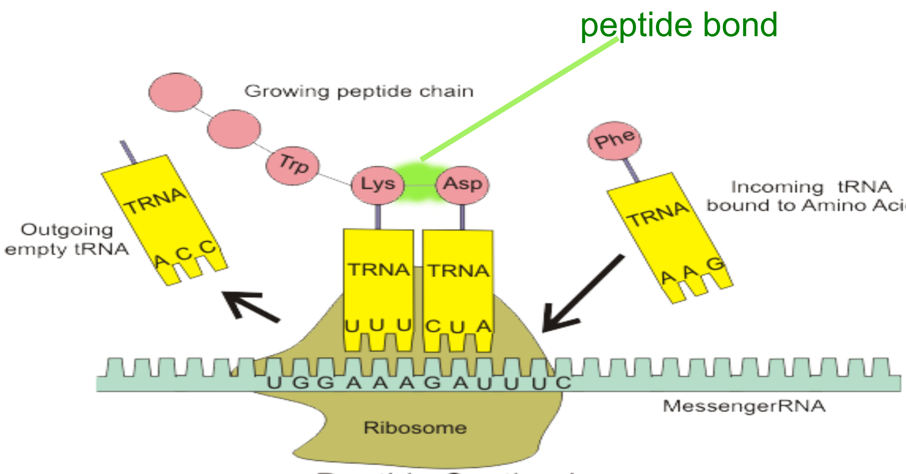
Amino acids

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



The amino acid sequence of polypeptides is coded for by genes

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



Peptide Synthesis

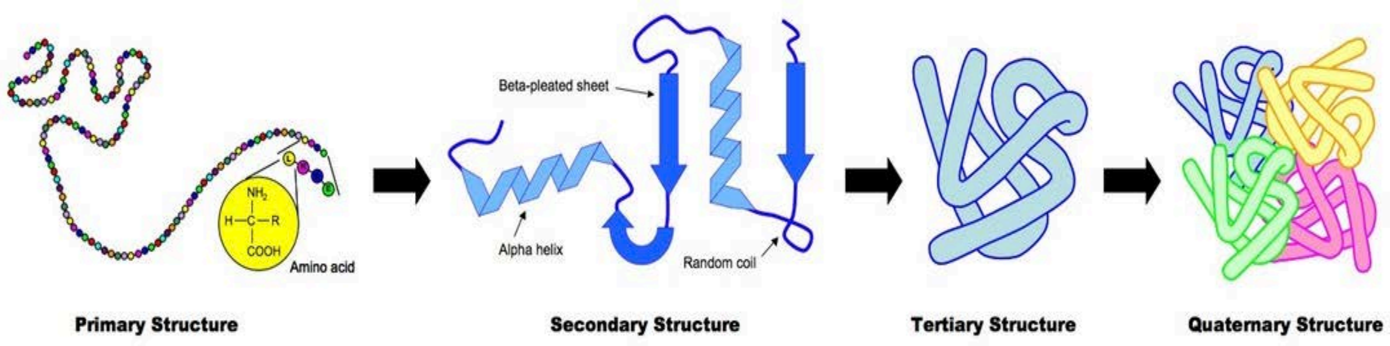
- Genes are simply **codes for making polypeptides**
- **Messenger RNA** is a message from the nucleus to the ribosome-instructions for how to put the polypeptide together.
- The **genetic code** is the **sequence of bases on mRNA**-this tells the ribosome which **amino acids** to use
- The sequence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

Three-dimensional conformation of a protein

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

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

Four levels of protein structure



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

Functions of proteins

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

Protein example

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

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

Versatility of proteins

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

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

Every individual has a unique proteome

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

Definition of Genome

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

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

Definition of proteome

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

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

Denaturation of proteins

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

2.5 Enzymes

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

Definitions

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

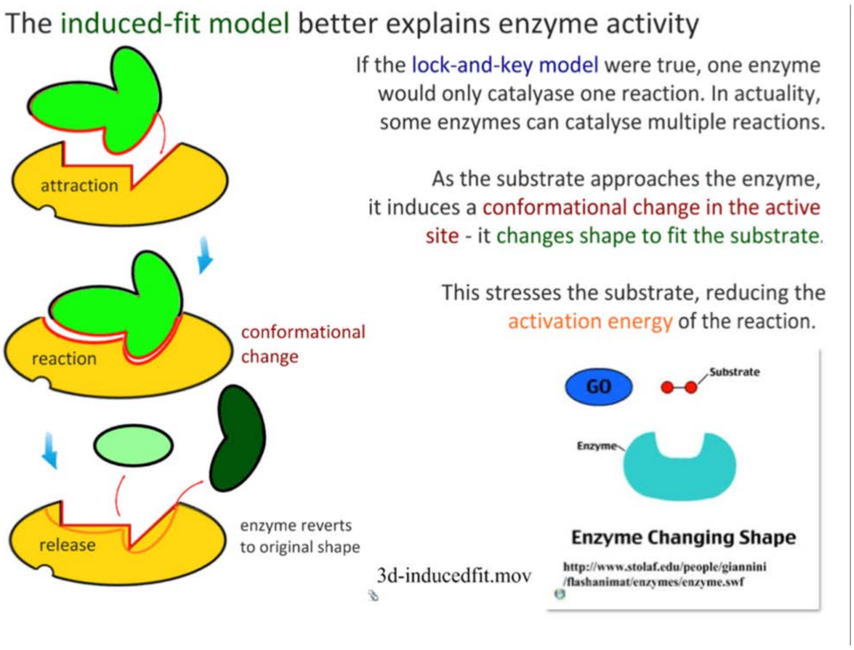
Active Site: The region on an enzyme's surface to which the substrate binds and which catalyses the reaction.

Substrate: Reactant in a biochemical reaction.

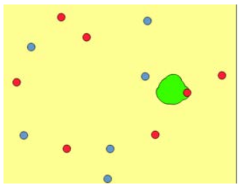
Denaturation: A structural change in a protein that results in a loss of biological properties.

Active site

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



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



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

Denaturation of proteins

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

Explain the effect of certain factors on enzyme activity

Temperature:

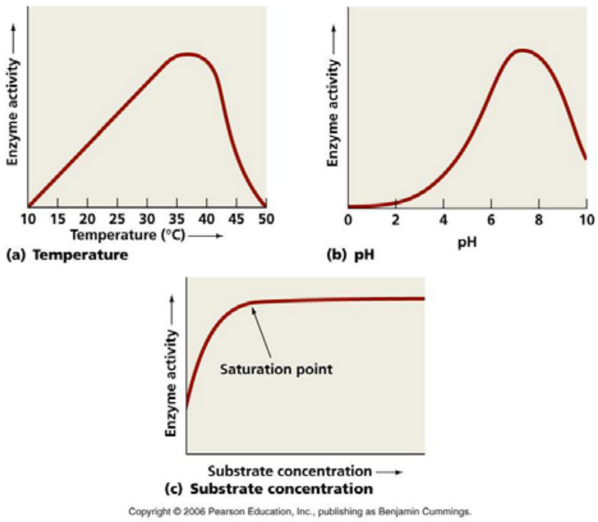
- Increasing temperature increases the kinetic energy of enzyme and substrate, leading to more frequent collisions and a higher rate of activity.
- At a certain temperature an optimum rate of reaction is achieved.
- Above this temperature the enzyme starts to denature and the rate of activitydecreases.

pH:

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

Substrate Concentration:

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



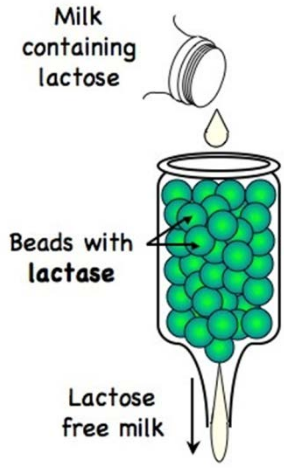
Immobilized enzymes are widely used in industry.

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

Reasons for using enzymes:

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

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

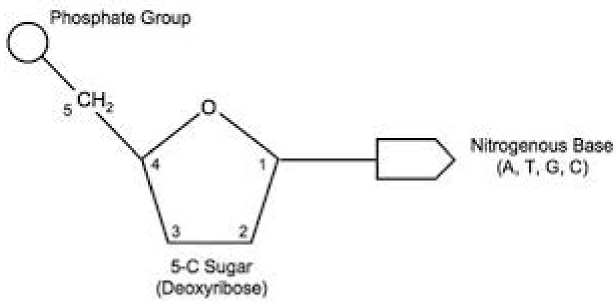


- Lactose is a disaccharide sugar present in milk composed of monosaccharides glucose and galactose.
- Lactase is the enzyme that breaks down lactose into its two monosaccharides.
- Humans are born with the ability to digest milk (lactase produced) but as we grow older, most humans lose the ability to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

2.6 Structure of DNA and RNA

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

Nucleotides are the building blocks of nucleic acids

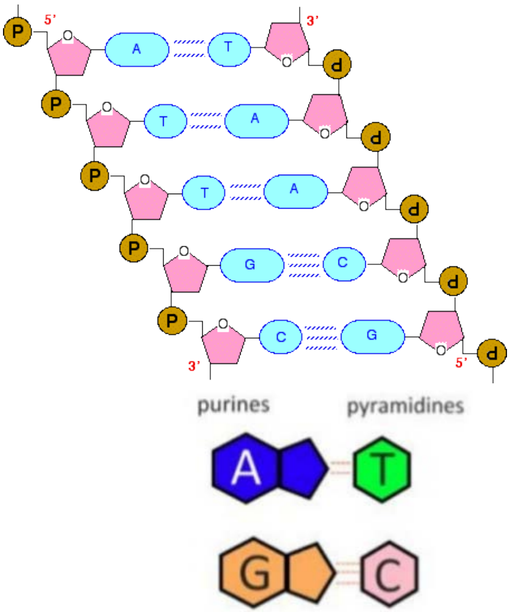


- Nucleic acids are one of the major carbon-based groups. There are three major examples of nucleic acids in nature: ATP, DNA and RNA.
- Both DNA and RNA are polymers of nucleotides. Individual nucleotides are referred to as monomers and always consist of three major parts: one phosphate group, one 5-carbon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

Difference between RNA and DNA

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

Explain how DNA nucleotides form a double helix



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

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

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

2.7 DNA replication, transcription, and translation

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

Replication of DNA

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

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

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

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

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

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

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

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

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

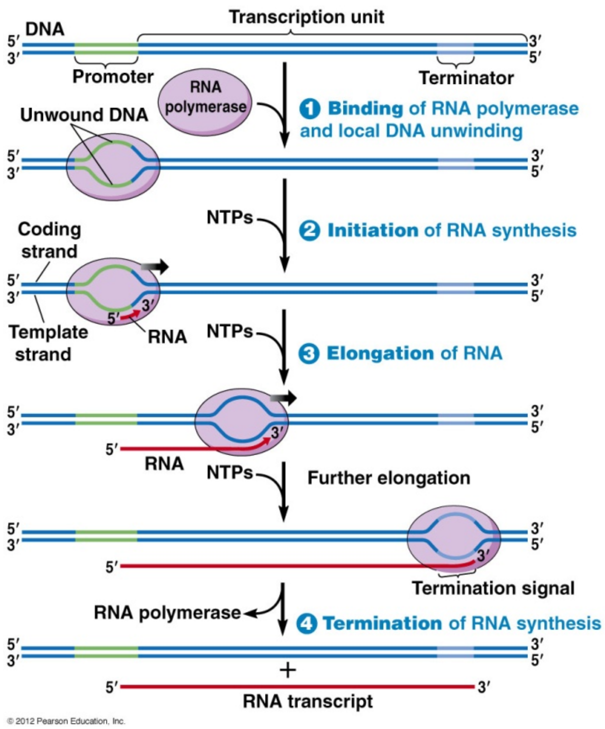
- Denaturation: DNA sample is heated to separate it into tow strands.
- Annealing: DNA primers attach to opposite ends of the target sequence.
- Elongation: A heat-tolerant DNA polymerase (Taq) copies the strands.
- One PCR cycle yields two strand of new DNA

Transcription

Definitions

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

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



Three main types of RNA are predominantly synthesised:

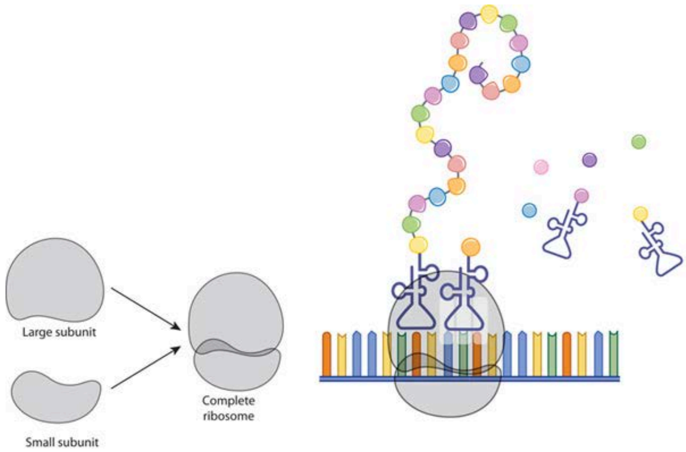
- Messenger RNA (mRNA): A transcript copy of a gene used to encode a polypeptide
- Transfer RNA (tRNA): A clover leaf shaped sequence that carries an amino acid
- Ribosomal RNA (rRNA): A primary component of ribosomes

Translation is the synthesis of polypeptides on ribosomes.

Definitions

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

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



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

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

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

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

Second letter

First letter	U	C	A	G	Third letter
U	UUU Phe	UCU Ser	UAU Tyr	UGU Cys	U
U	UUC Phe	UCC Ser	UAC Tyr	UGC Cys	C
U	UUA Leu	UCA Ser	UAA STOP	UGA STOP	A
U	UUG Leu	UCG Ser	UAG STOP	UGG Trp	G
C	CUU Leu	CCU Pro	CAU His	CGU Arg	U
C	CUC Leu	CCC Pro	CAC His	CGC Arg	C
C	CUA Leu	CCA Pro	CAA Gln	CGA Arg	A
C	CUG Leu	CCG Pro	CAG Gln	CGG Arg	G
A	AUU Ile	ACU Thr	AAU Asn	AGU Ser	U
A	AUC Ile	ACC Thr	AAC Asn	AGC Ser	C
A	AUA Ile	ACA Thr	AAA Lys	AGA Arg	A
A	AUG Met	ACG Thr	AAG Lys	AGG Arg	G
G	GUU Val	GCU Ala	GAU Asp	GGT Gly	U
G	GUC Val	GCC Ala	GAC Asp	GGC Gly	C
G	GUA Val	GCA Ala	GAA Glu	GGA Gly	A
G	GUG Val	GCG Ala	GAG Glu	GGG Gly	G

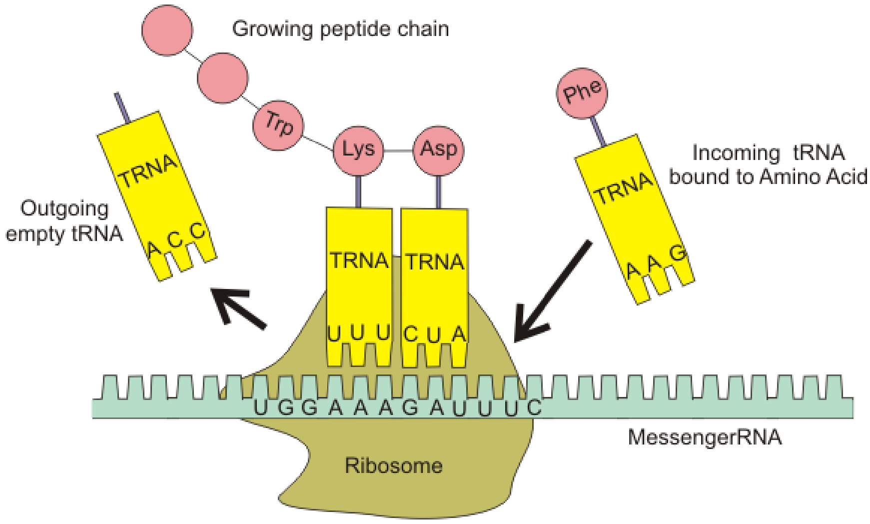
Key:

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

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

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

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



Peptide Synthesis

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

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

2.8 Cell respiration

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

Reasons for cell respiration

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

Anaerobic respiration

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

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

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

Aerobic respiration

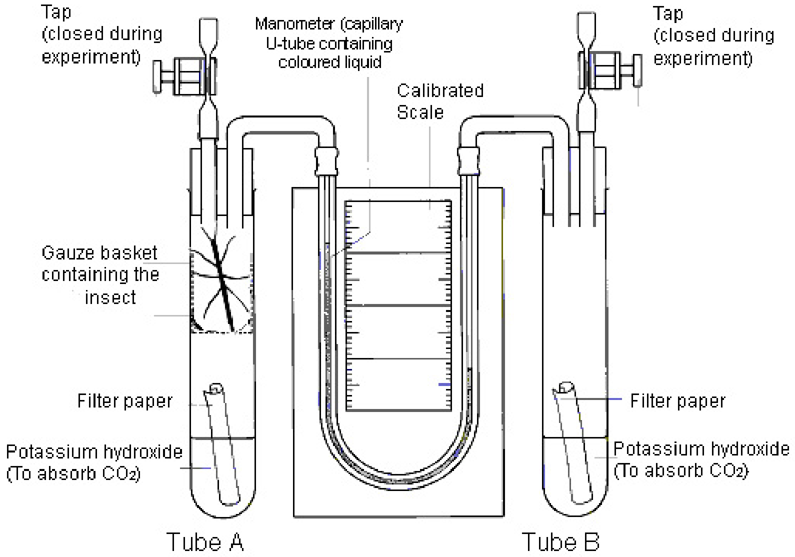
- Aerobic respiration also begins with glycolysis which produces 2 pyruvate molecules per glucose.
- Aerobic respiration occurs in the mitochondria.
- Aerobic respiration is much more efficient than anaerobic respiration as the glucose molecule is fully oxidized.
- The products created in the redox reactions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

Summary

Net ATP Gain for anaerobic respiration: 2

Net ATP Gain for anaerobic respiration: 36

The Respirometer



2.9 Photosynthesis

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

Production of carbon compounds

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

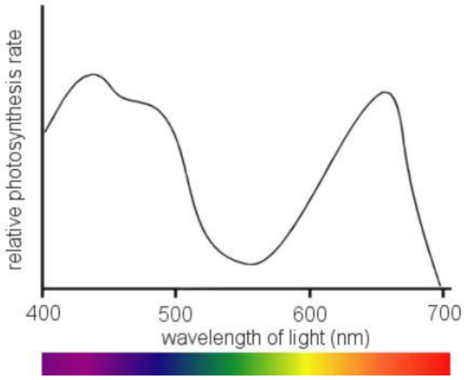
Light frequency

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

Action spectrum

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

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



Limiting factor of photosynthesis

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

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