UNIT 2 - BIOLOGICAL MOLECULES

2.2 - The building blocks of life
The 4 most common elements in living organisms in order of abundance that account for more than 99% of all the atoms in every organism:

- Hydrogen
- Carbon
- Oxygen
- Nitrogen

Simple biological molecules are very little in variety, e.g. there are only 20 different amino acids, but so many different proteins. This is because smaller biological molecules combine together to form larger, more diverse molecules, known as macromolecules.

2.3 - Monomers, polymers and macromolecules
Macromolecules are giant molecules made up of smaller molecules. The 3 main macromolecules in living organisms are:

- Polysaccharides: made up of monosaccharides
- Proteins (also known as polypeptides): made up of amino acids
- Nucleic acids (also known as polynucleotides): made up of nucleotides

Macromolecule - a large molecule such as a polysaccharide, protein or nucleic acid

Macromolecules are also described as **polymers** because they are made up of repeating subunits that are similar or identical to each other, also known as **monomers**. Monomers are joined by covalent bonds including:

- The glycosidic bond
- The peptide bond
- The ester bond

Polymer - a giant molecule made from many similar repeating subunits joined together in a chain; the subunits are much smaller and simpler molecules known as monomers.

Making biological polymers
Making biological polymers from monomers is simple because the same reaction is repeated over and over again. This reaction involves joining two monomers by the removal of a water molecule, a.k.a a condensation reaction. The opposite (adding water) can be done to break down the polymer, a.k.a hydrolysis.

Naturally occurring polymers:	Industrially produced polymers:
Cellulose	Polyester
Rubber	Polyethene
Starch	Polyvinyl chloride (PVC)
Chitin	Nylon

Monomer - a relatively simple molecule which is used as a basic building block for the synthesis of a polymer; many monomers are joined by covalent bonds to make the polymer; common examples of monomers are monosaccharides, amino acids and nucleotides

Condensation reaction - a chemical reaction involving the joining together of two molecules by the removal of a water molecule

Hydrolysis - a chemical reaction in which a chemical bond is broken by the addition of a water molecule; commonly used to break down complex molecules into simpler molecules

Monosaccharide - a molecule consisting of a single sugar unit and with the general formula $(CH_2O)_n$.

2.4 - Carbohydrates
All carbohydrates contain carbon, hydrogen and oxygen. '-hydrate' refers to water; the hydrogen and oxygen atoms are always present in the ratio of 2:1. The general formula for a carbohydrate is $C_x(H_2O)_y$. Carbohydrates are divided into three main groups:

- Monosaccharides
- Disaccharides
- Polysaccharides

Monosaccharides:

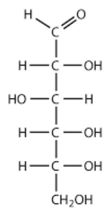
- Dissolve easily in water (form sweet-tasting solutions)
- Consist of one sugar molecule
- General formula of $\mathbf{(CH_2O)_n}$

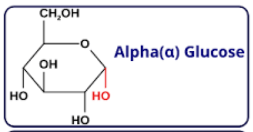
The main types of monosaccharides – when classified according to the number of carbon atoms in each molecule – are trioses (3C), pentoses (5C), and hexoses (6C). Common hexoses are:

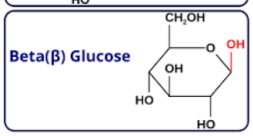
- Glucose

∟ Fructose
∟ Galactose

Molecular and structural formulae
The molecular formula for hexose is written as $C_6H_{12}O_6$. The most common monosaccharide is glucose and its structural formula is:







This is a straight-chain formula. The atoms are displayed in a straight line. In nature however, glucose is found in a **ring structure**, meaning this straight-chain is folded in on itself. This makes the molecule more stable.

Alpha glucose (α-glucose) is what the ring is referred to when the OH bond is below the plane of the ring. Beta glucose (β-glucose) is when the OH bond is above the plane of the ring.

Two forms of the same chemical are known are isomers, and the extra variety provided by both alpha and beta glucose types has important biological consequences.

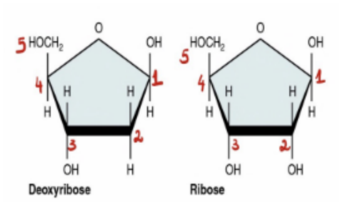
Functions of monosaccharides in living organisms

Monosaccharides are commonly used as energy sources in respiration due to their large number of carbon-hydrogen bonds which can be broken to release energy. The most important monosaccharide in this process is glucose.

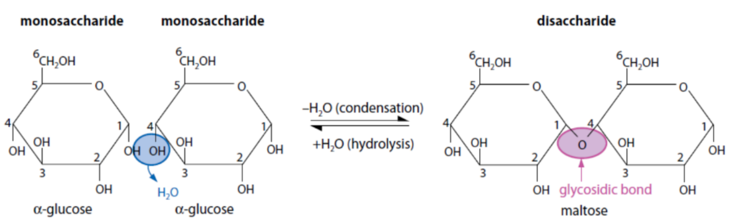
Monosaccharides are also important as they are the monomers for larger molecules, e.g., glucose is used to make starch, glycogen and cellulose.

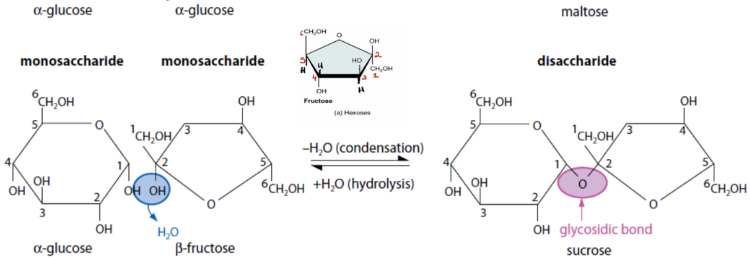
Pentoses, such as ribose and deoxyribose, join together to make RNA and DNA, respectively. The general formula for pentoses is $C_5H_{10}O_5$, with the exception of deoxyribose whose general formula is $C_5H_{10}O_4$.

Disaccharides and the glycosidic bond



Disaccharides are also sugars and are formed when two monosaccharides join together after a condensation reaction (when a water molecule is removed) to form a glycosidic bond. The three most common disaccharides are:
∟ Maltose (glucose + glucose)
∟ Sucrose (glucose + fructose)
∟ Lactose (glucose + galactose)





★ <u>Maltose</u>
∟ Formed during the digestion of starch by amylase (enzymes), a process that occurs in animals and germinating seeds
∟ Germinating seeds are used to brew beer. The conversion of starch to maltose is known as <u>malting</u>, and the maltose collected is then fermented into alcohol.

★ <u>Lactose (milk sugar)</u>
∟ An important source of nutrition for young mammals which is digested slowly and provides a steady release of energy

★ <u>Sucrose (cane sugar)</u>
∟ The most abundant disaccharide in nature, mainly found in plants as a transport sugar because of its solubility.
∟ Relatively unreactive and so does not interfere with metabolism
∟ Commercially available sugar

Glycosidic bond - a C — O— C link between two sugar molecules, formed by a condensation reaction; it is a covalent bond.

Polysaccharides
Polysaccharides are polymers made by joining many monosaccharides together through condensation. The most important polysaccharides are:
∟ Starch
∟ Glycogen
∟ Cellulose

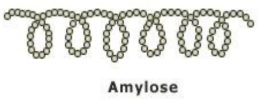
Polysaccharides are NOT sugars.

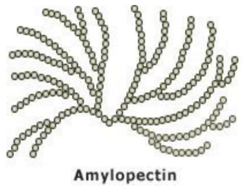
★ Starch and glycogen

∟ Starch and glycogen are both polymers of glucose, as this monosaccharide is the main source of energy.

∟ Starch is an energy storage molecule found in plants, not animals, and is made up of α-glucose molecules. It has two components, **amylose** and **amylopectin**, both which accumulate to form large, visible starch grains.

∟ Glycogen is found in the liver and muscle tissue of animals and is also a polymer of α-glucose. Its structure is almost identical to that of amylopectin, but it is even more branched.





Amylose

Amylose is a straight, unbranching chain made up of α-glucose molecules joined by 1-4 glycosidic bonds.

The one-sided bonds cause the structure to curl up and form a helical shape, making it more compact.

In the presence of potassium iodide, this structure turns the solution **blue-black** in colour.

Amylopectin

∟ Amylopectin is made up of shorter chains of 1-4 glycosidic bonds than amylose.

It is very branched, with 1-6 glycosidic bonds between the branches and the main body of the structure, resulting in more glucose residues than amylose

∟ In the presence of potassium iodide, this structure turns the solution **red-purple** in colour.

Polysaccharide - a polymer whose subunits are monosaccharides joined together by glycosidic bonds

Glycogen - a polysaccharide made of many glucose molecules linked together that acts as a glucose store in liver and muscle cells.

★ Cellulose

∟ A polymer of β-glucose and, unlike starch and glycogen, it is a structural molecule used to strengthen cells.

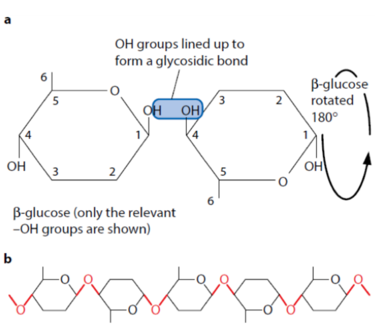
∟ 20-40% of a plant cell's cell wall is made up of cellulose

∟ Since β-glucose molecules have one OH group pointing upwards and one pointing downwards, every molecule must be rotated 180° (flipped 180°) so that glycosidic bonds can be made. B 1-4 bonds result in a straight chain rather than a curled one.

∟ The OH groups in cellulose point out in all directions, and there are hydrogen bonds between H from OH groups and O from ring or OH groups

∟ Hydrogen bonds, on their own, are relatively weak, but when present collectively, as in cellulose between chains, provide immense strength.

∟ Microfibrils are made up of 60-70 cellulose molecules cross-linked by hydrogen bonds. Microfibrils make up fibres which have immense tensile strength (almost equivalent to that of steel).

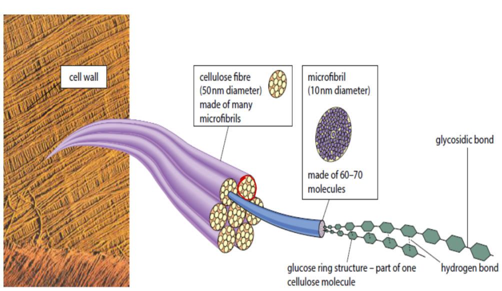


Functions of cellulose

∟ They form several layers around plant cells and prevent the cells from bursting due to the pressure by water entry by osmosis, which makes the cell turgid, providing support for the plant.

∟ The arrangement of fibres also helps determine the shape of the cell as it grows.

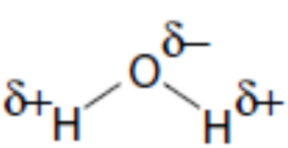
∟ It is also freely permeable to water and solutes both which are vital for the functioning of a cell.



Cellulose - a polysaccharide made from beta glucose subunits; used as a strengthening material in plant cell walls

Dipoles and hydrogen bonds

When atoms are held together by covalent bonds, they share electrons with each other. Sometimes, the distribution of electrons across the molecule is not even, and this unequal distribution of charge is called a dipole. For example, in water, the electrons are not shared equally between H and O, and so this leads to the O atom having a delta negative charge, and the H atoms having delta positive charges.



In water, the negatively charged oxygen of one molecule is attracted to the positively charged hydrogen of another. This attraction is called a hydrogen bond.

Hydrogen bond - a relatively weak bond formed by the attraction between a group with a small positive charge on a hydrogen atom ($H^{\delta+}$) and another group carrying a small negative charge ($^{\delta-}$), e.g. between two – $O^{\delta-}$ $H^{\delta+}$ groups.

Dipoles occur in many different molecules, particularly where there is an — OH, –CO or — NH group. Hydrogen bonds can also form between these groups because of the attraction between positively and negatively charged atoms.

Molecules with dipole groups are said to be polar. Polar molecules are therefore attracted to water and so referred to as hydrophilic (and are soluble in water). Molecules that do not have dipole bonds are said to be non-polar, and repel water and are referred to as hydrophobic (and are not soluble in water).

2.5 - Lipids

Lipids are a varied group of chemicals that are organic molecules insoluble in water. Most lipids are formed by combining fatty acids with alcohol. The most common lipids are fats and oils. Fats are solid at r.t.p and oils are liquid at r.t.p, chemically they are very similar.

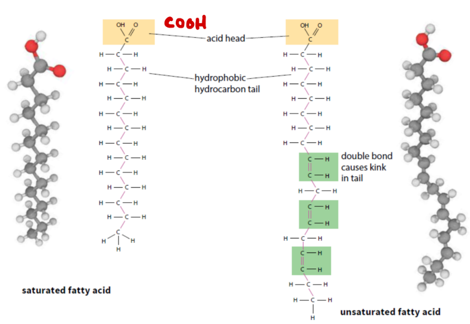
Fatty acids

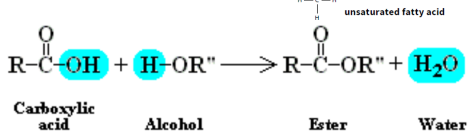
Fatty acids contain the acidic group –COOH–, known as a carboxyl group, which forms the 'head' of the fatty acid molecule. The common fatty acids have long hydrocarbon tails consisting of chains of carbon atoms combined with hydrogen.

The tails of some fatty acids have double bonds between neighbouring carbon atoms (–C=C–). These fatty acids are described as being 'unsaturated' and form unsaturated lipids. These double bonds make the lipids melt more easily. If there is more than one double bond in the fatty acid, it is described as polyunsaturated (only one double bond: monounsaturated). Animal lipids are often saturated and plant lipids are often unsaturated.

Alcohols and esters

Alcohols are a series of organic molecules that contain a hydroxyl group (–OH), attached to a carbon atom. Glycerol is an alcohol with 3 hydroxyl groups. The reaction between an acid and an alcohol produces an ester. The chemical link between the acid and the alcohol is known as the ester bond or ester linkage.





Ester bond/ ester linkage - a chemical bond represented as — COO —, formed when an acid reacts with an alcohol.

Triglycerides

The most common lipids are triglycerides, which are fats and oils. When a triglyceride is made, the final molecule contains three fatty acid tails and three ester bonds. These tails can vary in length depending on the fatty acid used.

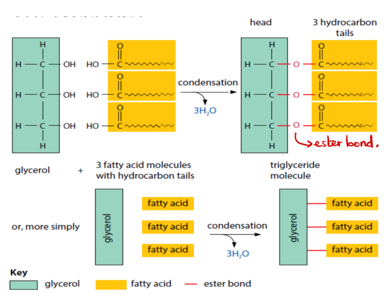
Triglycerides are insoluble in water but soluble in certain organic solvents such as ethanol, as hydrocarbon tails are nonpolar and so are hydrophobic.

Functions of triglycerides

- They are very good energy reserves because of their large number of C-H bonds
- They act as insulators below the skin and are stored in places such as around vital organs to protect them as well

They are also a metabolic source of water as when oxidised during respiration produce CO_2 and water.

Seeds like soybean are commercial sources of oil



Triglycerides - a type of lipid formed when three fatty acid molecules combine with glycerol, an alcohol with three hydroxyl (–OH) groups

Phospholipids

Phospholipids are a special type of lipid that contain glycerol, two fatty acid chains and a phosphate group (one of the OH of glycerol combines with the phosphate group instead of a third fatty acid). Since phospholipids are made up of both hydrocarbon tails (fatty acids) and a polar molecule (phosphate), they are both hydrophilic and hydrophobic. Phospholipids are therefore the perfect material for cell membranes, and are why they are referred to as 'semi permeable'.

2.6 - Proteins

Proteins are one of the three main macromolecules needed in every living organism. More than 50% of the dry mass of most cells is made up of protein. The functions of proteins include:

- Enzymes - many enzymes are proteins
- Proteins are essential components of cell membranes

- Hormones such as insulin and glucagon are proteins
- The oxygen-carrying pigments in the blood (haemoglobin and myoglobin) are proteins
- Antibodies are proteins
- Collagen is a protein (a structural one found in the bones and skin)
- Keratin, found in the hair and nails, is a protein
- Proteins may also be storage products such as casein in milk and ovalbumin in egg white

All proteins are made of the same basic monomers: amino acids.

Amino acids

There are only 20 different amino acids, but many different proteins. The general structure of amino acids is:
All amino acids have a central carbon atom, bonded to an amino group, **$-NH_2$**, and a carboxylic acid group, **–COOH**. The third component is an H atom.

The fourth and final group bonded to the central carbon atom is the R group. The simplest R group in an amino acid is just another hydrogen (H) atom (example is glycine).

The peptide bond

Two amino acids can bond together to form a dipeptide. One amino acid loses its hydroxyl group (OH group), and the other loses hydrogen from its amino group. This leaves the carbon atom of the first amino acid free to bond with the nitrogen atom of the second. This is called a peptide bond, and this reaction is an example of a condensation reaction.

Peptide bond - the covalent bond joining neighbouring amino acids together in proteins; it is a C–N link between two amino acid molecules, formed by a condensation reaction.

A molecule made up of many amino acids joined together is called a polypeptide. This is another example of a polymer. A protein may be made up of just one polypeptide chain, or more. Proteins can be broken back down into amino acids by breaking the peptide bonds.

Primary structure

A polypeptide or protein molecule may contain several hundred amino acids linked in a long chain. The particular amino acids, and the sequence which they appear in, is known as the primary structure.

Secondary structure

The amino acids in a polypeptide chain have an effect on each other. This is because of a polypeptide chain's ability to bend back on itself to coil into a corkscrew shape, forming a secondary structure.

Polypeptide - a long chain of amino acids formed by condensation reactions between the individual amino acids; proteins are made of one or more polypeptide chains.

Primary structure - the sequence of amino acids in a polypeptide or protein.

Secondary structure - the structure of a protein molecule resulting from the regular coiling or folding of the chain of amino acids (an α-helix or β-pleated sheet).

A tightly coiled chain is referred to as an α-helix. An α-helix structure is due to hydrogen bonding between the oxygen of the C=O group and the hydrogen of the NH group of two amino acids.
Sometimes the hydrogen bonding can result in a looser, straighter shape than the alpha helix, and is then called a **β-pleated sheet**.

Although the hydrogen bonds are strong enough to hold the two sheets/coils together, they are easily broken by high temperatures and pH changes (which is why enzymes, which are proteins, have optimum temperatures and pHs which we should not exceed).

α-helix - a helical structure formed by a polypeptide chain, held in place by hydrogen bonds; an α-helix is an example of a secondary structure in a protein.

β-pleated sheet - a loose, sheet-like structure formed by hydrogen bonding between parallel polypeptide chains; a β-pleated sheet is an example of a secondary structure in a protein.

Tertiary structure

In many proteins the secondary structure itself is coiled or folded to form the tertiary structure. There are four types of bonds that keep the proteins in tertiary structures folded in exact shapes:

- Hydrogen bonds - these can form between a wide variety of R groups. Hydrogen bonds are weak in isolation but many bonds together can form a strong structure.

- Disulfide bonds - these form between two cysteine molecules. Cysteine molecules contain sulphur atoms, and the disulfide bond forms when the sulphur atoms in neighbouring cysteines join together to form a strong bond.

- Ionic bonds - these form between R groups containing amino and carboxyl groups.

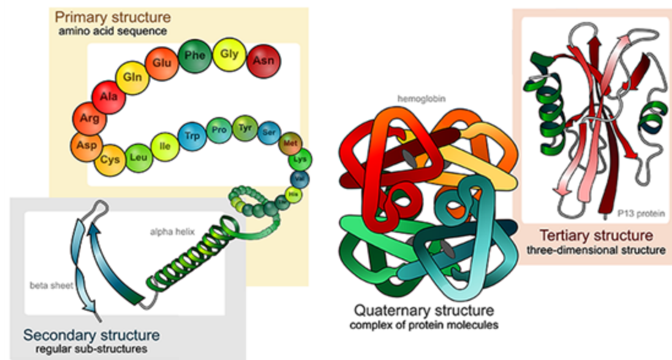
- Hydrophobic interactions - these occur between non-polar R groups. These R groups are hydrophobic and tend to avoid water as much as possible. If the protein is in a typical watery environment, these R groups will point inwards, and this affects the overall shape and 3D structure of most proteins, such as enzymes.

Quaternary structure
Many proteins are made up of two or more polypeptide chains, and so are described as having a quaternary structure. Haemoglobin is an example of such a protein.

Tertiary structure - the compact structure of a protein molecule resulting from the three-dimensional coiling of the chain of amino acids.

Quaternary structure - the three-dimensional arrangement of two or more polypeptides, or of a polypeptide and non-protein component such as haem, in a protein molecule.

Haemoglobin - the red pigment found in red blood cells, whose molecules contain four iron atoms within a globular protein made up of four polypeptides.



Globular proteins
A protein whose molecules curl up into a spherical shape such as myoglobin or haemoglobin is known as a globular protein. These proteins are spherical because the polypeptide chain/chains curl up so that their hydrophobic R groups point inwards, and their hydrophilic R groups point outwards. Globular proteins are therefore usually soluble in water, because water molecules cluster around their outward-pointing R groups.

Many globular proteins, since they're soluble, have functional properties rather than structural ones. Their precise shape is the key to their function, e.g. enzymes.

Globular protein - a protein whose molecules are folded into a relatively spherical shape, often has physiological roles and is often water-soluble and metabolically active e.g. insulin, haemoglobin and enzymes.

Haemoglobin - a globular protein
Haemoglobin is a globular protein made up of 4 polypeptide chains: 2 alpha globin (141 amino acids) and 2 beta globin chains (146 amino acids). Each chain contains a haem group, also known as a prosthetic group (non-amino acid part of the protein). Each haem group contains an iron ion. One oxygen atom binds to one iron atom forming oxyhaemoglobin, and there are four O_2 molecules in each haemoglobin molecule.

- Sickle cell anaemia is caused when a glutamic acid (polar) beta chain is substituted with valine (non polar). This reduces the solubility of the molecule and causes dangerous symptoms, such as a non-flexible red blood cell that is not soluble.

Sickle cell anaemia - a genetic disease caused by a faulty gene coding for haemoglobin, in which haemoglobin tends to precipitate when oxygen concentrations are low.

Collagen - a fibrous protein
Collagen is the most common type of protein found in animals (it makes up over 25% of the total protein in mammals). It is an insoluble, fibrous protein. Skin, cartilage, bones, tendons, teeth and the walls of blood vessels all rely on collagen to strengthen them. Collagen is made up of three non-identical polypeptide chains (1000 amino acids long), each in a helix shape but not as tightly wound as an alpha helix.

The three chains are wound around each other to form a triple helix (also referred to as tropocollagen). These chains are held together mainly by hydrogen bonds, and some covalent bonds. Glycine is present after every three amino acids, and lies on the inside of the strands. Its small size allows the three strands to lie close together and form a tight coil. Collagen is made up of a large number of repeating amino acid sequences.

Collagen - the main structural protein of all animals; known as 'white fibres', the fundamental unit of the fibre consists of three helical polypeptide chains wound around each other, forming a 'triple helix' with an immense tensile strength.

Fibrous proteins
Proteins that don't fold into a ball and form long strands of polypeptide chains are known as **fibrous proteins**. Their secondary structure is the most important and they have little to no tertiary structure. They are insoluble in water and tough, with structural rather than functional roles in the body.

Intermediate proteins are those that are fibrous but soluble in water, for example soluble fibrinogen which forms soluble fibrin when blood clots (otherwise it is soluble as it is carried around in blood plasma).

Fibrous protein - a protein whose molecules have a relatively long, thin structure that is generally insoluble and metabolically inactive, and whose function is usually structural, e.g. keratin and collagen are fibrous proteins.

2.7 - Water
Water is the most important biochemical of all living organisms. Without it, life would not exist on this planet. Although it is a simple molecule, water has some unique properties.

Required for life on earth. Water makes up 70-95% of the mass of a cell. It also provides a living environment for organisms across 3⁄4 of the planet. A molecule as small as water should be gas at r.t.p., but hydrogen bonding makes it a liquid. The hydrogen bonds increase its latent heat of vaporisation, which is the measure of the heat energy needed to vaporise a liquid. Water is a polar solvent.

Water molecules collect around polar molecules and separate them, this is dissolving. Allows molecules/ions to move about and react. Most chemical reactions in living organisms take place in solution. Water molecules also push non-polar molecules into the same space making them insoluble.

High latent heat of vaporisation:
• Hydrogen bonds have to be broken before liquid can turn to gas
• Evaporation causes cooling
• Latent heat of fusion is also high, prevents freezing of habitats
• Density and freezing properties
• Ice is less dense than water (should not be)
• Expands below 4 degree, hence density decreases
• Ice floats, insulating water underneath and increasing chances of
survival in cold climate (e.g. in Antarctica where there are still fish living under ice caps)
• Changes in density also cause current which allow nutrients to mix