Bio Factsheet

Number 91

Taxonomy and Classification

By studying this Factsheet the student should gain:
- **an understanding of the need for classification of organisms and the methods involved in classification.**
- **the ability to use and design dichotomous keys.**

The principles and importance of taxonomy

Classification is the process of sorting a variety of items into manageable groups. The study of biological classification is called **taxonomy** or **systematics**. A universally accepted system of classification is important for scientists if they are to communicate about an organism, confident in the knowledge that they are talking about the same thing. It also enables rapid access to information about a particular type of organism. The aim of classification in biology is that it reflects the evolutionary relationships (phylogeny) between organisms. As evolutionary knowledge has increased over the years it has been necessary to modify and update the classification accordingly.

Methods of classifying organisms

One of the simplest ways of sorting things into groups is to look for differences. Does the organism show a particular feature? If it does put it one group, if it does not put into the other group. Sorting into 'haves' and 'have nots' is the basis for what is described as **artificial classification**. This is a useful approach to identifying organisms through the creation of dichotomous keys (see later).

A **natural classification** system uses similarities between organisms. These similarities can be of two types, homologous and analogous characteristics:

- **Homologous** characteristics have an underlying similarity of origin, structure and position irrespective of function. For example, the flipper of a dolphin, arm of a human, wing of a pigeon and wing of a bat are homologous because they are all modifications of the same structure, the vertebrate pentadactyl (5 fingered) limb.

- **Analogous** characteristics have similarity of function but they are not homologous. For example, the wings of insects and birds have the same function, flight, but their structures are very different. The wing of an insect is not developed from the basic pentadactyl limb.

A modern system of natural classification of organisms uses morphological, anatomical, biochemical, behavioural, chromosomal and genetic fingerprinting characteristics in an attempt to classify organisms according to their evolutionary (phylogenetic) relationships. Species are placed in the same group only on the basis of shared homologous features and shared evolutionary history.

The taxons of the classification

A **taxon** is a grouping of organisms which share some basic features. Every taxon has a status, for example, phylum, class, order and so on which it shares with other taxa, and an individual name, for example, the phylum Arthropoda. There are basically seven levels of taxon; from the largest to the smallest these are:

kingdom, phylum, class, order, family, genus and species.

> ***Exam Hint:-*** *An easy way to remember this order is by using the saying: King Philip Came Over From Germany Swimming*

A **species** is defined as a group of organisms that shows many marked phenotypic similarities in terms of external morphology, internal anatomy, biochemistry and behaviour. In addition, individuals within a species have the potential to breed with others in the group, producing **viable (fertile) offspring** that are themselves capable of producing viable offspring. The species is usually taken to be the basic taxon (category) for a classification hierarchy.

Sometimes it is possible to recognise sufficient, subtle but consistent variation within members of a species to justify subdividing the group. Such groups are called sub-species.

An internationally accepted system exists to name organisms. **Linnaeus** introduced the **binomial nomenclature system** in the eighteenth century. Each species has two Latin names. The first names the **genus** and always has a capital initial letter. The second names the particular **species** within the genus. This name always has a lower-case initial letter.

Where it is obvious which genus is being referred to, the generic part of the name may be abbreviated to its initial letter (see the prokaryote in table 1 overleaf). If a sub-species is recognised then a third name may be used, once more starting with a small initial letter. It is accepted practice to use *italics* when a binomial is in *print* or <u>underlined</u> when <u>hand-written</u>.

> ***Remember*** *- A group of related* ***species*** *forms a* ***genus*** *and related genera form a* ***family****. Several related families group to form* ***orders****, orders into* ***classes****, classes into* ***phyla*** *(singular phylum) and phyla into* ***kingdoms****.*

The classification of living organisms into five kingdoms

It is currently accepted that there are five kingdoms. These are called:

Prokaryotae; **Protoctista**; **Fungi**; **Plantae**; **Animalia**.

The taxonomic divisions are illustrated by the classification of five organisms in Table 1 overleaf. (You do not have to remember all of these names – check on your specification to determine which organisms are listed).

> ***Exam Hint****: - Make sure that you have learnt the characteristic features of each kingdom. Questions about these are asked frequently.*

Table 1. Classification of some organisms in the five kingdoms

Taxon	*E.coli*	Saw wrack	Yeast	Horse chestnut	Human
Kingdom	Prokaryotae	Protoctista	Fungi	Plantae	Animalia
Phylum	Gracilicutes	Phaeophyta	Ascomycota	Angiospermophyta	Chordata
Class	Proteobacteria	Phyophyceae	Ascomycetes	Dicotyledoneae	Mammalia
Order	(gamma subdivision)	Fucales	Endomycetales	Sapindales	Primates
Family	Enterobacteriacae	Fucaceae	Endomycetaceae	Hippocastanaceae	Homidae
Genus	*Escherichia*	*Fucus*	*Saccharomyces*	*Aesculus*	*Homo*
Species	*coli*	*serratus*	*cerevisiae*	*hippocastanum*	*sapiens*

The distinguishing characteristics of each kingdom.
Terms marked with * are explained in the glossary.

Prokaryotae*
- Cells have no nucleus.
- Cells have no membrane-bound organelles.
- Cells lack organelles based on a 9 + 2 arrangement of microtubules.*
- Cells have circular DNA.

Examples: all bacteria, including blue-green bacteria.

Protoctista
- Organisms found in this kingdom are eukaryotes* that have characteristics that exclude them from any of the other kingdoms. If an organism is eukaryotic, but is not a member of the Fungi, Plantae or Animalia then it is a member of the Protoctista.

Examples: all protozoa such as *Amoeba*, all nucleated algae and slime moulds.

Fungi
- Eukaryotes.
- Possess outer walls made from polysaccharides. The walls contain chitin but no cellulose.
- Heterotrophic nutrition, either saprophytic or parasitic. Not photosynthetic.
- Store carbohydrate as glycogen.
- Vegetative part of most fungi involves coenocytic* hyphae* that form a mycelium.*
- Reproduce by spore production. The spores have no flagella.

Examples: *Mucor* (pin mould), *Penicillium* and *Agaricus* (mushroom)

Plantae
- Multicellular eukaryotes.
- Cells have cellulose walls.
- Majority possess chloroplasts and are photosynthetic autotrophs.

Examples: mosses, ferns and flowering plants.

Animalia
- Multicellular eukaryotes.
- Heterotrophic nutrition.
- Simpler animals are diploblastic* and show radial symmetry*.
- More complex animals are triploblastic* and show bilateral symmetry*.
- Some triploblastic animals have a coelom*.

Examples: jellyfish, tape worms, earthworms, insects, fish, birds, mammals.

Glossary of terms

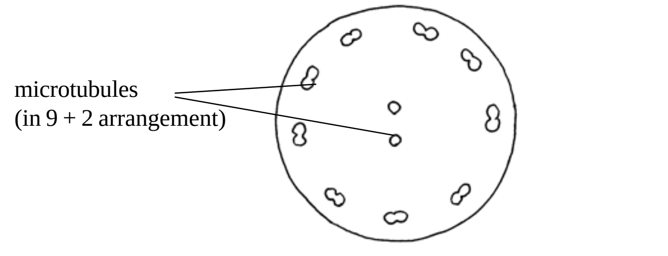
Prokaryotic: This refers to minute cells which lack a membrane-bound nucleus, lack membrane-bound organelles, and lack any organelles based on a 9 + 2 arrangement of microtubules. They have a single circular chromosome (DNA) and may also contain small ringlets of DNA known as plasmids.

Eukaryotic: This refers to cells which have a membrane-bound nucleus with chromosomes, membrane-bound organelles, such as mitochondria, and organelles with a 9 + 2 arrangement of microtubules, such as centrioles.

Microtubules: These are long, hollow, cylindrical structures made of a protein called tubulin. They run in all directions through the cytoplasm, making up the cytoskeleton.

They also are arranged into a 9 + 2 arrangement of parallel running tubules, making up the structure of centrioles, cilia and flagella. A transverse section through a flagellum is shown in Fig 1.

Fig 1. Electron micrograph of a flagellum in transverse section.



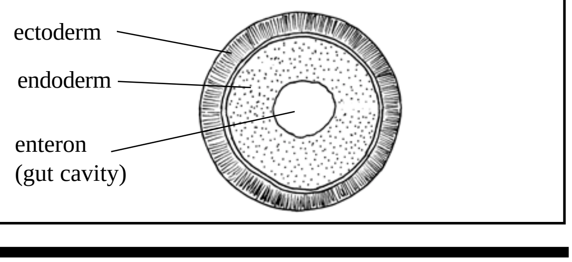
Hyphae: These are the white thread-like structures that form a network making up the body of a fungus.

Mycelium: This is the whole body of the fungus, made up of hyphae.

Coenocytic: This refers to a structure consisting of a mass of cytoplasm and nuclei but not divided into cells. (‘Syncytial’ is often used as an alternative word for coenocytic).

Diploblastic: This refers to an animal that has two basic germ layers in its body, the ectoderm and the endoderm. Germ layers consist of cells that can differentiate into particular tissues. For instance, ectoderm cells can differentiate into nervous tissue, endoderm cells differentiate into the lining cells of the digestive tract. Fig 2 shows a transverse section through a diploblastic animal (sea anemone).

Fig 2. Transverse section through a diploblastic animal



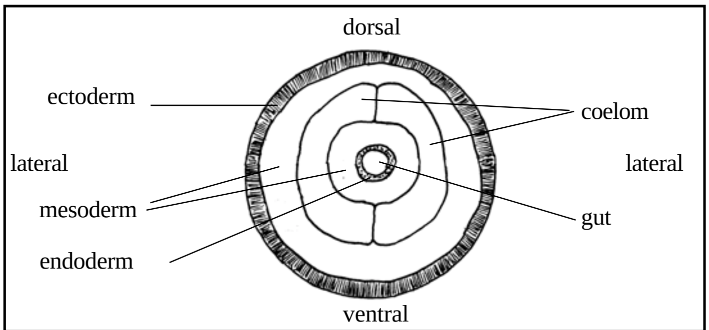
Radial symmetry: Refers to an animal (or flower) that can be cut in any vertical plane to produce two mirror image halves. This has the advantage that stimuli can be received equally well from all directions and responses made in all directions. The sea anemone in Fig 2 illustrates radial symmetry.

Triploblastic: This refers to an animal that has three basic germ layers in the body, the ectoderm, mesoderm and endoderm. The mesoderm can differentiate into blood, muscle tissues and skeletal tissues. Fig 3 shows a section through a triploblastic animal, of earthworm type.

Bilateral symmetry: This refers to an animal (or flower) that can only be cut down one vertical axis to produce two mirror image halves. This symmetry allows development of specialisation into anterior, posterior, dorsal, ventral and lateral parts of the body (Fig 3).

Coelom: This is a body cavity which develops inside the mesoderm. It gives room to enable the organs to move. A coelom can be seen in Fig 3.

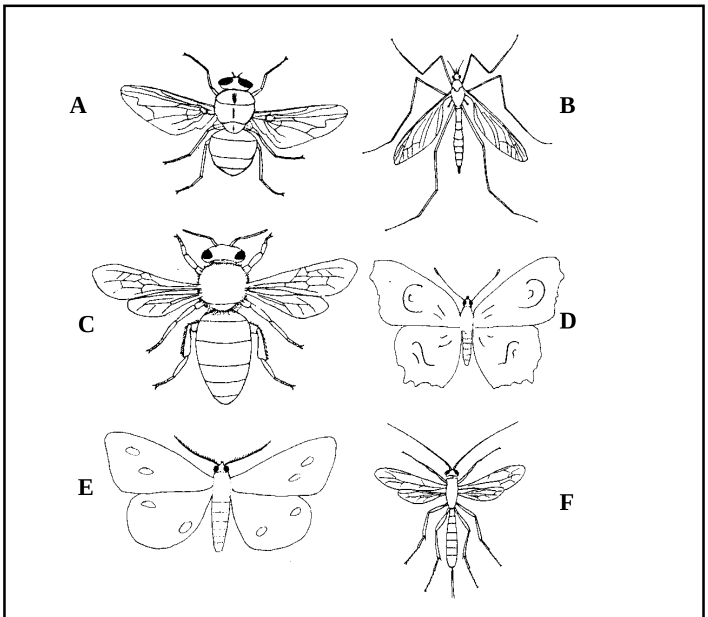
Fig 3. Transverse section through a triploblastic coelomate animal



Dichotomous keys

Keys are used for categorising and identifying organisms. In a dichotomous key, the defined group of organisms is divided into <u>two</u> subgroups on the basis of one easily observed characteristic. The procedure is repeated with each of the subgroups, using a different characteristic in each case, until all the types of organism have been separated into their own subgroup. Each stage of the key must have no more than two alternatives. The key below illustrates how the six insects shown in Fig 4 may be separated.

Fig 4. Drawings illustrating features of six types of insect.



There are numerous ways of doing the key. The following is an example only.

1.	insect has 1 pair of wings	go to 3
2.	insect has 2 pairs of wings	go to 5
3.	abdomen has 4 segments	Species A
4.	abdomen has 7 segments	Species B
5.	antennae clubbed	Species D
6.	antennae not clubbed	go to 7
7.	wings small in area relative to body	go to 9
8.	wings much larger than body	Species E
9.	abdomen/body is thin	Species F
10	abdomen/body is thick	Species C

> ***Exam Hint:*** *– A common error made by students is to have more than two alternatives in one or more steps of their key. Only truly dichotomous keys are acceptable to the examiners. Only a single characteristic should be used at each step.*

Practice Questions

1. The table below refers to four of the five taxonomic kingdoms.

Kingdom	Features	Examples
Fungi		
Protoctista		
Plantae		
Animalia		

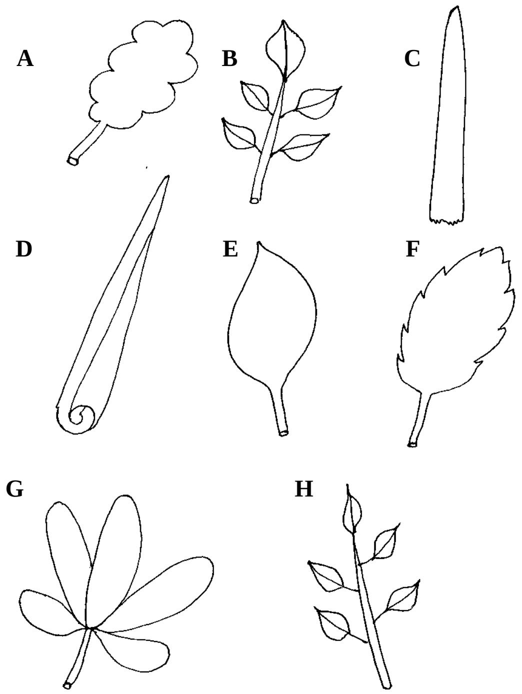
(a) Select features from the following list and write them in the appropriate features box on the table. Some features may be used more than once, or may not be relevant. You should write <u>three</u> features in each box.

has eukaryotic cells, has prokaryotic cells, has cellulosic cell walls, has chitinous cell walls, autotrophic, heterotrophic, consists of hyphae, often unicellular or groups of similar cells, always multicellular, have nervous coordination. 4

(b) Select organisms from the following list and complete the table by placing them in the appropriate examples box. Give <u>two</u> examples in each box.

Green algae, *Penicillium*, Ferns, Mushrooms, Bacteria, *Amoeba*, Malarial parasite, Dicotyledons, *Mucor*, Frog, Moss, Viruses, Tapeworm, Spider. 4

2. Devise a dichotomous key which would distinguish the following leaves. Only use features that are visible in the drawings.



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3. The full classification of the tiger is as follows:

Kingdom:	**Animalia**
Phylum:	**Chordata**
Class:	**Mammalia**
Order:	**Carnivora**
Family:	**Felidae**
Genus:	***Panthera***
Species:	***P. tigris***

(a) (i) Suggest two features of tigers that place them into the animal kingdom. 2

(ii) Suggest two features of tigers that place them in the class Mammalia. 2

(iii) Suggest one feature of a tiger that places it in the order Carnivora. 1

(b) (i) The family Felidae is the cat family. Suggest another family of animals which is classified in the Carnivora. 1

(ii) The genus Panthera includes the tigers and panthers. Name another genus of the family Felidae. 1

(c) The classification of a group of organisms is supposed to represent their phylogeny. What does this mean? 2

Answers

1.

Kingdom	Features	Examples
Fungi	eukaryotic, heterotrophic, consists of hyphae chitinous cell walls;	mushrooms *Penicillium* *Mucor*;
Protoctista	eukaryotic, heterotrophic (some), autotrophic (some), unicellular or groups of similar cells;	*Amoeba* green algae malarial parasite;
Plantae	eukaryotic, autotrophic, multicellular, cellulosic cell walls;	moss ferns dicotyledons;
Animalia	eukaryotic, heterotrophic, multicellular, have nervous coordination;	tape worm spider frog;

(a) 1 mark per box with three correct features and no incorrect features. 4
(b) 1 mark per box with two correct examples and no incorrect examples. 4

2.

1.	leaves simple/not divided	go to 3
2.	leaves compound/divided into leaflets	go to 11
3.	leaves spear/lance-shaped/isobilateral.	go to 5
4.	leaves with broad lamina/dorsi-ventral	go to 7
5.	leaf rolled/curled	leaf D
6.	leaf flat	leaf C
7.	leaf with smooth margin	leaf E
8.	leaf with shaped margin	go to 9
9.	margin lobed	leaf A
10.	margin serrated	leaf F
11.	leaflets all arise from tip of petiole	leaf G
12.	leaflets arise along side of petiole	go to 13
13.	leaflets arise opposite to each other	leaf B
14.	leaflets arise alternately/not opposite	leaf H

Allow 1 mark for each leaf correctly separated. 8
Allow 1 mark for a correct dichotomous key. 1
Accept alternative keys if correct and clear**.**

3. (a) (i) has nervous coordination;
is non-photosynthetic/heterotrophic; 2

(ii) has skin with hair in follicles;
viviparous/has gestation periods/young born from uterus;
has mammary glands/young fed on milk; 2

(iii) only eats meat/ref. to dentition; 1

(b) (i) dog family/Canidae/bear family/Ursidae/any other correct example; 1

(ii) *Leo*/lion genus/*Felis*/domestic cat genus/any other correct example; 1

(c) the classification represents the evolutionary history/evolutionary affinities of organisms;
the closer two types of organisms are in the classification, the closer their evolutionary relationship; 2

Acknowledgements:
This Factsheet was researched and written by David Baylis
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Bio Factsheet

Number 8

The Cell Surface Membrane

The cell surface membrane (formerly called the plasma membrane) surrounds the cytoplasm of eukaryotic cells. The membrane forms a selectively permeable barrier, controlling the substances that enter and leave the cell and therefore enables the cell to regulate its internal environment.

Structure
The cell surface membrane is approximately 7.5nm thick and consists of a bilayer of lipids along with a highly variable component of protein. Some of these proteins are embedded in the surface of the membrane whilst others (intrinsic proteins) span the entire width of the membrane. This is known as the **fluid mosaic model** (Fig 1).

Lipids
There are three types of lipid in the cell surface membrane.

1. Phospholipids - which make up 75% of the lipid. Phospholipids are amphipathic molecules - this means that they have a dual nature in that one end of the phospholipids (the phosphate group) is hydrophilic (water-loving and polar) whilst the other end of the phospholipid (the fatty acid chains) is hydrophobic and non-polar. The phospholipid bilayer forms spontaneously with the non-polar fatty acid chains facing inwards towards each other and the polar phosphate groups facing outwards into the extra-cellular fluid and the inside of the cell (both of which are water-based environments).

   The interaction between the hydrophobic and hydrophilic ends helps give the membrane stability and it is also these lipids which give the membrane selective permeability. Lipid soluble (hydrophobic) molecules easily pass through the membrane by diffusion whilst hydrophilic substances cannot diffuse through; instead they cross the membrane via water-filled pores or channels in intrinsic proteins.

2. Glycolipids - which make up 5% of membrane lipids. Glycolipids occur on the external surface of the cell surface membrane and the carbohydrate portion of the glycolipid extends into the intercellular space and is called a **glycocalyx**. These are important in cell-to-cell recognition.

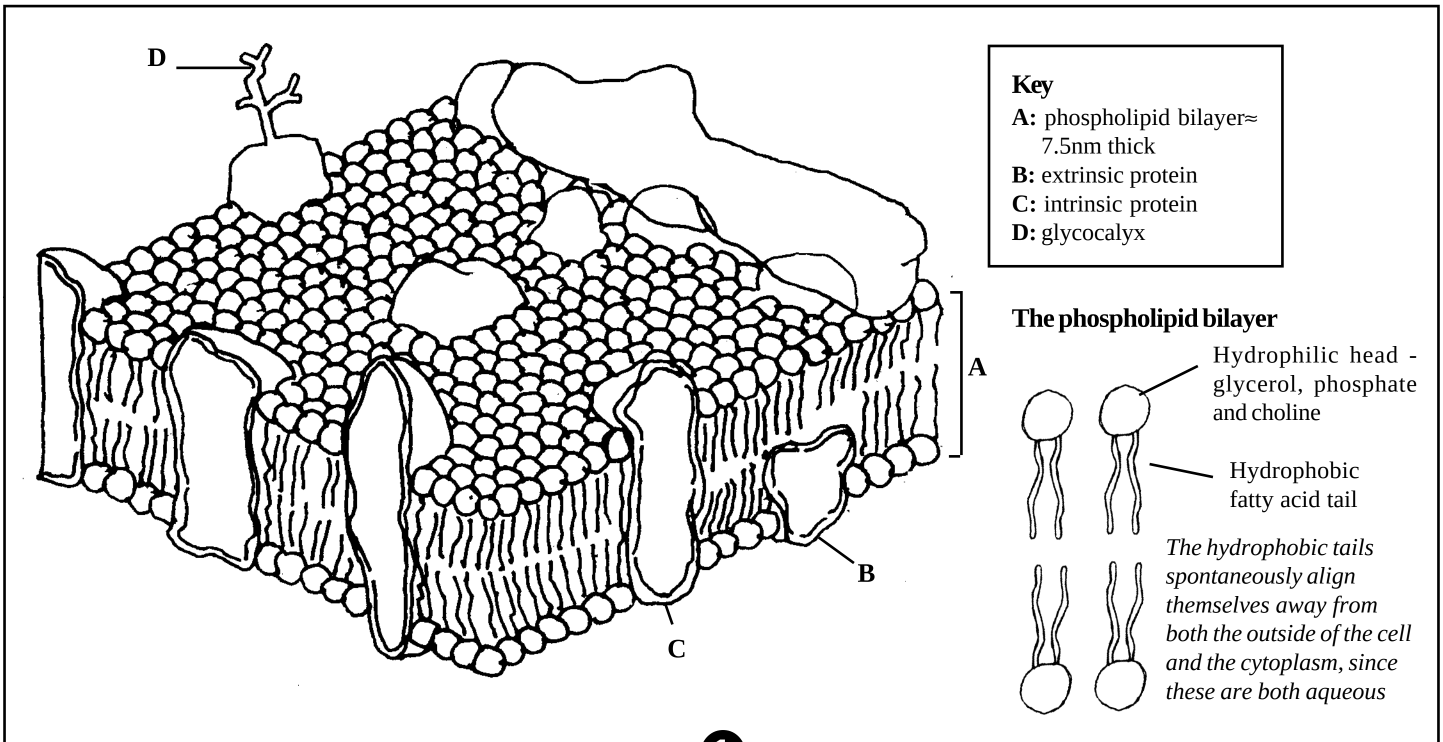
3. Cholesterol - a steroid which makes up 20% of lipids in animal membranes but is rarely found in plant cell membranes.

All lipids can move sideways (laterally) within the membrane and exchange position with each other. This gives the membrane **fluidity** which is essential in processes such as phagocytosis. The degree of fluidity of cell surface membranes is determined by:

1. The length of the fatty acid side chains (the longer the chains, the lower the fluidity).
2. The proportion of the fatty acids which are saturated (the higher the percentage of saturated fats, the lower the fluidity).
3. The steroid content (the higher the steroid content, the lower the fluidity).

> ***Exam Hint*** *- Although most candidates can recall the name of the model (fluid mosaic) a surprising number of candidates are unable to sketch the arrangement of phospholipids in the model. Similarly many candidates appear confused about which part of the phospholipid molecule is polar.*

Fig 1. The fluid mosaic model of the cell surface membrane



Proteins

Intrinsic proteins - those which span the entire membrane - are usually glycoproteins. They have four main functions:

1. To act as channels. By maintaining very different concentrations of ions on either side of the membrane, the cell surface membrane maintains an electrochemical gradient between the inside and outside of the cell which is essential for the efficient functioning of, for example, the sodium/potassium pump.
2. Transporters. For example, some proteins are able to identify and attach to specific substances such as nutrients, neurotransmitters or hormones.
3. Receptors. Some proteins recognise and bind to target molecules such as hormones. For example, the surface membrane of cells in the collecting duct of the kidney recognise and respond to ADH.
4. Enzymes. For example, ATPase.

As in lipids, intrinsic proteins have a hydrophobic and hydrophilic region and the interaction between these regions confers stability on the membrane. Extrinsic proteins are embedded in, but do not span, the membrane and many have a carbohydrate portion (glycocalyx) which extends into the intercellular space.

Transport across the cell surface membrane

Substances may move across the membrane by:

1. Diffusion
2. Osmosis
3. Facilitated diffusion
4. Active transport

1. Diffusion. This is the movement of molecules or ions from a region where they are at a high concentration to a region where they are at a lower concentration until the concentrations of the two regions are equal and a dynamic equilibrium is established.

The rate of diffusion is proportional to the concentration gradient but is also influenced by the size of the ions and the distance over which the diffusion must occur. Substances which can diffuse across the cell surface membrane include oxygen, carbon dioxide, steroids, the fat-soluble vitamins (A,D,E,K), glycerol, alcohols and ammonia.

2. Osmosis. This is a specialised form of diffusion and may be defined as the diffusion of water molecules from a region where they are at a high concentration to a region where they are at a low concentration through a partially permeable membrane. The cell effectively controls the amount of water which enters across the plasma membrane by regulating the concentration of ions in the cytoplasm via the sodium/potassium pump.

3. Facilitated diffusion. This is considerably faster than normal diffusion and is used to transport molecules such as glucose, fructose, non fat-soluble vitamins, urea and many ions across the membrane.

Typical exam question

Commonly, exam questions concentrate on two key principles of facilitated diffusion:
(a) That it occurs down the concentration gradient, not against it.
(b) That no ATP is required.

Occasionally, application questions are set which test, for example, a candidate's ability to infer that the mechanism by which insulin homeostatically regulates blood concentration of glucose is by altering the rate of facilitated diffusion into cells.

Using the transport of glucose as an example, there are four key steps in facilitated diffusion:

(i) The outside of the cell surface membrane contains transport protein molecules which bind with glucose. Different cells have different types of glucose transporter.

(ii) The protein changes shape.

(iii) The glucose is transported through the membrane to the other side.

(iv) The glucose detaches from the transporter protein and the protein reverts to its original shape. The glucose is then immediately phosphorylated. This keeps the concentration of free glucose inside the cell very low, so maintaining the diffusion gradient.

The rate of facilitated diffusion is proportional to the concentration gradient and to the number of channels or transporter proteins that are available. The key point to remember is that facilitated diffusion occurs along and not against the normal diffusion gradient.

4. Active Transport. Ions such as sodium (Na^+), potassium (K^+), chloride (Cl^-), hydrogen (H^+) and molecules such as amino acids and glucose may be transported across the cell surface membrane actively - i.e. ATP is required and the movement is against the concentration gradient. Note that all of these substances can cross the membrane by facilitated diffusion if the concentration gradient is the right way round and if transporter channels are available.

Active transport commonly involves a protein which acts as a Na^+/K^+ pump. Most cells have hundreds of these pumps per square micron.

The Na^+/K^+ pump

(i) On the inside of the cell sodium ions bind to the membrane

(ii) This triggers the breakdown of ATP into ADP and the energy which is released is used to phosphorylate the protein which forms the pump.

(iii) The protein changes shape and sodium is transported to the outside of the cell.

(iv) The changed shape of the cell now allows potassium ions on the outside of the cell to bind to the protein.

(v) This triggers dephosphorylation of the protein - that is, the phosphate group is removed.

(vi) This changes the shape of the protein and potassium is transported to the inside of the cell.

(vii) There is a tendency for sodium ions to diffuse back into the cell and potassium ions back out of the cell. Since the membrane is more permeable to potassium that sodium, more ions leave the cell than enter. This reduces the tendency of water to enter the cell by osmosis - thus the Na^+/K^+ pump is a method of controlling cell volume.

Exam Hint *- Most candidates are able to differentiate between simple diffusion and active transport but very few seem able to relate the properties of substances to the mechanism by which they are able to cross the cell surface membrane and enter cells. Also, candidates show great confusion between facilitated diffusion and active transport.*

It is transport proteins of this kind which are used to actively transport substances such as glucose against their concentration gradient in the epithelial cells of the ileum and the proximal convoluted tubule cells of the nephron.

Active transport of glucose:

(i) Sodium ions are pumped out of the cell against the electrochemical gradient.

(ii) Glucose molecules and sodium ions bind to transport proteins which span the membrane.

(iii) Sodium ions then diffuse back across the membrane i.e. into the cell carrying glucose with them.

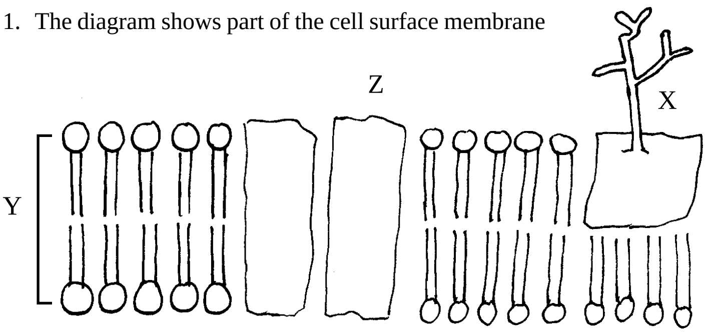
(iv) Glucose and sodium ions move apart once they are in the cell. Through this mechanism, glucose can be concentrated in particular cells, sometimes against huge concentration gradients.

Endocytosis

Phagocytosis and pinocytosis are different forms of endocytosis - when substances are taken into the cell across the plasma membrane through the formation of vesicles. In phagocytosis, solid particles or substances which are too large to cross the membrane are taken into the cell, whereas in pinocytosis, minute droplets of extra-cellular fluid are taken into the cell. In phagocytosis, the cell surface membrane produces two extensions called pseudopodia which surround the solid particle which is to be taken into the cell. The pseudopodia fuse and create a vacuole around the particle. In pinocytosis, the cell surface membrane invaginates, which allows the fluid to flow inwards. The liquid is then enclosed within a vesicle. Both phagocytosis and pinocytosis are only possible as a result of the **fluidity** of the membrane which is itself determined by the lipids of the membrane.

Practice Questions

1. The diagram shows part of the cell surface membrane



(a) Identify structure:

(i) X (1 mark)
(ii) Y (1 mark)
(iii) Z (1 mark)

(b) State one function of structure X. (1 mark)

(c) (i) Explain why the cell surface membrane can be said to be fluid. (1 mark)

(ii) Outline one way in which membrane fluidity is essential to cell function. (2 marks)

2. Complete the table below which compares the processes of diffusion, facilitated diffusion and active transport.

	Simple Diffusion	Facilitated Diffusion	Active Transport
Is ATP required?	N		Y
Rate of movement		Fast	
Direction of transport in relation to concentration gradient	With		Against

(4 marks)

Answers

Semicolons indicate marking points.

1. (a) (i) Glycocalyx;

(ii) Phospholipid bilayer;

(iii) Intrinsic protein;

(b) Cell recognition/receptor;

(c) (i) Lipids/proteins can move laterally/change places;

(ii) Allows endo/exocytosis;
eg. phagocytes attacking pathogens;
eg. pinocytosis; *(any two)*

2.

	Simple Diffusion	Facilitated Diffusion	Active Transport
Is ATP required?	N	N	Y
Rate of movement	Slow	Fast	Fast
Direction of transport in relation to concentration gradient	With	With	Against

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Bio Factsheet

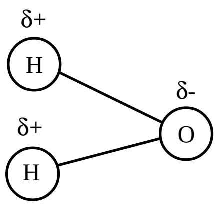
Number 30

The Biological Importance of Water

Water (H_2O) is the most abundant molecule in cells, whole organisms and on earth. This is a consequence of the unique physical and chemical properties of water. This Factsheet will briefly explain the significance of these physical and chemical properties, then discuss the primary roles of water in animals and plants.

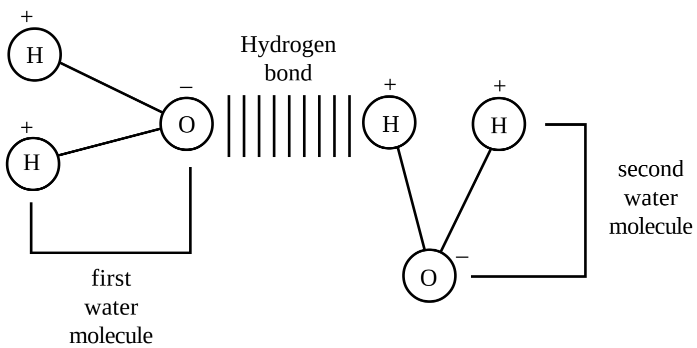
Water is a polar molecule i.e. it has both positively charged and negatively charged areas. Water is made up of two positively charged hydrogen atoms and one negatively charged oxygen atom (Fig 1).

Fig 1. The polarity of water molecules



As a result of this polarity (the uneven distribution of charges), adjacent water molecules are attracted to and become bonded to each other. The slight positive charge of a hydrogen atom of one molecule is attracted to the slight negative charge of an adjacent oxygen atom. A hydrogen bond forms between them (Fig 2).

Fig 2. Hydrogen bond between two water molecules



The individual hydrogen bonds are weak but collectively they make water very stable i.e. it remains a liquid over a huge range of temperatures (0-100°C). This is vital in living organisms.

1. Solvent properties

Polar molecules and ionic compounds such as sodium chloride dissociate in water. Sodium chloride (NaCl or 'salt') is made up of a positively charged sodium ion (Na^+) and a negatively charged chloride ion (Cl^-). As a result of the opposite charges, the two ions are attracted to each other and a bond forms between them. When the salt is added to water the sodium and chloride ions split apart (dissociate). They do this because the force of attraction between the negatively charged part of the water molecule and the positively charged sodium ion is greater than the forces of attraction between the Na^+ and the Cl^- ion. The negative part of the water molecule attracts and pulls away the positive part of the salt molecule. Similarly, the positive part of the water molecule attracts and pulls away the negatively charged chloride ion. Both the Na^+ and Cl^- become surrounded by water molecules; in other words they become hydrated. Polar substances which dissociate in water in this way are said to be **hydrophilic**.

Some large molecules have strong **intramolecular** forces and do not dissociate or dissolve in water. However, some of these molecules do have charged areas on their surface, which attract a layer of water around the molecules.

This layer of water means that the molecules remain dispersed, which prevents them joining together and settling out. This is known as a colloid or colloidal suspension; the water molecules which surround the large molecule are weakly bound to the molecule and cannot move away from its surface. This is important because such molecules provide an osmotic effect, helping to draw water into the blood vessels, for example.

The fact that water is an extremely effective solvent is of great biological importance. All of the substances which are essential for the functioning of cells and whole organisms (glucose, amino acids, fats, vitamins, respiratory gases etc.) are transported around in solution. Similarily, all metabolic reactions, catalysed by enzymes, occur in solution.

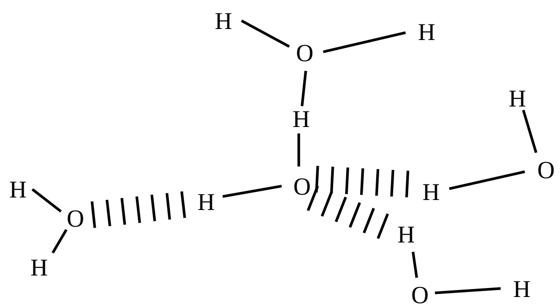
To summarise, the charged nature of the water molecule (i.e. its polarity), gives it stability and allows it to act as a solvent - both essential properties to living organisms.

2. Thermal properties

The hydrogen bonding between water molecules is also responsible for the unique thermal properties of water. Water has a high specific heat capacity i.e. it takes a lot of energy to raise the temperature of water or conversely, a lot of energy can be lost before the temperature of water starts to fall. This is crucial for living organisms which need to maintain particular temperatures in order to optimise enzyme activity. The high water content of cells and tissues helps them to maintain a constant temperature. In this way water acts as a **temperature buffer**.

Hydrogen bonding is also responsible for the fact that ice is less dense than water and therefore floats. As the temperature of water decreases, the kinetic energy of the individual molecules decreases and the molecules slow down. This allows each molecule to form the maximum number of hydrogen bonds with other water molecules (Fig 3).

Fig 3. The stable structure formed by hydrogen bonds in ice



To achieve this structure, the water molecules spread out i.e. expand to accommodate more bond formation. Because ice floats i.e. water freezes from the top down, many organisms are able to survive below the surface of the ice.

Conversely, when water molecules do escape from the water surface during evaporation, a lot of energy is released with them. As a result, evaporation (e.g sweating or panting) is an efficient cooling mechanism, allowing living organisms to maintain a constant body temperature. The properties and functions of water in living systems are summarised overleaf.

FUNCTION	EXAMPLES/EXPLANATIONS
Transport	Uptake of minerals by plants from soil across root hairs occurs in solution. Transpiration stream and water-based movement of sugars and amino acids, hormones etc. in phloem occurs in solution. All transport fluids used in animals (e.g. cytoplasm, blood, plasma and tissue fluid) are water-based. Many essential metabolites dissolve completely e.g. glucose, amino acids,vitamins and minerals. Larger molecules e.g. proteins are transported as colloids. Transpiration stream is held together by cohesion (water molecules hydrogen bond to other water molecules) and adhesion (water molecules bind to side of xylem vessel). Such forces also give rise to capillarity in tubes of very small diameter. Low viscosity of water enables it to flow easily through tubes e.g. xylem vessels.
Chemical reactions (metabolism)	Combination of thermal stability and excellent solvent properties makes water an ideal environment for chemical reactions. All enzyme reactions of photosynthesis, respiration, excretion etc. occur in solution. Water also acts as a reactant for example, in: 1. Light dependent stage of photosynthesis when photolysis splits water to release electrons which move to photosystem II (PSII) and then through electron carriers in non-cylic photophosphorylation pathway (NCP). 2. Hydrolytic reactions (e.g. digestive enzymes).
Temperature control	High specific heat capacity allows water to act as a buffer; essential in endothermic organisms that need to maintain a constant body temperature in order to optimise enzyme activity and thereby regulate metabolism. High incidence of hydrogen bonding also makes at it difficult for water molecules to evaporate. When they do so, much energy is released and this is involved in cooling mechanisms. Water remains a liquid over a huge temperature range - essential for metabolism and useful for aquatic organisms which avoid freezing.
Support	In plant cells water confers turgidity. This is essential for example, in: 1. Maintaining maximum leaf surface area, hence light absorption, hence photosynthesis. 2. Maintaining aerial parts of the plant to maximise seed dispersal or pollination. Loss of water in very hot conditions may lead to leaves wilting. This decreases their surface area, hence light absorption, temperature and water loss. In animals, water-filled tissues also contribute to skeletal support. In organisms which possess a hydrostatic skeleton (e.g. annelids), water is the major component of the fluid in the coelom against which muscles can act. For aquatic organisms, water provides support through buoyancy.
Movement	Nastic movements, i.e. those which do not involve growth in a particular direction as a response to a directional stimulus, depend upon the osmotic inflow of water into tissues, e.g. the opening and closing of flowers or ‘snapping’ of the carnivorous Venus Fly Trap. Organisms such a earthworms and leeches use their hydrostatic skeletons to move around. Longitudinal and circular muscles are able to contract against the incompressible watery fluid of the coelom.
Reproduction	Organisms which employ sexual reproduction use water to bring the male and female gametes together in the process of fertilisation. In mammals the foetus develops in a water filled sac which provides physical and thermal stability. Bryophytes release antherozoids in moist conditions which use flagella to swim to oospheres by chemotaxis.

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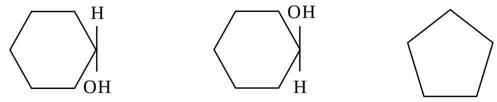
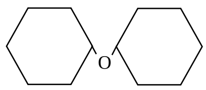
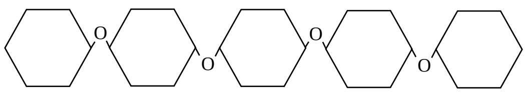
Bio Factsheet

Number 39

Carbohydrates: Revision Summary

Carbohydrates contain 3 elements: Carbon (C), Hydrogen (H) and Oxygen (O). Thus, if we remove water from carbohydrates, all that remains is carbon. Carbohydrates can be divided into 3 categories; monosaccharides, disaccharides and polysaccharides (Table 1).

Table 1. Structure of monosaccharides, disaccharides and polysaccharides

Category	Example	Site	Structure
Monosaccharide (made of 1 sugar molecule)	glucose fructose galactose	fruit fruit, nectar milk	 α-glucose β-glucose fructose
Disaccharide (made of 2 monosaccharides joined together)	maltose = α-glucose + α-glucose sucrose = glucose + fructose lactose = glucose + galactose	germinating seeds phloem tissue, fruit milk	 maltose
Polysaccharide (made of many monosaccharides joined together)	starch = polymer of glucose glycogen = polymer of α-glucose cellulose = polymer of β-glucose chitin = polymer of glucosamine (glucose with an amino acid attached)	chloroplast stroma muscle cells plant cell wall exoskelteton of arthropods	 cellulose

Monosaccharides and Disaccharides

Monosaccharides and disaccharides are **sugars**. They all have the basic formula $(CH_2O)_n$ and can be classified according to how many carbon atoms they contain.

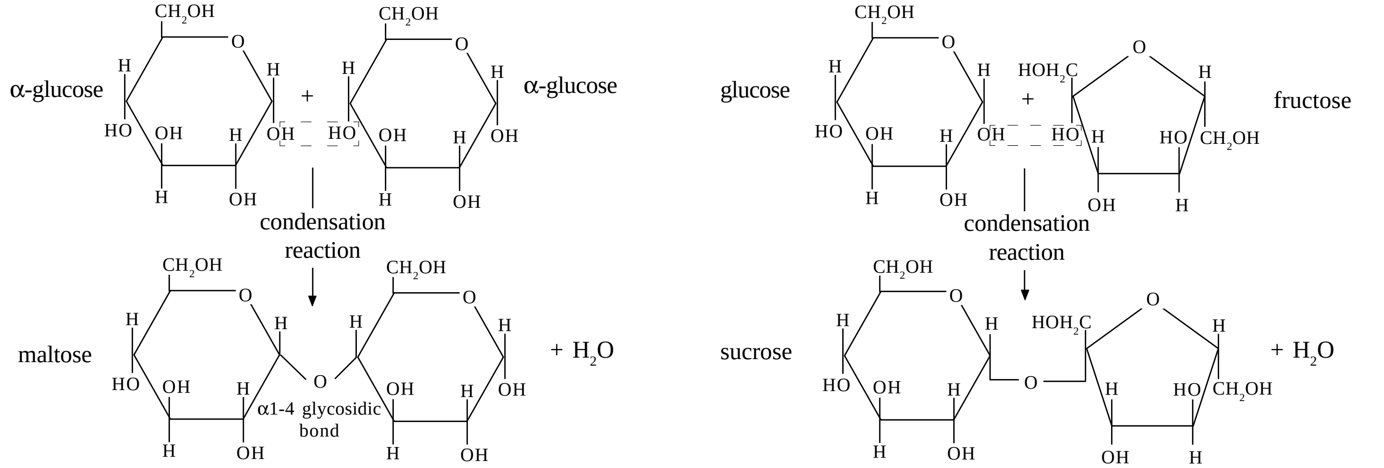
3C = **tri**ose sugars e.g. glyceraldehyde $C_3H_5O_2$
5C = **pent**ose sugars e.g. ribose $C_5H_{10}O_5$
6C = **hex**ose sugars e.g. glucose $C_6H_{12}O_6$

Formation of disaccharides - typical exam questions

Common exam questions include:
1. Name the reaction involved when a disaccharide is formed
2. Name the type of bond formed
3. Show, by drawing a diagram, how a disaccharide is formed

Questions 1 and 2 are very simple - Disaccharides form in a condensation reaction which forms a glycosidic bond. The only way to get Question 3 correct is to practice! Fig 1 shows how maltose and sucrose are formed from their monosaccharides.

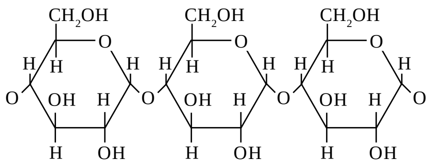
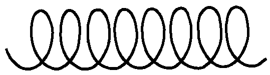
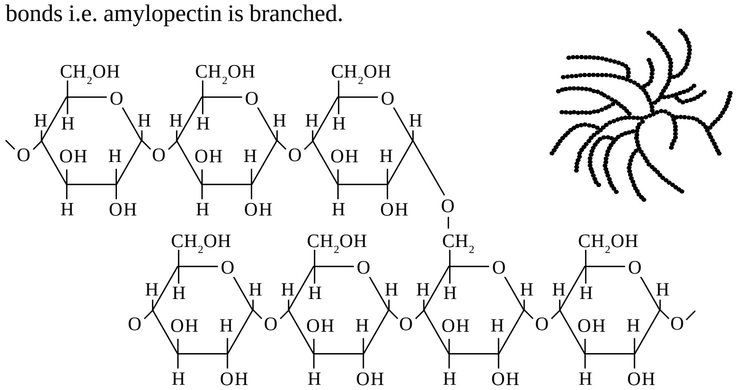
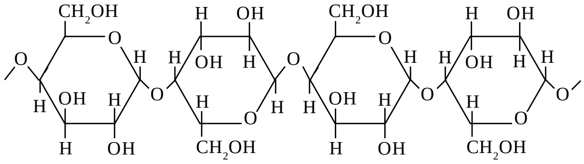
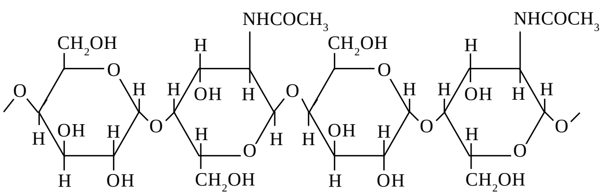
Fig 1. Formation of maltose and sucrose from their monosaccharides



Polysaccharides

Polysaccharides are polymers i.e. they are made up of many repeating units. Three polysaccharides which commonly feature in exam questions are starch, cellulose and glycogen. By far the most common question asks "How is the structure of polysaccharides related to their function?". It should be noted that all 3 have the advantage that they are insoluble in water and therefore have no osmotic effect i.e. effect on water potential and are unable to diffuse out of the cell. More specific features are summarised in Table 2.

Table 2. Structure:Function of polysaccharides

Polysaccharide	Structure	Structure:Function
Starch – Main storage polysaccharide in plants.	Made of two polymers of α-glucose; amylose and amylopectin **amylose** – a chain of glucose molecules joined by α-1,4-glycosidic bonds which, by hydrogen bonding, form a helix. It is this helix which holds and forms a complex with iodine when we test for starch   **amylopectin** – glucose molecules joined by α-1,4-glycosidic bonds **but** after every 25 glucose molecules adjacent chains are connected by α-1,6-glycosidic bonds i.e. amylopectin is branched. 	Insoluble in water, therefore good **storage** compound e.g. in stroma of chloroplasts The helix forms a compact shape which allows tight packing and is therefore an excellent storage molecule. Amylopectin has many protruding ends (glucose molecules) which can be hydrolysed rapidly – allows rapid release of glucose to provide energy via respiration. Starch from different sources is unique. Each source has characteristic proportions of amylose and amylopectin and the lengths of these two molecules differ. Thus, microscopic analysis of a starch grain can be used to identify which type of plant it came from.
Glycogen – main storage polysaccharide of animal and fungal cells.	Similar structure to amylopectin (in that it is a polymer of α-glucose) of starch but has many more branches and the branches are shorter. Glycogen is even more compact than amylopectin.	**Compact storage** molecule in mammalian liver and in fungal cells and can be broken down to release glucose. The structure of glycogen allows faster hydrolysis than starch which is important as animals may need emergency glucose faster than plants.
Cellulose – structural polysaccharide in plants.	Long unbranched chains of glucose linked by β-1,4-glycosidic bonds. The individual chains are then linked to each other by hydrogen bonds. These are formed into **strong** microfibrils. 	Hydrogen bonding prevents water entering the molecule. Cellulose is therefore resistant to enzyme hydrolysis which makes it an excellent **structural** polysaccharide. Cellulose cell walls provides protection to all plant cells. Humans cannot digest cellulose but herbivores have bacteria and protoctists in their digestive system which produce cellulase (β-1,4-glycosidase). The long unbranched fibrous structure provides great mechanical strength.
Chitin – structural polysaccharide found in hard exoskeletons of all arthropods and in hyphal walls of many fungi.	Made of glucosamine units (glucose + amino acid) and is linked by β-1,4-glycosidic bonds. 	The presence of the amino group causes even more hydrogen bonding between the chains than in cellulose. Chitin is therefore an extremely **resilient** and **tough** polysaccharide.

Testing for Carbohydrates

The most common tests for carbohydrates are summarised in Table 3.

Table 3.Common carbohydrate tests

Test	Reagent	Method	Positive result
Starch	Iodine	Add 2-3 drops of iodine	Blue/black precipitate (ppt) forms
Reducing Sugar e.g. glucose fructose maltose	Benedicts' reagent	Add volume of Benedicts' reagent = volume of test solution. Mix. Heat to 70°C (Do not boil because this would split a disaccharide e.g. sucrose into reducing sugars (glucose and fructose) and give a false positive test)	Solution turns from blue to pale green to yellow to orange to brick red ppt of copper (I) oxide. The intensity of the colour, which can be measured accurately using a colorimeter, indicates how much reducing sugar was present.
Non-reducing sugar e.g. sucrose	Benedicts' reagent	To $2cm^3$ test solution add $1cm^3$ dilute HCl. Boil. Cool and neutralise with excess NaOH. Repeat test for reducing sugar	Brick red ppt

Functions of carbohydrates: a summary

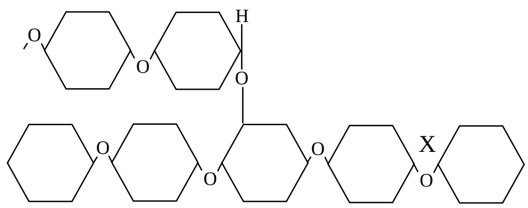
1. Immediate respiratory substrates e.g. glucose
2. Energy stores e.g. glycogen in mammals
   starch in plants
3. Structural components e.g. cellulose in plant cell walls
   chitin in arthropod exoskeleton
   pentose sugars - ribose and deoxyribose are components of RNA and DNA respectively.
4. Metabolites i.e. intermediates in biochemical pathways
5. Cell-to-cell attachment molecules e.g. combined with proteins to form glycoproteins or lipids to form glycolipids on plasma membrane
6. Transport e.g. sucrose in plant phloem tissue

Digestion of polysaccharides

	Stage	Enzyme
Starch	Starch → Maltose	salivary and pancreatic amylase. α amylase breaks 1-4 links randomly. β amylase breaks alternate 1-4 links.
	Maltose → Glucose	Maltase in intestinal juice
Glycogen	Glycogen → Glucose	β cells in islets of Langerhans secrete glucagon which activates enzymes for glycogenolysis
Cellulose	Herbivores have bacteria and protoctists in their digestive systems	Cellulase (β-1,4-glycosidase)

Practice questions

1. The diagram shows part of a starch molecule



(a) Name the type of bond found at position X (1 mark)
(b) Name the reaction which formed this bond (1 mark)
(c) Explain how the structure of this molecule is related to its function (2 marks)

2. Outline a biochemical test which you could use to distinguish between a solution of glucose and a solution of sucrose (3 marks)

Answers

Semicolons indicate marking points

1. (a) Glycosidic;
   (b) Condensation;
   (c) Compact/tightly packed/ref to amylase helix;
   efficient storage;
   amylopectin glucose units;
   allow rapid hydrolysis/release of glucose;

2. Add Benedicts' reagent to each solution;
   heat to 60-80°C;
   glucose solution would give brick red precipitate;
   sucrose solution would not change;

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Bio Factsheet

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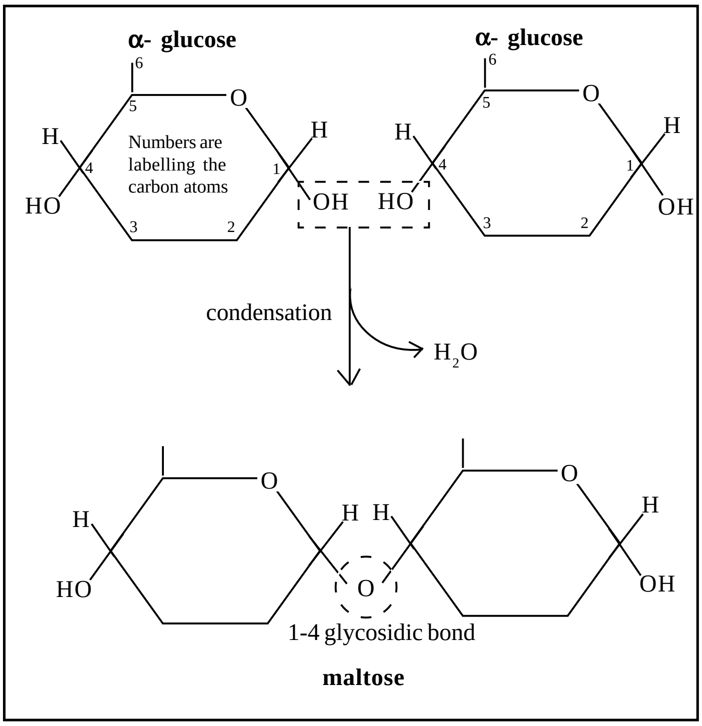
The Structure and Function of Polysaccharides

This Factsheet summarises:
- The structure of the polysaccharides starch, glycogen and cellulose.
- The functions of polysaccharides.
- How structure is related to function.

Structure
The key points are:
- Polysaccharides are organic molecules made up of carbon (C), Hydrogen (H) and Oxygen (O).
- They are polymers ie they are large molecules (macromolecules) made up of simple units (building blocks) repeated many times.
- Glucose is the commonest monomer from which the macromolecule or polymer is formed.
- These simple units –or monomers – are held together by bonds formed in condensation reactions in which a molecule of water is formed as two monomers are joined .
- These bonds are called glycosidic bonds (Fig1).

Fig 1



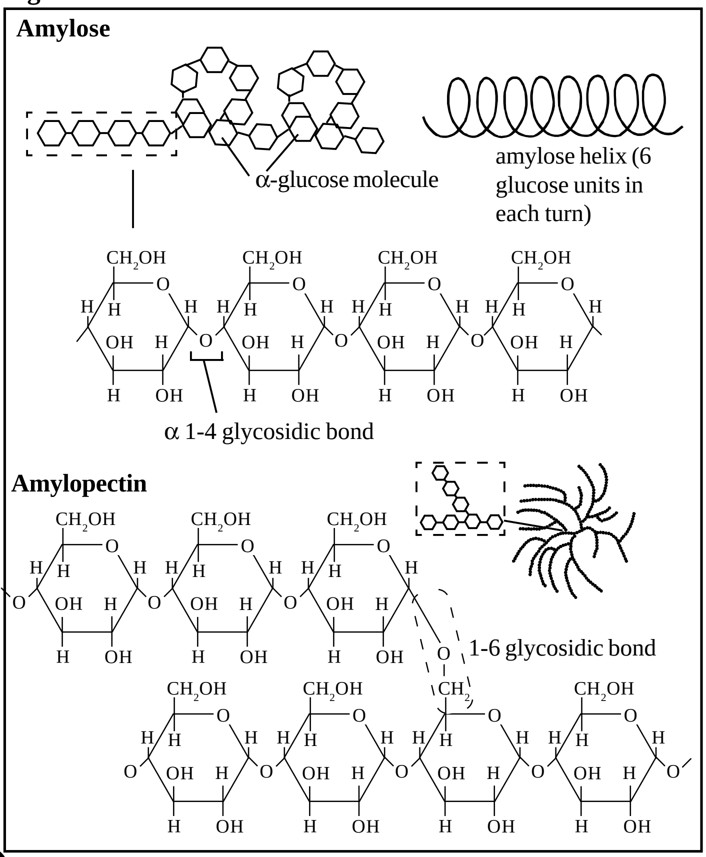
The polysaccharides that come up repeatedly in the exams are starch, glycogen and cellulose.

Typical exam questions on this topic
- Outline what is meant by a condensation reaction or draw/ label a diagram showing the reaction.
- Explain how structure fits function in eg starch, glycogen and cellulose.
- Describe in extended prose the significance of polysaccharides in animals and plants.

Occasionally, you might be asked to comment on the biological significance of other polysaccharides – chitin, for example, but because these aren't specifically mentioned in any specification you can usually just make up something which is biologically sensible –we'll explain this later on in the Factsheet.

Starch
Starch is a polymer of α-glucose.
It is a mixture of two substances: amylose and amylopectin.
Typically, starch = 20% amylose, 79% amylopectin and 1% phosphates/fatty acids but the precise composition varies between species (remember starch is **only** found in plants).
Amylose and amylopectin have very different structures (Fig 2).

Fig 2.



Amylose
Alpha-glucose molecules form an unbranched chain that coils itself into a helix (like a spring).
Significance of this? The helix is compact, making it a good storage molecule.
The glucose molecules are joined by 1-4 linkages (meaning that carbon atom 1 of one glucose molecule links with carbon atom 4 of the next glucose molecule).

Amylopectin
Alpha-glucose molecules form long, branched chains.
Significance? Long chains means few "ends" making amylopectin difficult to break down = good for storage.
The glucose molecules within the branches are 1-4 links (as in amylose) but where the branch joins the main chain, a 1-6 link forms.

The mixture of amylose and amylopectin is built up into large starch grains in potato tubers, many seeds and the stroma of chloroplasts, where they act as energy stores.

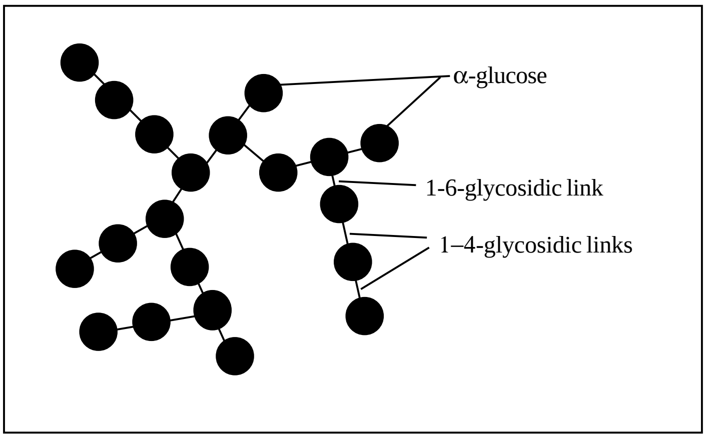
Exam questions don't usually ask you explicitly about the way in which the structure of amylose and amylopectin fit their function, rather they usually expect you to mention these details when asked about starch as a whole. So remember:

- starch is compact = good for storage.
- insoluble = osmotically inactive.
- too big to pass through membranes = inactive/good for storage.
- provides many glucose molecules = good respiratory substrate.

Exam Hints
Many candidates mistakenly appear to believe that:
1. *Long chains of starch provide support. They had clearly confused the roles of starch and cellulose.*
2. *Starch stores something else – inside its helix.*
3. *Starch is soluble.*
4. *Cell walls are made of starch.*

Glycogen
α- glucose polymer.
Branched like amylopectin but has shorter 1,4 chains and many more branches (Fig 3).

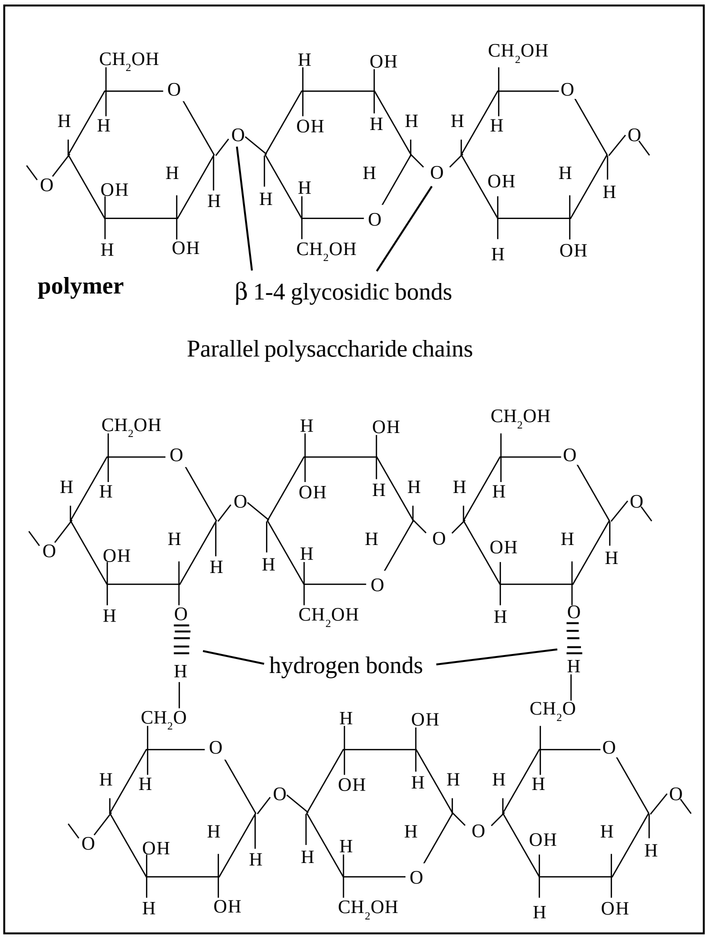
Fig 3. Glycogen



Significance? More branches and shorter chains = more "ends" = faster to breakdown when energy is needed. Whereas starch is the storage molecule in plants, glycogen is the store in animals, fungi and bacteria that may suddenly need to release their stores.

In humans, glycogen is stored mainly in the liver and muscles and is important in helping to regulate blood glucose levels.

Cellulose (Fig 4)



Polymer of beta glucose arranged in long, straight chains.
Whereas starch and glycogen are storage molecules, cellulose is a structural polysaccharide.
Cellulose is mechanically strong because:
(i) the inverted arrangement of successive glucose molecules means that thousands of hydrogen bonds form.
(ii) cellulose molecules are tightly cross-linked to form microfibrils
(iii) the microfibrils form fibres.

Within plant cell walls the fibres are arranged in layers running across each other, are interwoven and these layers are held or "glued" together by a matrix of other substances.

Significance?
Cellulose cell walls need to be strong to maintain turgidity so that leaves are held in a position to absorb maximum sunlight. Stems remain flexible but firm in winds etc.
The gaps in the walls allow permability.

Critisms of students answers
Roles of starch and cellulose in plant cells are often confused.
Some candidates believe that the cell walls of prokaryotes are made of cellulose. They are made of murein.
Many candidates mistakenly suggest that cellulose is the storage carbohydrate that is hydrolysed to glucose to provide the plant with energy.

Candidates often confuse the 3-D structure of celluose and starch with the beta - pleated sheets of proteins.

Fundamental errors seen in recent papers
- *both starch and cellulose are proteins.*
- *that starch is essential for photosynthesis.*
- *that cellulose absorbs light.*

Chitin
Polymer of N – acetylglucosamine
Like cellulose, it has β 1-4 glycosidic links

Significance? Very strong structural component of the exoskeletons of arthropods (e.g. insects and crustacea).

Summary

Storage

Plants — *Starch*
Animals, fungi and bacteria — *Glycogen*

Both compact ∴ good use of space.
Both insoluble ∴ no osmotic/ water potential effect.

↓ Hydrolysis

Glucose = high energy respiratory substrate.

Structural

Plants — *Cellulose*
Arthropods — *Chitin*

Both mechanically strong to provide protection and in the case of plants, to maintain turgidity.

Cellulose permeable to allow gas exchange for photosynthesis/ respiration.

Typical exam questions

1. Fill in the table –type questions. Place a tick in the box if the statement is correct, place a x in the box if it is incorrect.

Statement	**Starch**	**Cellulose**	**Glycogen**
Storage molecule in plants			
Polymer of beta glucose			
Strengthened by thousands of hydrogen bonds			
A mixture of two polysaccharides			
Only found in fungi			

Statement	**Starch**	**Cellulose**	**Glycogen**
Storage molecule in plants	✓	✗	✗
Polymer of beta glucose	✗	✓	✗
Strengthened by thousands of hydrogen bonds	✗	✓	✗
A mixture of two polysaccharides	✓	✗	✗
Only found in fungi	✗	✗	✗

2. Questions relating the structure of the polysaccharide to its functions.

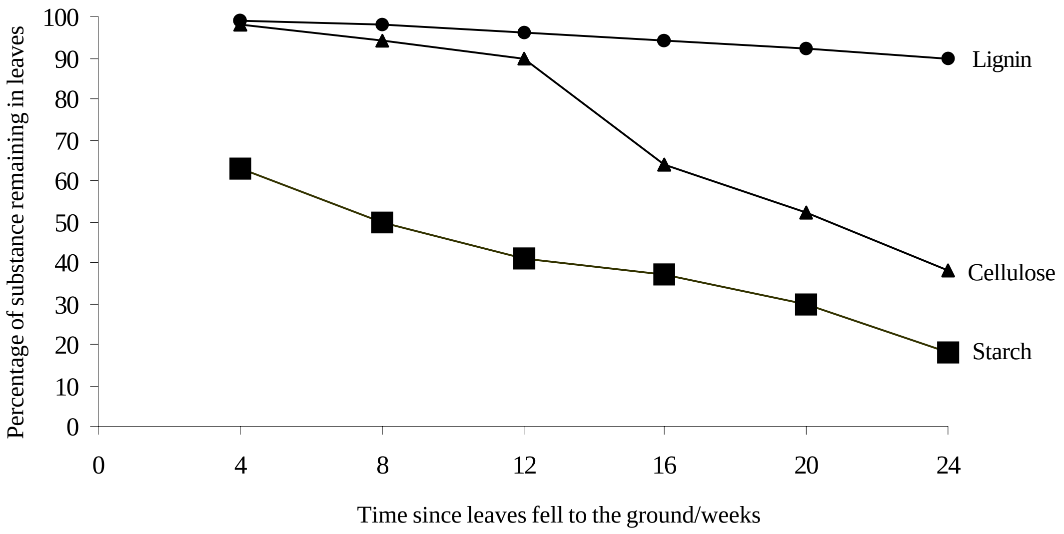
The key here is to be precise. You MUST be able to explain why the various properties of starch, for example, suit it to its role as a storage molecule; for example, its *insolubility* means that it *will not affect the water potential* of the cell. You must give both the **property** and the **significance** of this property to be awarded the marks.

3. Applied Questions

The examiners like to test your ability to ***synthesise*** – pull together bits of info from different parts of the spec. This needs practice because it means putting together info from last October with info from last Jan and last week………..and being able to think about cellulose, microorganisms and enzymes, for example, all at once (Biology isn't really a lot of separate topics – it all hangs together if you can make the connections)

Consider Fig 5. It shows the percentage of lignin, cellulose and starch that remain in leaves that have fallen to the ground.

Fig 5



Typical question: Comment on the trends shown in the graphs.

1. You are not expected to know the answer off by heart, nor are your teachers supposed to have shown you this graph.
2. Stay calm and think.

- You know leaves decay.
- You know that decay is carried out by invertebrates, bacteria and fungi.
- Invertebrates such as earthworms break up the leaves, increasing the surface area of the material (and increasing its moisture content and pH).
- All of this makes the leaves more digestible by bacteria and fungi.
- They use extracellular enzymes.
- They have enzymes for breaking down the bonds in starch but cannot easily breakdown lignin.

(and now we get to the polysaccharide bit)

- Looking at the data, you can see that more starch has been removed than cellulose and that very little lignin has been removed.
- This is because starch is easier to digest than cellulose.
- Because starch is a energy storage molecule whereas cellulose (and lignin even more so) is a structural substance, it is deliberately resistant to breakdown.

Easy!

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Transport Mechanisms in Cells

The internal environment of the cell is isolated from its surroundings by the cell membrane. The cell membrane regulates transport of substances in and out of cells (Factsheet 8 - The cell surface membrane).

This Factsheet will describe transport mechanisms which occur inside cells and their functions within the cells. (Similar mechanisms also operate in the cell surface membrane). The mechanisms are:

- **diffusion and facilitated diffusion.**
- **active transport.**
- **proton pumps.**
- **cytoplasmic streaming.**
- **transport in vesicles.**

The internal volume of the cell is huge compared with the size of the molecules within the cell. Some of these molecules need to be distributed fairly evenly throughout the cytoplasm, for example, amino acids (so that they stand a better chance of meeting and combining with transfer-RNA molecules for use in polypeptide synthesis). Other molecules need to be transported to and from specific locations in the cell. For example, polypeptides must be transported from the rough endoplasmic reticulum to the Golgi body (so that they can combine to make proteins, or combine with other substances to make, for example, nucleoproteins).

Remember*:- water is often referred to as 'the universal solvent' because it will dissolve a very wide range of substances. It thus allows them to be transported, either by diffusion, in solution, through the body of water, or by actual flowing of the water itself, carrying the dissolved substances.*

Intracellular membranes

Membranes inside cells, forming such structures as mitochondria, chloroplasts, smooth and rough endoplasmic reticulum and Golgi body, all have a similar structure to the cell surface membrane, although the relative proportions of the molecular components may differ. For example, membranes surrounding chloroplasts contain very little carbohydrate.
Intra-cellular membranes may:

- act as reaction surfaces,
- act as intracellular transport systems (vesicles),
- provide separate intracellular compartments, thus isolating different
- chemical reactions.

Intracellular transport thus requires transport of solutes to, away from, and across membranes.

Diffusion

Diffusion is defined as, 'the net movement of molecules or ions from a region of their high concentration to a region of their low concentration'. It will occur in the cell wherever a concentration gradient exists and will continue until the diffusing substance is evenly distributed. Examples of diffusion inside cells are:

- oxygen absorbed through the cell membranes of animals and plants, or released from the photosynthesising chloroplasts of plants, will diffuse towards the mitochondria where oxygen is being used in aerobic respiration.
- carbon dioxide absorbed into photosynthesising plant cells will diffuse from the cell membrane towards and into the chloroplasts, to be used in photosynthesis. Respiratory carbon dioxide in non-photosynthetic plant cells and in animal cells will diffuse from where it is produced, by decarboxylation reactions in the mitochondria and cytoplasm, to the cell membrane where it is released from the cell. (Some of the carbon dioxide will diffuse in the form of hydrogen carbonate ions).
- glucose and other sugars, amino acids and ions absorbed through the cell membranes of animal and plant cells will diffuse throughout the cell to where they are used. Glucose, amino acids and other products of photosynthesising cells will diffuse from the chloroplasts to where they are used in the cell.

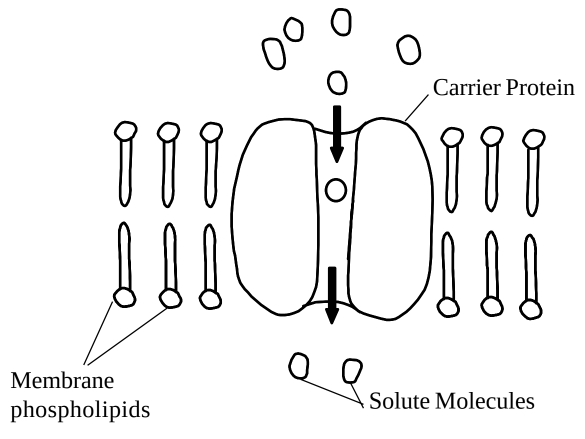
Facilitated diffusion is a process that enables diffusion to occur across membranes, for example, membranes of chloroplasts, mitochondria and endoplasmic reticulum. Facilitated diffusion is the 'passive movement of molecules down a concentration gradient across a membrane, and involves special carrier proteins in the membrane'. The carrier proteins may:

- contain special hydrophilic (water-liking) channels through which solutes can pass, or
- move in the membrane forming openings (gates), ferrying the solutes across.

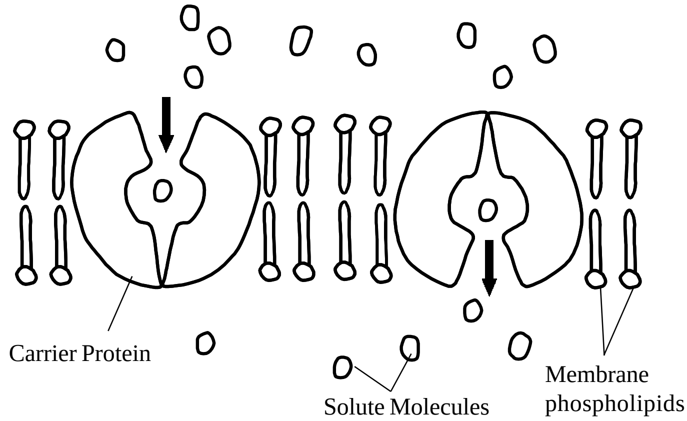
Facilitated diffusion does not require an energy source such as ATP to drive it.

Fig. 1. Facilitated diffusion

a) Hydrophilic channel allows solutes through



b) Carrier protein opens (forms a 'gate') allowing solutes through



In facilitated diffusion the carrier protein can transport the solute either way depending on the concentration gradient. Carrier proteins are specific to particular solute molecules. The carrier protein for the facilitated transport of glucose is called a **permease.** The glucose is bound to the permease on one side of the membrane and is released from the permease on the other side of the membrane, as in fig. 1.(b) above. In a plant cell, glucose may be released through chloroplast membranes and absorbed into plastids (amyloplasts) to be stored as starch.

Active transport

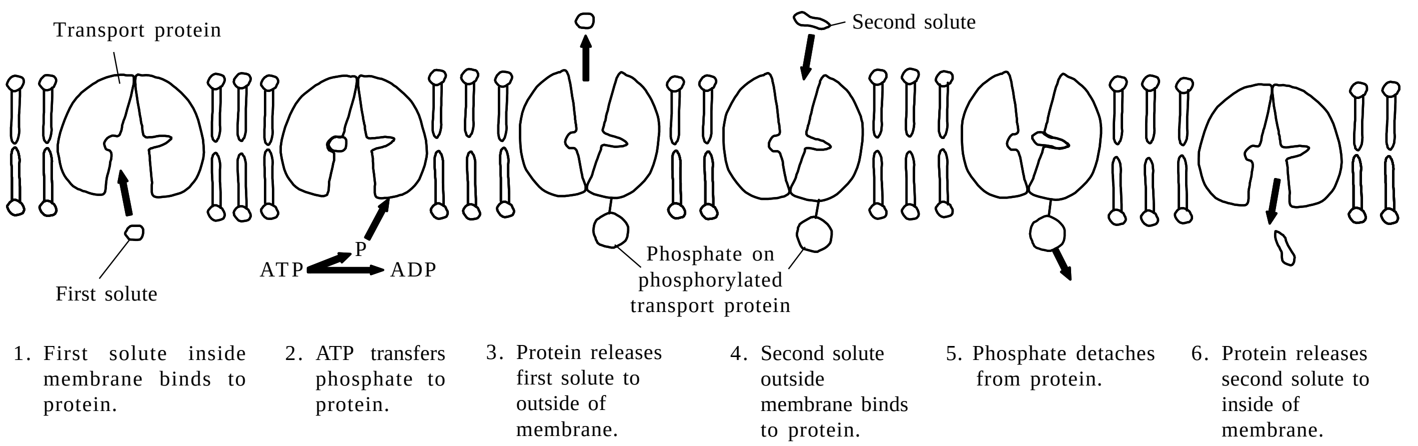
Active transport is the movement of substances, usually against a concentration gradient, across a membrane, and involves the expenditure of energy. The energy usually comes from ATP, generated by respiration in the mitochondria. Active transport involves carrier proteins in the membrane. The carriers are specific to the substances they transport. The carriers may move:

- a single substance in a single direction (**uniport** carriers) For example, some calcium pumps.
- two substances in the same direction (**symport** carriers) For example, glucose-sodium pumps.
- two substances in opposite directions (**antiport** carriers). For example sodium-potassium pumps.

A calcium pump is involved with the regulation of calcium concentrations inside the cell. The cytoplasm normally has a calcium concentration of around 10^{-7} moles dm^{-3}. The spaces of the endoplasmic reticulum have a calcium concentration around 10^{-3} moles dm^{-3}. The calcium pump on the endoplasmic reticulum membranes pumps calcium from cytoplasm into the endoplasmic reticulum, creating a 10,000 fold concentration increase. A similar pump is used to pump calcium ions back into the sarcoplasmic reticulum of muscle, after contraction.

The exact mechanisms of active transport pumps are uncertain but a probable mechanism is illustrated in figure 2.

Fig. 2. Possible mechanism for active transport (antiport).



The ATP donates energy-rich phosphate to the transport protein thus activating it to bond with the specific solutes.

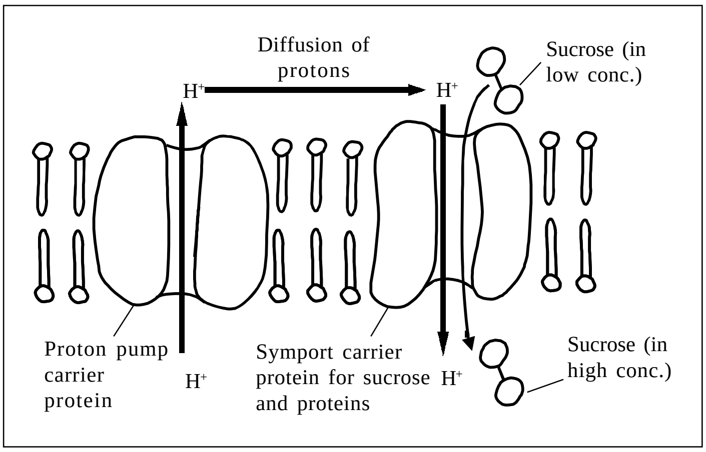
Proton pumps

These are active transport mechanisms use to transport hydrogen ions (protons) across membranes. Proton pumps are present in the vacuolar membranes (tonoplasts) of plant cells, yeasts and fungi, in the endoplasmic and lysosomal membranes of animal cells, in the inner mitochondrial membrane and in chloroplast thylacoid membranes.
In many cases proton pumps enable other molecules to be transported with the protons. For example:

- sucrose is transferred across membranes (for example, chloroplast membranes, cell surface membrane) in conjunction with protons,
- ATP in the mitochondria is released by a proton pump mechanism during aerobic respiration,
- ATP in the chloroplasts is released by a proton pump mechanism during the light-dependent stage of photosynthesis.

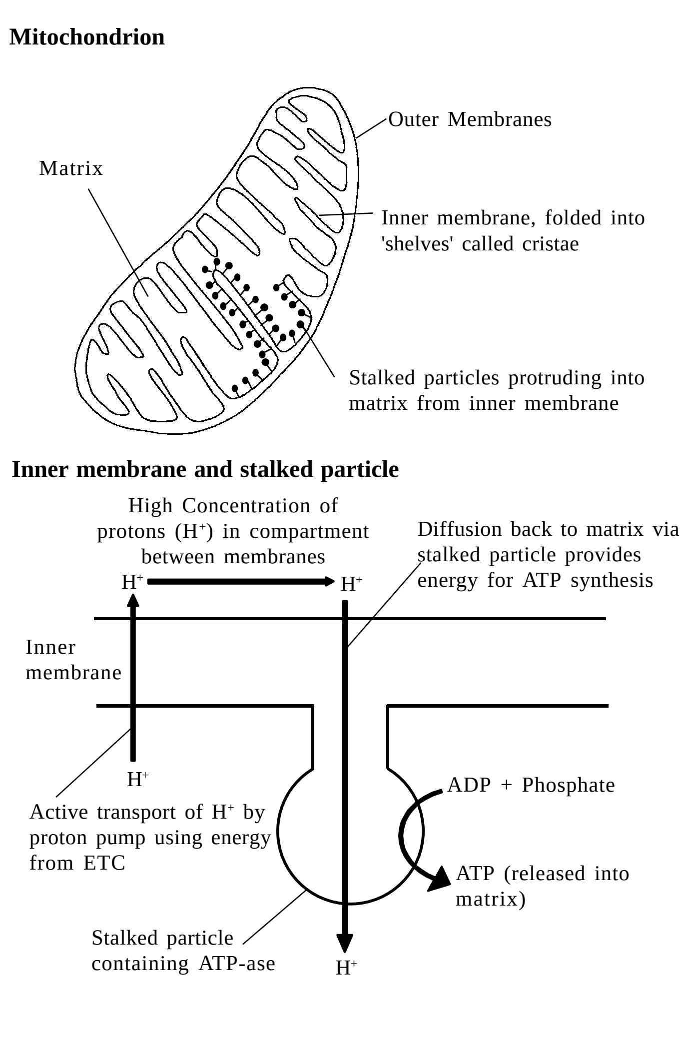
This is an example of **cotransport** in which the active transport of one substance indirectly drives the movement of another substance against a concentration gradient. The proton pump actively drives protons across the membrane (using energy from ATP). This forms a high concentration of protons which then diffuse back across the membrane via the symport carrier protein. This, by an unknown mechanism, enables sucrose to be actively transported across the membrane via the symport carrier, against the sucrose concentration gradient.

Fig. 3. Transport of sucrose across membranes



The proton pump operating across the inner mitochondrial membrane uses energy from the electron transport chain (ETC) to pump protons from the mitochondrial matrix into the compartment between the inner and outer mitochondrial membranes. The protons accumulate so that a steep concentration gradient exists between the compartment and the matrix. The inner membrane is impermeable to protons except through channels located in the stalked particles of the inner membrane. The protons diffuse back to the matrix through these channels and this provides energy to drive the synthesis of ATP from ADP and phosphate. The enzyme ATP-ase, in the stalked particles catalyses the ATP synthesis.

Fig. 4. ATP synthesis in the mitochondrion



The proton pump enabling ATP generation in chloroplasts works in a similar way. It is situated in the thylacoid membranes and releases the ATP to the stroma.

> ***Exam Hint**: – questions on cotransport have been asked several times in recent exams. The main example tested is the active transport mechanism of glucose (and galactose) which works in conjunction with a sodium pump (instead of a proton pump).*

Cytoplasmic streaming

Diffusion is a relatively slow process and so many cells speed up movement of materials by cytoplasmic streaming. Under the microscope, evidence of streaming can be seen in the movement of food vacuoles around an *Amoeba* cell, or in the movement of chloroplasts around the vacuole of a palisade mesophyll cell. Movement of such organelles, due to the streaming of cytoplasm, is called **cyclosis**. The streaming may involve all the cytoplasm or just part of it – plant cells tend to show streaming that circulates the cytoplasm in definite currents around the tonoplast membrane of the vacuole. Mass flow along the length of sieve tube elements, in phloem, is thought to involve cytoplasmic streaming.

The streaming is generated by active movements of actin microfilaments which are bound to the endoplasmic reticulum. Myosin, also bound to the endoplasmic reticulum, interacts with the actin filaments and pulls them moving the endoplasmic reticulum. This moves the nearby cytoplasm along. The interaction of actin and myosin requires energy from ATP.

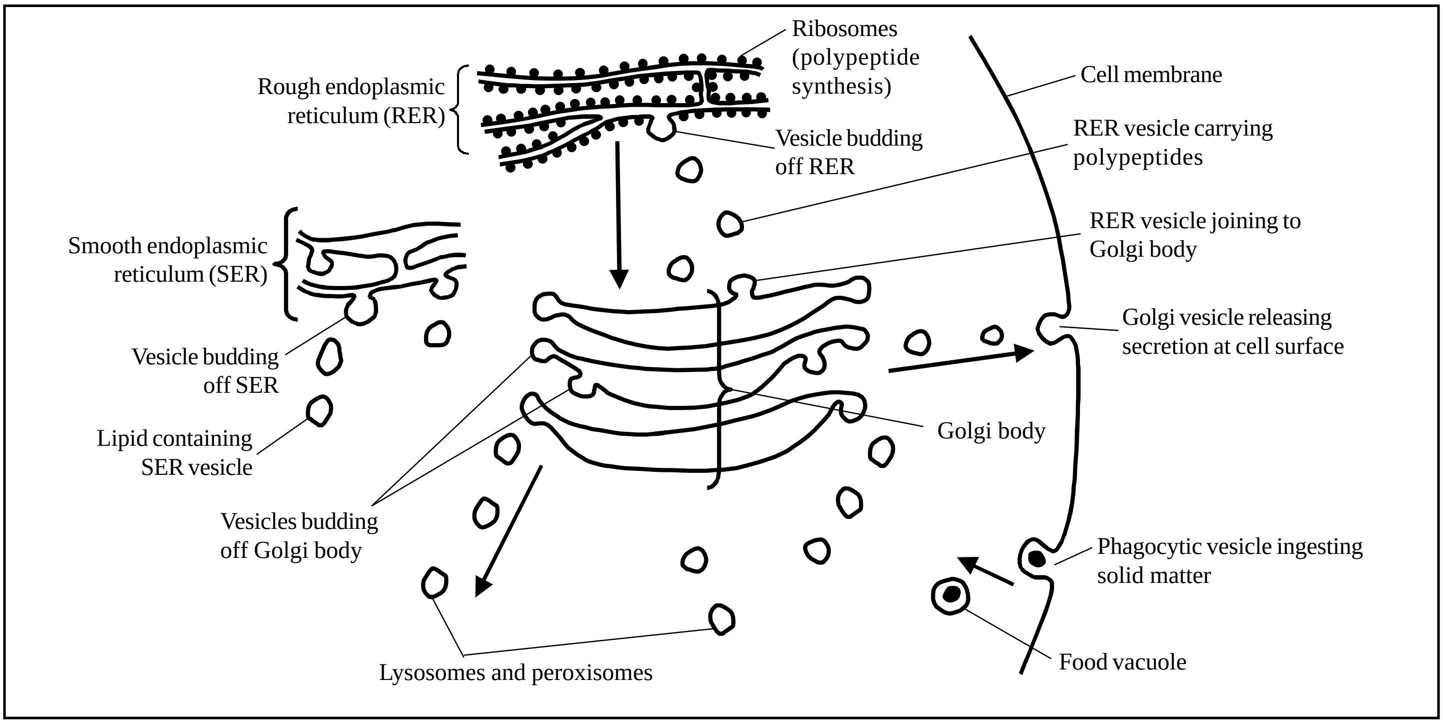
> ***Remember** – actin and myosin are contractile proteins They make up the structure of muscle fibres and are responsible for muscle contraction.*

Transport in vesicles

Vesicles are membrane bound sacs formed from various organelles within the cell used to transport substances throughout the cell or to specific locations of the cell. Examples are:

- vesicles budded off from the rough endoplasmic reticulum that migrate to the Golgi body and fuse with it. They carry polypeptides synthesized in the rough endoplasmic reticulum for processing into proteins and other derivatives by the Golgi body.

Fig 5. Examples of vesicles in a cell



- vesicles bud off from the Golgi body, containing substances synthesized by the Golgi body. These substances are often enzymes and the vesicles may:
  1. move to the cell surface membrane, fuse with it and release their contents to the outside (**secretory vesicles**).
  2. contain protein splitting enzymes (lysozyme) and disperse throughout the cytoplasm as **lysosomes**. These can be involved in intracellular digestion when required.
  3. contain peroxidase enzymes and disperse throughout the cytoplasm as **peroxisomes**.

  These are used to break down toxic hydrogen peroxide produced by cell metabolism.

- vesicles also bud off from the smooth endoplasmic reticulum. These transport lipid substances that may be dispersed throughout the cell, or released at the cell surface (for example, secretion of steroid hormones).

- vesicles budded off from the cell surface membrane into the cytoplasm. These may be **phagocytic vesicles** which engulf solid material from outside the cell and bring it into the cytoplasm (forming a food vacuole) or **pinocytic vesicles** which ingest liquid material from outside the cell to bring it into the cytoplasm.

Practice Questions

1. Read through the following passage about active transport and then complete it by inserting appropriate words or phrases into the gaps.

   Active transport can transport substances across membranes against a …………………….. . The substance is transported using a specific ………………. and requires the use of energy. The calcium pump in cells obtains energy from …….. . In mitochondria the synthesis of ATP, from the ……………….. , is enabled by a …………. pump. The driving energy for this comes from the …………………………. . A similar mechanism exists in the …………….. membranes of the chloroplast, enabling generation of ATP from the …………………… stage of photosynthesis. **Total 8**

2. Glucose can be transported across membanes by facilitated diffusion or by active transport in conjunction with sodium ions. Suggest possible mechanisms for:
   a) the transfer of glucose across a membrane by facilitated transport, and **4**
   b) the transfer of glucose across a membrane by active transport. (Hint – refer back to sucrose transport using a proton pump). **5**

   Total 9

3. Complete the following table relating to transport by cytoplasmic vesicles. **Total 4**

Substance carried	Type of vesicle	Where vesicle was formed	Function
Polypeptides			
Protease enzymes			
Lipids			
Peroxidase enzymes			

4. Suggest explanations for the following:
   (a) Exposure of mitochondria to cyanide ions prevents ATP synthesis by the mitochondria. **4**
   (b) Cytoplasmic streaming in plant cells is slowed up by exposure to cold conditions. **4**
   (c) Liver (hepatic) cells contain more cytoplasmic vesicles than plant parenchyma cells. **4**

   Total 12

Answers

1. concentration gradient; carrier (protein); ATP; stalked particles; proton; electron transport chain/ETC; thylacoid; light-dependent; **Total 8**

2. (a) specific carrier protein in membrane reacts with glucose; carrier protein called a 'permease';
   releases glucose on the other side of the membrane/ forms a gate/ channel to allow passage of glucose;
   can go either way across the membrane depending on the concentration gradient; **4**
   (b) sodium pump carries sodium ions across membrane using a specific carrier protein; driven by energy from ATP;
   produces high concentration of sodium ions which can only diffuse back through the membrane at 'sodium – glucose gates';
   diffusion back of sodium ions provides energy to carry glucose molecules through membrane; ref to symport carrier; **5**

   Total 9 marks

3.

Substance carried	Type of vesicle	Where vesicle was formed	Function
Polypeptides	Rough endoplasmic reticulum/RER	Rough endoplasmic reticulum/RER	Transport polypeptides to Golgi body;
Protease enzymes	Lysosomes	Golgi body	Intracellular digestion of proteins;
Lipids	Smooth endoplasmic reticulum/SER	Smooth endoplasmic reticulum/SER	Storage /secretion of lipids/steroids;
Peroxidase enzymes	Peroxisomes	Golgi body	Breakdown of toxic peroxides;

Total 4

4. (a) cyanide ions block cytochrome oxidase/prevent the electron transport chain from working;
   thus no energy is available to drive the proton pumps on the inner membrane;
   thus no protons/hydrogen ions diffuse back through the stalked particles to the matrix;
   thus ATP-ase in the stalked particles is not activated to synthesise ATP from ADP and phosphate; **4**

   (b) cytoplasmic streaming requires ATP as energy source;
   to make actin microfilaments combine with myosin, thus pulling the endoplasmic reticulum which moves the cytoplasm;
   ATP synthesis/use requires enzymes/ref ATP-ase;
   enzymes are temperature dependent and slow up in cold conditions; **4**

   (c) liver cells are metabolically much more active compared to plant parenchyma cells;
   synthesize many proteins/plasma proteins/fibrinogen and so many RER vesicles will be present;
   synthesize and store lipids so many SER vesicles will be present;
   detoxify peroxides and so many peroxisomes will be present; **4**

   Total 12

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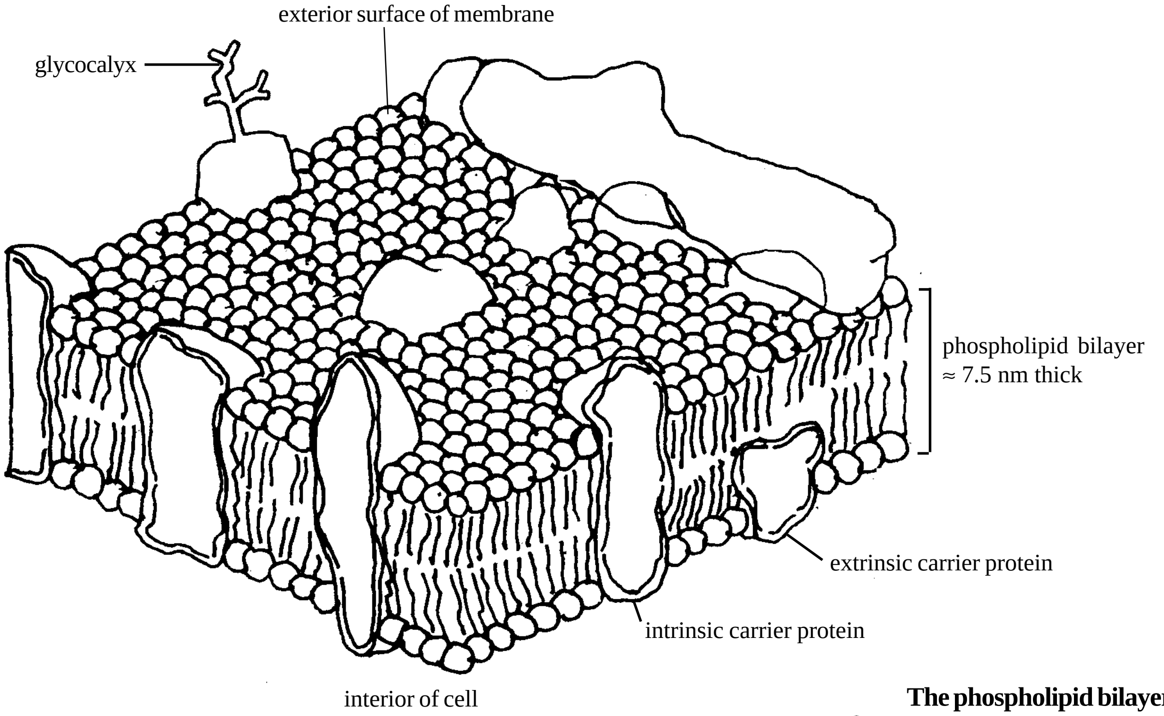
Active Transport

Active transport is the movement of molecules or ions across a differentially permeable membrane up a concentration or electrochemical gradient. Active transport is not passive, it requires ATP. In fact, in some cells nearly 50% of all the energy used is for active transport.

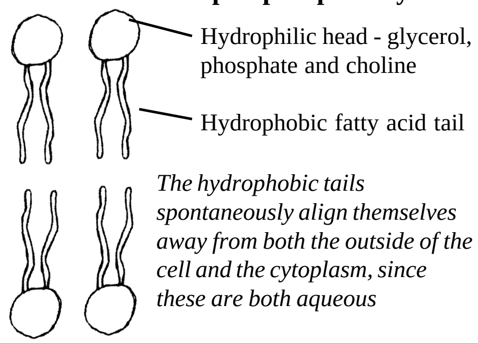
Active transport involves transport proteins. These proteins span the cell surface membrane (Fig 1).

Fig 1. Cell surface membrane (fluid mosaic model)



Glycocalyx -	allow cell recognition
Proteins -	intrinsic: span the membrane extrinsic: embedded in one half
Lipids -	phospholipids, glycolipids, cholesterol

The phospholipid bilayer



Transport proteins may move:
- A single substance in a single direction across a membrane
- Two substances in the same direction across a membrane
- Two substances in opposite directions across a membrane

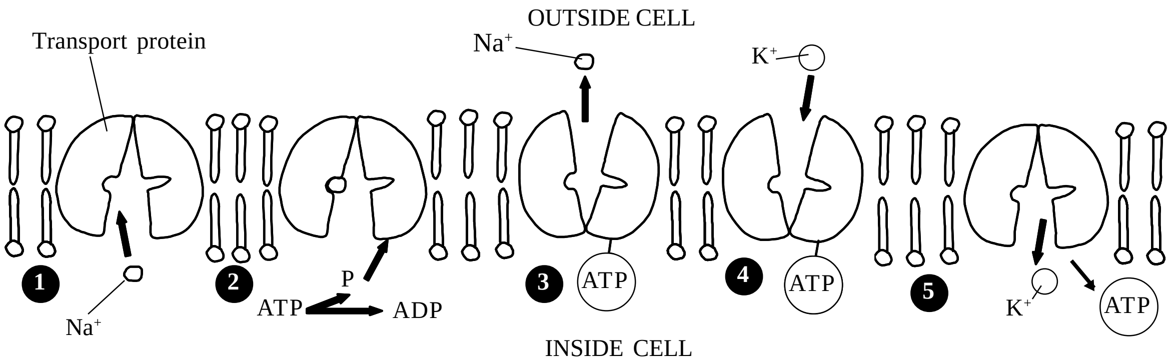
The process of active transport is still not fully understood. However, it is the general principles only that are important at this level and these can be illustrated by a form of active transport that occurs in almost every animal cell: the sodium-potassium pump (Fig 2).

Exam Hint: *You do not need to be able to reproduce Fig 1. However you may be asked to:*
1. *Draw a simple diagram of the phospholipid bilayer and recall its approximate width*
2. *Describe the functions of the phospolipids, proteins and the glycoycocalyx*
3. *Explain how the properties of the phospholipids influence the properties of the membrane*

The sodium - potassium pump

The sodium concentration is much greater outside the cell than inside it. There is therefore a tendency for sodium ions to diffuse into the cell down their concentration gradient. In order to work against this tendency the cell uses active transport to push out more of the sodium ions. By removing sodium ions in this way the cell reduces the volume of water that enters it by osmosis. Thus, one function of the sodium-potassium pump is to help the cell regulate its volume.

Fig. 2. Sodium-potassium pump

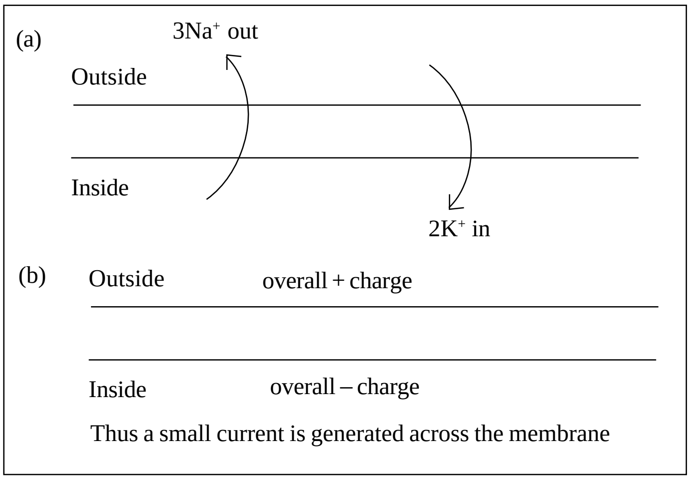


The ATP donates energy-rich phosphate to the transport protein thus activating it to bond with the specific solutes.

1. Sodium ions bind to the transport protein at specific binding site
2. This triggers hydrolysis of ATP into ADP and phosphate. The phosphate binds to the protein, phosphorylating it.
3. Phosphorylation causes the protein to change shape. This propels the sodium ion to the other side of the membrane i.e out of the cell, allowing it to enter the tissue fluid that bathes the cell.
4. Potassium ions in the tissue fluid now bind to the protein at their specific binding site (which is a different site to where the sodium ions bond).
5. This triggers dephosphorylation of the protein (i.e. the phosphate becomes detached from the protein carrier). Dephosphorylation causes the protein to change back to its original shape and this propels the potassium ion into the cell.

For each cycle of the pump, i.e. for each ATP molecule used, three sodium ions are expelled and two potassium ions are brought in. The net effect is to make the inside of the cell less positively charged i.e. more negatively charged relative to the outside (Fig 3). Thus, an electric current is generated across the membrane. In nerve cells, this is the basis of the membrane potential.

Fig 3 Sodium and potassium ions create the membrane potential



The major examples of active transport that feature on A level and Scottish Higher specifications are summarised in Table 1.

Table 1. Active Transport in animals and plants

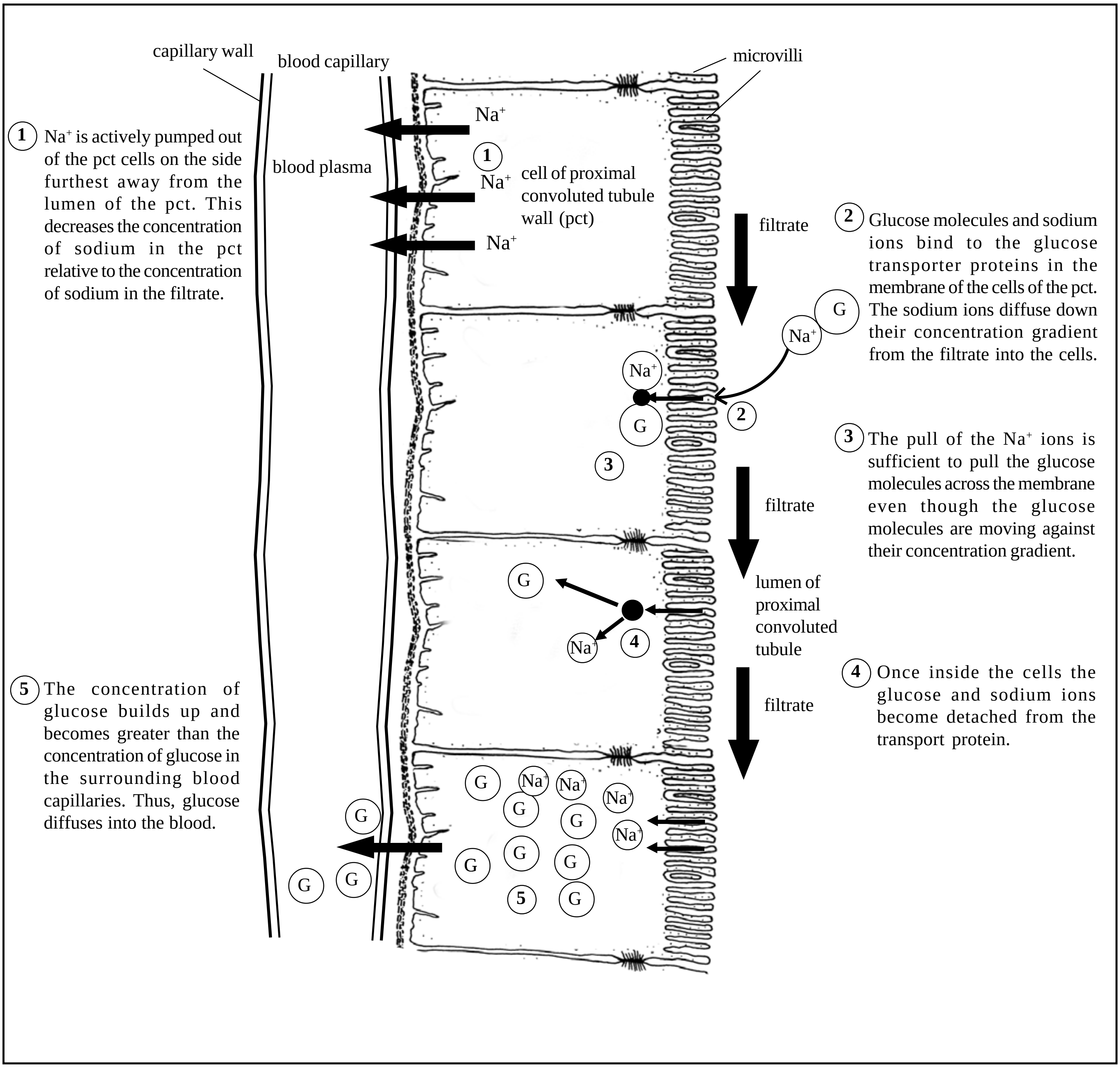
Location	**Process**
Root hair cells	Active transport of ions into the root hair
Guard cells of stomata (stomatal opening)	K^+ ions pumped into guard cells from epidermal cells. This lowers the water potential of the guard cells, drawing water in osmotically. Guard cells swell but the toughened wall around the pore is stiff and the pore of the stomata is pulled open
Placenta	Amino acids are actively transported from the mother to the foetus
Almost all animal cells	Sodium-potassium pump maintains low intracellular sodium concentration, helping to regulate cell volume and generating a resting potential
Proximal convoluted tubules of kidney	Active transport of sodium ions allows reabsorption of glucose from the filtrate

Examples of Active Transport

The proximal convoluted tubules of the nephron

Remember that the glomerular filtrate that enters the lumen of the cells of the convoluted tubule contains many substances that the body wishes to reabsorb: glucose and amino acids being good examples. Fig 4 shows how reabsorption of glucose is achieved.

Fig 4. Reabsorption in the proximal convoluted tubules



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Bio Factsheet

Number 22

Protein synthesis I - Nucleic Acids

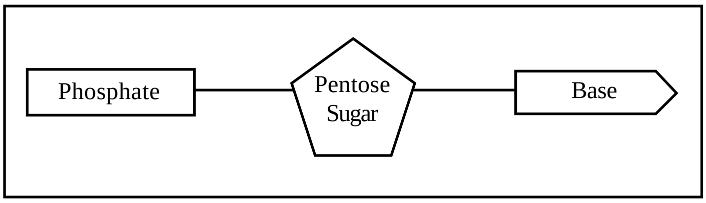
Proteins are large, organic molecules which play a fundamental role in metabolic activities including nutrition, respiration, transport, sensitivity, co-ordination and reproduction.

The characteristics of cells and organisms are determined by the particular proteins which are present. The synthesis of these proteins involves two types of nucleic acid; DNA and RNA. **DNA** is contained within the nucleus of a cell and carries the code to determine which particular proteins are made. Various forms of **RNA** then carry this information to the cytoplasm of the cell and assemble the protein. To understand protein synthesis, you must first have an understanding of DNA and RNA.

Nucleic acids

DNA and RNA are both nucleic acids. Nucleic acids are macromolecules (large molecules) made up of chains of individual units called **nucleotides**. Each nucleotide is made up of 3 parts (Fig 1):

Fig 1. Diagrammatic representation of a nucleotide



1. A **phosphate group** (H_3PO_4), which is the same in all nucleotides.

2. A **pentose (5 carbon atoms) sugar**. This sugar can either be **ribose** sugar ($C_5H_{10}O_5$) or **deoxyribose** sugar ($C_5H_{10}O_4$)

3. One of five **nitrogenous bases**. These bases are divided into two types, depending on their structure (Fig 2):
   (a) **Purines** - Bases made up of one six-sided ring and one five-sided ring.
   (b) **Pyrimidines** - Bases made up of a single six-sided ring. The details of these rings is given in Table 1.

Fig 2. The ring structure of pyrimidines and purines

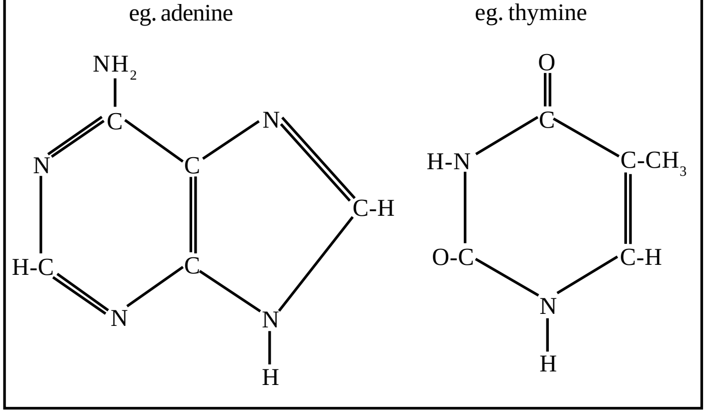
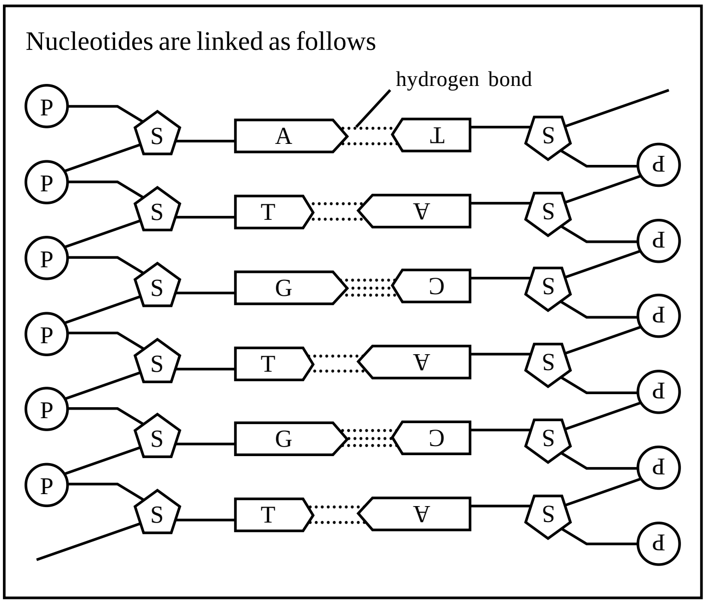


Table 1. Nitrogenous bases in nucleic acids

Ring structure	Base	Symbol	Nucleic acid
Purine (double)	Adenine Guanine	A G	DNA/RNA DNA/RNA
Pyrimidine (single)	Cytosine Thymine Uracil	C T U	DNA/RNA DNA RNA

The three components of nucleotides are joined together by **condensation** reactions (through the removal of water). Individual nucleotides are then joined together by similar condensation reactions between the phosphate group of one nucleotide and the pentose sugar of another (Fig 3). This linkage of nucleotides forms long chains, called **polynucleotides**, which make up nucleic acids.

Fig 3. Formation of a polynucleotide



From Fig 3, it can be seen that polynucleotides have a 'backbone' of phosphate and sugar, with the nitrogenous bases projecting inwards.

> ***Exam hint -*** *Not all Examination Boards require candidates to be able to recognise purines and pyrimidines but all expect candidates to know that purines are larger molecules than pyrimidines and that A and G are purines etc.*

Comparing DNA & RNA
DNA and RNA are both vital in protein synthesis. Table 2 summarises the similarities and differences between these two macromolecules:

Table 2. Comparison of DNA and RNA

DNA	RNA
Formed in nucleus	Formed in nucleus
Predominantly found in nucleus	Found throughout the cell
Double strand of nucleotides - coiled into a double helix. The two strands are linked by hydrogen bonding between the bases (Fig 3): Cytosine with Guanine, Adenine with Thymine	Single strand of nucleotides which can be folded into different shapes
Pentose sugar present - Deoxyribose	Pentose sugar present - Ribose
Bases present: Cytosine, Guanine, Adenine, Thymine	Bases present: Cytosine, Guanine, Adenine, Uracil
Larger molecule	Smaller molecule
One basic form	Three main forms: messenger RNA, transfer RNA, ribosomal RNA
Ratio of 1:1 for adenine:thymine, and cytosine:guanine	Ratio of adenine:thymine, and cytosine:guanine variable

***Exam hint** - Do **not** confuse thymine with thiamine.*

To summarise, DNA and RNA are both made up of nucleotides. In DNA, there are two nucleotide strands which are wound around each other at approximately every ten bases. Thus DNA forms a helix. The strands are **anti-parallel** - i.e. they run in opposite directions to each other. The two strands of nucleotides which make up the DNA double helix are held together by the **hydrogen bonding** between nitrogenous bases. This paring is always as follows:

- **Adenine with Thymine (A-T)**
- **Cytosine with Guanine (C-G)**

The different structures of the bases result in two hydrogen bonds being formed A to T (A=T), and three hydrogen bonds between C to G (C≡G).

The bonding of the nitrogenous bases ensures that purines always bond with pyrimidines, and more specifically, A to T and C to G. The precise nature of this bonding is biologically important for two reasons:

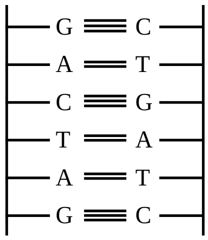
1. The structure of DNA remains exact and regular. This is vital since DNA carries the heredity material for an individual.
2. DNA can exist as a very long sequence of bases, with an enormous variety in order, to carry the large amount of genetic information for an individual.

DNA Replication

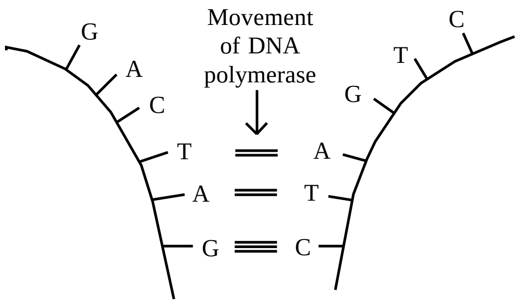
The replication of DNA takes place shortly before cell division, during a phase of the cell cycle called **interphase**. DNA replication is said to be **semi-conservative**. This means that when two new double helixes of DNA are produced, one of the strands of each helix is from the original (parental) DNA strand and the other is new. The sequence of diagrams in Fig 4 illustrate the replication of DNA.

Fig 4. Replication of DNA

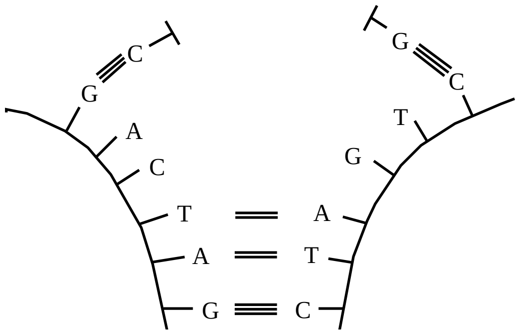
1. A portion of the DNA double helix about to be replicated



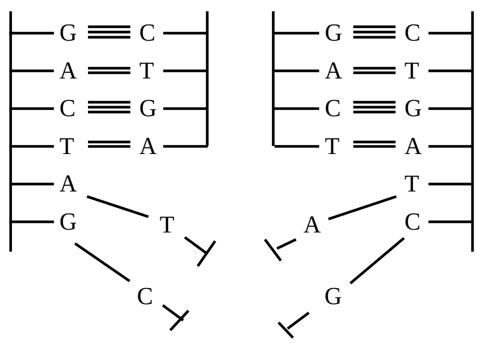
2. Replication has started. The enzyme **DNA polymerase** moves along the DNA double helix unwinding it and 'unzipping it' by breaking the hydrogen bonds between the nitrogenous bases.



3. **Free nucleotides** in the nucleoplasm of the nucleus are attracted to the exposed complementary bases and form new hydrogen bonds with them.



4. DNA polymerase continues to move along the DNA, exposing the bases for free nucleotides to come into and bond. Once these new nucleotides are in place they bond together (phosphate to deoxyribose sugar) forming a new strand of DNA.



5. Replication is now complete, forming two identical strands of DNA which are exact copies of the original strand. This method is said to be semi-conservative, since each strand retains **half** of the original DNA material.

Evidence for semi-conservative DNA replication
The evidence for semi-conservative DNA replication came from experiments by **Matthew Meselsohn** and **Franklin Stahl**, two scientists at the California Institute of Technology, using the bacterium *Escherichia coli*. Matthew and Franklin experiments can be explained in the following series of steps:

1. *E. coli* were cultured in a growth medium containing nitrogen in the form of the isotope ^{15}N (known as 'heavy nitrogen').
2. By leaving the E. coli in the culture for a long enough period of time, all DNA in the *E. coli* became made up of 'heavy nitrogen'. This meant that the molecular weight of the DNA in these *E. coli* was measurably greater.
3. The *E. coli* containing the 'heavy nitrogen' were then placed into a medium containing normal nitrogen (^{14}N), so that any new DNA manufactured would be from this normal nitrogen.
4. The *E. coli* was allowed to divide once and the first generation cells were then collected.
5. When the DNA was extracted from these cells and the relative weight determined using a centrifugation technique, the molecular weight of the DNA was found to be **intermediate** between heavy and light types. This confirmed that the DNA was made up of one original (heavy) strand of DNA and one new (light) strand of DNA - Semi-conservative replication.

Practice Questions

1. Define the following terms:
   (a) DNA double helix (3 marks)

   (b) complementary base pairing (3 marks)

   (c) semi-conservative replication of DNA (2 marks)

2. (a) Read through the following account of DNA replication, then find the most appropriate word or words to complete the account.

During DNA replication, the enzyme …………………………… binds to the DNA double ……………………………This causes the DNA to …………………………… and breaks the …………………………… bonds between the nucleotides. These nucleotides are bound together at …………………………… bases. The base adenine binds with …………………………… and …………………………… binds with guanine. Free nucleotides found in the …………………………… bind with the exposed bases producing two strands of DNA. The process is said to be …………………………… because in both of the two DNA strands produced, one sequence of nucleotides is new and the other is from the ……………………………DNA. (10 marks)

(b) When a sample of DNA is extracted from the nucleus of a cell, chemical analysis showed that 38% of the bases were adenine. What percentage of the bases are guanine (3 marks)

3. DNA and RNA are major molecules involved in the transfer of hereditary material and protein synthesis.
   (a) To which group of molecules do DNA and RNA belong? (1 mark)

   (b) DNA and RNA are both composed of nucleotide sub-units. Describe the structure of a nucleotide. (3 marks)

   (c) State four similarities and four differences between a DNA molecule and an RNA molecule (8 marks)

Answers

Marking points are shown by semicolons

1. (a) Two strands of nucleotide;
   held together by hydrogen bonding;
   coiled or twisted around each other (approximately every 10 bases).

   (b) hydrogen bonding between pairs of organic bases;
   (projecting from the sugar-phosphate backbone of nucleic acids);
   pairing occurs between adenine-thymine, guanine-cytosine in DNA;
   pairing between adenine-uracil, guanine-cytosine in RNA.
   (Any 3)

   (c) Half of the original parent molecule is retained/conserved;
   half is composed of new nucleotide molecules.

2. (a) DNA polymerase;
   helix;
   unwind;
   hydrogen;
   nitrogenous/exposed;
   thymine;
   cytosine;
   nucleoplasm/nucleus;
   semi-conservative;
   parental/original.

   (b) 38% adenine, ∴ 38% thymine;
   remaining 24% is cytosine and guanine (50% each);
   ∴ 12% guanine.

3. (a) nucleic acids.

   (b) phosphate;
   ribose/5C sugar;
   nitrogenous base;
   components joined by condensations reactions

   (c) (see Table 2)

Acknowledgements;
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Bio Factsheet

www.curriculum-press.co.uk Number 165

Surface Area and Volume

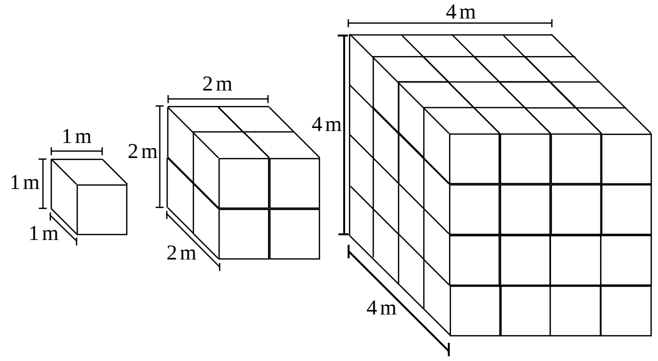
The surface area to volume ratio is a crucial biological concept. It helps explain, amongst other things why:
- organisms that rely upon diffusion are condemned forever to be small
- tapeworms are extremely efficient parasites
- as organisms get bigger, they need internal transport systems
- microvilli are an essential part of our intestines
- plants that live in arid areas have unusual –shaped leaves
- Hippos need to stay in the water during the day

This concept appears on the exam papers of all the Boards every year – but it often comes up in very well camouflaged questions!

This Factsheet will help you to:
- understand the importance of the concept, and
- spot it in exam questions

The surface area of an organism is the area its outer surface covers. Imagine a square organism (Fig 1).

Fig 1. Surface area to volume ratios of differently sized cubes



surface area	$6m^2$	$24m^2$	$96m^2$
volume	$1m^3$	$8m^3$	$64m^3$
surface area:volume	6:1	3:1	1.5:1

Its surface area is 6 x L^2 where L =the length of one side. If L =1cm then its SA =$6cm^2$
Its volume is L^3 or 1^3 =$1m^3$
Its SA to V ratio is 6:1 = 6

Now, let's double its size:
SA = $6x2^2$ =$24cm^2$ i.e. area has DOUBLED
V = 2^3 = $8cm^3$ i.e. volume has OCTUPLED
Its SA:V ratio is 24:8 = 3:1

Now lets double the size again:
SA = $6x4^2$ = 96 cm^2
V = 4^3 = 64 cm^3
SA:V ratio is 96:64 = 1.5:1

So, as organisms get bigger, their surface area increases by the square of their size, but their volume increase by the cube of their side length. **The increase in volume is always greater than the increase in surface area**. This is true for cubes, spheres, or any other object whose size is increased without changing its shape.

So: The smaller the organism, the greater it's SA :V ratio
As an organism gets bigger, its SA:V ratio goes down

Organisms have both physiological and anatomical adaptations to compensate for changes in the surface area to volume ratio associated with size differences.

Heat loss

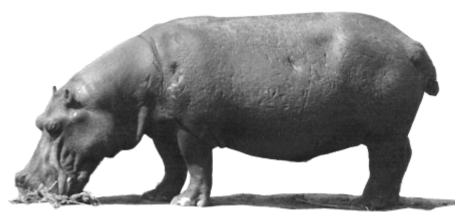
Small animals have a large SA:V ratio
∴ If they are homethermic (i.e. a bird or a mammal) they will lose heat much faster than a large animal
∴ they must therefore produce more heat to keep warm
∴ they tend to have higher metabolic rates than large homeotherms

Sometimes, you will be expected to apply this knowledge to try to explain the behaviour of large mammals that live in hot climates. For example, the hippopotamus is a large mammal that lives in tropical Africa.

Question: Using your knowledge of SA:V ratios, suggest why the hippo spends most of the day partly submerged in lakes and rivers, coming out at night to feed on vegetation.

A large mammal will have a ***small*** SA:V ratio (look at Fig 2 which illustrates how much volume there is for each square centimeter of skin).

Fig 2 hippo



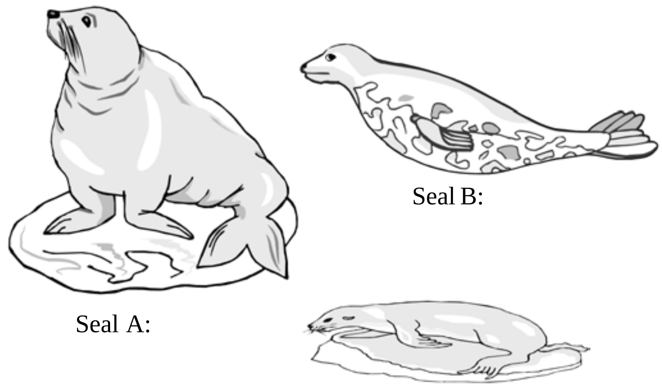
Answer: The huge mass of cells will be producing metabolic heat from respiration;
There is relatively little skin surface to lose this heat/small SA:V ratio
In any case, it's in the tropics - air temperatures are high;
Its fat stores will limit heat loss;
Hence, it spends the hot days in the cooler water;
Emerging during the much cooler nights.

Note: Hippos are not on any A level spec – the examiners expect you to be able to apply simple biological principles to new situations

All marine mammals are relatively large sized in comparison with terrestrial mammals. Even the smallest seal, the ringed seal, weighs 50 kilograms. Once again, the relative size of different seals may be an indication of the temperature of the environment in which they live.

Fig 3 shows three species of seal (a mammal), A, B and C.

Fig 3.



Seal A:

Seal B:

Seal C:

Seal A:
Habitat: very cold seas of the Arctic
length 2.3, mass 380 kg.

Seal B
Habitat: slightly warmer seas
length 1.4 m, mass 180 kg

Seal C
Habitat: warmest of the three habitats
length 0.6 m mass 80 kg

Question: How is seal A adapted for life in the very cold arctic waters?

Answer: Small SA:V ratio;
Therefore rate of heat loss low;
Thick blubber offers insulation;
Small limbs so reduced area for heat loss;

Note: it would not be correct to say that seal A loses least heat; it has a bigger surface area so it will lose a lot, but the rate of heat loss will be less. In the exam, be precise.

Internal transport systems

Small, unicellular organisms have a large surface area over which gas exchange may take place. Diffusion is adequate for supplying oxygen and getting rid of carbon dioxide across the outer cell surface membrane. But as an organism gets larger, its surface area to volume ratio decreases and this makes a specialised transport system essential (Fig 4).

Fig 4. Specialised transport system

Amoeba

- Diffusion is fast enough over very small distances

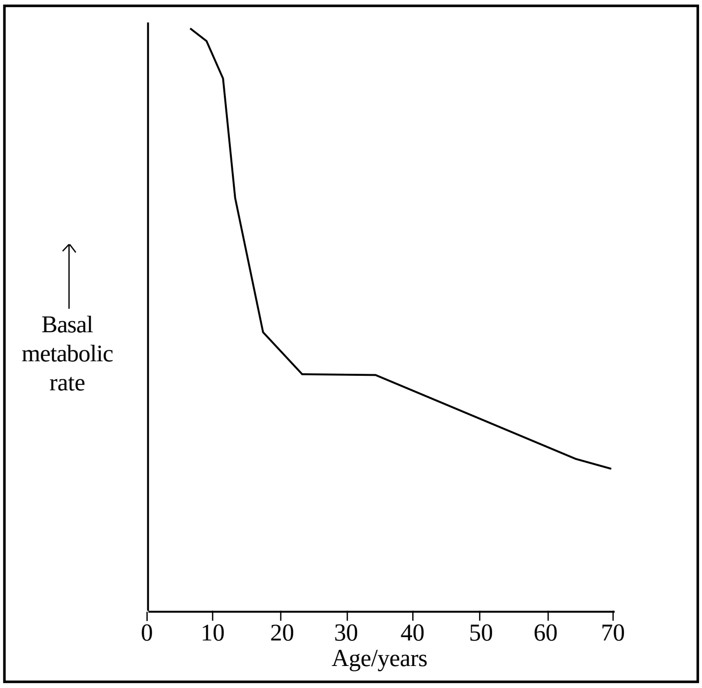
cheetah

- Diffusion path is too long/diffusion is too slow in large, multicellular organisms which are active
- Have low SA:V ratios
  Multicellular organism needs more oxygen, faster
- Allows aerobic respiration to generate sufficient ATP
- Needs to get rid of CO_2 or urea quickly because they are toxic

One response to the problems of declining SA:V ratios with increasing size is to increase surface area –many organisms exhibit such structures:
- leaves on trees
- microvilli on the lining of the small intestine
- root hairs
- extensive capillaries
- the convoluted walls of arteries
- flattened segments of tapeworm to aid absorption and reduce resistance to the flow of substances through the intestine
- alveoli in lungs
- lamellae in gills

Basal metabolic rate (BMR)
The basal metabolic rate is the amount of energy required to maintain basic physiological functions when at rest. Fig 5 shows the changes in BMR in males between the ages of 10 and 70.

Fig 5. Basal metabolic rate



It may come as a surprise to see how the BMR declines sharply between the ages of 10-20. BMR is, in fact, directly proportional to body surface area. Between the ages of 10-20 years the BMR declines rapidly as adolescent growth leads to a decrease in S.A. / mass.

Red blood cells

Question: How does the shape of a red blood cell allows it to take up a large volume of oxygen in a short time?

Anawer. It has a large surface area to volume ratio;
For diffusion;

> ***Exam Hint***
> *Here is an extract from a Chief examiner's report on a similar question:*
>
> *Candidates often chose to ignore the instruction about **shape**, and produced inappropriate answers relating to there being no nucleus or the red blood cell having haemoglobin. No credit was given for responses that talked only about the surface area of the cell; the examiners wanted the all-important principle of the surface-area to volume ratio.*

Conclusion

The concept of surface area: volume ratios comes up in lots of different topics and it isn't always immediately obvious that the question is asking about this concept. Make sure that you understand the principle and practice using the key terms

Practice Questions

1. (a) The table below shows the size of 4 animals. Complete the table by calculating the surface area, volume and SA :V ratio for each animal.

Animal	Size (cm)	**Surface Area (cm^2)**	**Volume (cm^3)**	**Surface area to Volume Ratio**
1	1x1x1			
2	2x2x2			
3	3x3x3			
4	4x4x4			

(b) All other things being equal, which organism would have most difficulty keeping warm in a cold environment? Explain your answer.

2. The equation below represents Fick's Law of diffusion across membranes

$$\mathbf{J = DA \frac{\Delta c}{\Delta x}}$$

J = net rate of diffusion
D = diffusion constant of dissolved solute
A = area of the membrane
Δc = concentration difference across membrane
Δx = thickness of membrane

(a) Use Fick's Law to explain why the efficiency of oxygen transport across the alveolar surfaces of a mammalian lung is improved by the surfaces:
(i) having a large area.
(ii) being a thin membrane.
(iii) having an efficient blood supply.

Answers

1. (a)

Animal 1	$6cm^2$	$1m^2$	6:1
Animal 2	$24cm^2$	$8m^2$	3:1
Animal 3	$54cm^2$	$27m^2$	2:1
Animal 4	$96cm^2$	$64m^2$	1.5:1

2. (a) (i) if A is large then J must be large and so more oxygen can be diffused;
(ii) if Δx is small then J must be large and so more oxygen can be diffused;
(iii) an efficient blood supply will carry oxygen away more efficiently;
thus Δc will be large and so J will be large so more oxygen can be diffused;

(b) as Amoeba grows the distance for oxygen to diffuse from the (surrounding) water into the centre of the cell increases;
this is Δx and if this is increased J is reduced;
thus the central regions of the Amoeba cell become deprived of oxygen above a certain cell size;
division reduces it to a more suitable size for efficient gas exchange;

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Bio Factsheet

Number 1

The kidney: excretion and osmoregulation

Kidneys have two main functions.
1. **They are excretory organs, removing nitrogenous and other waste from the body.**
2. **They play an important part in maintaining a constant internal environment by helping to regulate pH, water and sodium ion concentrations in the blood and tissues. This Factsheet will focus on the role of the kidney in excretion and osmoregulation.**

Excretion
Surplus nitrogen-containing compounds such as amino acids have to be broken down in the body because they are toxic and are then excreted as ammonia, urea or uric acid (Table 1).

Table 1. Nitrogenous excretory products

Excretory product	Source
Urea	Deamination of amino acids via the ornithine cycle in the liver
Uric acid	Deamination of purines (adenine and guanine)
Ammonia	Deamination of amino acids. Ammonia is secreted into the urine by cells in the kidney tubule

***Exam Hint** - Don't confuse urea and urine. Urea is made by the deamination of amino acids in the liver. Urine is the fluid produced by the kidneys.*

Some important biological properties of these three substances are summarised in Table 2.

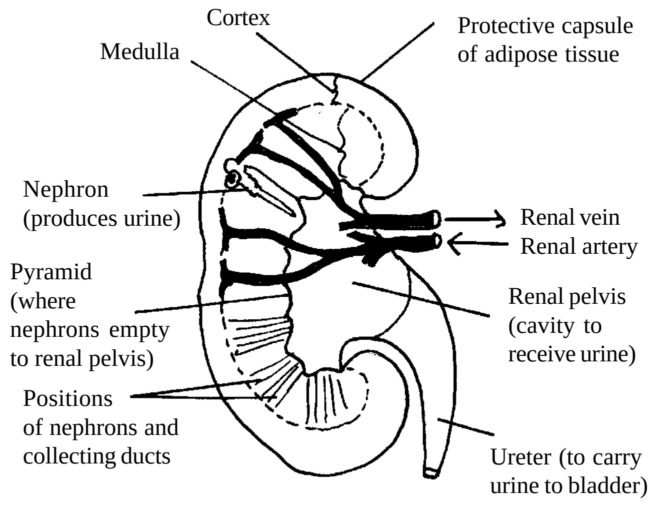
Table 2. Biological properties of excretory products.

	Ammonia	Urea	Uric acid
Solubility	Very high	High	Very low
Amount of water necessary to remove from body	Very large	Medium	Very little
Toxicity	High	Medium	Low
Molecules of ATP needed	0	4	8

From this you can work out that:
- Freshwater fish excrete ammonia. Although it is very poisonous, fish are surrounded by large amounts of water so the ammonia can easily be diluted to safe levels.
- Mammals excrete nitrogen mainly as urea. Urea requires more energy in the form of ATP for its production but is much less toxic than ammonia and fairly soluble. It therefore does not require large amounts of water to remove it from the body.
- Birds excrete nitrogen mainly as uric acid. Flight demands a low body mass. Removing nitrogenous waste as uric acid means that large amounts of water are not required. Insects also excrete uric acid. As they are so small, they are very prone to water loss so it is important that they do not lose large amounts of water in excreting nitrogenous waste.

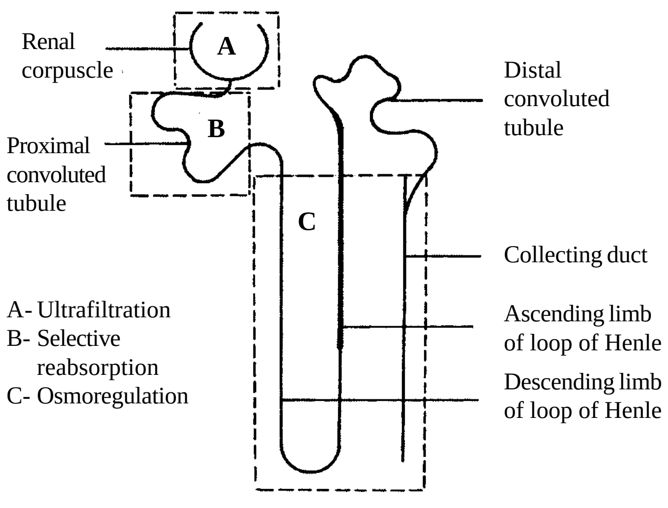
Basic kidney structure
The basic structure of the mammalian kidney is shown in Figure 1.

Figure 1. Vertical section through mammalian kidney.



Each kidney contains a million coiled tubes called nephrons and it is in the nephron that urine formation occurs. Each nephron is divided into a number of distinct regions with particular functions labelled A, B, C (Figure 2).

Figure 2. The kidney nephron

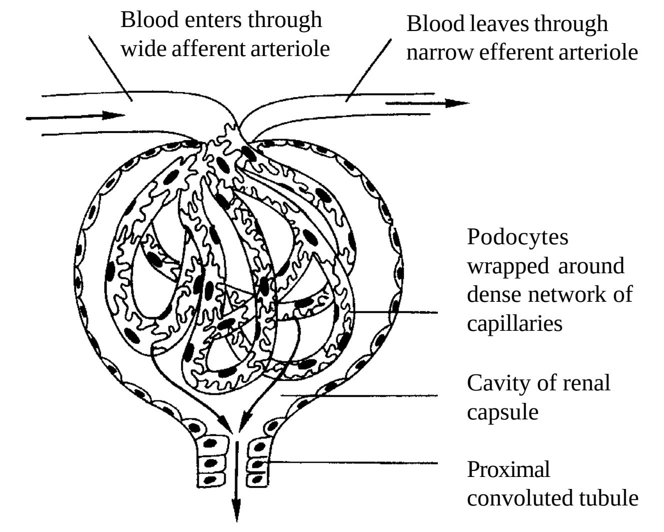


A. Ultrafiltration (Figure 3).
The Bowman's capsule contains a dense capillary network called the glomerulus. Blood flows into these capillaries through a wide **afferent** arteiole and leaves through a narrower **efferent** arteriole. The blood pressure inside these capillaries is high because:

1. The renal artery contains blood at very high pressure which enters the glomerulus via the short afferent arteriole.
2. The efferent arteriole has a smaller diameter than the afferent arteriole.

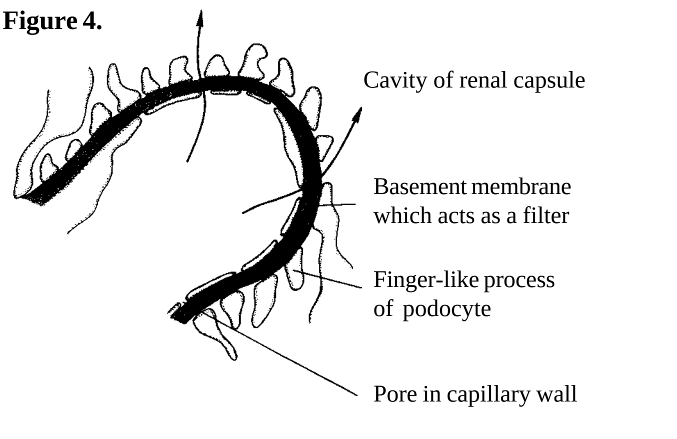
The high pressure forces small molecules such as water, glucose, amino acids, sodium chloride and urea through the filter i.e. from the blood in the glomerular capsule across the basement membrane of the Bowman's capsule and into the nephron. This type of high-pressure filtration is known as **ultrafiltration.** The fluid formed in this way is called **glomerular filtrate**. Large molecules such as plasma proteins and blood cells do not pass through the filter because they are too big.

Figure 3. Structure of Bowman's capsule.



The structure of the filter (Figure 4).
Blood plasma is separated from the filtrate by two rows of cells, the lining cells of the capillary and the **podocytes** which make up the inner layer of the capsule. The capillaries have pores in their walls which the molecules in the plasma are able to pass directly through. The small molecules then pass through the basement membrane and once through this, they can pass between the processes of the podocyte directly into the cavity of the renal capsule. The actual filter is just the basement membrane and this is extremely thin.

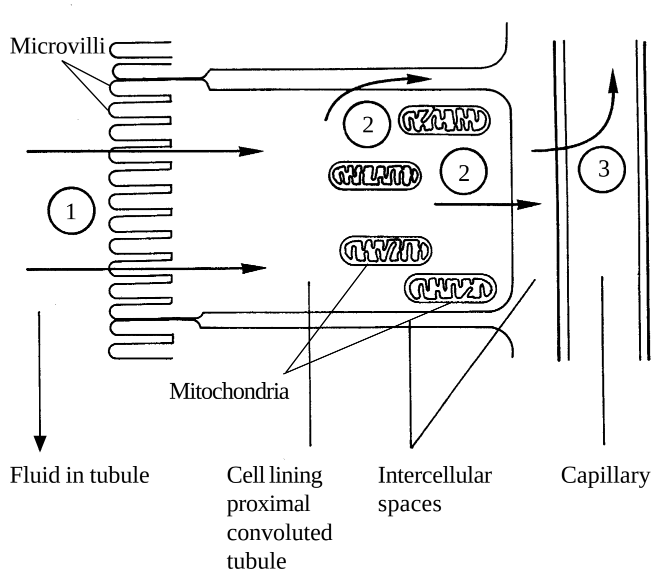
Figure 4.



Typical exam question
Ultrafiltration often comes up in application questions, i.e. those questions which test a candidate's ability to apply factual knowledge to new situations. Often, candidates will be asked to make inferences about kidney malfunction from an analysis of the constituents of urine. If large molecules such as plasma proteins or red blood cells are present, the implication is that the filtration mechanism in the Bowman's capsule is not working properly. The presence of many small molecules such as amino acids would tell us nothing about the filtration mechanism, but would imply damage to the proximal convoluted tubule, where selective reabsorption occurs.

B. Selective reabsorption in the proximal convoluted tubule
The filtrate contains toxic substances such as urea which it is necessary to remove from the body but it also contains substances such as glucose which are required by the body. The function of the proximal convoluted tubule is to reabsorb these useful substances (Figure 5).

Figure 5. Reabsorption in the proximal convoluted tubule.



1. Glucose **diffuses** into the cells which line the proximal convoluted tubule. Microvilli increase the surface area for efficient absorption.
2. The glucose is **actively** transported out of the cells into the intercellular spaces. Mitochondria supply the necessary ATP.
3. Once in the intercellular spaces, the glucose diffuses through the walls of the capillaries and is transported away by the blood.
4. Active transport of glucose out of the tubule cells maintains a concentration gradient so more glucose is able to diffuse out of the tubule fluid.

Similar mechanisms result in the reabsorption of many of the **amino acids** and up to 90% of the **sodium ions** from the tubule fluid. The removal of all these soluble substances results in an osmotic gradient between the fluid in the tubule and the cells which line it. Water is therefore drawn out of the tubule fluid by osmosis, and passes into blood. This process is responsible for 85-90% of water reabsorption in the Nephron. It is only the remaining 10-15% which is regulated in the loop of Henle and collecting duct.

Typical exam question
State three ways in which the cells of the proximal convoluted tubule are adapted for efficient reabsorption.

C. Osmoregulation (Figure 6)

The ability to produce concentrated urine is important in allowing terrestrial mammals to conserve water. The loop of Henle and the collecting duct form a system known as a **countercurrent multiplier** whose function is to remove water from the fluid in the tubule and produce a concentrated urine.

1. Na^+ and Cl^- ions are actively pumped out of the ascending limb. The ions accumulate in the interstitial fluid. This lowers the water potential of the interstitial fluid. The tendency is for water to osmotically follow the Na^+ and Cl^- ions but it cannot since most of the ascending limb is impermeable to water.

2. Water is drawn out of the descending limb and into the interstitial fluids by osmosis. This makes the fluid in the descending limb more and more concentrated.

3. By the time the fluid in the descending limb has reached the bottom of the limb, it has lost a lot of water and is very concentrated. The fluid surrounding the bottom of the loop - in the medulla of the kidney - is also very concentrated because of the accumulation of Na^+ and Cl^- ions. The direction of the concentration gradient is shown by the arrow.

4. The fluid then enters the ascending limb. As it moves up the ascending limb, sodium ions are actively pumped out of it.

5. This makes the fluid at the top of the ascending limb very dilute again.

6. The fluid then empties into collecting ducts which pass through the very concentrated medullary region.

7. Under the influence of the hormone ADH, the wall of the collecting duct becomes permeable to water which is therefore osmotically drawn out of the collecting duct and into the blood capillaries in the region.

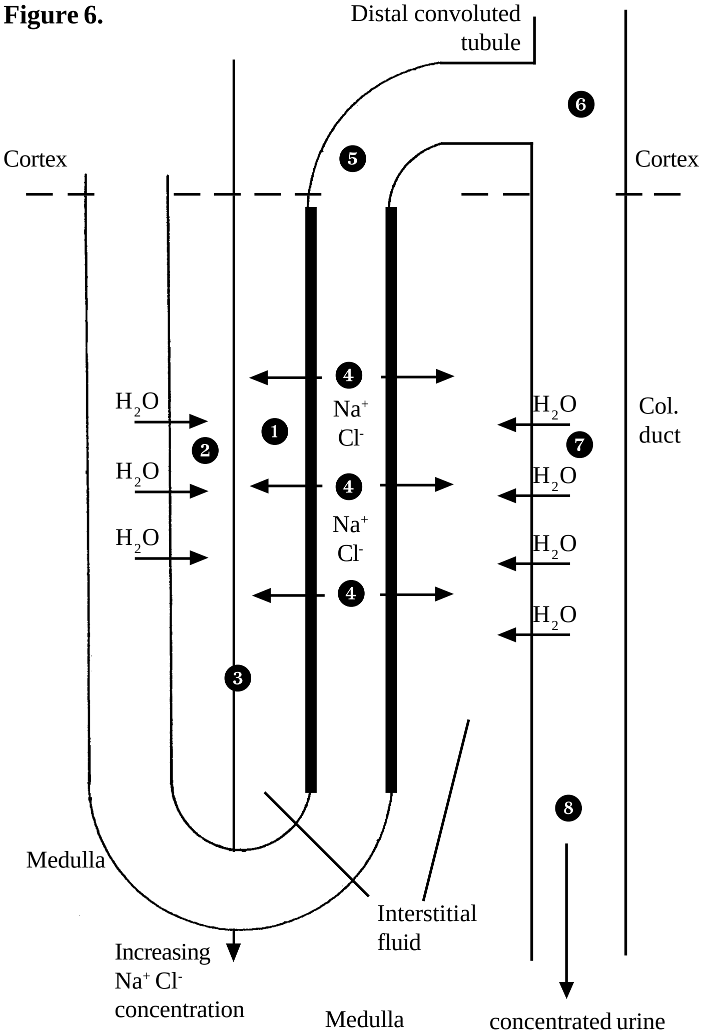
8. By drawing water out of the fluid in the collecting duct, a very concentrated urine can be produced. By regulating the permeability of the collecting duct (via ADH), the amount of water in the blood and the concentration of the urine can be controlled.

Typical exam question

Individuals who are unable to produce ADH suffer from diabetes insipidus. Describe the likely symptoms of this condition.

Exam Hint *- The longer the loop of Henle, the more concentrated the urine that can be formed. A nephron from a frog or a toad doesn't have a loop of Henle so these animals are unable to produce concentrated urine. Small mammals such as gerbils that live in deserts have nephrons with very long loops of Henle. These animals can produce extremely concentrated urine, thus reducing water loss from the body. This is often tested as an application question.*

Figure 6.



What controls ADH?

The osmotic concentration of the blood is monitored by **osmoreceptors** in the hypothalamus. Blood pressure is monitored by **baroreceptors** which are widely dispersed throughout the circulatory system. Both types of receptor can send impulses to the posterior pituitary gland to start/stop ADH release.

If too much water is lost from the body:
1. The volume of blood plasma falls, its osmotic concentration therefore increases and blood pressure falls.

2. Osmoreceptor and baroreceptors detect these changes and an impulse is sent to the posterior pituitary gland.

3. ADH is released.

4. ADH increases the permeability to water of the collecting duct and the distal convoluted tubule.

5. More water is therefore drawn out of the collecting duct and distal convoluted tubule back into the blood. This restores the volume and pressure of the blood and reduces its osmotic concentration.

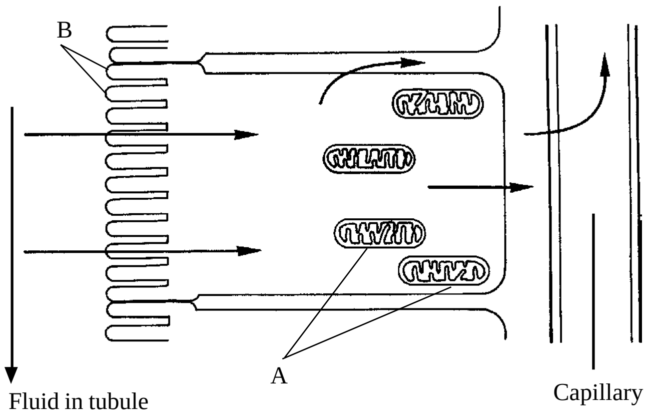
6. The stimulus to the posterior pituitary is switched off.

If the osmotic concentration of the blood falls or if blood pressure increases, less ADH is released, less water is reabsorbed, resulting in a large volume of dilute urine. This restores the osmotic concentration and pressure of the blood.

Practice questions

Semicolons indicate marking points.

1. The diagram shows a cell from the proximal convoluted tubule in the nephron.



(a) Outline the function of:
(i) Component A (*2 marks*)
(ii) Component B (*2 marks*)

(b) Suggest explanations for each of the following:
(i) The presence of glucose in the urine of a person who has consumed large amounts of glucose (*2 marks*)
(ii) The presence of protein in the urine of a person suffering from high blood pressure. (*2 marks*)

2. (a) Outline the process of ultrafiltration (*3 marks*)

(b) The diameter of the efferent arteriole can be decreased by muscle contraction. Suggest what effect this would have on the process of ultrafiltration (*2 marks*)

3. The table shows the composition of fluids drawn from different regions of a mammalian kidney.

	Concentration in fluid (g/100cm^3)		
Substance	**Plasma**	**Glom. filtrate**	**Urine**
Glucose	0.08	0.07	0
Sodium	0.33	0.31	0.33
Urea	0.028	0.028	1.9
Protein	7	0	0

(a) Suggest an explanation for the difference in composition of the plasma and urine (*3 marks*)

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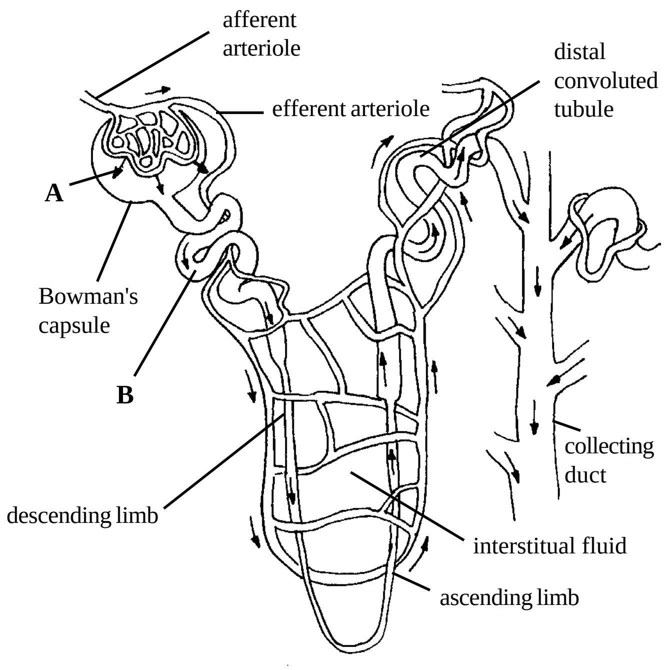
4. The diagram represents part of a mammalian kidney nephron.



(a) State the name of the major process which occurs in region:
(i) A (*1 mark*)
(ii) B (*1 mark*)

(b) Suggest why some desert mammals have very long loops of Henle (*2 marks*)

Answers

1. (a) (i) Provide ATP;
for active transport of glucose into intercellular spaces;

(ii) Provide large surface;
for diffusion of glucose;

(b) (i) No. of glucose molecules exceeds No. of carriers in proximal cell;
therefore unable to be actively transported;

(ii) High pressure forces proteins through basement membrane;
pressure may damage membrane;

2. (a) High blood pressure;
because of short afferent arteriole;
narrow efferent arteriole;
forces small molecules through basement membrane; (any 3)

(b) Increase it;
by increasing pressure;

3. (a) All glucose reabsorbed in proximal convoluted tubule;
Sodium concentration remains the same because active pumping out of ions is balanced by corresponding water loss;
Urea is concentrated through reabsorption of water in distal convoluted tubule and collecting duct;

4. (a) (i) Ultrafiltration
(ii) Selective reabsorption

(b) To conserve water;
the longer the loop the more water can be reabsorbed;

Bio Factsheet

Number 54

Water Potential

Water potential strikes fear into many students. However, in reality there are only five typical questions:
1. Here are two cells with different water potentials. Which way will water move?
2. Use water potential theory to explain why water enters and moves across roots.
3. Explain each part of the equation Ψ = Ψ s + Ψ p.
4. How can water potential theory be used to explain turgor and plasmolysis?
5. Interpret the water potential graph.

Water potential is defined as **"the tendency of water to enter or leave a cell".** Water moves from a region of high water potential to a region of lower water potential. A crucial point to learn is that the highest water potential is 0. All other water potential values are negative numbers and water moves towards the region with the more negative water potential. Water potential is measured in kilopascals (kPa).

Imagine two cells A and B (In reality, the numbers in the diagram are ridiculous – water potential would never be this low, but they illustrate the point).

A	B
-110kPa	-111kPa

Cell B (-111kPa) is more negative than cell A. Since water always moves to the cell with lower water potential, water would move from cell A to cell B. Usually in exam questions, the numbers are a bit trickier.

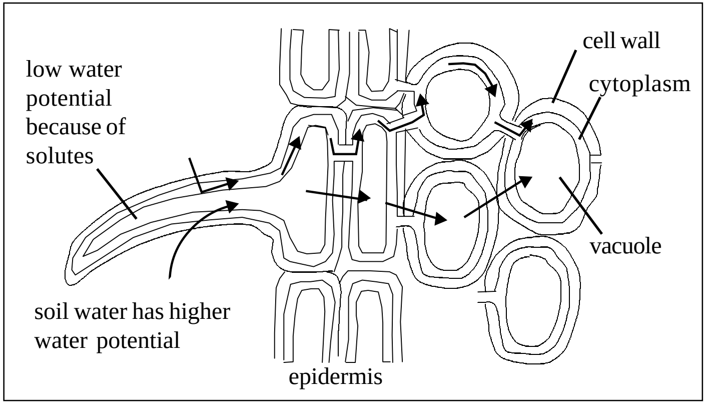
A	B
-110.4kPa	-110.5kPa

Some students find that the decimal points confuse things. Keep calm -110.5 is more negative than –110.4 (110.5 is further away from 0) so, again, water would move from cell A to B.

Water potential explains why water enters roots and how water moves across roots.

The movement of water into roots
Roots absorb water through their root hairs. Root hairs consist of a single cell (Fig 1). Root cells contain solutes and this lowers their water potential.

Fig 1. Movement of water into and across the root



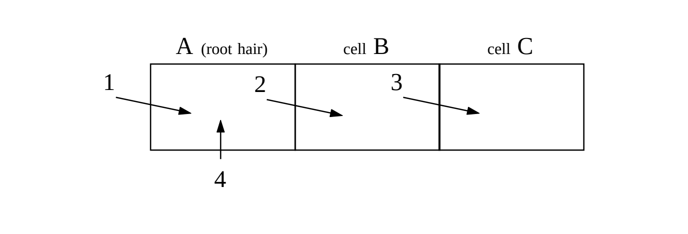
The water in the soil outside the root hair also contains some solutes, but not as many as the cell sap. So the water potential of the sap vacuole (of the root hair) is much lower than the water potential of the soil solution. Since water moves to areas of lower water potential, water moves from the soil solution into the vacuolar sap of the root hair.

Water potential also explains how water moves from cell to cell across the root. Remember that water moves from region of high water potential (soil) to region of low water potential (root hair cell). The water then has to move across the root from cell to cell.

The movement of water across the root

1. Water enters the root hair cell. This increases the water potential of that cell i.e. it becomes less negative (Fig 2).

Fig 2. Movement of water across the root



2. Cell A now has a higher water potential than cell B, so water moves from cell A to cell B
3. When cell B takes this water, its own water potential now increases, so its water potential is higher than C. Now water moves from B to C and so on across the cells of the root.
4. When A loses some water to B, the water potential of A decreases (because the solutes are now in less water and therefore more concentrated), so more water from the soil moves in, etc.

***Exam Hint** - Many candidates really struggle to explain what is going on in plant cells purely and simply because they are unsure about the structure of a typical cell. Make sure you can draw a plant cell and label the cell wall, cell membrane and vacuole.*

In order for water to enter the vacuole of a plant cell it must cross:
1. the cell wall
2. the cytoplasm
3. the tonoplast (Fig 3.)

When water enters the vacuole the volume of the vacuole increases. This pushes the cytoplasm against the cell wall, which stretches. The pressure of the cell contents pushing against the cell wall is called the **turgor pressure**. In turn, the cell wall is said to be pushing back against the cytoplasm with opposing force. When a cell has taken in as much water as it possibly can and the cell contents are being pushed against the cell wall with maximum force, the cell is said to be **turgid**.

Imagine a cell which is now placed in a solution which has a high concentration of solutes. Since solutes lower water potential the solution will have a low water potential. Water will be drawn out of the plant cell and the vacuole will begin to shrink. Eventually a point will be reached when the protoplast (the living part of the cell) is about to become detached from the cell wall (Fig 4), this point is known as **incipient plasmolysis**. When the protoplast becomes detached the cell is said to be **plasmolysed**

Fig 3. A turgid plant cell

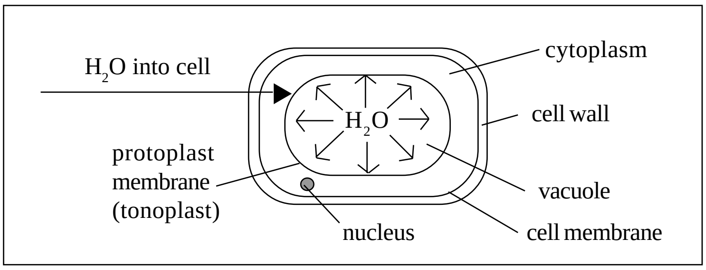


Fig 4. Incipient plasmolysis

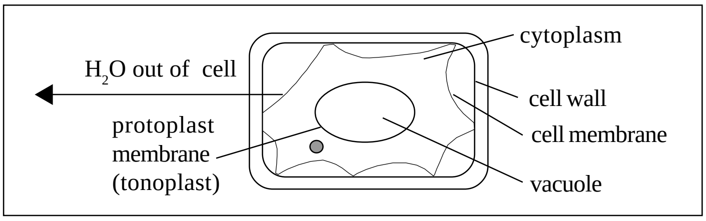
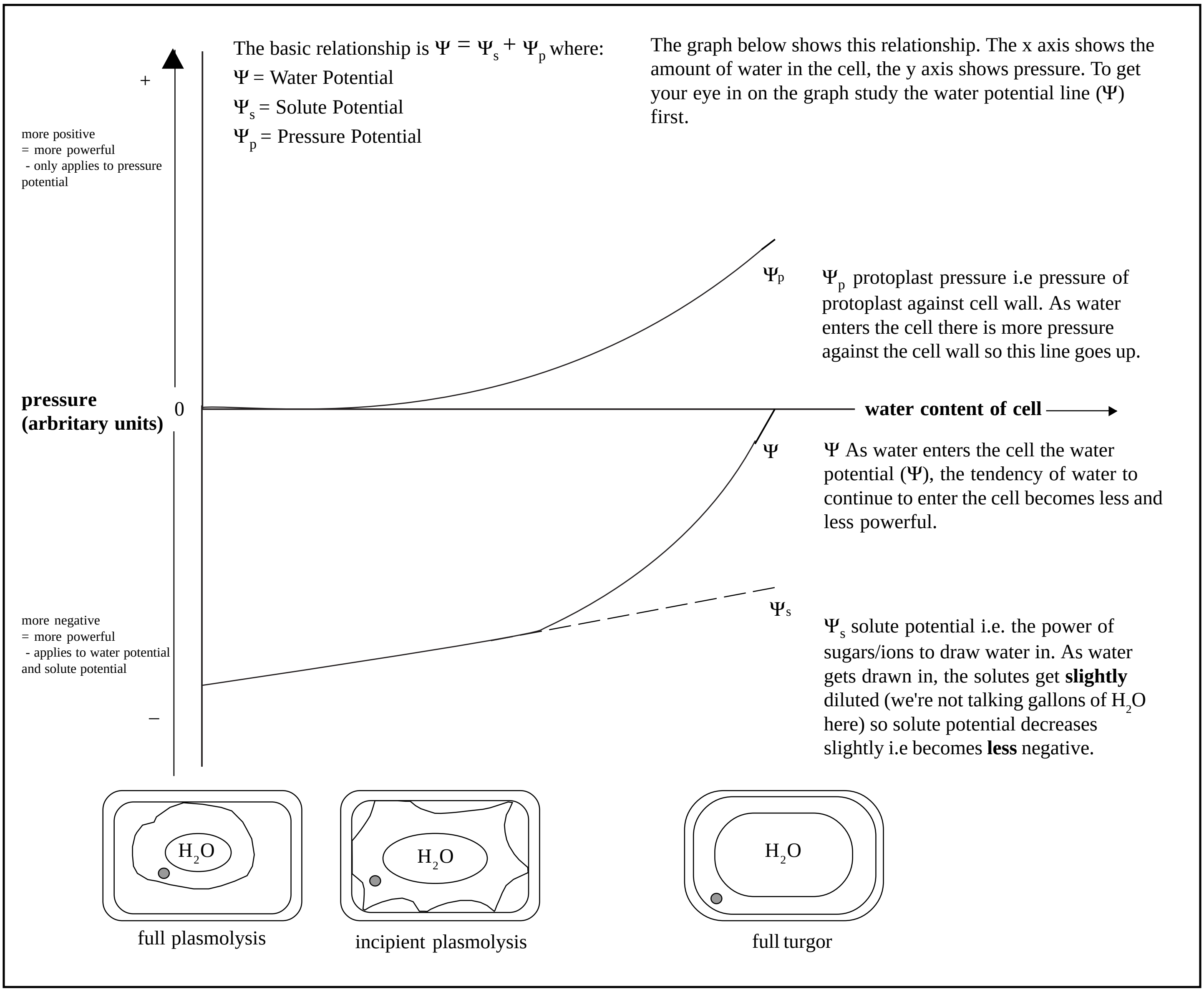


Fig 5. The water potential graph



Acknowledgements; *This Factsheet was researched and written by Kevin Byrne.* ***Curriculum Press, Unit 305B, The Big Peg, 120 Vyse Street, Birmingham. B18 6NF***
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Case Study 3
Galapogas finches
Darwin noted that the finches on the islands which make up the Galapogas Archapelago are different from those on the mainland of South America. Island finches had different beak sizes and shapes. Darwin proposed the following hypothesis to explain this.

Finches arrive from mainland with no or few competitors, population size, hence competition for food increases

↓

Mutations produce some finches with very small beaks which increase their ability to catch insects, whilst other birds developed large beaks which give them a selective advantage in cracking open tough seeds or eating fruit

↓

After many years the two populations developed into different species

↓

Similar **adaptive radiation** led to the development of several finch species each adapted to a particular food, possessing different beaks

Biologists are still arguing about whether the different species of finch evolved together on one island or whether different species evolved on different islands each adapted to the particular food source found there. If the latter is true then the present distribution (almost all islands contain more than one species) must be the result of re-invasion.

Typical exam question
State 3 pieces of evidence which can be used to support the theory of evolution.

	Evidence
Palaeontology – study of fossils	Fossils show: i. increasing diversity of form ii. gradual change = adaptation e.g. fore-limb of horse iii. ecological progression – plants appear before animals, insects before insect pollinated flowers etc.
Comparative anatomy	i. Adaptive Radiation All mammals possess a pentadactile limb but this has developed into different forms in different species because of the different selective pressures in these organisms' environments. ii. Convergent Evolution The opposite of adaptive radiation. Distantly related organisms resemble one another because they have adapted similarly to similar aspects of their environments.
Biochemistry	DNA and protein analysis Comparison DNA sequences show that it is 99.9% certain that chimps are humans' closest relatives

Exam Hint *- It is worth considering the common misunderstanding which thousands of candidates make every year when discussing this topic. In answering questions on the peppered moth many such candidates will write:*

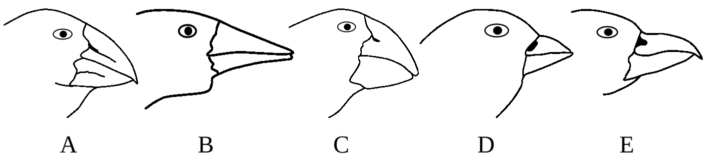
"The air became polluted so the moth changed colour/became black/ decided to become black"

This statement is completely untrue. Black moths were around - probably in very small numbers - before the Industrial Revolution, as a result of mutation. The changed environment turned a selective disadvantage into a selective advantage but the moths didn't ***choose*** *anything. Genetic change is accidental.*

However, it is also worth noting that this is not the whole story. In some parts of England (e.g. East Anglia) which are unpolluted, it is the black carbonaria which is most frequent and even in very polluted environments the pale form still exists in low numbers. Scientists believe that this means that predation by birds is not the only selective pressure. The black carbonaria form does seem to have some other selection advantage. Recent studies suggest that this may concern the greater survival ability of the caterpillar of the black carbonaria form.

Practice Questions

Diagrams A to E below show the heads of five of the ten species of finch inhabiting a volcanic oceanic island in the Galapagos group. The Galapagos islands lie about 1000 km from the South American mainland.



(a) What major differences between the five species is shown in the diagram? (1 mark)

(b) How might this difference be related to the habits of the finches? (3 marks)

(c) Darwin suggested that these finches probably descended from a common ancesteral stock of finches. Suggest how these ancesteral finches may have reached the Galapagos islands. (2 marks)

Answers
Semicolons indicate marking points

(a) Shape of beak;

(b) Different diets;
some eat insects some eat seeds/nuts;
beaks become adapted over many generations by variation mechanisms and most efficient forms are selected;

(c) Ancestors from South American landmass/Ecuador blown by storms/winds;
or carried on driftwood;

Acknowledgements;
This Factsheet was researched and written by Kevin Byrne
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Bio Factsheet

www.curriculum-press.co.uk Number 170

Answering Exam Questions: Classification and Keys

Examination questions relating to classification almost exclusively test factual knowledge. In order to answer the questions well, it is essential to learn the classification details that are included on the specification you are studying. The ability to apply your knowledge, or to observe data and apply it, may be tested by asking you to design or solve keys. This Factsheet should also help you to develop a good examination technique. Poor examination technique can lose you a lot of marks.

Example 1

(a) (i) What is meant by the term 'taxon'? 1

(ii) What is meant by the term 'species'? 2

(b) List the following taxonomic groups in sequence according to the number of species they contain. Start with the group with the greatest number of species. 1

class family genus kingdom order phylum

(c) Give three ways in which cells of the kingdom Prokaryotae differ from those of all other kingdoms. 3

Answers and comments

(a) (i) **A taxon is a grouping of organisms which share some basic features;** 1

This would score the 1 mark available, so do not be tempted to expand your answer by detailing different levels of taxon (for example - kingdom, genus). Candidates often lose the mark by stating 'a taxon is a group of animals…' or 'a taxon is a group of plants …' The definition must embrace <u>all organisms</u>.

(a) (ii) **A species is a group of organisms which can interbreed; to produce fertile offspring;** 2

To score both marks you must indicate that the organisms can interbreed within the group, also that the offspring they produce are fertile/can also reproduce. Instead of giving the definition above, candidates often write 'a species is a group of similar organisms which cannot interbreed with other groups of organisms/are separated from other organisms by breeding barriers'. This is a negative answer – it is stating what a species cannot do, rather than what a species can do. At the most it would only score 1 of the 2 marks available.

(b) The answer is **kingdom, phylum, class, order, family, genus;** 1

Candidates often get this wrong, usually forgetting the sequence 'class, order, family.'

A good idea to remember the sequence is to learn the saying '**K**ing **P**hilip **C**ame **O**ver **F**rom **G**ermany'.

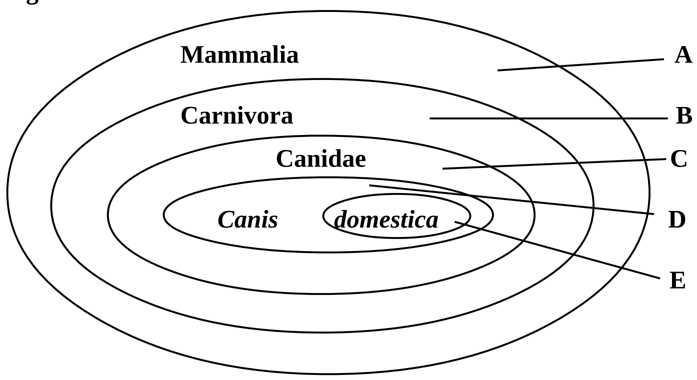
(c) Any three of: **no nucleus; no membrane bound organelles/ named organelles/mitochondria; don't divide by mitosis/divide by binary fission; have only 70S/small ribosomes; circular DNA/only one chromosome; have plasmids; cell wall made of murein; have slime capsule/fimbriae/pili;** maximum 3 marks

Don't be tempted to give more than three points. If you list four points, one of which is incorrect, you will lose a mark. The question asks for prokaryotic features so don't be tempted to describe eukaryotic features. Try to give three distinct comments, for example, one relating to organelles, one relating to DNA and one relating to ribosomes. If you make two comments about organelles, for example, they may only score one mark because they are alternatives in the mark scheme rather than separate mark points.

Example 2

(a) The mammals form a class called the Mammalia within the phylum Chordata. The domestic dog, *Canis domestica*, is a type of mammal. Fig 1 below shows the groups in the Mammalia to which the dog belongs.

Fig 1



(i) Name the taxons A to E. 1

(ii) The Brown Bear , *Ursus arctos*, belongs to another group in the Carnivora, called the Ursidae. Add this information in the relevant taxons, to Fig 1. 1

(b) The diagrams below show two systems of classification of animals. Fig 2 shows a simple hierarchy. Fig 3 shows a phylogenetic system.

Fig 2

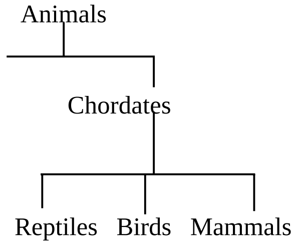
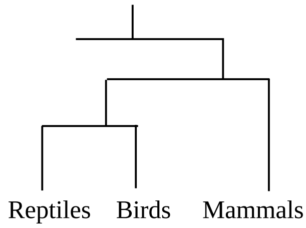


Fig 3



(i) What is meant by a 'hierarchy'? 1

(ii) Explain how a phylogenetic system differs from a simple hierarchy. Refer to figs 2 and 3 to illustrate your explanation. 4

Answers and comments

(a) (i) **A = Class, B = Order, C = Family, D = Genus, E = Species;** 1

To score the mark all the taxons must be correctly named. There is no way around this – you must learn their sequence.

(ii) **C – Ursidae, D – Ursus, E – arctos;** 1

To score the mark all three names must be written on Figure 1 in the correct positions. A common error made by candidates is just to write the names in the text – these answers would not score because the question asked for them to be put in the correct circles on the diagram. Another common error made by candidates in this type of response is to draw another set of three circles and to write the names in them. This approach would only score providing the circles for the Mammalia and Carnivora were also drawn.

Remember the convention that generic names must start with a capital letter but specific names must only have small letters, for example, *Ursus arctos.*

(b) (i) A hierarchy is **large groups split into smaller groups which do not overlap;** 1

Candidates commonly write 'in a hierarchy the organisms are placed into groups' which is not enough to score a mark.. To score the mark there should also be reference to the sub-division into smaller groups and to the non-overlapping nature of these sub-groups.

(ii) **A phylogenetic system is based on evolutionary history; it indicates the ancestry of groups/shows points of divergence; for example, fig 3 shows that reptiles and birds separated after mammals/reptiles and birds are more closely related than mammals and birds/mammals and reptiles; a hierarchical system is based on shared characteristics; for example, in fig 2 reptiles birds and mammals are separated but given equal status;** maximum 4 marks

It is important that the question rubric is obeyed and that both fig. 2 and fig.3 are referred to in the answer – otherwise marks will be lost. Don't just refer to the shapes of the diagrams – comments such as 'more complicated/has more layers/like a staircase' are often seen in answers to this type of question – they do not score marks. To score the marks reference must be made to the evolutionary biology involved, using both diagrams to illustrate your answer.

Example 3

(a) The dodder, *Cuscuta epithymum*, is an unusual flowering plant. It is a parasite which grows on, for example, clover, gorse and heather. The adult dodder has no roots and has colourless leaves reduced to small scales.

(i) Give one feature of the dodder which it shares with all other plants but does not share with organisms in other kingdoms. 1

(ii) Complete the table below to show the classification of dodder.

Kingdom	
	Angiospermophyta
	Dicotyledoneae
	Monopetalae
	Convolvulaceae
Genus	
Species	

3

(b) A gardener observed that common poppies and long-headed poppies in his garden appeared to be interbreeding to form hybrid poppies. Suggest how you could find out whether the common poppy and the long-headed poppy are different species. 3

Answers and comments

(a) (i) **any feature shared by all plants but not shared by all members of any other kingdom – for example, cellulose cell wall/ large vacuole/permanent vacuole/show alternation of generations;** 1

A common error is to state a feature which is only common to flowering plants or gymnosperms, for example, 'produces pollen/ovules/seeds'. Remember, the feature you state must also apply to mosses, liverworts, ferns, horsetails and club mosses.

(ii)

Kingdom	**Plantae;**
Phylum	Angiospermophyta
Class	Dicotyledoneae
Order	Monopetalae
Family ;	Convolvulaceae
Genus	**Cuscuta**
Species	**epithymum ;**

1 mark for 'plantae', 1 mark for 'phylum + class + order + family', 1 mark for 'Cuscuta + epithymum'. 3

A common error is to mix up the sequence 'class, order, family'. The genus and species names were given early in the question, - the genus name can be recognised because it has the capital letter. In questions like this, candidates often fail to read the question carefully enough, and miss these names.

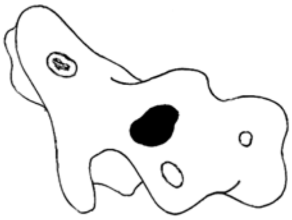
(b) **attempt to cross hybrid plants; by pollen transfer using a paint brush; if they produce seeds try to grow them; if they are different species seeds may not be produced/any seeds produced will not germinate/plants will be sterile;** max 3

It is not sufficient to cross the two types of poppy to see if hybrids are formed – the question tells you that this is so. The hybrids themselves must be crossed to see if they produce fertile seeds that will germinate to produce fertile offspring.

The word 'viable' is sometimes incorrectly used, instead of 'fertile'. When 'viable' is applied to a seed, it simply means that the seed will germinate. The plant produced may still be sterile. The examiners in this type of question are looking for the term 'fertile seed' – that will germinate to produce a plant capable of successful sexual reproduction.

Example 4

The diagram shows an Amoeba. This is a single-celled organism.



(a) Amoeba belongs to the kingdom Protoctista. Explain why Amoeba is not,
  (i) a prokaryote, 2
  (ii) a fungus. 2
  Give a different answer for each case.

(b) (i) Distinguish between radial symmetry and bilateral symmetry. 2

  (ii) Name a radially symmetrical animal and a bilaterally symmetrical flower. 2

Answers and comments

(a) (i) **presence of a nucleus; membrane bound/named organelles; only 80S ribosomes; no cell wall;** max 2 marks

  (ii) **no cell wall; has no chitin; is motile; only one nucleus; has no hyphae;** max 2 marks

  Note from the question that the answers must be different – 'no cell wall' will only be awarded once. To include the same point in both answers would be poor exam technique and would lose a mark.

(b) (i) **radial symmetry is when an animal/flower can be cut in any vertical plane to produce two mirror image halves; bilateral symmetry is when an animal/flower can only be cut down one vertical plane to produce two mirror image halves;** 2

  Note that the two halves are 'mirror images' of each other. A very common error is to write that they are 'equal or identical halves'. They are not.

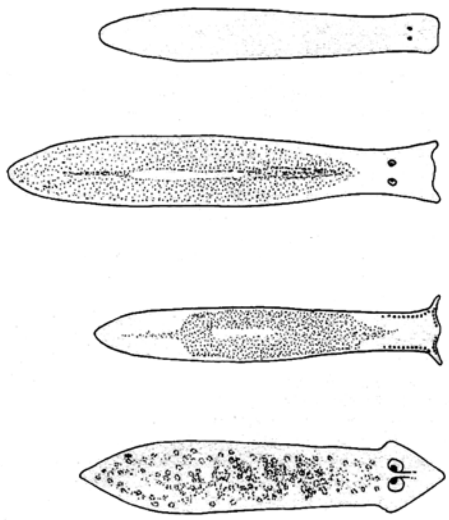
  Often candidates are tempted to give extra information about the advantages of the two types of symmetry. Refrain from this, unless the question asks for it, because it wastes time and may lose marks if you make errors.

  (ii) **any Cnidarian/Hydra/sea anemone/jelly-fish;**
  any flower of the Papilionaceae/lupin/broom/vetch/gorse; 2

  Don't be tempted to give more than one example in each case. A list of animals or flowers which includes an error will not score.

Example 5

The drawings below show the features of four different planarian flatworms.



Use the key below to identify the four flatworms, A, B, C and D.

1.	Many small eyes around the margin of the head	***Polycelis***
	Two eyes near the centre of the head	go to 2
2.	Head rounded with no obvious tentacles	***Phagocata***
	Head with lateral or anterior tentacles	go to 3
3.	Triangular head with lateral tentacles	***Dugesia***
	Rounded head with anterior tentacles	***Crenobia***

4 correct identifications = 4 marks

Answers and comments

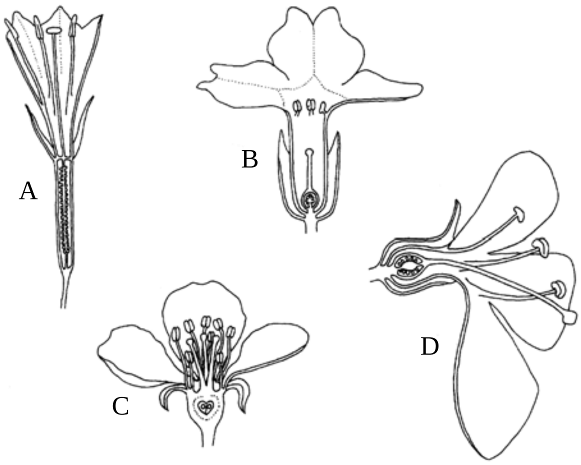
A = Phagocata; B = Crenobia; C = Polycelis; D = Dugesia; 4

This type of question is testing your ability to observe details of organisms and to apply your observations to solve a key. It is very important to read the key carefully and apply all the criteria within each step to your choice of organism.

Polycelis was actually identified in the first step of the key, but, because it had tentacles many candidates missed this (perhaps not observing the many small marginal eyes) and tried to identify it at step 3.

Example 6

The drawings below show four different flowers cut in half vertically.



(a) State three features shown in the drawings which could be used to distinguish between the flowers. 3

(b) Using only these three features, construct a simple dichotomous key to separate the flowers. 7

Answers and comments

(a) **radial symmetry versus bilateral symmetry; superior ovary versus inferior ovary/other floral parts attach to receptacle below ovary versus other floral parts attached to receptacle above ovary; floral parts/stamens basically in whorls of three versus floral parts/stamens basically in whorls of five; long stamen filaments versus short stamen filaments; filaments attached to petals versus filaments attached to receptacle; one stigma versus several stigmas; stigmas below anthers versus stigmas above anthers; numerous ovules versus few ovules;**

Any 3 for maximum 3 marks

The examiners would credit any other valid differences, provided they were visible on the drawings. To score the marks the feature and its comparison must be stated. For example, 'filament length' would not score but 'long versus short filaments' would.
Flowers have different symmetries' would not score – 'radial and bilateral symmetry' must be stated.

Although this question is testing your powers of observation and discernment, unless you have learnt floral structure thoroughly you will find it difficult to express what you see. It is essential that you learn your biology even for questions of this nature.

(b)

1.	**Flower radially symmetrical**	**go to 2;**
	Flower bilaterally symmetrical	**flower D;**
2	**Flower with several stigmas**	**flower C;**
	Flower with a single stigma	**go to 3;**
3	**Flower with very short filaments**	**flower B;**
	Flower with long filaments	**flower A;**

truly dichotomous key;

1 mark per correct key step and one mark for a complete dichotomous key. 7

Obviously, a large number of different keys can be designed because the flowers show many differing characteristics. Examiners will give credit for any correct key.

An error in a key usually has a 'knock-on' effect, making later steps incorrect. Because of this examiners usually find it impossible to award marks after an error and so there is the potential, to lose a lot of marks. To reduce the risk of this, make sure that:

- you only use features seen in the drawings.
- you keep it simple – only use <u>one</u> contrasting feature per step – candidates often try to use two or more features per step, making it likely that errors will occur.
- make sure you only use two lines/alternatives per step (a dichotomous key). A common error is to have three lines/ alternatives in a step. This is a trichotomous key which is not acceptable.

Acknowledgements:
This Factsheet was researched and written by Martin Griffin.
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Bio Factsheet

Number 52

Data Interpretation Questions: Temperature Regulation

Temperature regulation is one form of **homeostasis**. Birds and animals are endothermic, that is, they are able to maintain a high body temperature by internal heat production. In contrast, the temperature of **ectotherms** depends upon the external environmental temperature. Although endothermy has been removed from some A Level Biology syllabuses, the topic is still tested in data interpretation questions, since it can be used to illustrate several important biological principles.

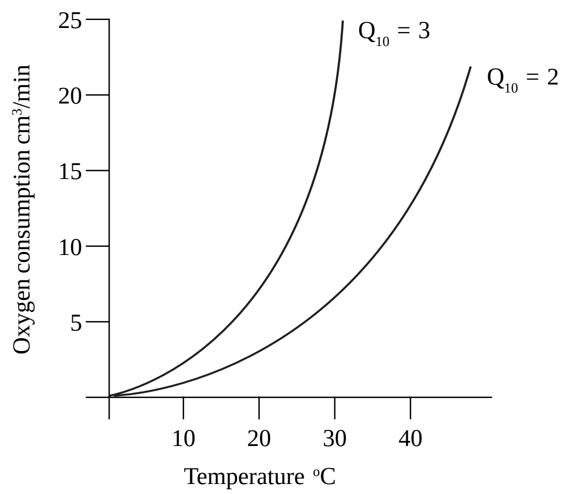
The effect of temperature on metabolic processes

Generally, as temperature increases, the rate of a metabolic process also increases. Since it is difficult to directly measure the actual rate of most metabolic processes, the rate of oxygen consumption is often used as an index of the rate.

The increase in rate caused by a temperature increase of 10°C is known as Q_{10}. For example, if the rate of a process doubles, the Q_{10} would be 2, if it triples it would be 3.

Fig 1 shows the increase in oxygen consumption caused by increased temperature for processes with Q_{10} = 2 and 3. Enzyme controlled reactions, up to the optimum temperature, have a Q_{10} of 2.

Fig 1. Temperature and oxygen consumption



Recall Questions: Answering diagram and application questions is alwalys easier if you know the factual background to a topic. In terms of questions on this topic it is important that you understand how adaptation to regulated body temperature works - the table below lists some of the most commonly examined examples.

Structural	1. Hairs trap air, which is a poor conductor. Long hairs shade skin, e.g. camels. 2. Subcutaneous fat is a poor heat conductor; it therefore acts as an insulator, e.g. polar bears. 3. Sweat glands cool the animal because they use latent heat when sweat evaporates. 4. Counter-current arrangement of arteries and veins in the legs of arctic mammals, e.g. in bears, the veins are wrapped around arteries, so the blood of arteries is cooled by the venous blood, therefore decreasing heat loss.
Physiological	1. Thermoreceptors in hypothalamus and under the skin. 2. Erector muscles enable hairs to become erect, trapping more insulating air. 3. Vasoconstriction of skin arterioles decreases blood volume near skin surface, therefore decreasing heat loss. 4. Shivering – uncontrollable contraction of muscles generates metabolic heat. 5. Reduction of core temperature when in very cold conditions to decrease heat transfer.
Behavioural	1. Hippos/elephants spray water over themselves, which cools them when it evaporates. 2. Avoidance of hottest parts of day, e.g. by staying under cover, burrowing in sand, or, if too cold, huddling together, e.g. penguins, so that their collective surface area is reduced. 3. Raising of feathers and withdrawal of head and feet into feathers to conserve heat in birds, e.g. pigeons.

There are three typical exam questions set on the type of graph shown in Fig 1:

1. Plot a graph given the tabulated data.
2. Calculate the change in the volume of oxygen consumption for a stated change in temperature.
3. Comment on the significance of the change in the volume of oxygen consumed.

1. Plotting the graph

Imagine you are asked to plot the data shown in Table 2.

Table 2.

Temperature (°C)	Rate of oxygen consumption (cm^3/min)
0	2.5
10	3.8
20	9.0
30	24.1

There are likely to be at least four available marks:

(i) For using a suitable scale on the x and y axes.

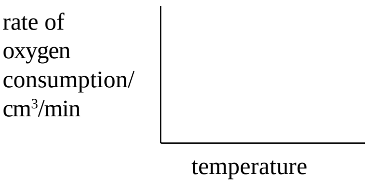
(ii) For labelling the x and y axes correctly.

(iii) For plotting the points correctly.

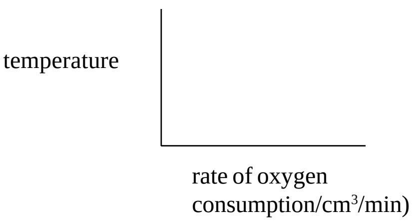
(iv) For joining the points with a **straight** line (Institute of Biology recommendations).

If graph paper is provided, you should ensure that your graph fills half of the page.

Every year a small but significant percentage of students plot the graph the wrong way round. It should be:



but many students will plot:



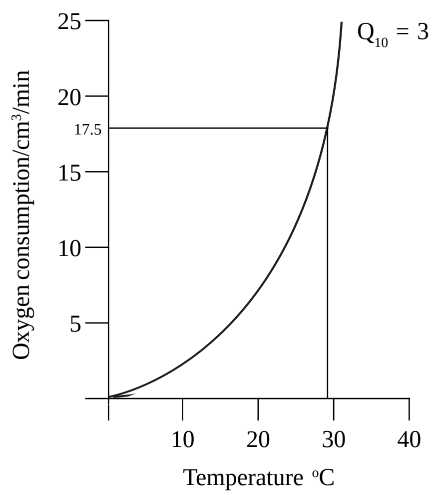
To get it (and every graph in future) the right way round, ask yourself one question: "**Which variable determines/controls/influences the other?**" (Here the two variables are temperature and oxygen consumption.) The determining variable always goes on the x (bottom) axis. Temperature clearly determines oxygen consumption, so it is temperature which goes on the x axis.

2. Calculating the change in oxygen consumption, given a change in temperature

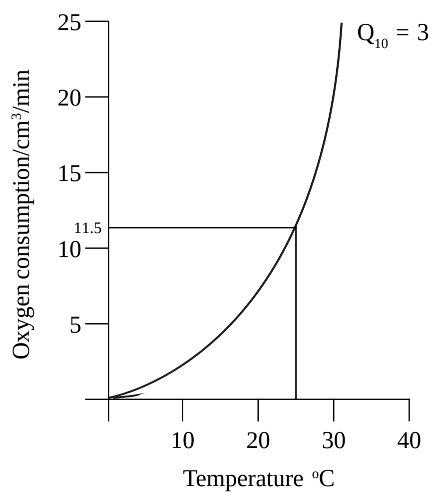
For example, calculate the change in oxygen consumption caused by a temperature change from 25°C to 29°C.

This is simple:

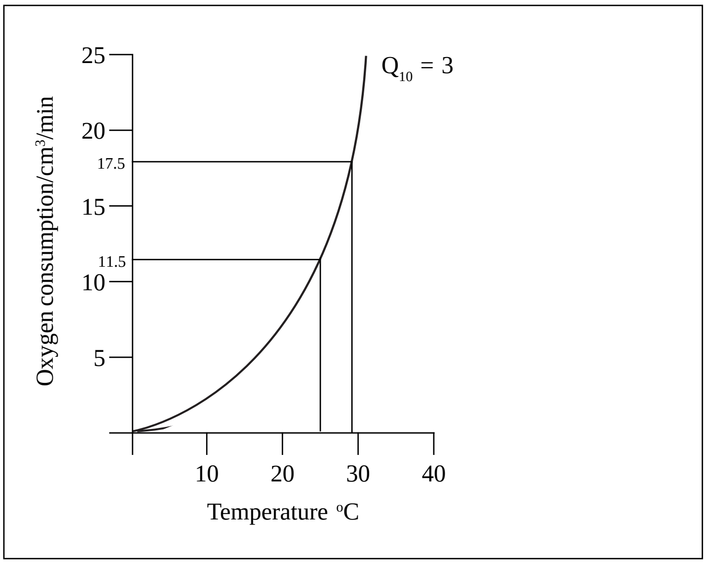
1. Read off the volume of oxygen used at 29°C by drawing a ruler line up from 29°C until it hits the curve and then drawing a line from that point to the left hand axis.



2. Read off the volume of oxygen used at 25°C by drawing a ruler line up from 25°C until it hits the curve and then drawing a line from that point to the left hand axis.



The figure overleaf, on page three shows these two measurements on the same graph.



Thus the changes in oxygen consumption = 17.5 - 11.5 = 6cm^3/min

Note: you may be asked to calculate the **percentage change** in the volume of oxygen consumed when the temperature is increased from 25°C to 29°C. Again, do not panic. Learn off by heart the following rule:

Percentage change in volume of oxygen consumed:

$$= \frac{\text{the change } (17.5 - 11.5)}{\text{the original value } 11.5} \times 100 = \frac{6}{11.5} \times 100 = 52.1\%$$

The most common mistake here is to divide the change (6) by the wrong value for oxygen consumption – **always** use the starting value.

3. The significance

The examiners are usually asking you to comment on the significance of the extra oxygen needed when temperature increases. Aquatic organisms face particular problems. This is because, as water temperature increases, the solubility of oxygen decreases – thus, as the water warms up, it holds less oxygen. This is unfortunate for aquatic organisms whose body temperature rises with the surrounding water – their metabolic process will be speeding up, as will their oxygen consumption, at precisely the same time, as less is available in the water. For this reason, sudden temperature change in ponds, streams and rivers (e.g. if a factory or power station released warm water) can be fatal. The organism may be killed by the lack of oxygen rather than the harmful effects of the warm water on their tissues. The increased temperature of water is also a problem if it contains toxins, because as water temperature increases,

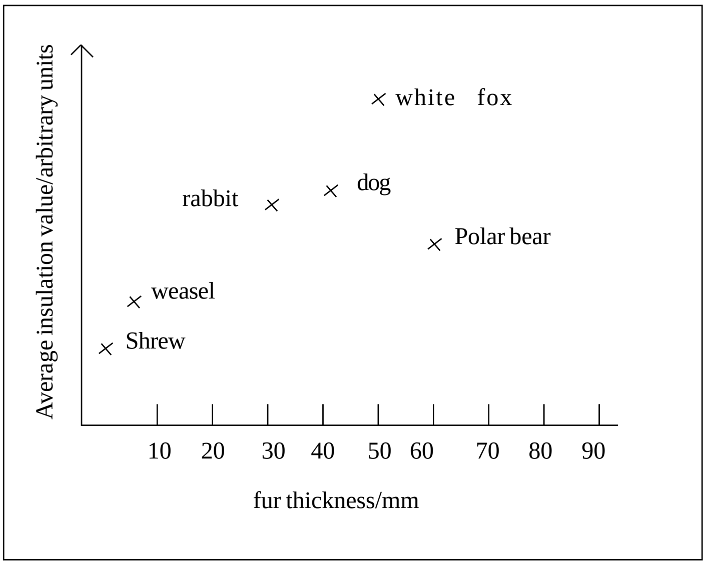
1. The toxin may enter the organism faster;
2. Once it has entered the organism's body, it will have a faster effect.

Heat Production

Insulation

Many animals possess fur which is a good insulator because it traps air. Generally, the thicker the fur, the greater the insulation value (Fig 2).

Fig 2. The insulation value of fur

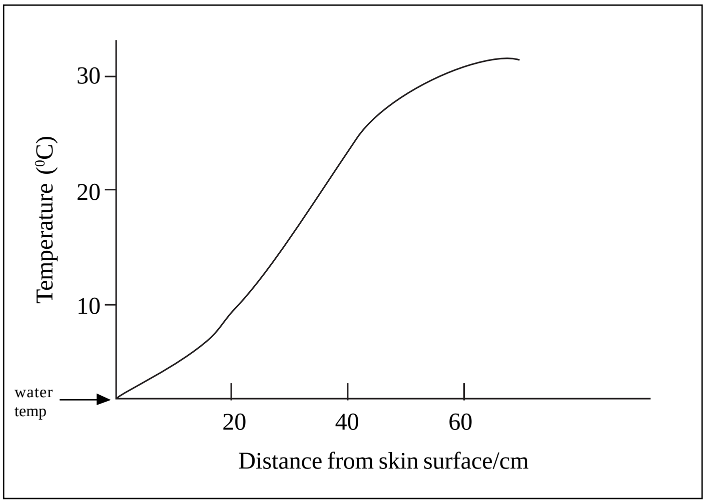


However, there are always going to be exceptions and these sometimes appear in application questions – those where the examiners expect you to apply your knowledge of basic principles to new, unusual situations. In Fig 2, the polar bear has thick fur, but that fur is offering surprisingly little insulation. The examiners may well ask you to suggest why. In these situations you should:

1. look carefully at the information provided. The left hand axis states that these are average values;
2. think about the habits of the organism with the unusual values. The polar bears spend a great deal of time in water. When submerged, the water will displace the insulating air and, indeed, heat loss to the water will be much faster than heat loss to air when the animal is out of the water. Thus, average insulation value is low.

Some aquatic animals use blubber to provide insulation. It is this which allows the polar bear to swim in icy water when its fur is providing no insulation at all. Similarly, the temperature of the skin surface of submerged seals is very similar to the water (Fig 3).

Fig 3. Seal body temperature

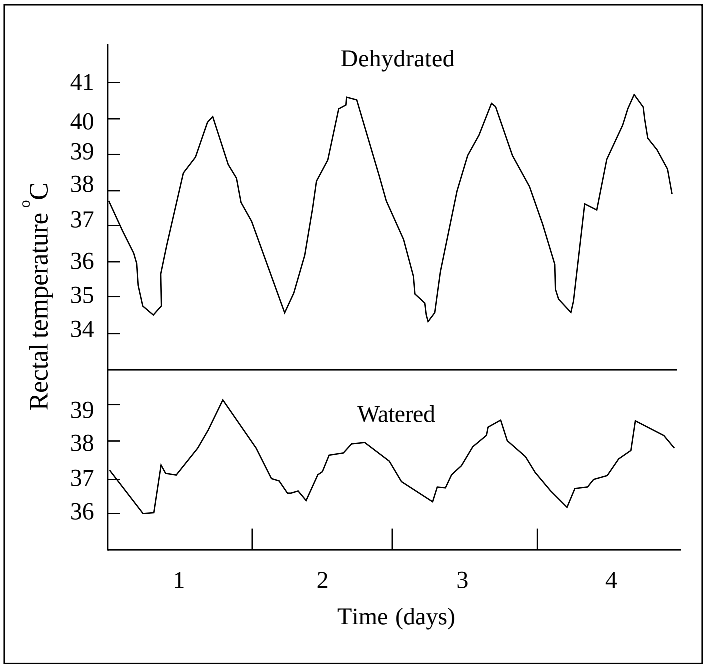


The significance of this is that, if the temperature of the skin is the same as the temperature of the water, then very little heat can be transferred to the water. The blubber beneath the seal's skin allows the body of the seal to remain 30°C warmer just 60cm from the surface of the skin. In contrast, if the seal begins to overheat, more blood is pumped through the blubber to the superficial layer of the skin. This increases heat loss to the environment.

Surface Area
Small animals have a larger surface area : volume ratio than large animals. This is why small, active organisms, such as shrews, need to keep eating – they are continually losing a lot of heat and their metabolic rate needs to be maintained at a high level. This is why most animals which **hibernate** are small – the difficulties of trying to maintain body temperature when the external temperature is very cold and when food is in short supply, are just too great. It is better to avoid the problems by decreasing metabolic rate, heart rate and respiration to a minimum. However, larger organisms still have problems and those that live in deserts have to face the problem of keeping cool whilst losing water.

Fig 4. illustrates daily temperature fluctuations in a well-watered camel and in one which has been deprived of water.

Fig 4. Rectal temperature of a dehydrated and watered camel



Typical exam questions would be:

1. Summarise the data shown.

2. Suggest an explanation for the difference in daily temperature fluctuation between the two camels.

1. "Summarise" means "describe concisely". Look for the trend. The temperature of both camels fluctuates, but the size of the fluctuation is much greater in the camel deprived of water. In other words, dehydration results in the camel having higher body temperature during the day – the camel is storing heat rather than sweating, something which only the well-watered camel can afford to do. Remember also that insulation works both ways – the thick hair of a camel can also reduce heat gain from the (hotter) environment, as well as decreasing heat loss when its own body temperature is higher than the environment.

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