B1.1 Carbohydrates and Lipids

Learning Outcomes

1SL **Chemical Properties Of A Carbon Atom Allow Formation Of Diverse Compounds To Enable Life**
Understand the nature of a covalent bond. 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”).

2SL **Production Of Macromolecules By Condensation Reactions That Link Monomers Into Polymers**
Be familiar with examples of polysaccharides, polypeptides and nucleic acids.

3SL **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.

4SL **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.

5SL **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.

6SL **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.

7SL **Role of glycoproteins in cell–cell recognition**
Include ABO antigens as an example.

8SL **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.

9SL **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.

10SL **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.

11SL **Triglycerides In Adipose Tissues For Energy Storage And Thermal Insulation**
The properties of triglycerides make them suited to long-term energy storage functions.
Relate the use of triglycerides as thermal insulators to body temperature and habitat.

12SL **Formation Of Phospholipid Bilayers Due To The Hydrophobic And Hydrophilic Regions**
Use and understand the term “amphipathic”.

13SL **Ability Of Non-Polar Steroids To Pass Through The Phospholipid Bilayer**
Include oestradiol and testosterone as examples. Identify compounds as steroids from molecular diagrams.

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?

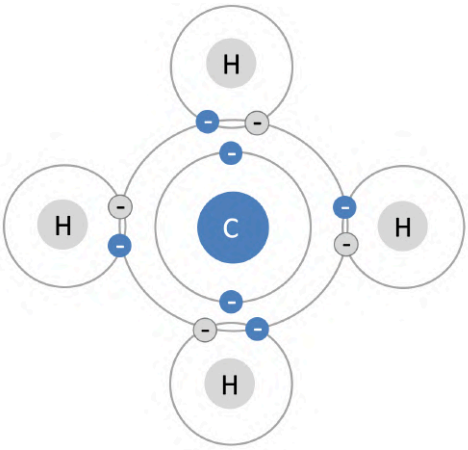
1SL Chemical Properties of a Carbon Atom Allow Formation of Diverse Compounds for Life

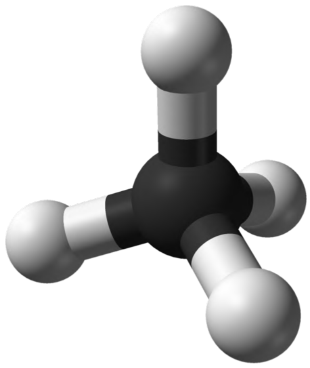
organic compound – a compound containing C-C or C-H bonds

All living things are made of organic compounds.
Smaller carbon molecules are usually not considered organic such as:
hydrogen cyanide (HCN), carbide (CaC_2) and oxides of carbon (CO_2 and CO).

Carbon atoms:

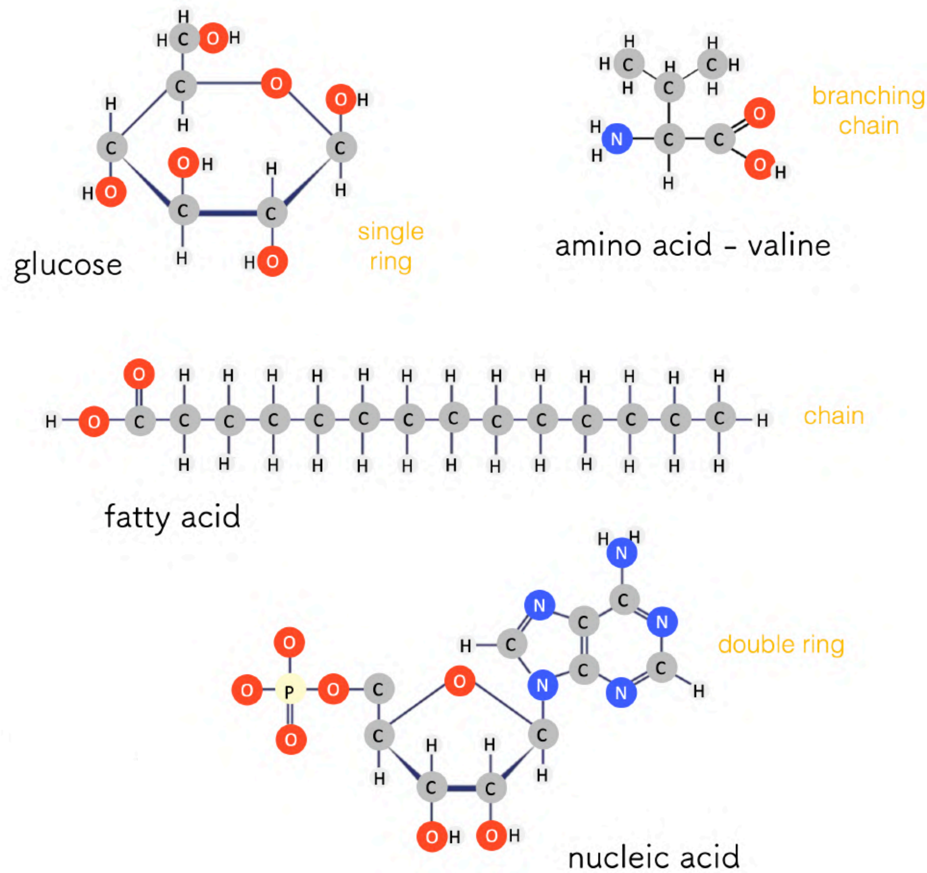
- can form 4 strong, stable covalent bonds (sharing of an electron pair) with non-metallic atoms
- single covalent bonds can allow rotation
- double covalent bonds are very strong and stable
- can form branched and unbranched chains and single and double rings structures.





Attached atoms move away from each other to form a tetrahedral shape.

Organic compounds include: carbohydrates, lipids, proteins and nucleic acids.



NOS
Scientific conventions are based on international agreements.
The International Bureau of Weights and Measures helps to coordinate these agreements.
For example measurements are based on the **International System of Units** or **SI** units based on the official French name *(Système international d'unités)* and the metric system is used.

Seven Base Units

property measured	name of unit	unit
time	second	s
mass	kilogram	kg
length	metre	m
temperature	kelvin	K
electric current		A
amount of substance	mole	mol
luminous intensity	candela	cd

The seven base units are taken from seven physical constants in nature.
For example the unit for time is based on the vibration of an electron in a cesium atom.

The 7 base units are used to derive the other 22 units.
For example a force in newtons (N) is derived from $kg.m.s^{-2}$

SI metric prefixes for each unit are

prefix name	symbol	power of 10	decimal	calculation
nano	n	10^{-9}	0.000 000 001	
micro	μ	10^{-6}	0.000 001	
milli	m	10^{-3}	0.001	= 1 / (10x10x10)
centi	c	10^{-2}	0.01	= 10x10
kilo	k	10^{3}	1 000	= 10x10x10
mega	M	10^{6}	1 000 000	

Worked example:
48.5×10^{-3} grams (g)
means 48.5 x 0.001
or 0.0485 grams (g)
or 48.5 milligrams (mg)

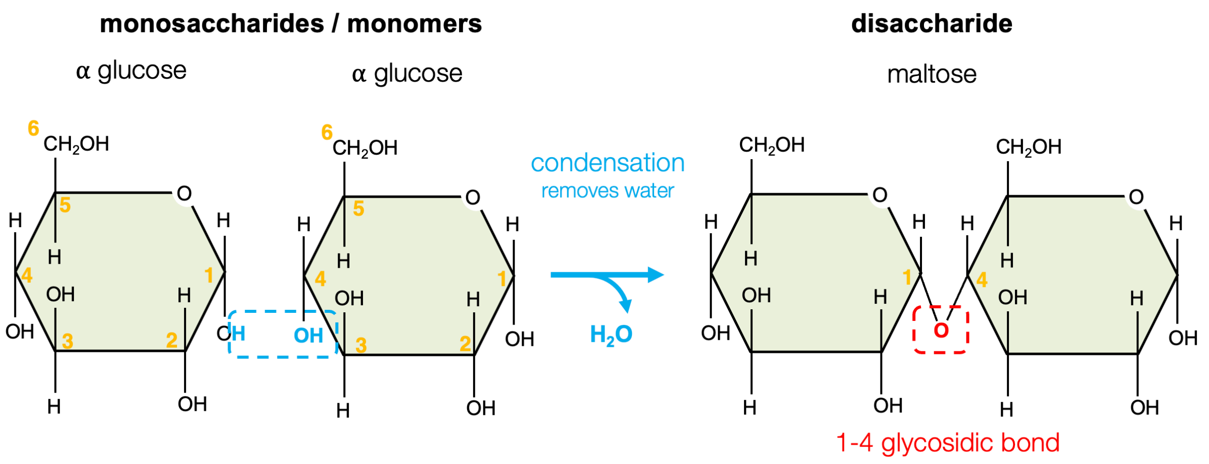
2SL Production Of Macromolecules By Condensation Reactions That Link Monomers Into Polymers

Macromolecules contain many atoms and examples include protein, DNA, RNA, and complex carbohydrates which all form polymers. Lipids are macromolecules but they are not a polymer. Polymers are consist of many repeating monomer units.
An oligopeptide, oligonucleotide and an oligosaccharide are examples of a short chain of monomers. Dipeptides, dinucleotides and disaccharides are examples of molecules made of two monomers.

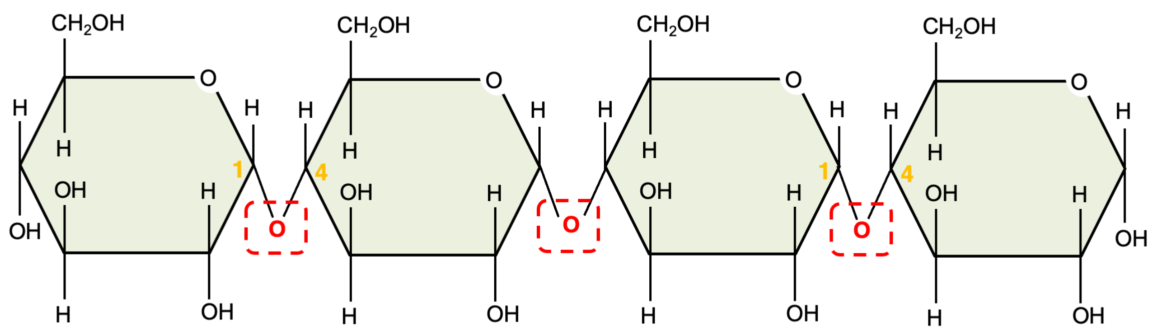
condensation reaction – forms a covalent bond by removal of a water molecule

hydrolysis reaction – breaks a covalent bond by addition of a water molecule

Example:
Monosaccharides are linked by a glycosidic bond C – O – C between carbon 1 and 4.
Side branches form if bonds are between carbon atoms 1 and 6.



polysaccharide



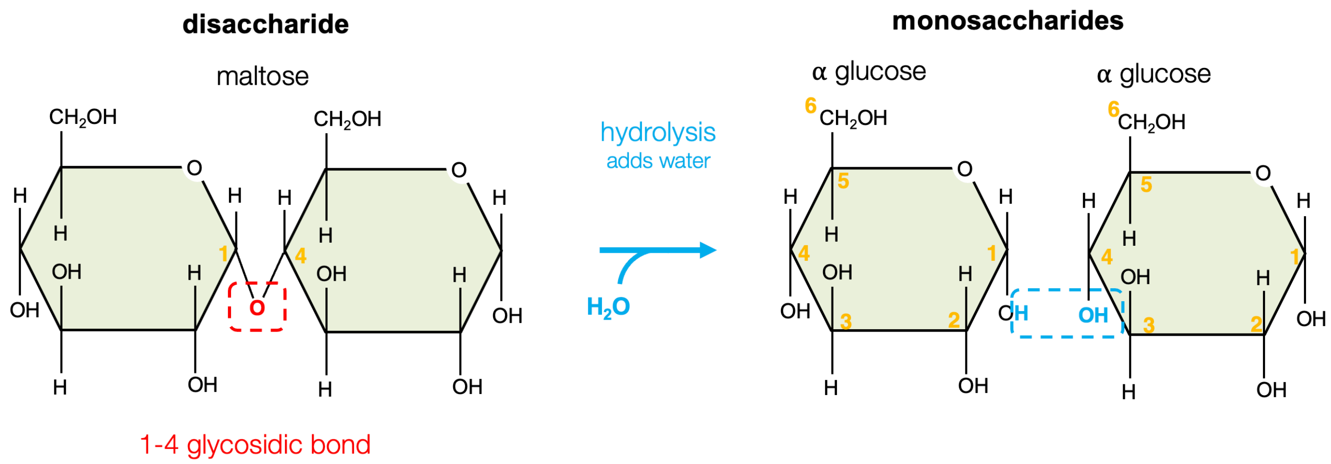
Condensation:
- o builds up monomers into polymers
- o removes an -OH (hydroxyl group) and -H (hydrogen) by forming a water molecule
- o forms a covalent bond
- o requires enzymes
- o usually requires energy in the form of ATP

3SL Digestion of Polymers into Monomers by Hydrolysis Reactions

Digestion of insoluble polymers into soluble monomers for absorption and assimilation is carried out by catabolic enzymes in a process called hydrolysis.

Hydrolysis:
- breaks down polymers into monomers during digestion
- adds an -OH (hydroxyl group) and -H (hydrogen) by splitting (lysis) a water (hydro) molecule
- breaks a covalent bond
- requires enzymes
- does not require energy in the form of ATP

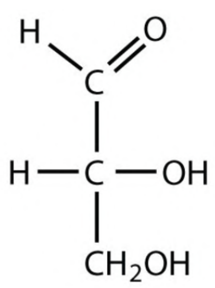
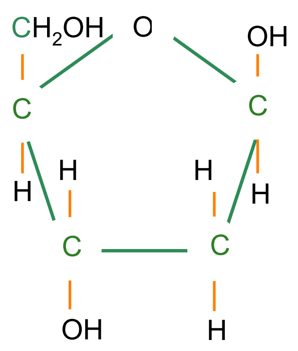
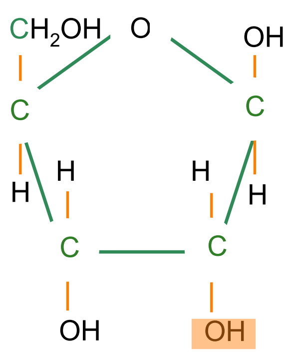
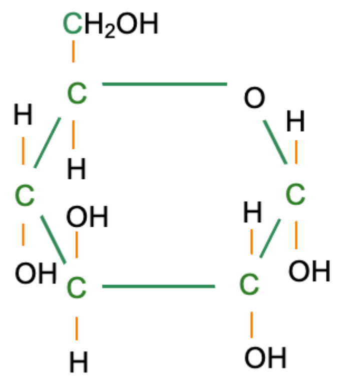
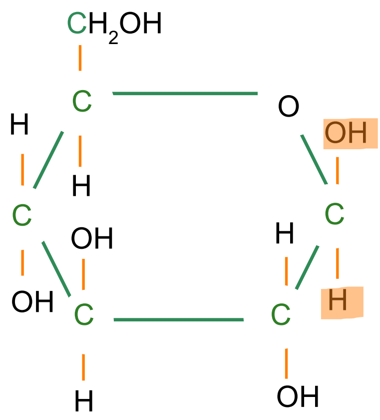
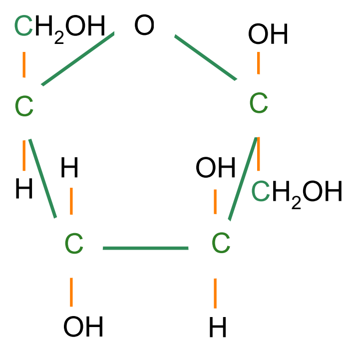
The monomers can be reused by cells to synthesize new polymers.



condensation	hydrolysis
removes a water molecule	adds a water molecule
anabolic – forms larger molecules	catabolic – forms smaller molecules
energy required	energy released
bonds are made	bonds broken
endothermic	exothermic
both require enzymes	
both involve water	

4SL Form and Function of Monosaccharides

Monosaccharides contain carbon hydrogen and oxygen (CHO) in a 1:2:1 ratio.

triose	pentose	hexose
$C_3H_6O_3$	$C_5H_{10}O_5$	$C_6H_{12}O_6$
 D-glyceraldehyde	 deoxyribose  ribose (note addition of OH)	 α-glucose  β-glucose (note flipped H and OH)  fructose

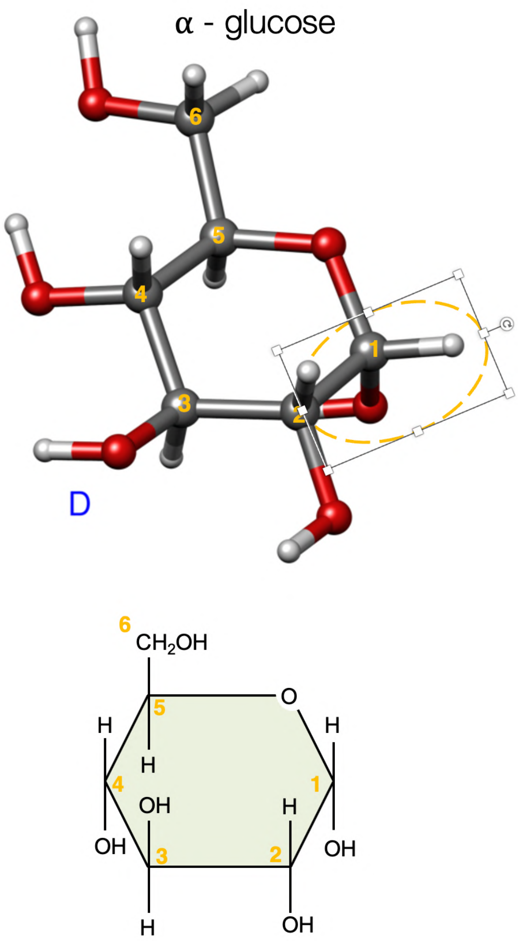
Glucose:

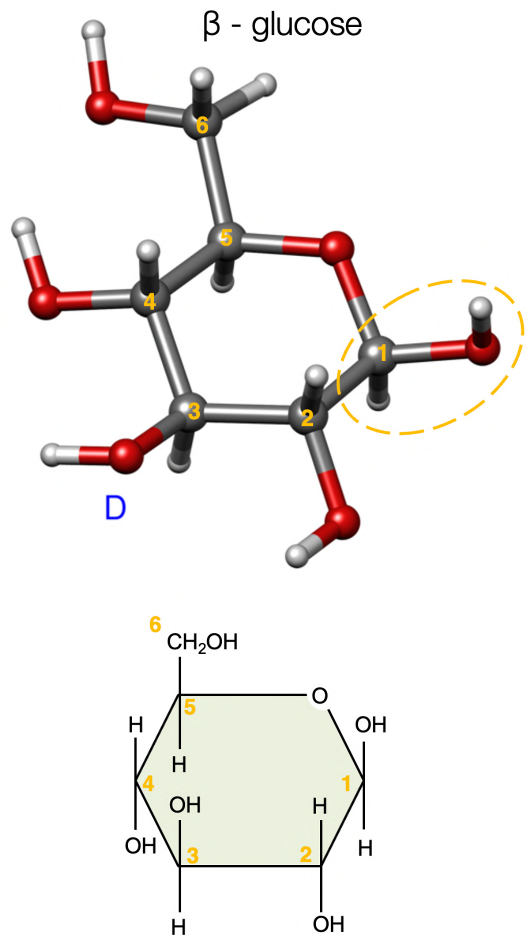
- is a polar molecule and highly soluble in water
  - easily transported in blood plasma and in the cytoplasm of the cell
  - requires a channel protein (eg GLUT) to cross a cell membrane by facilitated diffusion
- chemically stable and has no osmotic effect as a polymer (starch, glycogen, cellulose)
- used as an energy store as starch in plants and glycogen in mammals
  - one glucose yields 30-32 ATP in aerobic respiration

isomer – molecules with the same chemical formula but different arrangement of atoms

Glucose comes in two forms (isomers): α-glucose and β-glucose and this determines the three dimensional shape of the polymer produced.

The small differences between isomers can cause the molecules to function very differently.

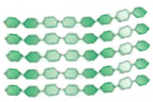




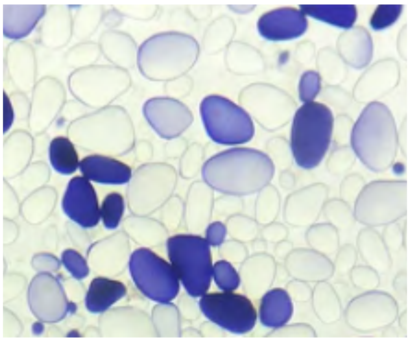
5SL Polysaccharides as Energy Storage Compounds

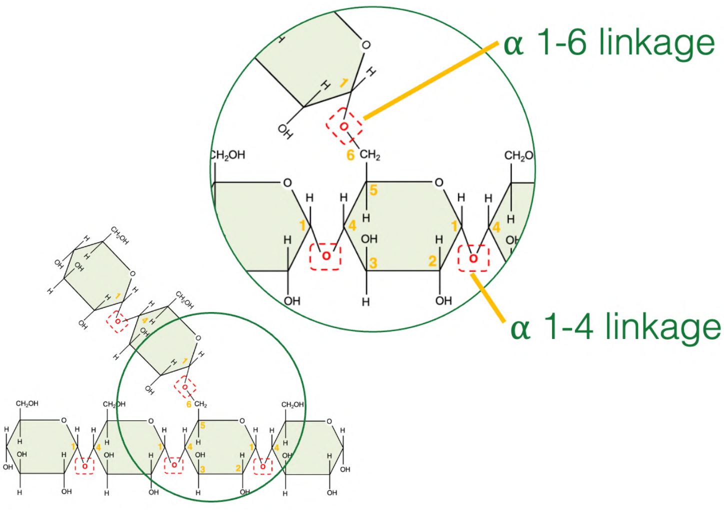
The polysaccharides starch and glycogen are excellent energy stores:

- compact
  - by *coiling* of the polymer due to glycosidic bonds between carbon 1 and 4
  - by *branching* of the polymer with glycosidic bonds between carbon 1 and 6
- insoluble
  - will remain within a cell, no osmotic effect so a cell will not burst
- metabolism
  - rapidly added to by condensation reactions
  - rapidly broken down by hydrolysis reactions (especially if highly branched)

	cellulose	starch		glycogen
		amylose	amylopectin	
location	plant cell wall	plant leaf cells root / stem / seeds	plant leaf cells root / stem / seeds	animal liver / muscle cells some bacteria and fungi
monomer	β-glucose	α-glucose	α-glucose	α-glucose
bond	1-4	1-4	1-4 1-6	1-4 1-6
branched	no	no	yes ≈ every 20 monomers	yes ≈ every 10 monomers
shape	 linear	 unbranched helix	 branched helix	 highly branched helix

Starch test - iodine fits into the middle of the helix of starch turning it blue-black.



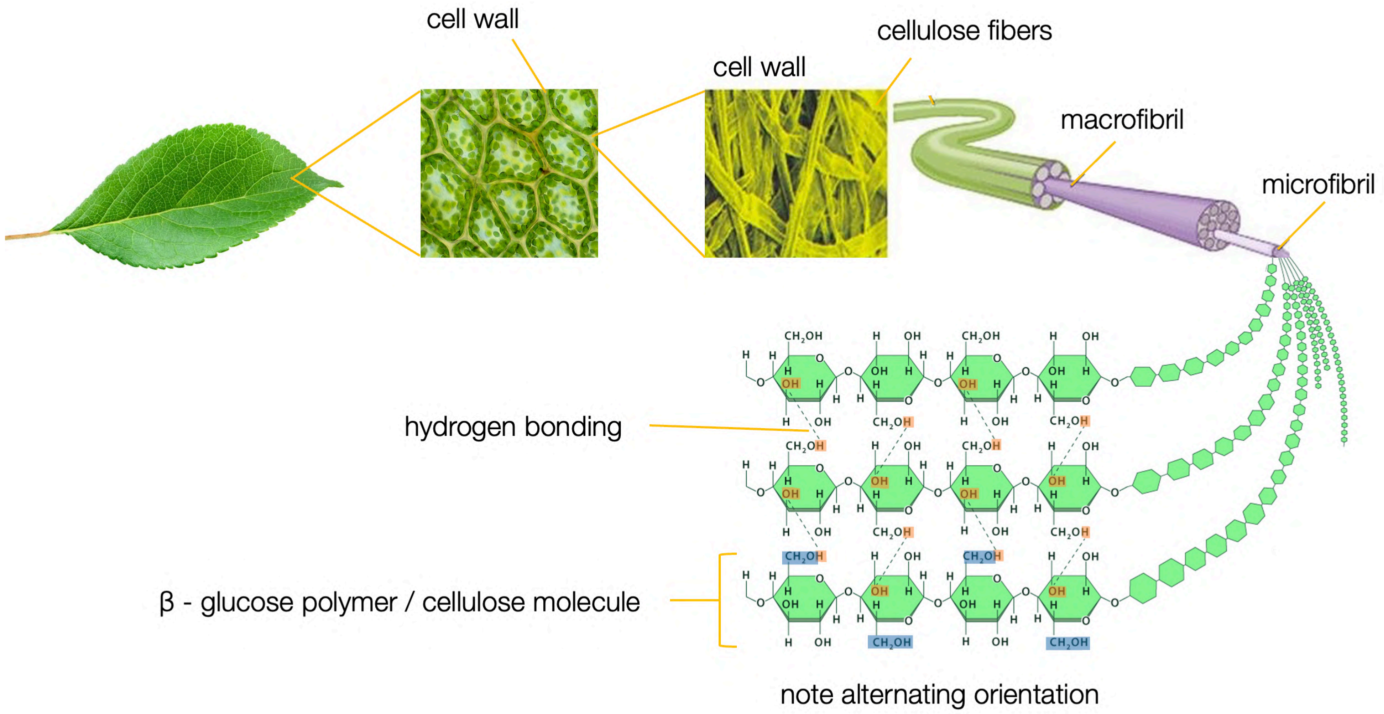


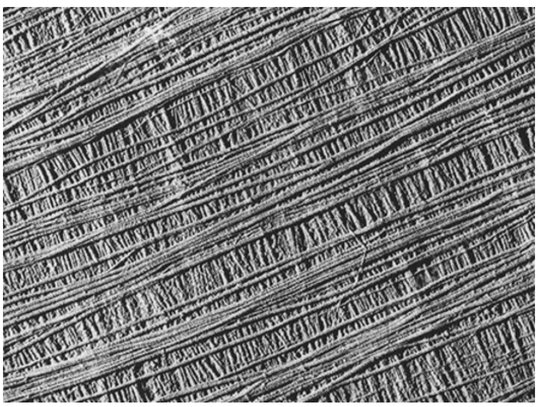
6SL Structure of cellulose related to its function as a structural polysaccharide in plants

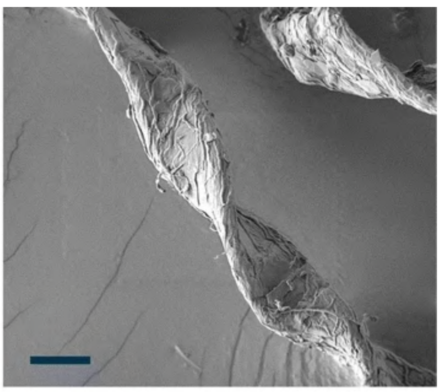
Cellulose:

- made from β-glucose molecules
- linked by carbon 1-4 glycosidic bonds
- monomers alternate in orientation upward and downward to make a straight chain
- unbranched
- hydrogen bonds link the long straight parallel molecules to form a cellulose microfibril
- bundles of microfibrils form a cellulose fiber
- has high tensile strength to prevent plant cells from bursting
- insoluble

View cellulose molecular structure.




Cellulose fibers of a cell wall.


Large cellulose fiber 10 µm

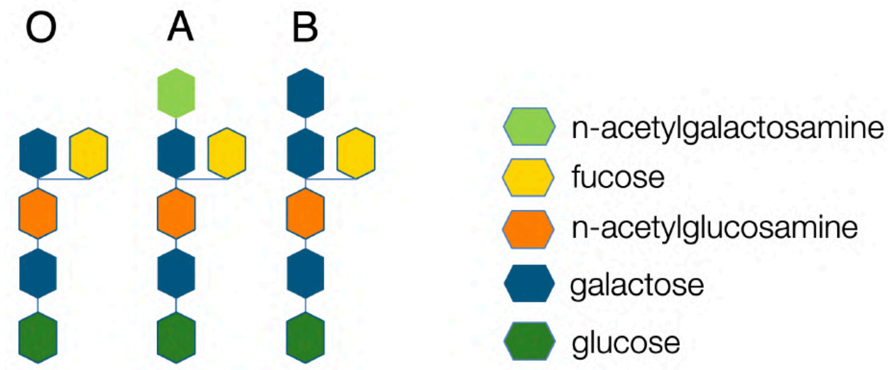
7SL Role of Glycoproteins in Cell-to-Cell Recognition

glycoprotein – a carbohydrate (usually an oligosaccharide) attached to a protein

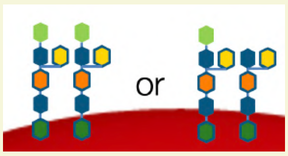
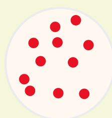
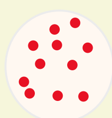
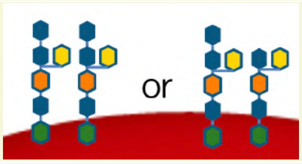
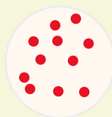
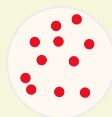
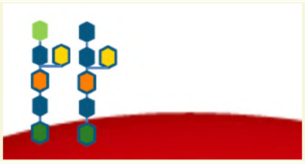
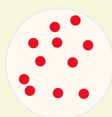
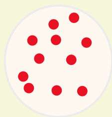
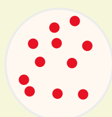
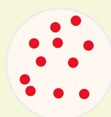
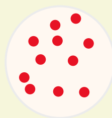
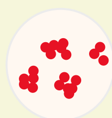
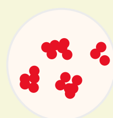
antigen – unfamiliar molecule that can stimulate production of antibodies

antibody – protein that binds to a specific antigen

Cell surface glycoproteins:
- outward facing oligosaccharides are anchored to a protein in the membrane
- allow linkage between adjacent cells to form a tissue
- allow cells to be recognized by the other cells with a complementary receptor
- allow cells to be recognized as foreign or infected



The ABO blood groups are determined by glycoproteins on the surface of the red blood cells. They can act as antigens. Transfusions with the wrong blood type can cause blood to clot.

blood group	genotype	cell surface antigen	antibodies in blood	reaction when mixed with blood types below			
				O	A	B	AB
A	$I^A I^A$ or $I^A I^i$		anti-B Y				
B	$I^B I^B$ or $I^B I^i$		anti-A Y				
AB	$I^A I^B$		none				
O	$I^i I^i$		anti-A anti-B Y Y				

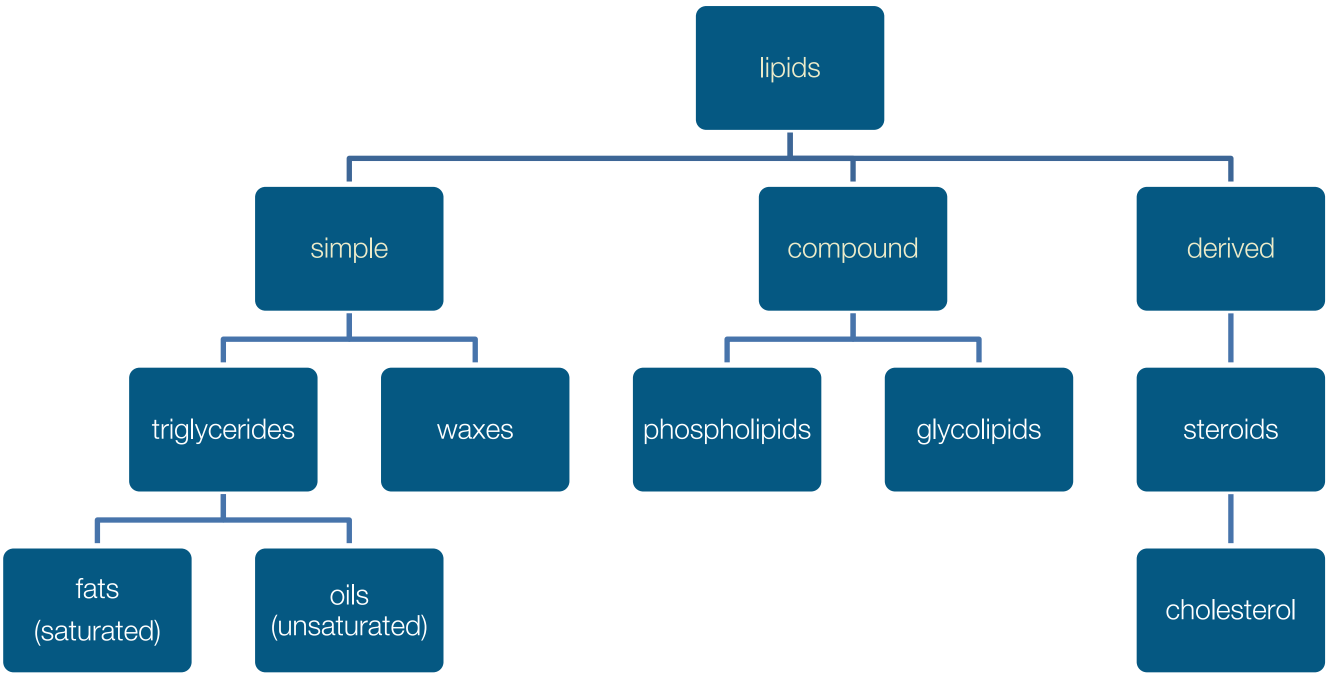
People with blood type O are universal donors and type AB are universal receivers.

8SL Hydrophobic Properties of Lipids

Lipids:

- organic
- non-polar molecules (no partial charges)
- dissolve in polar solvents such as organic solvents such as ether, acetone
- are hydrophobic - dissolve only sparingly in water
  - difficult to transport in the blood
  - provide excellent waterproofing waxes for leaf cuticles and oils for feathers
  - phospholipids form the cell membrane bilayer structure

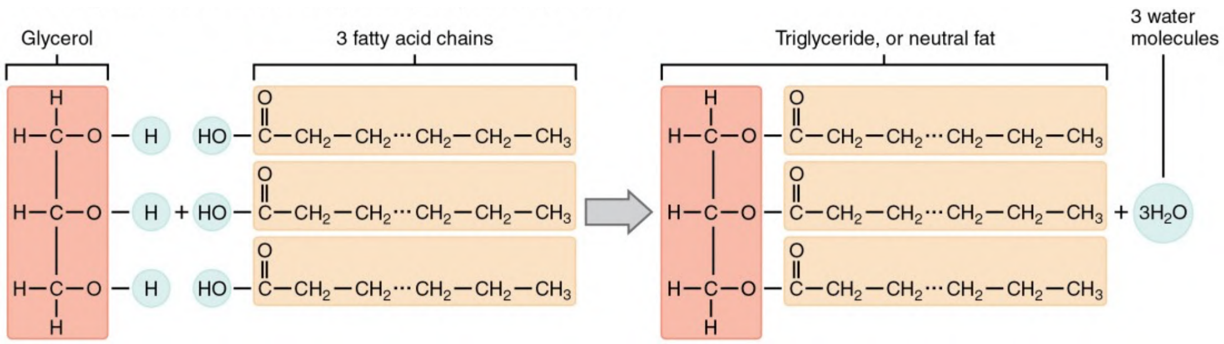
lipid types	melting point
oil	below 20°C
fat	between 20-37°C
wax	above 37°C
steroid	varied often >100°C



9SL Formation Of Triglycerides And Phospholipids By Condensation Reactions

Triglycerides:

- o composed of a glycerol linked to three fatty acids
- o linkage is by condensation reactions to form covalent ester bonds
- o bond is between the carboxyl (COOH) of the glycerol and hydroxyl (OH) of the fatty acid
- o may be a fat or an oil depending on the types of fatty acid attached



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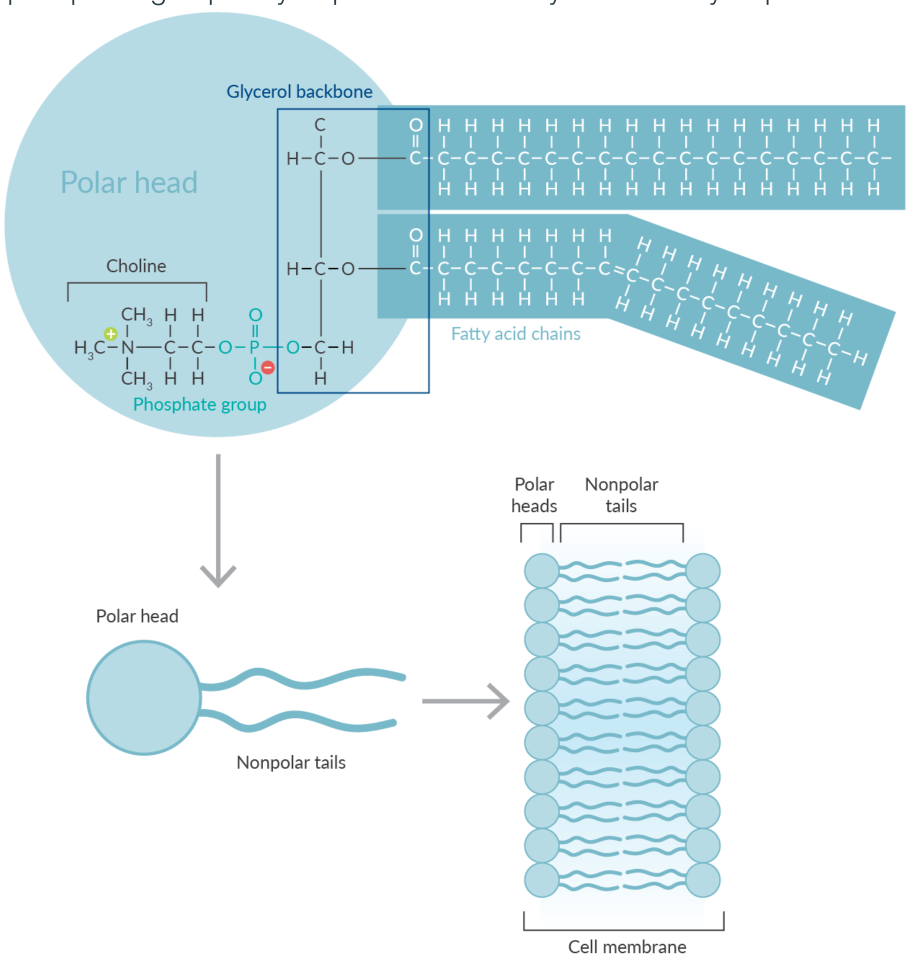
Phospholipids:

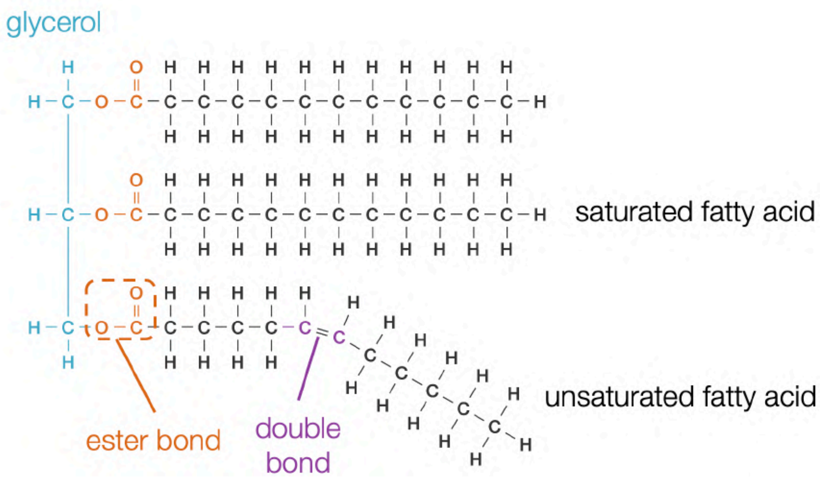
- o composed of a glycerol linked to two fatty acids and one phosphate group
- o by condensation reactions
- o forming covalent ester bonds
- o the phosphate group is hydrophilic and the fatty acids are hydrophobic

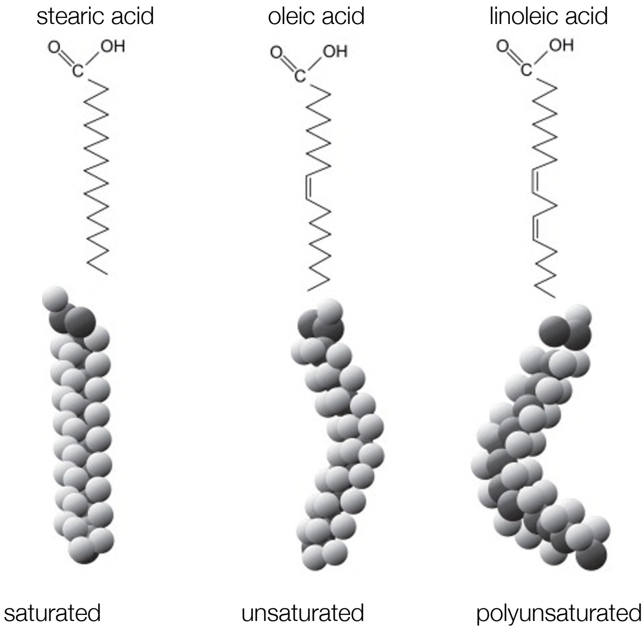


Cayman Chem

10SL Difference Between Saturated, Monounsaturated And Polyunsaturated Fatty Acids

Fatty acids:
- saturated - all carbon atoms are linked by single covalent bonds to hydrogen atoms
- monounsaturated - contain one double bond between two carbon atoms
- polyunsaturated - contain two or more double bonds between carbon atoms





Lichtenstein 2013

Double bonds put a bend in the fatty acid so they do not pack together as easily which lowers the melting point of the lipid.

fatty acid	carbons	double bonds	melting point (°c)
stearic acid	18	0	69
oleic acid	18	1	13
linoleic acid	18	2	-5

Triglycerides with saturated fatty acids have a higher melting point.
Those with more unsaturated fatty acids have a lower melting point.

11SL Triglycerides In Adipose Tissues For Energy Storage And Thermal Insulation

Triglycerides are used for energy storage.
Animals use saturated fats stored under the skin in adipose cells and around some organs.

adipocyte – fat cell

Triglycerides:

- chemically stable
- not soluble in water so can form pure droplets
  - droplets do not move out of the cell
  - droplets do not disrupt the osmotic balance of the cell
- add 1/6 as much to body mass as carbohydrates
  - as they contain twice the energy per gram of carbohydrate
  - as they are stored as pure droplets whereas when 1g glycogen is stored it is associated with 2g of water. This is especially critical for birds and bats.
- poor conductors of heat so act as insulators to reduce heat loss
- liquid at body temperature so able to absorb physical impacts to the body
- less dense than water which increases buoyancy of aquatic animals

In polar regions warm blooded mammals and birds have a thick layer of fat called blubber.
Such a layer acts as insulation and as an energy store during hibernation or when incubating eggs.

Respiration of lipids releases more water than carbohydrates.
This metabolic water is important for desert mammals and forms all the water intake for marine mammals that cannot drink salt water.

	Kangaroo Rat	Human
Daily Water Gain (milliliters):	60 ml	2600 ml
By ingesting solids	10%	33%
By ingesting liquids	0%	54%
By metabolism	90%	13%
Daily Water Loss (milliliters):	60 ml	2600 ml
In urine	23%	58%
In feces	4%	8%
By evaporation	73%	34%

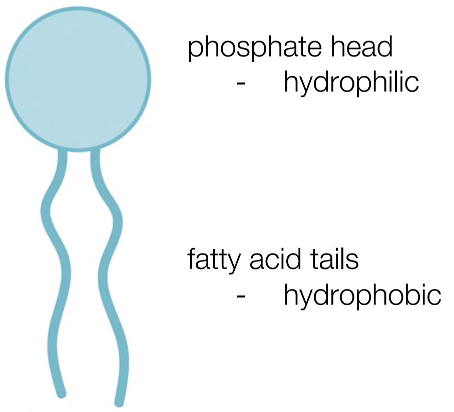
biology forums

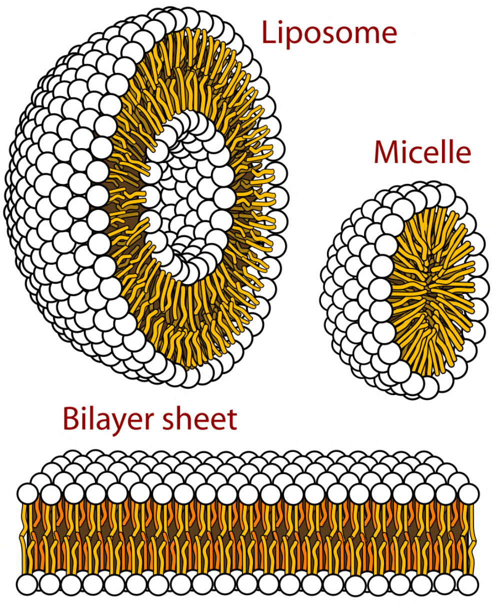
12SL Formation Of Phospholipid Bilayers Due To The Hydrophobic And Hydrophilic Regions

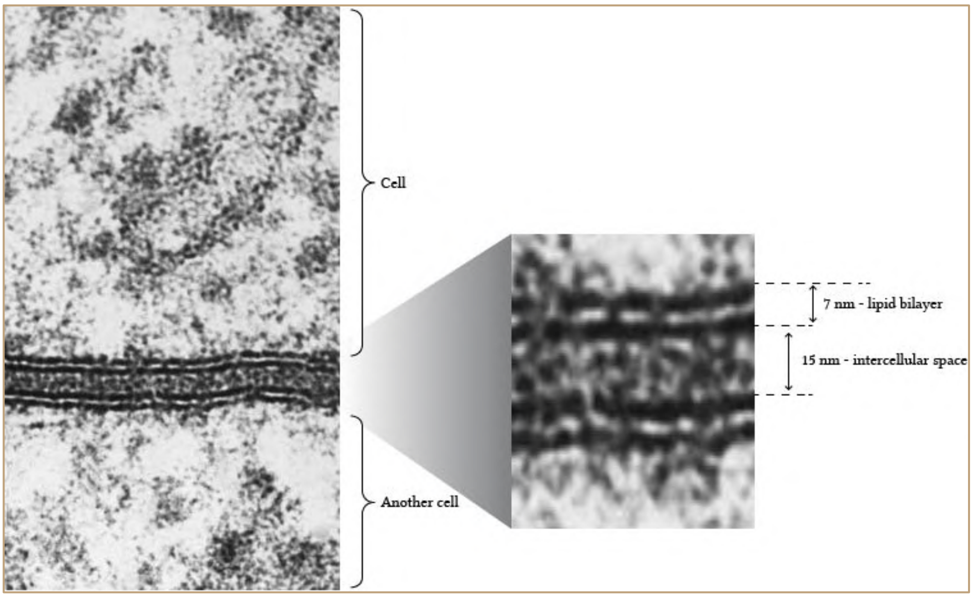
amphipathic – a molecule having both hydrophilic (polar) and hydrophobic parts (non-polar)

Phospholipids are a main component of cell membranes.
They are amphipathic with a hydrophilic phosphate head and a hydrophobic fatty acid tail.

When phospholipids are poured into water a lipid bilayer can form on the surface.
Hydrophobic tails flip inwards and hydrophilic heads are attracted outwards to the water.
A stable barrier forms between the internal and external watery environments of a cell.





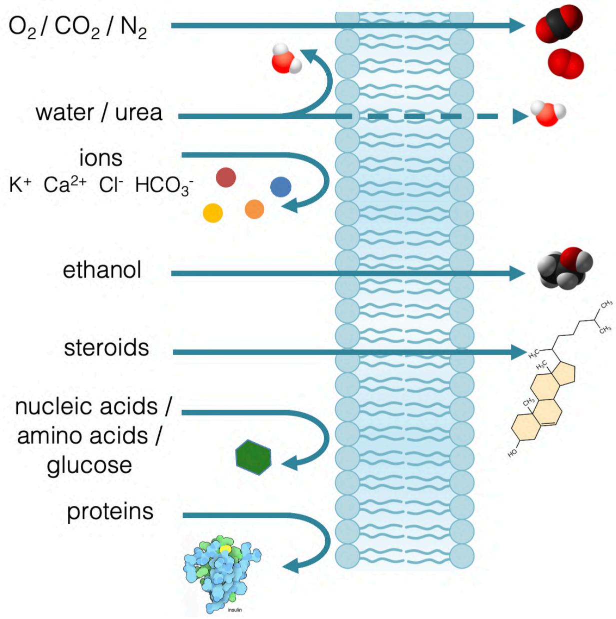


TEM plasma membranes of two cells.

13SL Ability Of Non-Polar Steroids To Pass Through The Phospholipid Bilayer

Small, non-polar and uncharged molecules can diffuse across a cell membrane.

Steroids:
- o small
- o have four fused carbon rings
- o amphipathic molecule with mainly hydrophobic parts (non-polar) and hydrophilic (polar)
- o able to pass through the cell membrane
    - this is an important feature as many steroids are hormones



Examples:
- oestradiol a female sex hormone
- testosterone a male sex hormone
- cortisol a hormone released by the adrenal gland when stressed
- cholesterol

Cholesterol is an important component of animal cell membranes.
Plant cell membranes use phytosterols.

Cholesterol is an amphipathic molecule:
- hydroxyl group (-OH) is hydrophilic and aligns with phospholipid heads
- steroid ring structure is rigid
- hydrocarbon tail is hydrophobic and flexible, it aligns with phospholipid tails

This reduces membrane fluidity and increases membrane thermal stability and flexibility.