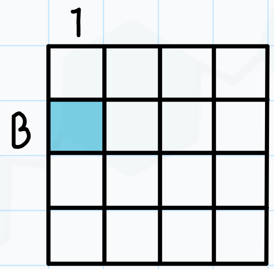
B1.1 CARBOHYDRATES AND LIPIDS

Guiding Questions
In what ways do variations in form allow diversity of function in carbohydrates and lipids?
How do carbohydrates and lipids compare as energy storage compounds?

Linking Questions
How can compounds synthesized by living organisms accumulate and become carbon sinks?
What are the roles of oxidation and reduction in biological systems?



Theme: Form and Function

Level of Organization: Molecules

Written and drawn by:

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SL LEARNING OUTCOMES

B1.1.1	Chemical properties of a carbon atom allowing for the formation of diverse compounds upon which life is based	Students should understand the nature of a covalent bond. Students should also understand that a carbon atom can form up to four single bonds or a combination of single and double bonds with other carbon atoms or atoms of other non-metallic elements. Include among the diversity of carbon compounds examples of molecules with branched or unbranched chains and single or multiple rings. **NOS:** Students should understand that scientific conventions are based on international agreement (SI metric unit prefixes "kilo", "centi", "milli", "micro" and "nano").
B1.1.2	Production of macromolecules by condensation reactions that link monomers to form a polymer	Students should be familiar with examples of polysaccharides, polypeptides and nucleic acids.
B1.1.3	Digestion of polymers into monomers by hydrolysis reactions	Water molecules are split to provide the -H and -OH groups that are incorporated to produce monomers, hence the name of this type of reaction.
B1.1.4	Form and function of monosaccharides	Students should be able to recognize pentoses and hexoses as monosaccharides from molecular diagrams showing them in the ring forms. Use glucose as an example of the link between the properties of a monosaccharide and how it is used, emphasizing solubility, transportability, chemical stability and the yield of energy from oxidation as properties.
B1.1.5	Polysaccharides as energy storage compounds	Include the compact nature of starch in plants and glycogen in animals due to coiling and branching during polymerization, the relative insolubility of these compounds due to large molecular size and the relative ease of adding or removing alpha-glucose monomers by condensation and hydrolysis to build or mobilize energy stores.
B1.1.6	Structure of cellulose related to its function as a structural polysaccharide in plants	Include the alternating orientation of beta-glucose monomers, giving straight chains that can be grouped in bundles and cross-linked with hydrogen bonds.
B1.1.7	Role of glycoproteins in cell–cell recognition	Include ABO antigens as an example.
B1.1.8	Hydrophobic properties of lipids	Lipids are substances in living organisms that dissolve in non-polar solvents but are only sparingly soluble in aqueous solvents. Lipids include fats, oils, waxes and steroids.
B1.1.9	Formation of triglycerides and phospholipids by condensation reactions	One glycerol molecule can link three fatty acid molecules or two fatty acid molecules and one phosphate group.
B1.1.10	Difference between saturated, monounsaturated and polyunsaturated fatty acids	Include the number of double carbon (C=C) bonds and how this affects melting point. Relate this to the prevalence of different types of fatty acids in oils and fats used for energy storage in plants and endotherms respectively.
B1.1.11	Triglycerides in adipose tissues for energy storage and thermal insulation	Students should understand that the properties of triglycerides make them suited to long-term energy storage functions. Students should be able to relate the use of triglycerides as thermal insulators to body temperature and habitat.
B1.1.12	Formation of phospholipid bilayers as a consequence of the hydrophobic and hydrophilic regions	Students should use and understand the term "amphipathic".
B1.1.13	Ability of non-polar steroids to pass through the phospholipid bilayer	Include oestradiol and testosterone as examples. Students should be able to identify compounds as steroids from molecular diagrams.

B1.1.1—Chemical properties of a carbon atom allowing for the formation of diverse compounds upon which life is based.

Biomolecules: molecules found in living organisms which are essential to living processes

All biomolecules contains the element carbon, this is why life is said to be "carb-based"

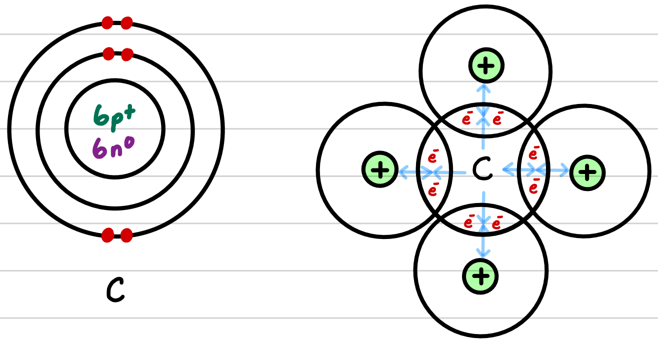
↳ what chemical properties allows carbon to form such a large variety of compounds necessary for life?

Chemistry review

↳ Atoms are most stable when their outer (valence) shell is complete or full. They can achieve this through bonding with other atoms by either transferring (ionic) or sharing (covalent) electrons

↳ The first shell can hold 2, second 8 and third 8. Carbon has 4 so readily shares these to get 8

- Carbon has 4 valence electrons, allowing it to form 4 **covalent bonds** with other atoms

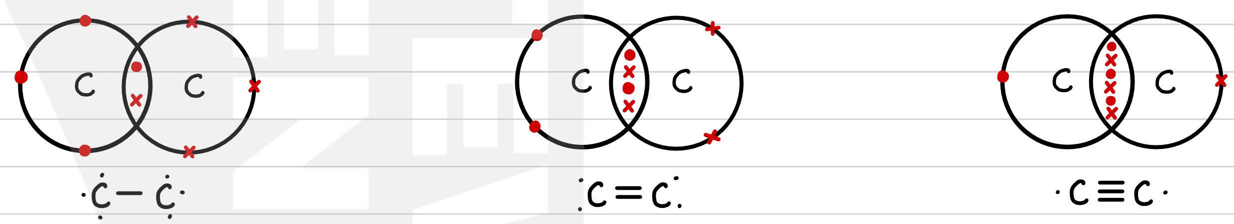


↳ electrostatic attraction between positive nuclei and a shared pair of negative electrons

↳ covalent bonds are the strongest type of bonds thus require a lot of energy to break – leading to stable compounds

- Carbon can share 1, 2, or 3 pairs of electrons with another atom forming:

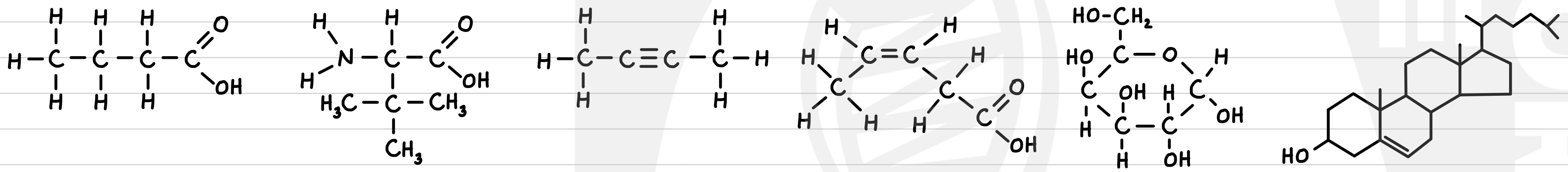
↳ single covalent bond ↳ double covalent bond ↳ triple covalent bond



- Carbon forms many molecular shapes:

↳ unbranched chains ↳ branched chains ↳ linear chains ↳ bent chains ↳ single rings ↳ multi-ringed

ex:



saturated fatty acid, valine amino acid, butyne, unsaturated fatty acid, glucose, cholesterol

- Carbon can form covalent bonds with other carbons and non-metal atoms, providing much diversity

↳ such as: Oxygen, Hydrogen, Nitrogen, Phosphorus, Sulfur

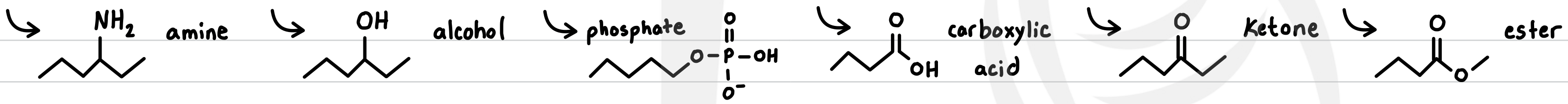
※ **organic molecule**: must contain carbon and hydrogen

ex: C_2H_5OH (ethanol), CH_4 (methane) are organic

CO_2 (carbon dioxide), NH_3 (ammonia) are inorganic

- carbon-based molecules can be short (1 carbon) or very long with no real limit (some containing thousands of carbons)

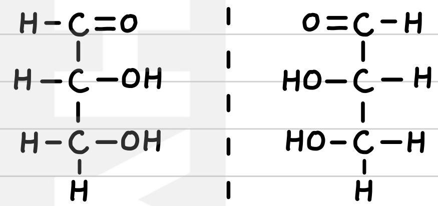
- many biomolecules have functional groups attached to a carbon skeleton. These groups have different properties and react differently



based on functional groups, carbon compounds can be organised into homologous series which have similar properties

- When there are different groups around a carbon, they can be arranged in different, mirrored orientations, each having different biological interactions

ex:



↳ called optical isomers and are named D and L

NOS: In all science disciplines unit conventions are based on international agreement → **International System of Units** (SI)

↳ this allows international collaboration and facilitates replicability and comparability of experiments and data

↳ 2 types of quantities: fundamental – independent of other variables ex: m, s, kg, K, mol, A, cd

derived – dependent on other variables ex: °C, kgm^{-3}, ms^{-2}, N, ω, V, Pa, Hz, V

← multiply (value gets larger)

divide (value gets smaller) →

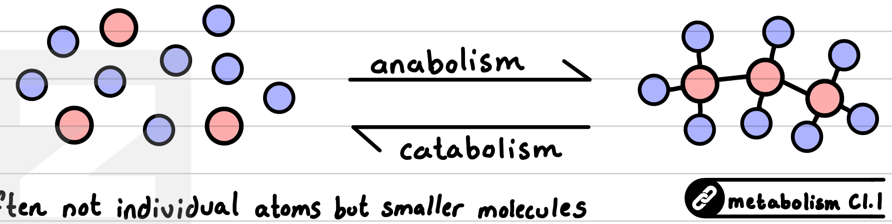
sci notation	10^{-9}	10^{-6}	10^{-3}	10^{-2}	10^{3}	10^{6}
SI prefixes	nano	micro	milli	centi	Kilo	mega
symbol	n	μ	m	c	k	M

ex conversion: 0.025 Km is how many micrometers?

$\frac{0.025\ \text{Km}}{} \times \frac{10^9\ \mu m}{1\ \text{Km}} = 25\,000\,000\ \mu m$ or $2.5 \times 10^7\ \mu m$

Biomolecules fall into 4 major groups: ① carbohydrates ② proteins ③ nucleic acids ④ lipids

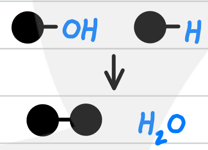
↳ these exist as simple single units, **monomers**, and can combine together to form larger more complex **polymers** or macromolecules



↳ the most important metabolic reactions occurring in living organisms are condensation and hydrolysis reactions

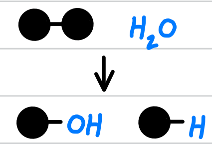
※ note: monomers are often not individual atoms but smaller molecules

Condensation reaction: where two molecules are combined together forming a larger more complex polymer and a molecule of water



↳ named after the fact water is produced ↳ an anabolic reaction and requires energy

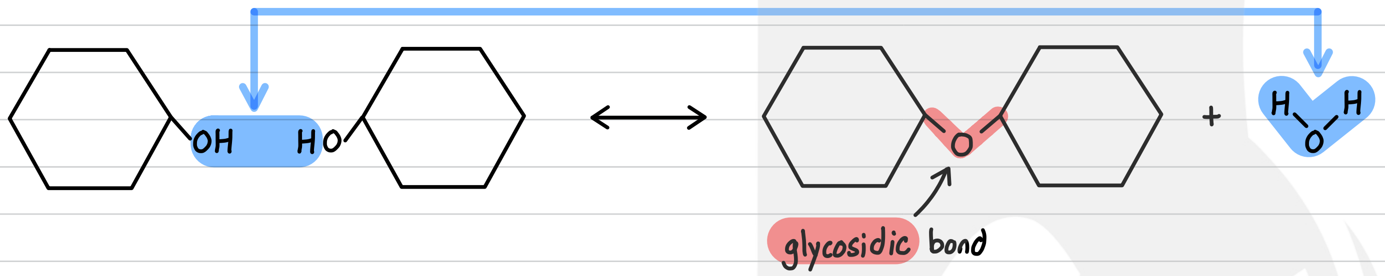
Hydrolysis reaction: where a polymer breaks down/is digested into 2 smaller, less complex molecules, using a split water molecule



↳ 'hydro' = water and 'lysis' = split, splitting using water ↳ a catabolic reaction and releases energy

Carbohydrates

↳ monomers: monosaccharides ⟷ dimer: disaccharide ⟷ polymer: polysaccharide



ex: glucose + glucose —maltose synthase→ / ←maltase— maltose

glucose + galactose —lactose synthase→ / ←lactase— lactose

glucose + fructose —sucrose synthase→ / ←sucrose— sucrose

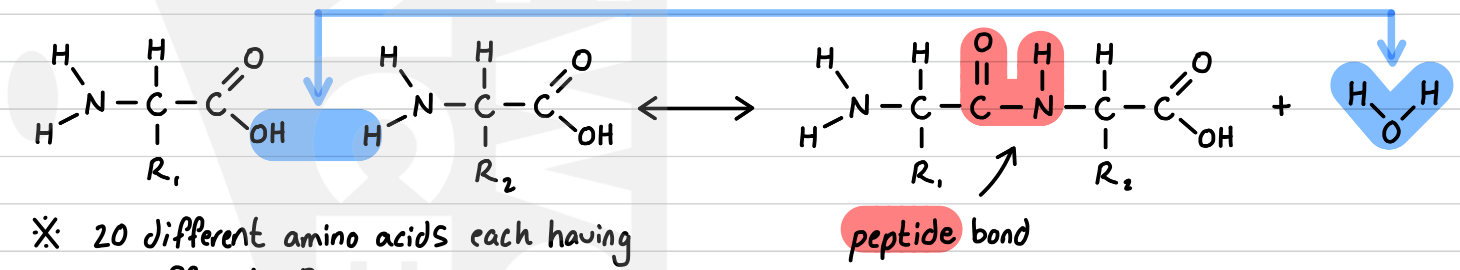
many α-glucose ⇌ glycogen / starch

many β-glucose ⇌ cellulose

Proteins

proteins B1.2

↳ monomers: amino acids ⟷ dimer: dipeptide ⟷ polymer: polypeptide



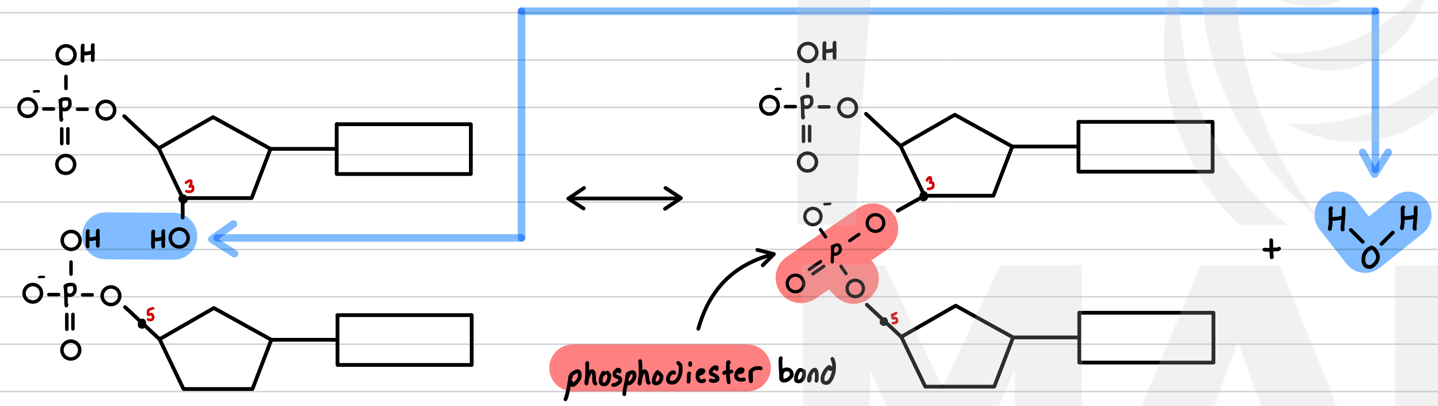
※ 20 different amino acids each having a different R group

ex: anabolic enzyme: ribozymes
catabolic enzymes: peptidase, pepsin, trypsin

※ how many water molecules are required to form a polypeptide made of 500 amino acids?
↳ 500 - 1 = 499 water molecules

Nucleic acids

↳ monomers: nucleotides ⟷ dimer: dinucleotide ⟷ polymer: DNA / RNA

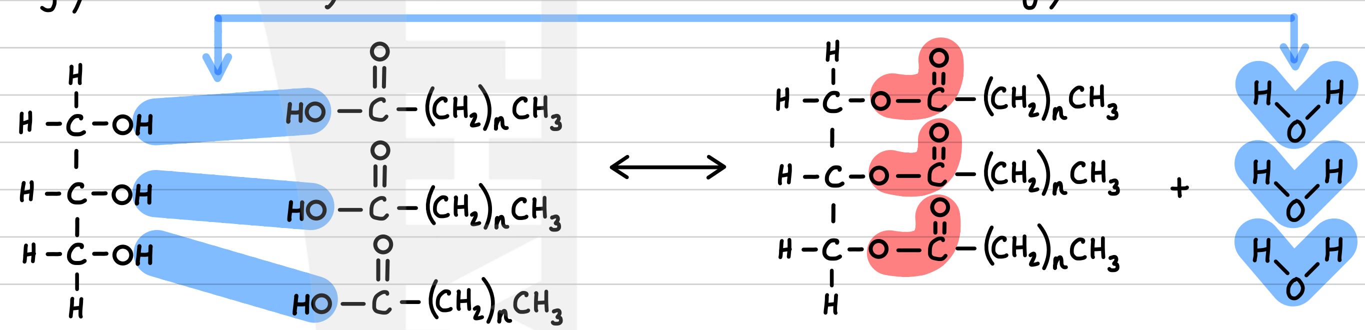


nucleic acids A1.2

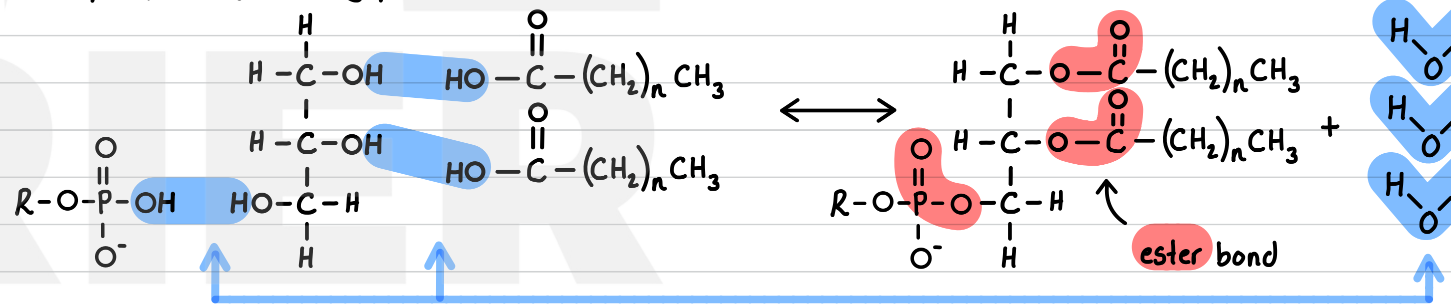
ex: anabolic enzymes: DNA polymerase, RNA polymerase, DNA ligase
catabolic enzymes: endonuclease, helicase

Lipids

↳ glycerol + 3 fatty acids* ⟷ triglyceride



↳ phosphate group + glycerol + 2 fatty acids* ⟷ phospholipid



※ lipids are technically not polymers as they are not composed of repeating units but different monomers

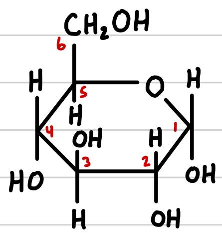
*can all be different or the same

Composition: all carbohydrates contain carbon, hydrogen, and oxygen

Structure: carbohydrates have the general formula $C_x(H_2O)_y$ where $x = 3-7$

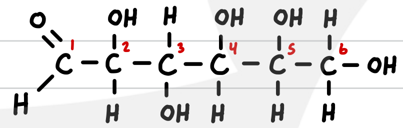
Form: monosaccharides made of 5 carbons (pentose) and 6 carbons (hexose) exist in multiple forms:

ring forms

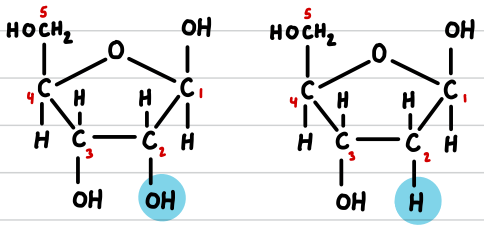


⟷

linear forms



↳ Pentose ring monosaccharides.

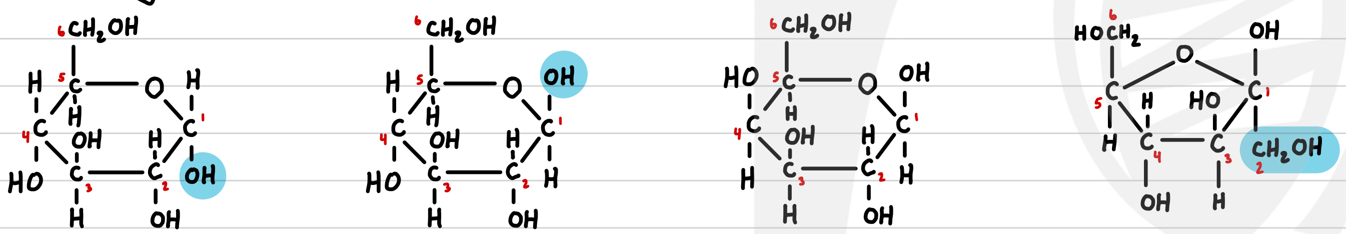


Chemistry review

Isomer: chemicals with the same chemical formula but different structural formulae

↳ while properties are mainly similar, they are recognized by enzymes and have a major effect on polymer construction

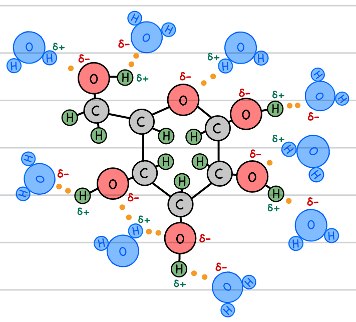
↳ Hexose ring monosaccharides are isomers ($C_6H_{12}O_6$):



Properties of monosaccharides: Glucose

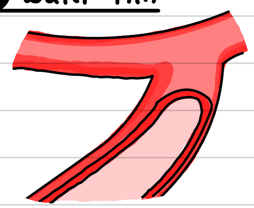
↳ **High solubility in water**

Due to the polarity of glucose it readily forms hydrogen bonds with water allowing it to dissolve readily



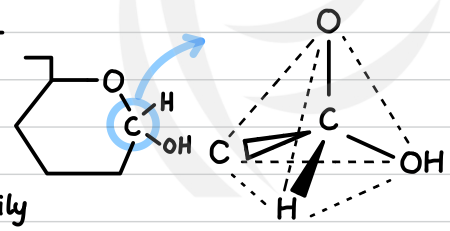
↳ **Easy transportability** (water A1.1)

Blood is mainly plasma which is mostly water, thus hydrophilic glucose dissolves and is easily transported throughout body



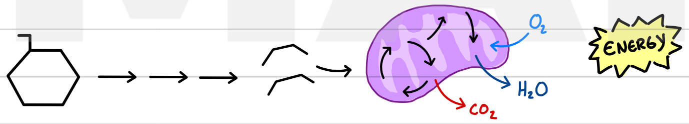
↳ **Molecular stability**

Glucose is composed of strong, stable covalent bonds which do not break easily



↳ **Energy yield** (cell respiration C1.2)

Glucose is oxidized in enzyme-reactions (respiration) and release a significant amount of energy

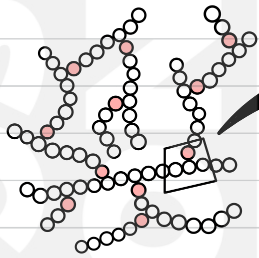
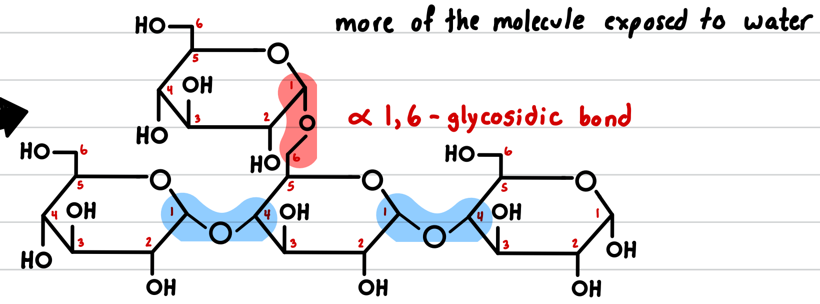


4 types of Polysaccharides:

※ more 1,6 branches = more soluble as more of the molecule exposed to water

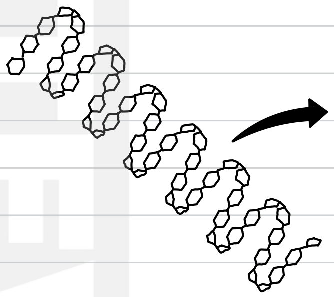
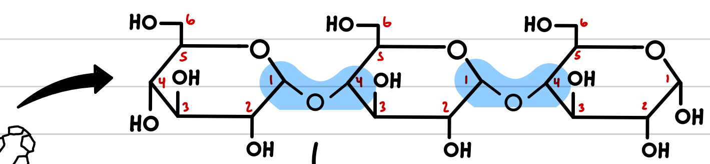
① Glycogen

- made of α glucose
- highly branched structure

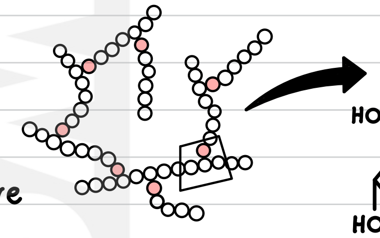
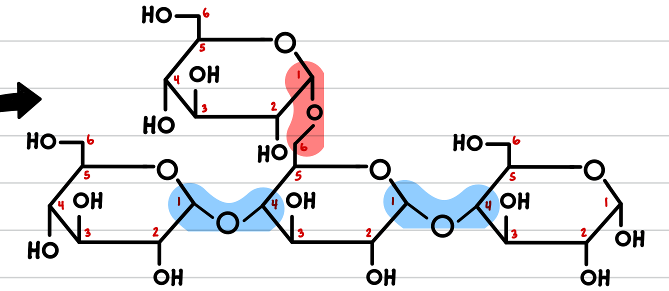
② Amylose

- comprises ~ 20-30% of starch
- made of α glucose
- unbranched, causing it to be linear and helical in shape

③ Amylopectin

- comprises ~ 70 - 80% of starch
- made of α glucose, branched structure

Glycogen and Starch as energy storage materials:

↳ Glycogen stored as a short-term energy reserve in animals within the liver and muscles

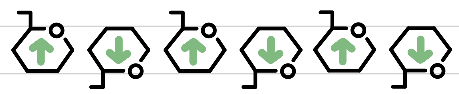
↳ Starch stored compactly into plastids in plants (such as chloroplasts) (cell structure A2.2)

↳ many branches cause them to coil and be compacted in small volume (glycogen is more branched)

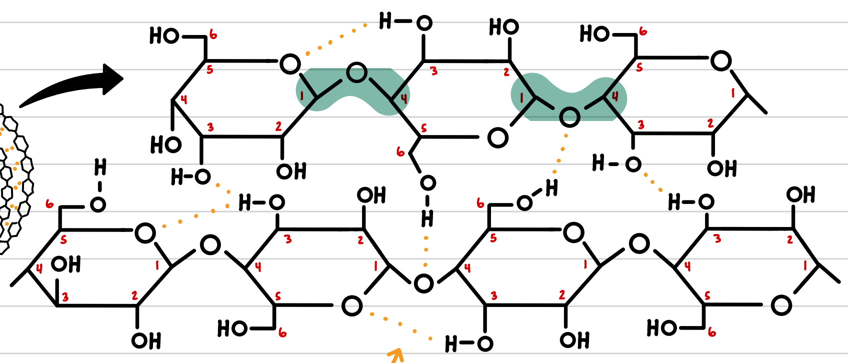
↳ very large molecules, thus do not contribute to osmotic pressure in cells

↳ no defined size, easy for enzymes to hydrolyze parts for rapid energy supply and to add subunits via condensation to store excess glucose (amylose a little less so as it is unbranched)

④ Cellulose



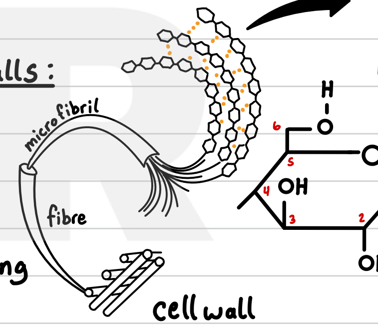
- made of β-glucose with each molecule flipped relative to its neighbour
- polymers are straight, unbranched chains
- form cross-linking hydrogen bonds with adjacent parallel chains forming microfibrils



Structural component of plant cell walls:

↳ fibres have high tensile strength able to resist turgor pressure

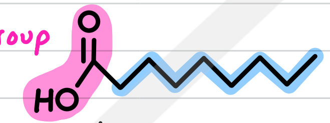
↳ cellulose insoluble in water, allowing materials to pass through freely

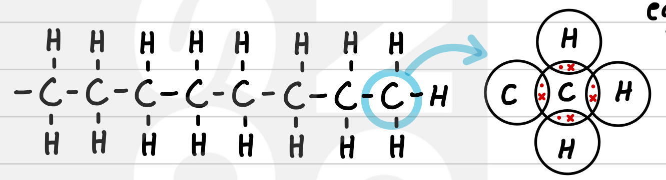


B1.1.8—Hydrophobic properties of lipids. B1.1.10—Difference between saturated, monounsaturated and polyunsaturated fatty acids. B1.1.12—Formation of phospholipid bilayers as a consequence of the hydrophobic and hydrophilic regions. B1.1.13—Ability of non-polar steroids to pass through the phospholipid bilayer

Lipids are a broad type of biomolecule which are **hydrophobic** (do not readily dissolve in aqueous solvents) → Lipids contain mainly **non-polar covalent** bonds, where pairs of electrons are equally shared between atoms

↳ lipids largely are composed of fatty acids, whose type will determine certain physical properties

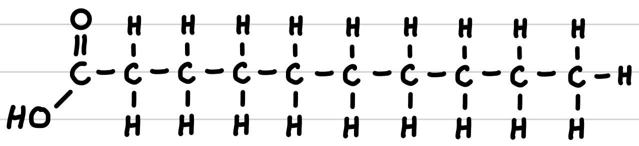




↳ no partial charges, no water interaction

↳ dissolves readily in non-polar solvents
ex: propanone, toluene

Saturated fatty acid

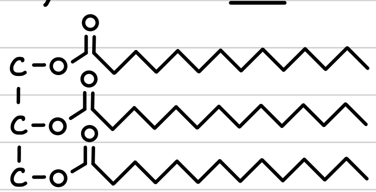


- all single C–C bonds, chain is 'saturated' with H atoms

uses: long-term energy storage in endotherms (warm-blooded) animals

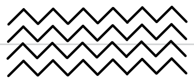
sources: animal fats (beef, pork, poultry) dairy products (butter, cheese)

- triglycerides with all saturated fatty acids are fat

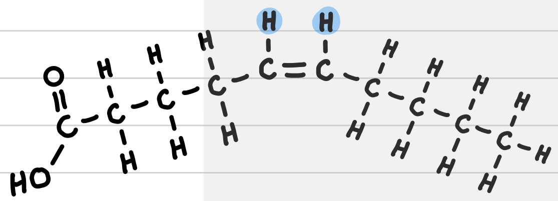


chain is straight

- high melting point (~20°C – 37°C)
solid at room temp
↳ chains pack tightly
↳ stronger intermolecular forces



monounsaturated cis- fatty acid

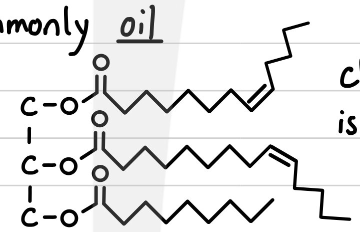


- one double C=C bond, chain is 'unsaturated' as 2 less H atoms

uses: energy storage in plants and ectotherms (cold-blooded) animals as liquid at lower temperatures and can efficiently access it

sources: olive and canola oil, almonds, cashews, avocados, sesame seeds

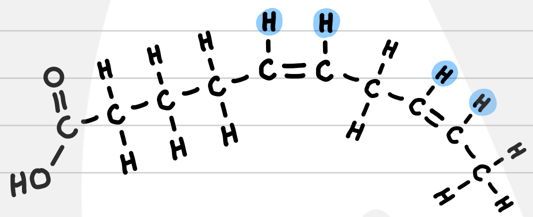
- triglycerides with 1 or more cis-mono unsaturated fatty acids are commonly oil



chain is bent

- low melting point (< 20°C)
liquid at room temp
↳ chains pack loosely
↳ weaker intermolecular forces

polyunsaturated cis- fatty acid



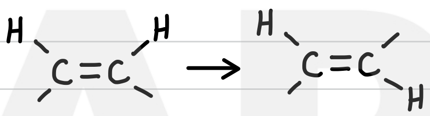
- >1 double C=C bond, chain is 'unsaturated' as 4+ less H atoms

sources: sunflower, corn, soya oil, walnuts, fish (salmon, tuna, sardines)

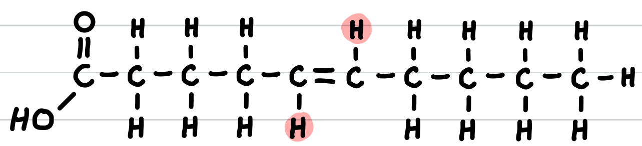
- triglycerides with 1 or more cis-polyunsaturated fatty acid are commonly oil

chain is bent twice

artificial partial hydrogenation:



unsaturated trans-fatty acids



H atoms on opposite sides → straight chain

- high melting point (solid at room temp)

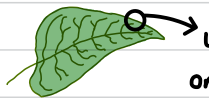
uses: fats can keep longer before spoiling

sources: cakes, cookies, pizza, popcorn, fries, doughnuts

Waxes are lipids made from an alcohol and fatty acid forming a long ester

↳ high melting point (>37°C)

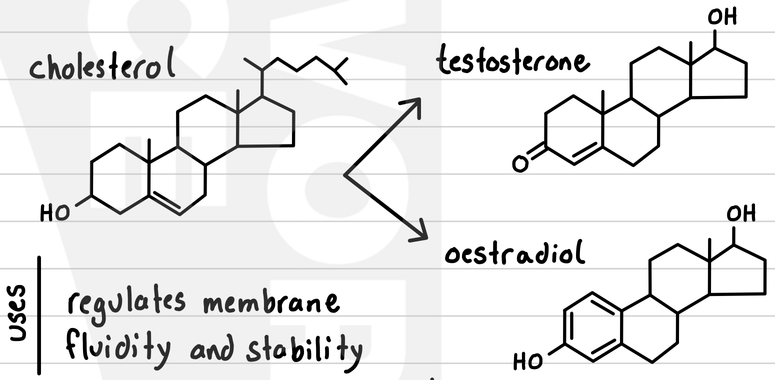
uses: due to their hydrophobic nature, are used to prevent water loss in plants



waxy cuticle on leaf surface

gas exchange B3.1

Steroids are lipids with a four-ringed structure (3 hexagons, 1 pentagon)



uses: regulates membrane fluidity and stability

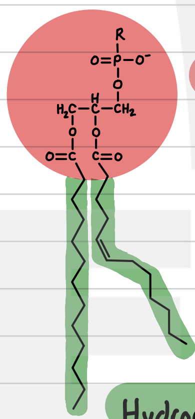
membranes B2.1

uses: major male and female mammal sex hormones
↳ produced by gonads and involved in development of primary and secondary sex characteristics

chemical signalling C2.1

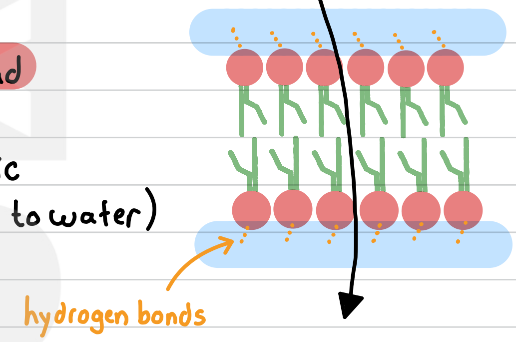
testosterone and oestradiol are non-polar (as they are mostly hydrocarbons)
↳ they pass freely through the non-polar core of a bilayer, allowing them to enter plasma membranes and cells directly

Phospholipids are **amphipathic** meaning they have both hydrophilic and hydrophobic regions



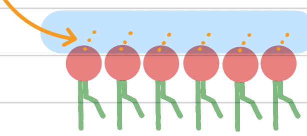
Phosphate head
↳ polar
↳ hydrophilic (attracted to water)

Hydrocarbon tails
↳ non-polar
↳ hydrophobic (repel water)



when immersed in water: tails face inwards (away from water) and heads face outward (toward water) forming a bilayer

membranes B2.1

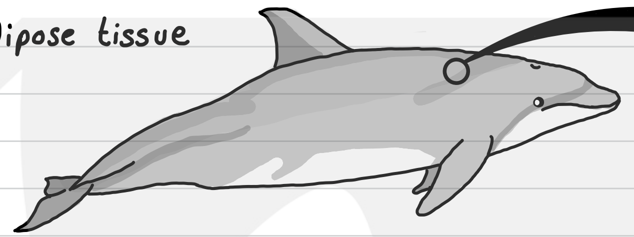


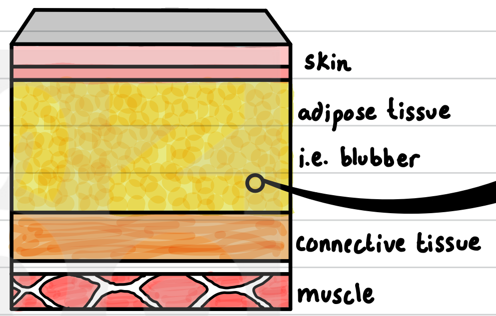
in contact with water: tails face away and heads dissolved forming monolayer

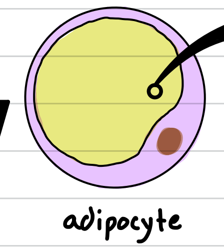
Triglycerides are stored in mammals in adipocytes (fat cells), forming adipose tissue

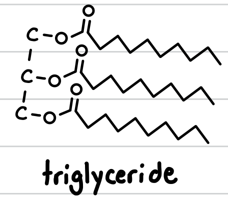
↳ adipose tissue mainly stored under the skin (subcutaneous fat)

↳ in aquatic and arctic mammals, this tissue is very thick and called blubber





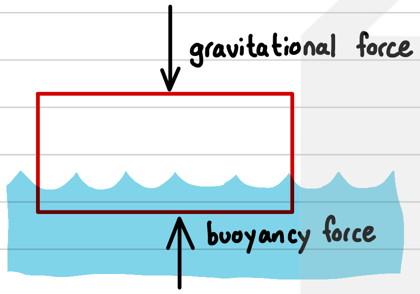


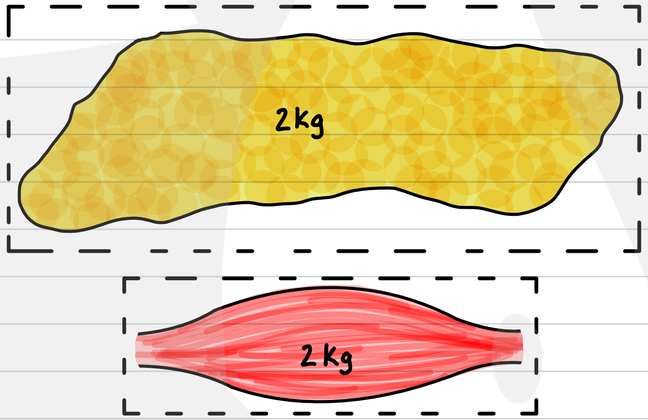


Fat as buoyancy aid

↳ Something is buoyant or floats when the volume of the displaced fluid is ≤ volume of itself

↳ the density of the object will influence its buoyancy as if object's density ≤ fluid density it will float





↳ fat is less dense than bone or muscle i.e. for the same mass, fat takes up more space ∴ more fat, more buoyant

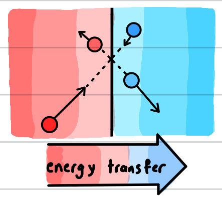
↳ to increase buoyancy, aquatic mammals have larger stores of fat, allowing them to float easier in the water

ex: some seals have up to 40% of their mass as blubber, allowing them to float readily in oceans

Fat as thermal insulator

water A1.1

↳ heat naturally moves from hotter to cooler areas



↳ A thermal insulator is something that does not readily allow heat to travel through (opposite to a thermal conductor)

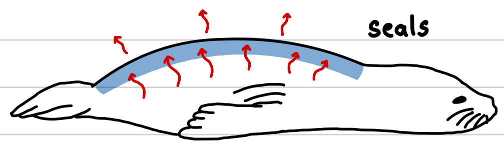
↳ Endotherms (warm-blooded) animals maintain a constant body temperature in their surroundings and habitats

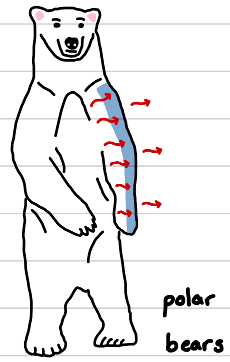
ex: very useful for arctic and marine animals

↳ triglycerides within adipose tissue are good thermal insulators so are able to trap heat

water A1.1

ex: arctic endotherms have large blubber stores which allow them to maintain high body temperature in cold environments by trapping heat generated from metabolic processes

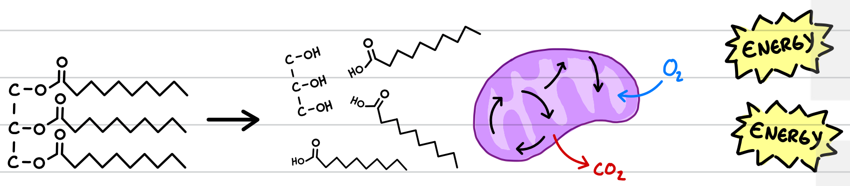




Fat as energy storage

Lipids are used as long-term energy storage (while carbohydrates as a short-term store)

↳ When oxidized in enzyme-reactions, they release twice as much energy as carbohydrates (gram-for-gram)

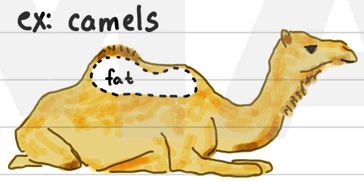


cell respiration C1.2

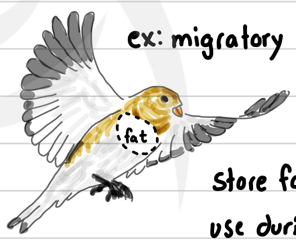
↳ release more water than carbohydrates when fully oxidized (due to more C-H), providing more metabolic water to the organism

↳ lipids are hydrophobic, so while carbohydrates need to be stored with water, lipids can be stored as pure droplets, allowing far more to be stored while contributing less to overall mass

ex: camels



store fat for later energy and water use when respired



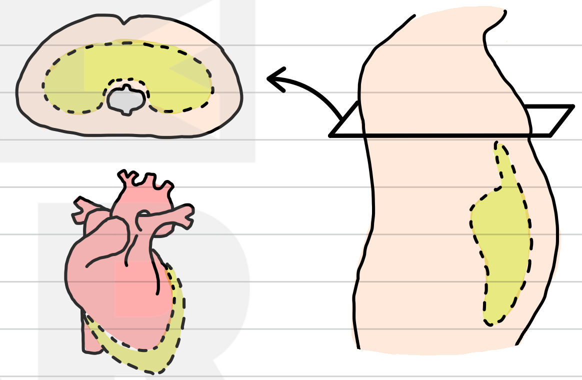
ex: migratory birds

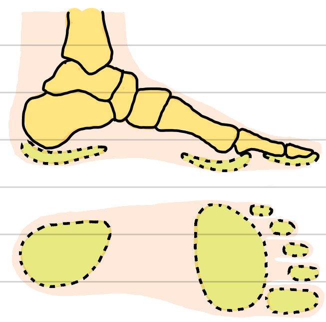
store fat for energy use during long flights

↳ they are insoluble in water so if stored in cytoplasm it will form droplets and not contribute to osmolarity

Fat as protection

↳ Fat is stored deep in the body which surround organs (visceral fat), acting as a cushion and protection from external forces and harm





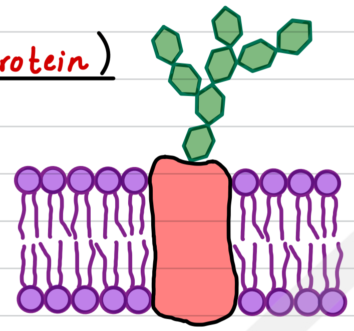
↳ fat pads in feet act as shock absorbers

Biomolecules can exist in combinations with others, for example:

membranes B2.1 water A1.1

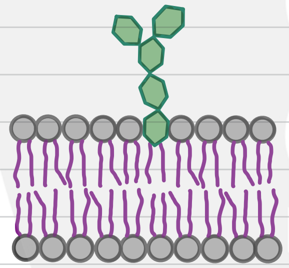
↳ **Glycoprotein** (Carbohydrate + protein)

carbohydrate chain bound to a protein located on the surface of cell membranes involved in cell-cell recognition



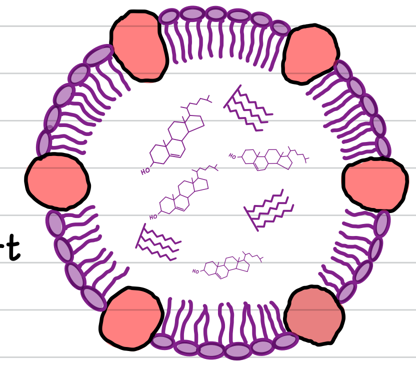
↳ Glycolipid (Carbohydrate + lipid)

carbohydrate chain bound to a lipid located on the outer surface of cell membranes involved in cell recognition and membrane stability



↳ Lipoprotein (lipid + protein)

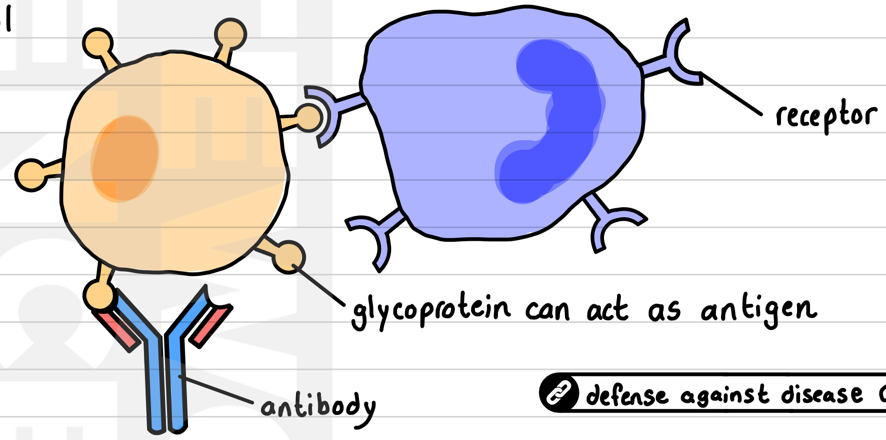
shell-like structure made of phospholipids and proteins whose function is to transport lipids (such as cholesterol or triglycerides) around the body via the blood plasma



↳ cells in an organism need the ability to differentiate 'self' from 'non-self' or foreign in order to mount a successful immune response and prevent disease

↳ all cells, even viruses have **antigens**, surface markers, which are commonly glycoproteins or proteins

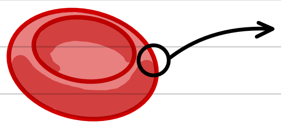
↳ the glycoproteins have a unique shape, giving it an 'ID' for the body's immune cells to analyze using its receptors and antibodies. If the antigen is identified as foreign, an immune response will be initiated



ABO blood groups

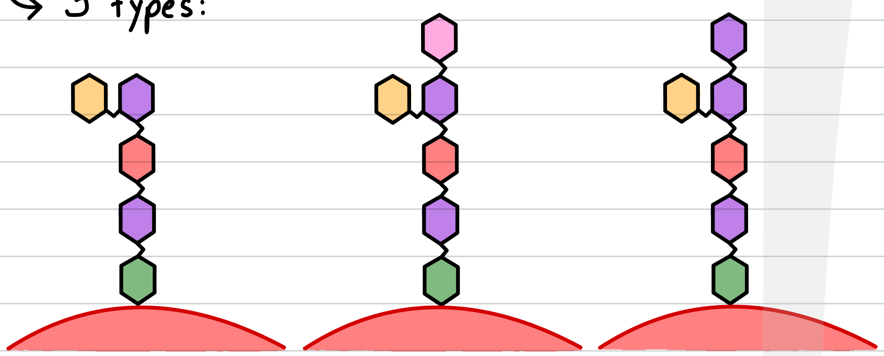
defense against disease C3.2

- red blood cells, erythrocytes, are specialized cells whose primary function is to transport O_2 to the body's tissues using the protein haemoglobin



→ the surface of red blood cells have specific glycoproteins acting as antigens and surface markers

↳ 3 types:

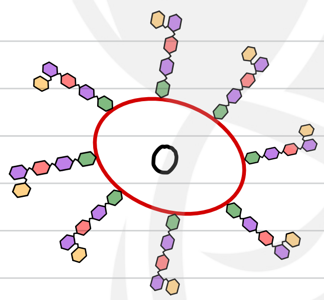


- glucose
- galactose
- N-acetylglucosamine
- fucose
- N-acetylgalactosamine

※ do not need to know these

- 4 main groups of blood cells, classified by the antigens on their surface:

※ actually 8 types due to Rh (-/+) factor

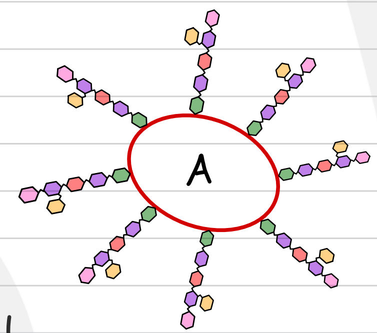


↳ O antigens (no A or B)

∴ can donate to O, A, B, AB as O antigen not recognized as foreign, "universal donor"

↳ produces anti-A and anti-B antibodies

∴ can only receive type O

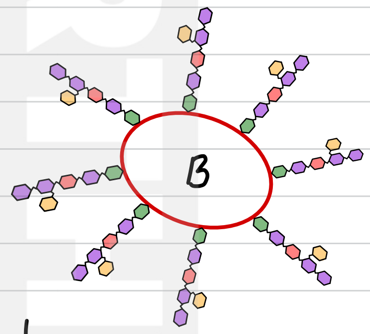


↳ only A antigens

∴ can donate to A and AB as A antigen recognized as foreign by type O and B

↳ produces anti-B antibodies

∴ can receive type O and A

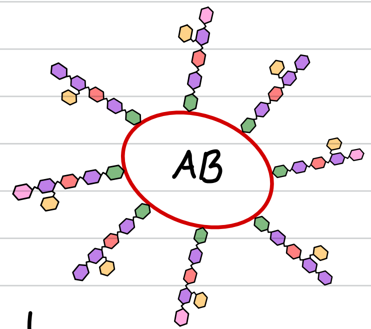


↳ only B antigens

∴ can donate to B and AB as B antigen recognized as foreign by type O and A

↳ produces anti-A antibodies

∴ can receive type O and B



↳ both A and B antigens

∴ can only donate to AB as A antigen foreign to O and B and B antigen foreign to O and A

↳ does not produce anti-A or anti-B antibodies

∴ can receive type O, A, B, AB "universal recipient"

BIBLIOGRAPHY