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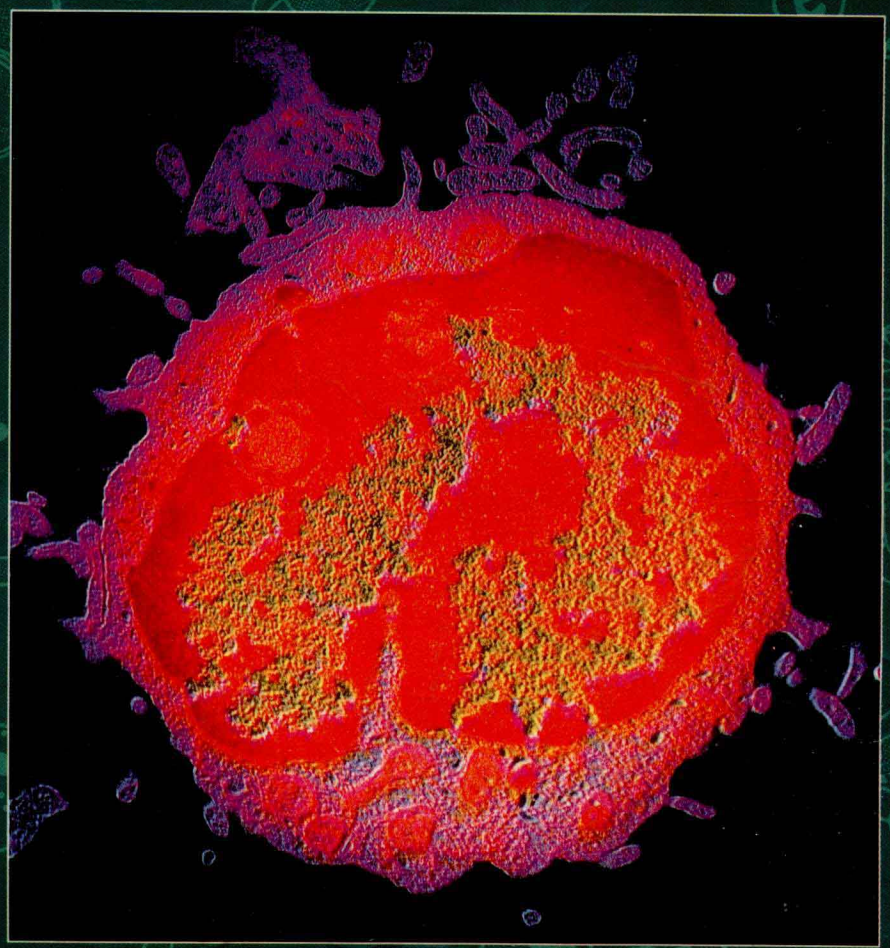
Advanced BIOLOGY

REVISION HANDBOOK



W R Pickering

Oxford University Press

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CELL STRUCTURE AND BIOCHEMISTRY

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Use of the light microscope

PREPARATION FOR LIGHT MICROSCOPY

FIXATION — preserves material in a life-like condition with minimum distortion

DEHYDRATION — removes traces of water from the fixed material

CLEARING — removes dehydrating alcohol so that material is made transparent

EMBEDDING — supports the material so that it is firm enough for sectioning

SECTIONING — prepares slices of material which are thin enough to allow light to pass through

STAINING — improves contrast between different structures (most biological material is transparent)

MOUNTING — embeds and protects material so that it is suitable for viewing over a long period

Methylene blue
- nuclei stain blue

Leishman's stain
- blood cells stain pink
- white blood cell nuclei stain blue

Safranin/light green
- a plant cell stain
- cytoplasm and cellulose stain green
- nuclei and lignin stain red
- chloroplasts stain pink

Haematoxylin/eosin
- nuclei stain blue
- cytoplasm stains pink

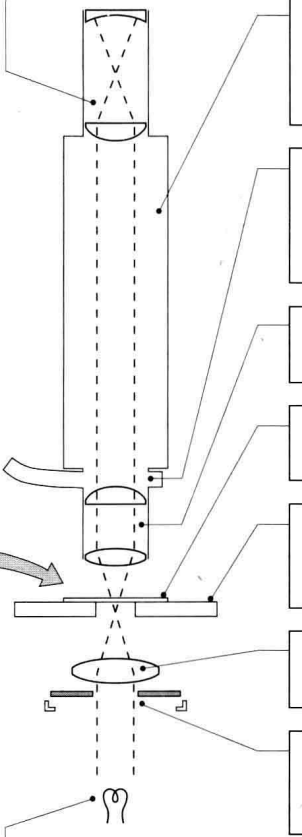
Feulgens stain
- chromosomes during cell division stain purple

Aniline blue
- fungal hyphae and spores stain deep blue

Eyepiece: produces a ***'real image';***

magnifies but does not *resolve* the image produced by the objective lens;

the eyepiece may be dismantled so that an *eyepiece graticule* may be inserted if the microscope is to be *used for measurement.*



Barrel: route for light rays from objective lens;

may be moved, using a simple racking system, so that object is in focus.

Turret: holds 2, 3 or 4 objective lenses, and can be rotated so that lenses of different focal lengths (hence magnification) can be used.

Objective lens: responsible for both *magnification* and *resolution* of the object.

Specimen/object: is supported on a transparent glass slide.

Stage: holds specimen in correct position relative to optical system at 90° to light path.

Condenser: the condenser focuses the light from the illuminator on to the specimen.

Iris diaphragm: controls amount of light reaching specimen. Best definition is obtained by *reduction* of intensity, not by its increase.

Substage illumination: 'white' light is most commonly used. Light of shorter wavelength (e.g. blue light), produced by changing bulb or with a system of filters, improves *resolution* of the object.

Light must only come from substage position: none on stage.

Transmission electron microscope

Cathode: metal electrode (commonly platinum) which emits high velocity electron beam. Electrons are negatively charged particles (e^-).

Anode: positively charged electrode at potential of 50 kV with respect to cathode - accelerates the electron beam.

Condenser: electromagnetic lens which focuses the electron beam on to the specimen.

Air lock/specimen port: allows the introduction of the specimen into the microscope without the loss of vacuum.

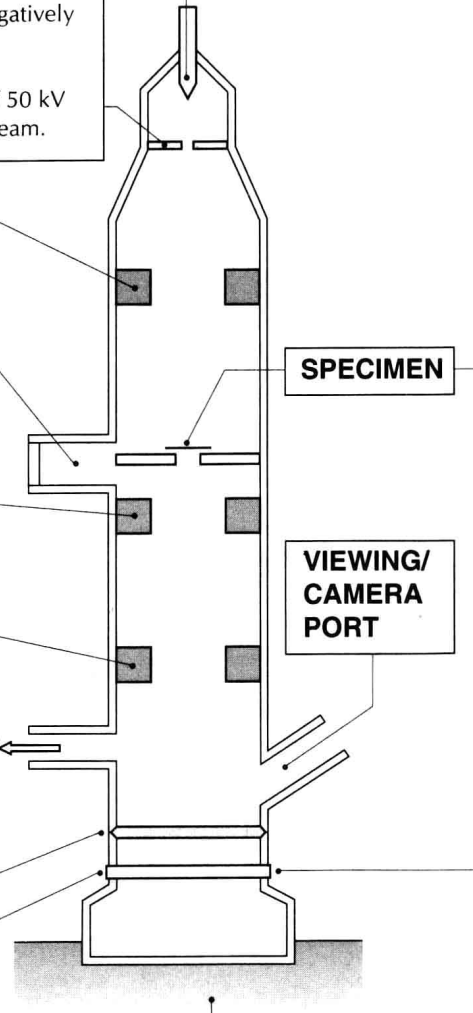
Objective: electromagnetic lens which focuses and magnifies (depending on applied voltage) the first image.

Projector: further magnification by selection of region of image to be viewed.

To vacuum pump: creation of vacuum to minimize electron scattering and any heating due to electron/air molecule collision.

Fluorescent, swing out, screen: coated with electron sensitive compounds - necessary since deflected electron beam (the image) cannot be viewed directly.

Photographic plate: allows a black and white permanent record of the image to be made. Printing may offer further magnification.



Concrete base: stable support which minimizes vibration and thus eliminates unwanted deflection of electron beam.

Sample is

Fixed: to avoid deformation of all cell components. Use small sample (rapid penetration) and immerse in *glutaraldehyde* or *glutaraldehyde/osmic acid.*

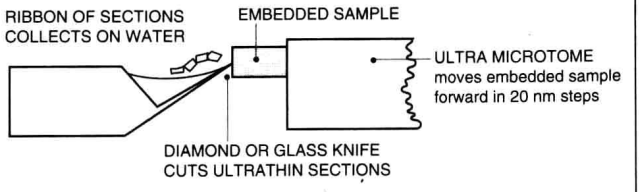
Dehydrated: to prepare material for infiltration by embedding or infiltration medium which is not miscible with water. Dehydration should be gradual to preserve fine detail, using a series of progressively increasing concentrations of *ethanol* or *propanone.*

Cleared: alcohol or propanone may be immiscible with embedding agents and so is replaced with a clearing agent (commonly *xylol*) which is miscible and also makes the material transparent.

Embedded: ready for *plastic* or *resin* is used to support the material so that it is not distorted during sectioning.

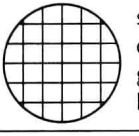
Sectioning

The material must be cut into *ultrathin sections* (20-100 nm thick) since the electron beam has very low penetrating power.



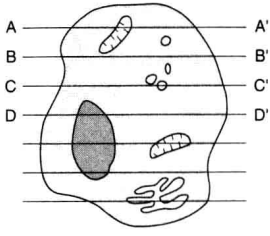
Staining: biological structures are transparent, or nearly so, to electrons. To increase electron beam deflection (i.e. contrast between different structures) sections are treated with *solutions of heavy metal salts* such as *uranyl* or *lead acetate.*

Mounting:



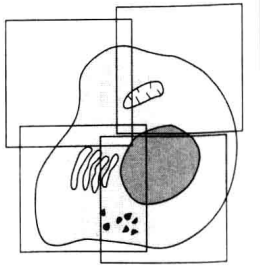
sections are supported on a small copper grid (~3 mm diameter). The electron beam may pass through the gaps in the grid (a glass slide would not permit transmission of electron beam).

IMAGE INTERPRETATION



A number of ultrathin sections, e.g. A-A', B-B', must be examined to provide a true three-dimensional representation of the sample.

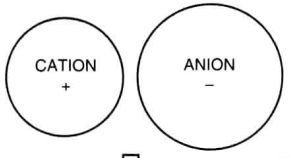
High magnification means that several photographs may be necessary to give a composite image of the specimen.



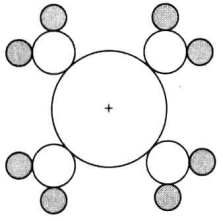
Physical properties of water

are explained by hydrogen bonding between the individual molecules

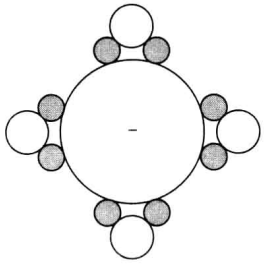
Solvent properties The polarity of water makes it an excellent solvent for other polar molecules ...



The electrostatic attractions between polar water molecules and ions are greater than those between the anion and cation.

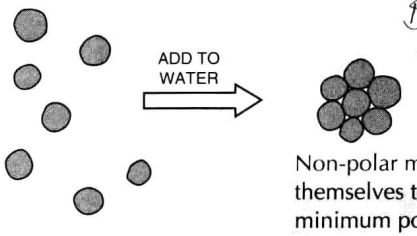


Ions become *hydrated* in *aqueous solution.*



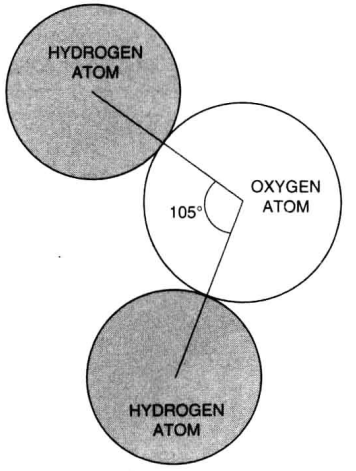
Such polar substances, which dissolve in water, are said to be *hydrophilic* ('water-loving').

... but means that non-polar (*hydrophobic* or 'water-hating') substances do not readily dissolve in water.

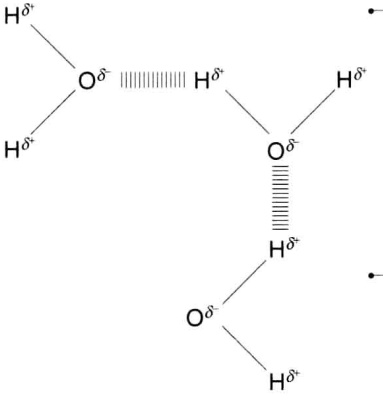


Basis of phospholipid bi-layer.

Non-polar molecules arrange themselves to expose the minimum possible surface to the water molecules.



Because hydrogen and oxygen atoms are different in *size* and *electronegativity* the water molecule (H_2O) is *non-linear* and *polar.*



Hydrogen bond - one water molecule may form hydrogen bonds with up to ***four*** other water molecules.

This polarity means that individual water molecules can form *hydrogen bonds* with other water molecules. Although these individual hydrogen bonds are weak, collectively *they make water a much more stable substance than would otherwise be the case.*

High specific heat capacity The specific heat capacity of water (the amount of heat, measured in joules, required to raise 1 kg of water through 1°C) is very high: much of the heat absorbed is used to break the hydrogen bonds which hold the water molecules together.

High latent heat of vaporization Hydrogen bonds attract molecules of liquid water to one another and make it difficult for the molecules to escape as vapour: thus a relatively high energy input is necessary to vaporize water and water has a much higher boiling point than other molecules of the same size.

Molecular mobility The weakness of individual hydrogen bonds means that individual water molecules continually jostle one another when in the liquid phase.

Cohesion and surface tension Hydrogen bonding causes water molecules to 'stick together', and also to stick to other molecules - the phenomenon of ***cohesion***. At the surface of a liquid the inwardly-acting cohesive forces produce a 'surface tension' as the molecules are particularly attracted to one another.

Density and freezing properties As water cools towards its freezing point the individual molecules slow down sufficiently for each one to form its maximum number of hydrogen bonds. To do this the water molecules in liquid water must move further apart to give enough space for all four hydrogen bonds to fit into. As a result water expands as it freezes, so that ice is less dense than liquid water and therefore floats upon its surface.

Colloid formation Some molecules have strong intramolecular forces which prevent their solution in water, but have charged surfaces which attract a covering of water molecules. This covering ensures that the molecules remain dispersed throughout the water, rather than forming large aggregates which could settle out. The dispersed particles and the liquid around them collectively form a ***colloid***.

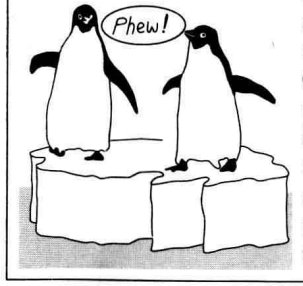
The biological importance of water depends on its physical properties

Solvent properties:
allow water to act as a transport medium for polar solutes.
For example, movements of minerals to lakes and seas;
transport via blood and lymph in multicellular animals;
removal of metabolic wastes such as urea and ammonia in urine.

Transpiration stream: the continuous column of water is able to move up the xylem because of cohesion between water molecules and adhesion between water and the walls of the xylem vessels.

Molecular mobility: the rather weak nature of individual hydrogen bonds means that water molecules can move easily relative to one another - this allows *osmosis* (vital for uptake and movement of water) to take place.

Expansion on freezing: since ice floats it forms at the surface of ponds and lakes - it therefore insulates organisms in the water below it, and allows the ice to thaw rapidly when temperatures rise. Changes in density also maintain circulation in large bodies of water, thus helping nutrient cycling. Floating ice also means that penguins and polar bears have somewhere to stand!



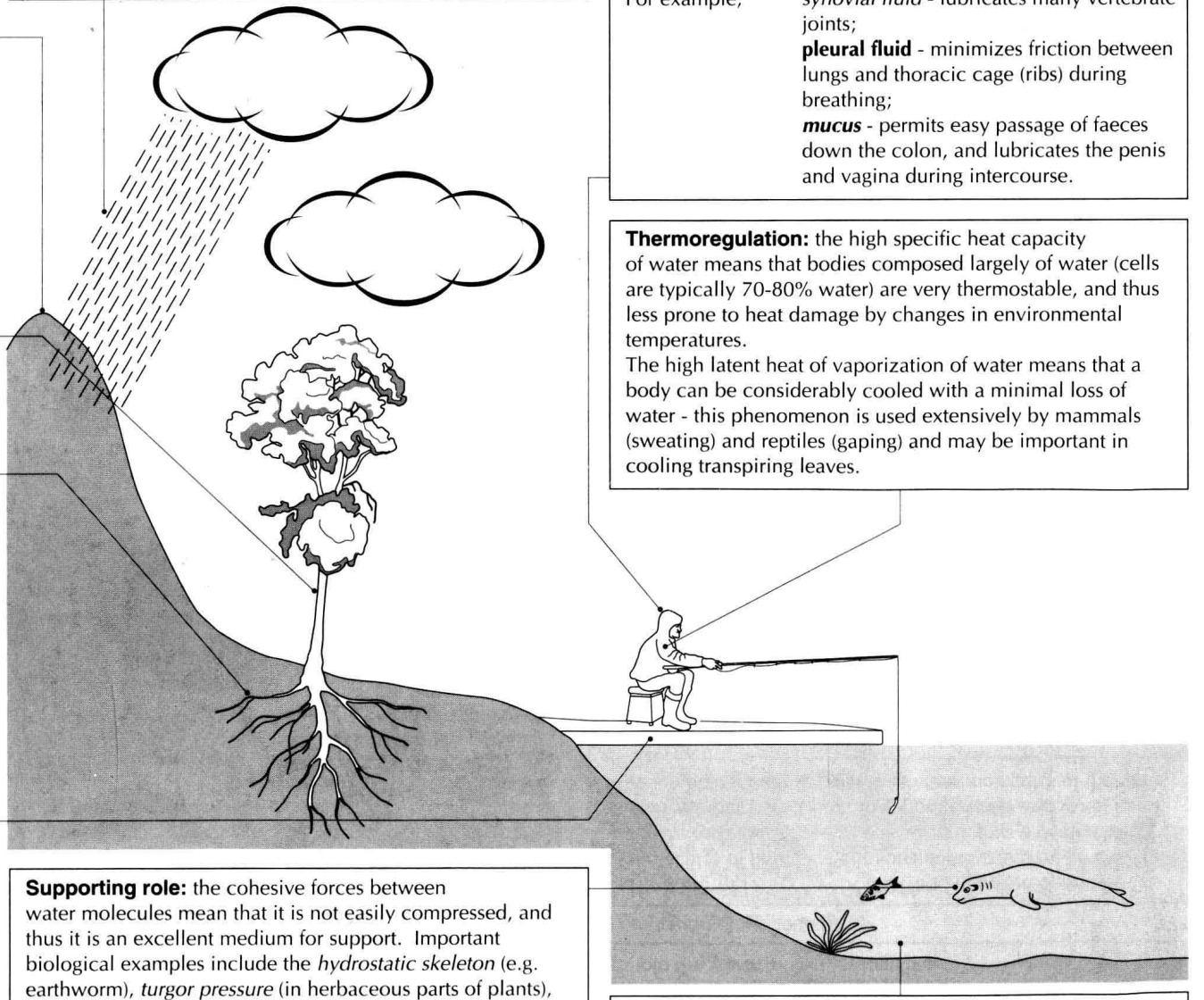
Metabolic functions
Water is used directly ...
1. as a reagent (source of reducing power) in photosynthesis
2. to hydrolyse macromolecules to their subunits, in digestion for example.

... and is also the medium in which all biochemical reactions take place.

Volatility/stability: is balanced at Earth's temperatures so that a water cycle of evaporation, transpiration and precipitation is maintained.

Lubricant properties: water's cohesive and adhesive properties mean that it is viscous, making it a useful lubricant in biological systems.
For example, *synovial fluid* - lubricates many vertebrate joints;
pleural fluid - minimizes friction between lungs and thoracic cage (ribs) during breathing;
mucus - permits easy passage of faeces down the colon, and lubricates the penis and vagina during intercourse.

Thermoregulation: the high specific heat capacity of water means that bodies composed largely of water (cells are typically 70-80% water) are very thermostable, and thus less prone to heat damage by changes in environmental temperatures.
The high latent heat of vaporization of water means that a body can be considerably cooled with a minimal loss of water - this phenomenon is used extensively by mammals (sweating) and reptiles (gaping) and may be important in cooling transpiring leaves.

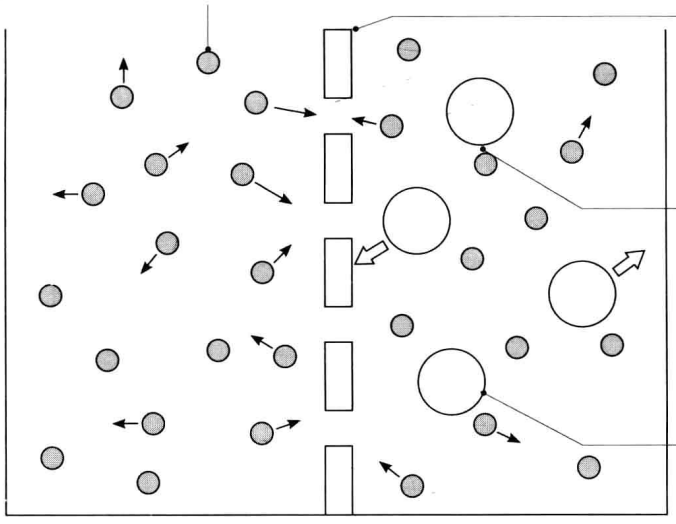


Supporting role: the cohesive forces between water molecules mean that it is not easily compressed, and thus it is an excellent medium for support. Important biological examples include the *hydrostatic skeleton* (e.g. earthworm), *turgor pressure* (in herbaceous parts of plants), *amniotic fluid* (which supports and protects the mammalian foetus) and as a *general supporting medium* (particularly for large aquatic mammals such as whales).

Transparency: water permits the passage of visible light. This means that photosynthesis (and associated food chains) is possible in relatively shallow aquatic environments.

Osmosis

Water molecules, like other molecules, are mobile. In pure water, or in solutions containing very few solute molecules, the water molecules can move very freely (they have a high ***free kinetic energy***). As a result, many of the water molecules may cross the membrane, which is freely permeable to water.



Partially permeable membrane allows the free passage of some particles but is not freely permeable to others. Biological membranes are ***freely permeable to water*** but have ***restricted permeability to solutes*** such as sodium ions and glucose molecules, i.e. they are ***selectively permeable.***

In a solution with many solute molecules the movement of the water molecules is restricted because of solute-water interactions. Fewer of the water molecules have a ***free kinetic energy*** which is great enough to enable them to cross the membrane.

Solute molecules cannot cross the membrane as freely or as rapidly as water molecules can.

MANY WATER MOLECULES CAN MOVE IN THIS DIRECTION

FEW WATER MOLECULES CAN MOVE IN THIS DIRECTION

THERE IS A NET MOVEMENT OF WATER MOLECULES IN THIS DIRECTION *

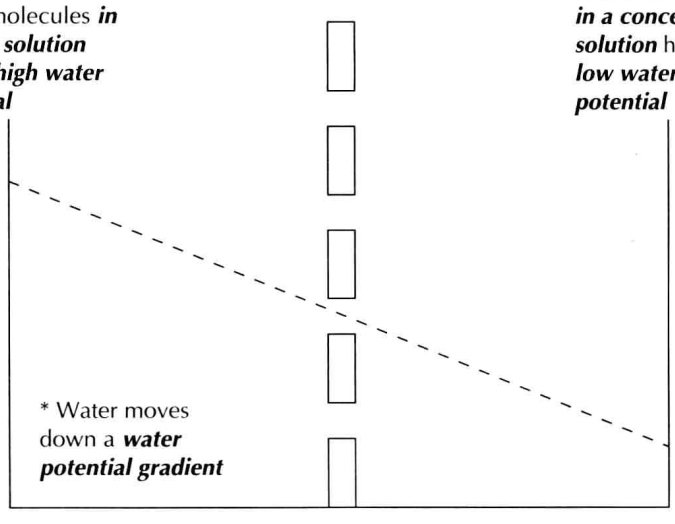
This movement of water depends on how many water molecules have sufficient free kinetic energy to 'escape from' the system

so that any system in which the water molecules have a ***high*** average kinetic energy will have a greater tendency to lose water than will a system in which the water molecules have a ***low*** average kinetic energy

and when describing water movements scientists replace the term ***free kinetic energy*** with the term ***water potential***, so that

Water molecules ***in a dilute solution*** have a ***high water potential***

Water molecules ***in a concentrated solution*** have a ***low water potential***



* Water moves down a ***water potential gradient***

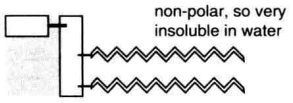
* In the absence of a partially permeable membrane all water molecules would quickly attain the same free kinetic energy and there would be no water potential gradient.

Osmosis is

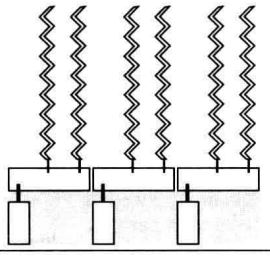
* ***the movement of water***
* ***down a water potential gradient***
* ***across a partially permeable membrane***
* ***to a solution with a more negative water potential.***

Structural components of membranes permit fluidity, selective transport and recognition, integrity and compartmentalization.

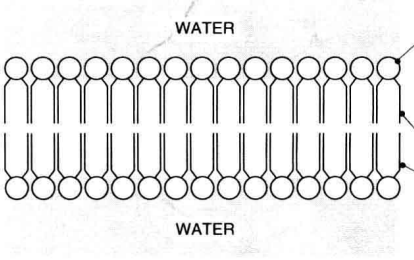
Because of the different solubility properties of the two ends of phospholipid molecules ...



... such molecules form a layer at a water surface



and a ***phospholipid bilayer*** can act as a barrier between two aqueous environments.

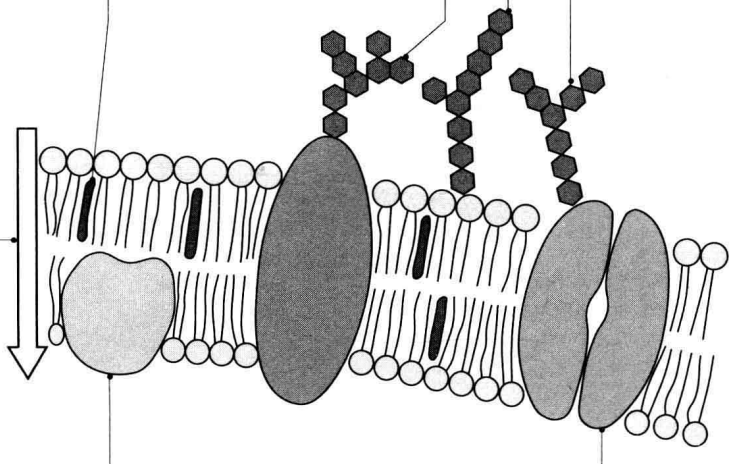


Hydrophilic heads point outwards: form hydrogen bonds with water

Hydrophobic tails point towards one another: this maximizes hydrophobic attractions and excludes water

Lipid composition influences membrane fluidity: unsaturated fatty acid tails are 'kinked', limit close packing of the hydrophobic tails and so ***increase*** fluidity, but cholesterol may interfere with lateral movement of hydrophobic tails and thus ***reduce*** membrane fluidity.

Surface carbohydrates (collectively the ***glycocalyx)*** are usually oligosaccharides which are positioned to aid in cell recognition functions.



Diffusion across the lipid bilayer is responsible for the movement of ***small, uncharged molecules.***

Thus O_2, H_2O, CO_2, urea and ethanol cross rapidly (they 'squeeze between') the polar phospholipid heads then dissolve in the lipid on one side of the membrane and emerge on the other.

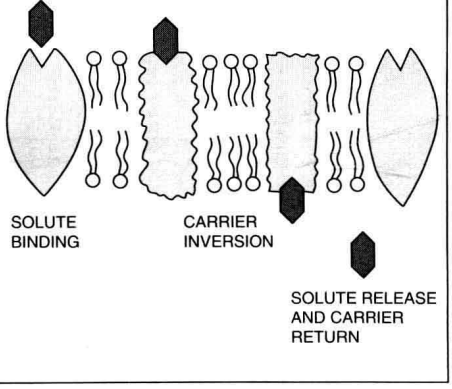
Large or ***charged molecules*** cannot cross the lipid bilayer.

Thus Na^+, K^+, Cl^-, HCO_3^- and glucose do not cross in this way.

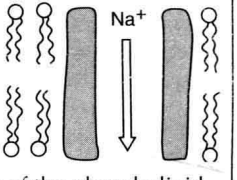
Active transport uses a ***carrier protein*** to transport a solute across a membrane but ***energy is required*** since transport may be ***against a concentration gradient.*** Typically ATP is hydrolysed and the binding of the phosphate group to the carrier changes the protein's conformation in such a way that the solute molecule is moved across the membrane.

Facilitated diffusion uses a ***carrier protein*** to transfer a molecule across a membrane ***along*** its electrochemical gradient. The binding of the solute alters the conformation of the carrier so that its position in the membrane changes and the solute molecule is discharged on the other side of the membrane. Glucose uptake by erythrocytes occurs in this way.

N.B. There is ***no requirement for ATP***, as there is ***no energy consumption.***



Diffusion through aqueous channels in pore proteins: transmembrane proteins may have aqueous channels through which charged molecules may pass and thus avoid the hydrophobic tails of the phospholipid molecules.



Some channels are open all of the time, but others are ***gated*** (they open and close only in response to a stimulus, such as a change in the membrane's electrical potential). Such ***gated channels*** are vital to the operation of nerve and muscle, where movements of Na^+, K^+ and Ca^{2+} initiate information transfer.

Animal cell ultrastructure

Lysosomes are sacs that contain high concentrations of hydrolytic (digestive) enzymes. These enzymes are kept apart from the cell contents which they would otherwise destroy, and they are kept inactive by an alkaline environment within the lysosome. They are especially abundant in cells with a high phagocytic activity, such as some *leukocytes*.

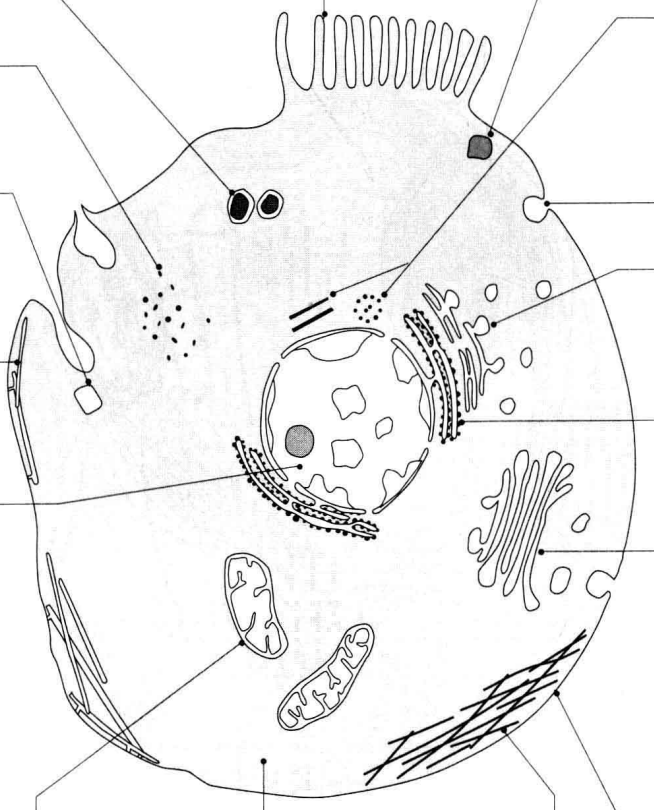
Free ribosomes are the sites of protein synthesis, principally for proteins destined for intracellular use. There may be 50 000 or more in a typical eukaryote cell.

Endocytic vesicle may contain molecules or structures too large to cross the membrane by active transport or diffusion.

Microtubules are hollow tubes of the protein *tubulin*, about 25 nm in diameter. They are involved in intracellular transport (e.g. the movement of mitochondria), have a structural role as part of the cytoskeleton and are components of other specialized structures such as the centrioles and the basal bodies of cilia and flagella.

Nucleus is the centre of the regulation of cell activities since it contains the hereditary material, DNA, carrying the information for protein synthesis. The DNA is bound up with histone protein to form chromatin. The nucleus contains one or more nucleoli in which ribosome subunits, ribosomal RNA, and transfer RNA are manufactured. The nucleus is surrounded by a double nuclear membrane, crossed by a number of nuclear pores. The nucleus is continuous with the endoplasmic reticulum. There is usually only one nucleus per cell, although there may be many in very large cells such as those of striated (skeletal) muscle. Such multinucleate cells are called coenocytes.

Microvilli are extensions of the plasmamembrane which increase the cell surface area. They are commonly abundant in cells with a high absorptive capacity, such as *hepatocytes* or cells of the *first coiled tubule of the nephron*. Collectively the microvilli represent a *brush border* to the cell.



Peroxisome is one of the group of vesicles known as *microbodies*. Each of them contains oxidative enzymes such as *catalase*, and they are particularly important in delaying cell ageing.

Centrioles are a pair of structures, held at right angles to one another, which act as organizers of the nuclear spindle in preparation for the separation of chromosomes or chromatids during nuclear division.

Secretory vesicle undergoing exocytosis. May be carrying a synthetic product of the cell (such as a protein packaged at the Golgi body) or the products of degradation by lysosomes. Secretory vesicles are abundant in cells with a high synthetic activity, such as the cells of the *Islets of Langerhans*.

Smooth endoplasmic reticulum is a series of flattened sacs and sheets that are the sites of synthesis of steroids and lipids.

Rough endoplasmic reticulum is so-called because of the many ribosomes attached to its surface. This intracellular membrane system aids cell compartmentalization and transports proteins synthesized at the ribosomes towards the Golgi bodies for secretory packaging.

Golgi apparatus consists of a stack of sacs called *cisternae*. It modifies a number of cell products delivered to it, often enclosing them in vesicles to be secreted. Such products include trypsinogen (from *pancreatic acinar cells*), insulin (from *beta-cells of the Islets of Langerhans*) and mucin (from ***goblet cells in the trachea***). The Golgi is also involved in lipid modification in cells of the ileum, and plays a part in the formation of lysosomes.

Mitochondrion (pl. mitochondria) is the site of aerobic respiration. Mitochondria have a highly folded inner membrane which supports the proteins of the electron transport chain responsible for the synthesis of ATP by oxidative phosphorylation. The mitochondrial matrix contains the enzymes of the TCA cycle, an important metabolic 'hub'. These organelles are abundant in cells which are physically *(skeletal muscle)* and metabolically *(hepatocytes)* active.

Cytoplasm is principally water, with many solutes including glucose, proteins and ions. It is permeated by the *cytoskeleton*, which is the main architectural support of the cell.

Microfilaments are threads of the protein *actin*. They are usually situated in bundles just beneath the cell surface and play a role in endo- and exocytosis, and possibly in cell motility.

Plasmalemma (plasmamembrane) is the surface of the cell and represents its contact with its environment. It is differentially permeable and regulates the movement of solutes between the cell and its environment. There are many specializations of the membrane, often concerning its protein content.

Typical plant cell contains chloroplasts and a permanent vacuole, and is surrounded by a cellulose cell wall.

Golgi body (dictyosome) synthesizes polysaccharides and packages them in vesicles which migrate to the plasmamembrane for eventual incorporation in the cell wall.

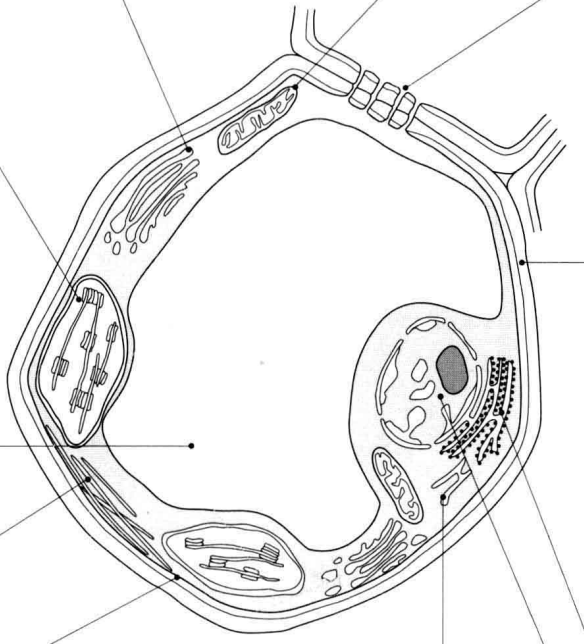
Mitochondrion contains the enzyme systems for ATP synthesis by oxidative phosphorylation. May be abundant in sieve tube companion cells, root epidermal cells and dividing meristematic cells.

Plasmodesmata are minute strands of cytoplasm which pass through pores in the cell wall and connect the protoplasts of adjacent cells. This represents the *symplast* pathway for the movement of water and solutes throughout the plant body. These cell-cell cytoplasm connections are important in cell survival during periods of drought. The E.R. of adjacent cells is also in contact through these strands.

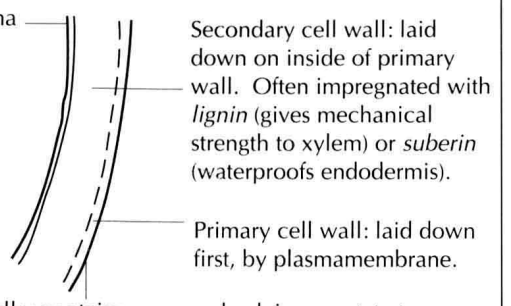
Chloroplast is the site of photosynthesis. It is one of a number of plastids, all of which develop from *proplastids* which are small, pale green or colourless organelles.

Other typical plastids of complex cells are *chromoplasts* which may develop from chloroplasts by internal rearrangements. Chromoplasts are coloured due to the presence of carotenoid pigments and are most abundant in cells of flower petals or fruit skins.

Leucoplasts are a third type of plastid common in cells of higher plants - they include *amyloplasts* which synthesize and store starches and *elaioplasts* which synthesize oils.



Cell wall is composed of long cellulose molecules grouped in bundles called *microfibrils* which, in turn, are twisted into rope-like *macrofibrils*. The macrofibrils are embedded in a matrix of *pectins* (which are very adhesive) and *hemicelluloses* (which are quite fluid). There may be a *secondary cell wall,* in which case the outer covering of the cell is arranged as:



Middle lamella: contains gums and calcium pectate to cement cells together.

The function of the cell wall is a mechanical one - pressure from the cell protoplast maintains cell turgidity. The wall is freely permeable to water and most solutes so that the cell wall represents an important transport route - the *apoplast system* - throughout the plant body.

Vacuole may occupy 90% of the volume of a mature plant cell. It is filled with cell sap (a solution of salts, sugars and organic acids) and helps to maintain turgor pressure inside the cell. The vacuole also contains anthocyanins, pigments responsible for many of the red, blue and purple colours of flowers. Vacuoles also contains enzymes involved in recycling of cell components such as chloroplasts. The vacuolar membrane is called the *tonoplast.*

Microtubules are hollow structures (about 25 nm in diameter) composed of the protein tubulin. They occur just below the plasmamembrane where they may aid the addition of cellulose to the cell wall. They are also involved in the cytoplasmic streaming of organelles such as Golgi bodies and chloroplasts, and they form the spindles and cell plates of dividing cells.

Rough endoplasmic reticulum is the site of protein synthesis (on the attached ribosomes), storage and preparation for secretion. The endoplasmic reticulum (E.R.) also plays a part in the compartmentalization of the cell.

Plasmamembrane (plasmalemma, cell surface membrane) is the differentially-permeable cell surface, responsible for the control of solute movements between the cell and its environment. It is flexible enough to move close to or away from the cell wall as the water content of the cytoplasm changes. The membrane is also responsible for the synthesis and assembly of cell wall components.

Smooth endoplasmic reticulum is the site of lipid synthesis and secretion.

Nucleus is surrounded by the nuclear envelope and contains the genetic material, DNA, associated with histone protein to form chromatin. The nucleus thus controls the activity of the cell through its regulation of protein synthesis. The nucleolus is the site of synthesis of transfer RNA, ribosomal RNA, and ribosomal subunits.

Cell membrane systems are important in intracellular division of labour. They allow compartmentalization and therefore efficiency through locations of multi-enzyme pathways.

Reverse pinocytosis (endocytosis) releases contents of vesicle into the extracellular environment.

Plasmamembrane

Lysosome contains hydrolytic enzymes which may digest ingested materials, redundant organelles ***(autophagy)*** or whole cells ***(autolysis).***

Trans Golgi network separates products ready for inclusion in secretory vesicles or in lysosomes.

Cisternae stack of Golgi 'processes' molecules often by adding or modifying carbohydrate 'signals' which direct the molecules to the correct cellular compartment.

Cis Golgi network collects sacs from the E.R. Any misdirected molecules, e.g. components of E.R. enzyme systems, are returned to the endoplasmic reticulum.

Protein synthesis at ribosomes on E.R. Newly-synthesized protein carries a 'signal' which ensures that the protein will enter the cisterna ready to be packaged within a sac and delivered to the Golgi apparatus.

Messenger DNA carries coded message for protein synthesis from nucleus to ribosomes.

Nucleolus is the site of manufacture of ribosomal subunits. It disperses in preparation for nuclear division, and is reassembled at the end of telophase.

Nucleoplasm contains a variety of solutes, including nucleoside triphosphates for DNA synthesis, and the enzyme complex (DNA polymerase) which regulates DNA replication and repair.

Endocytic vesicle contains product for export, e.g. mucoprotein from goblet cells, trypsinogen from pancreatic acinar cells and complex carbohydrates for plant cell wall synthesis.

The ***endoplasmic reticulum (E.R.)*** has a wide range of other functions:

1. ***Synthesis of lipids,*** e.g. reassembly of fats in gut epithelium.
2. ***Steroid synthesis***, e.g. in cells which secrete steroid hormones.
3. ***Control of Ca^{2+} concentration*** in skeletal muscle cells.

1, 2 and 3 all occur on smooth E.R.

4. ***Surface for enzyme systems***, e.g. the oxidizing system which detoxifies alcohol and other drugs in the liver.

Product molecules are moved through the stack in a precisely defined sequence.

Endoplasmic reticulum 'buds off' membranous sacs containing products of its metabolism. These products include proteins and lipids and may be for export (○) or for use within the cell (●).

Cisterna is an enclosed space within the membranes of the E.R.

Nuclear envelope is a double membrane, the outer of which is continuous with the E.R.

Nuclear pore can regulate the entry (e.g. ribosomal proteins) and exit (e.g. ribosomal subunits, messenger RNA) of molecules to and from the nucleus.

Nucleus contains coded information for protein synthesis as a series of genes on the chromosomes.

Chromatin is the genetic material, containing the coded information for protein synthesis in the cell. It is composed of DNA bound to basic proteins called ***histones.*** The DNA and histone are organized into ***nucleosomes.*** During nuclear division the chromatin condenses to form the ***chromosomes,*** and the chromatin containing DNA which is being 'expressed' (transcribed into mRNA) becomes visible as more loosely-coiled threads called ***euchromatin.***

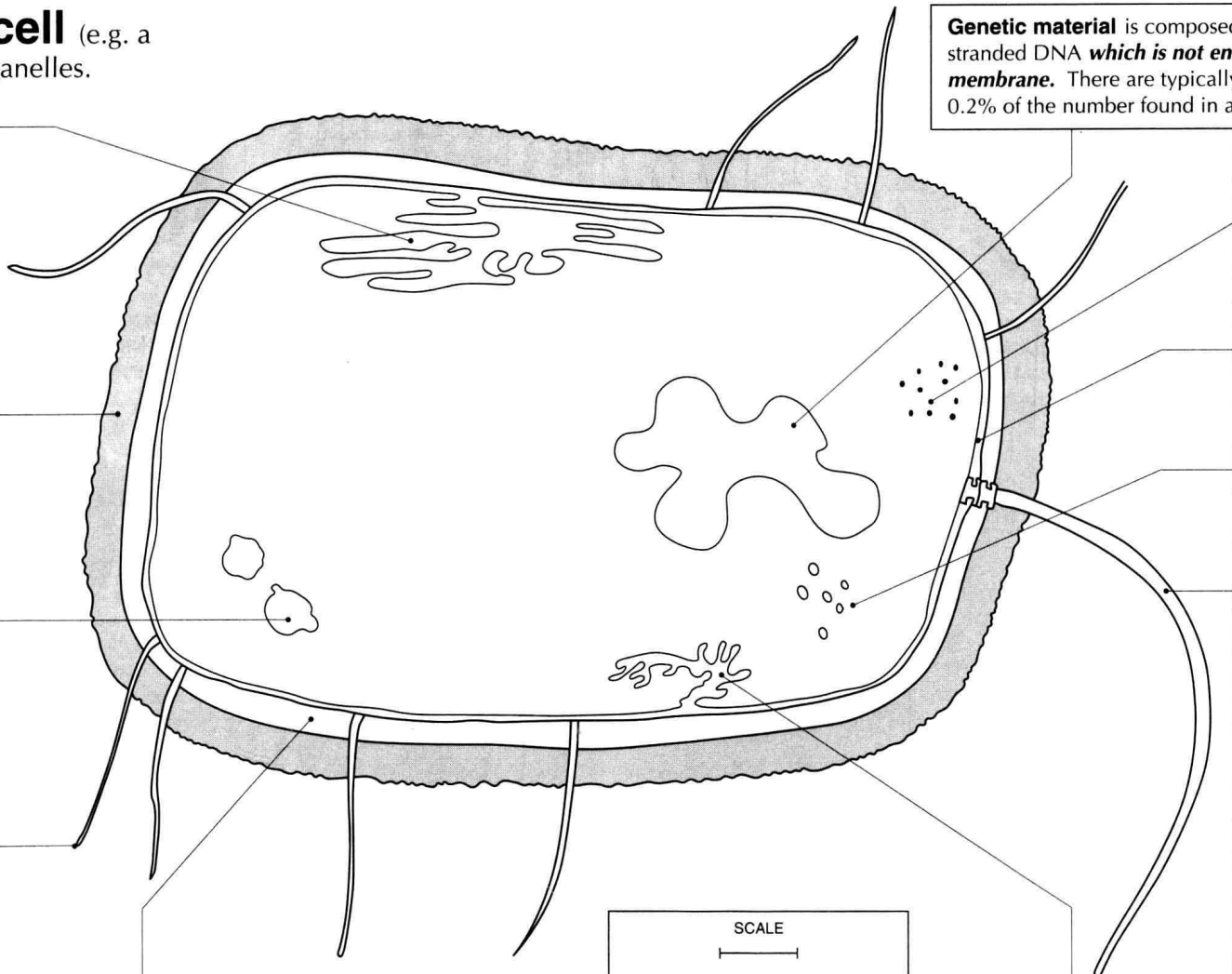
A prokaryotic cell (e.g. a bacterium) has no true organelles.

Photosynthetic membranes are surfaces for light-absorbing pigments, principally ***bacteriochlorophyll***, in green (e.g. *Chlorobium*) and purple (e.g. *Chromatium*) bacteria. N.B. Bacterial photosynthesis does not evolve oxygen.

Capsule is a gummy layer of mucilage which may unite bacteria into colonies (e.g. *Bacillus anthracis*) or confer protection (e.g. rough strain of *D. pneumoniae*).

Plasmids are short pieces of circular DNA which replicate independently of the cell genome. They have been widely exploited in recombinant DNA technology.

Pili (or fimbriae) are protein rods concerned with cell-cell attachment. The ***sex pilus*** is involved in DNA transfer during sexual reproduction.



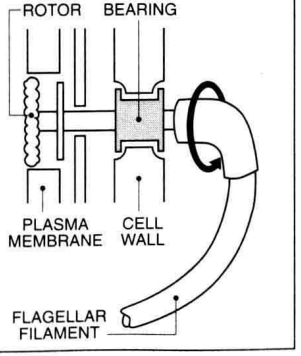
Genetic material is composed of a circle of double-stranded DNA ***which is not enclosed within a nuclear membrane.*** There are typically about 2000 genes, about 0.2% of the number found in a eukaryotic cell.

Ribosomes smaller than those in eukaryotes. They are scattered throughout the cytoplasm, not supported on an endoplasmic reticulum.

Plasmamembrane is a typical phospholipid bilayer.

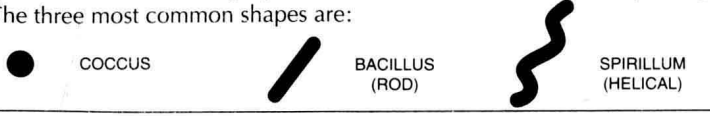
Food stores are typically lipid globules or glycogen granules.

Flagellum is responsible for motility of many bacteria. It is much simpler than the flagellum of a eukaryotic cell, being composed of a single cylinder of protein subunits (flagellin). The flagellum does not 'beat' but instead rotates about a 'bearing' anchored in the cell wall to produce a corkscrew motion which drives the cell along.



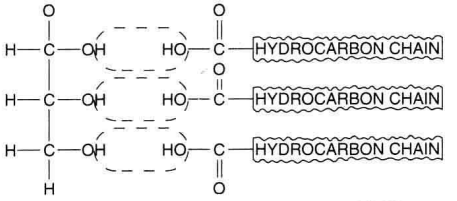
Mesosomes are infoldings of the plasma membrane on which the enzymes associated with respiration are located. A proton gradient generated across these membranes is used to drive the synthesis of ATP.

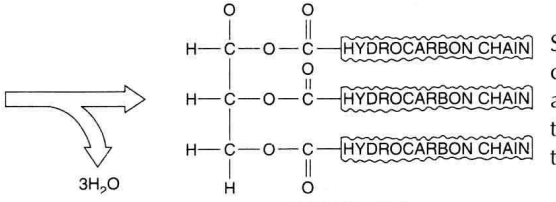
Cell wall has a rigid framework of ***murein***, a polysaccharide cross-linked by peptide chains. In ***gram-positive*** bacteria the wall is thickened with further polysaccharide and protein deposits, whilst in ***gram-negative*** bacteria the wall is thinner but coated with a lipid layer which provides protection against ***lysozyme*** and ***penicillin.***
The rigidity of the cell wall prevents osmotic damage (penicillin interferes with this in susceptible gram-positive bacteria) and confers shape on the cell. The three most common shapes are:



Lipid structure and function

TRUE LIPIDS are esters of fatty acids and alcohols, formed by condensation reactions. Many of their properties result from their insolubility in water.

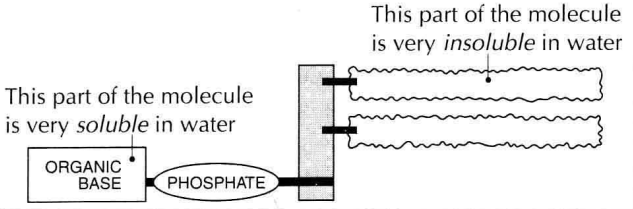




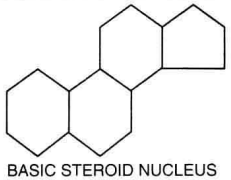
Since the hydrocarbon chains are long (19 C in arachidonic acid) most of the weight of the triglyceride is fatty acid.

Water-repellent properties: oily secretions of the sebaceous glands help to waterproof the fur and skin. The preen gland of birds produces a secretion which performs a similar function on the feathers.

Cell membranes: phospholipids (phosphatides) are found in all cell membranes. These molecules have a polar 'phosphate-base' group substituted for one of the fatty acids in a triglyceride.



Electrical insulation: myelin is secreted by Schwann cells and insulates some neurones in such a way that impulse transmission is made much more rapid.



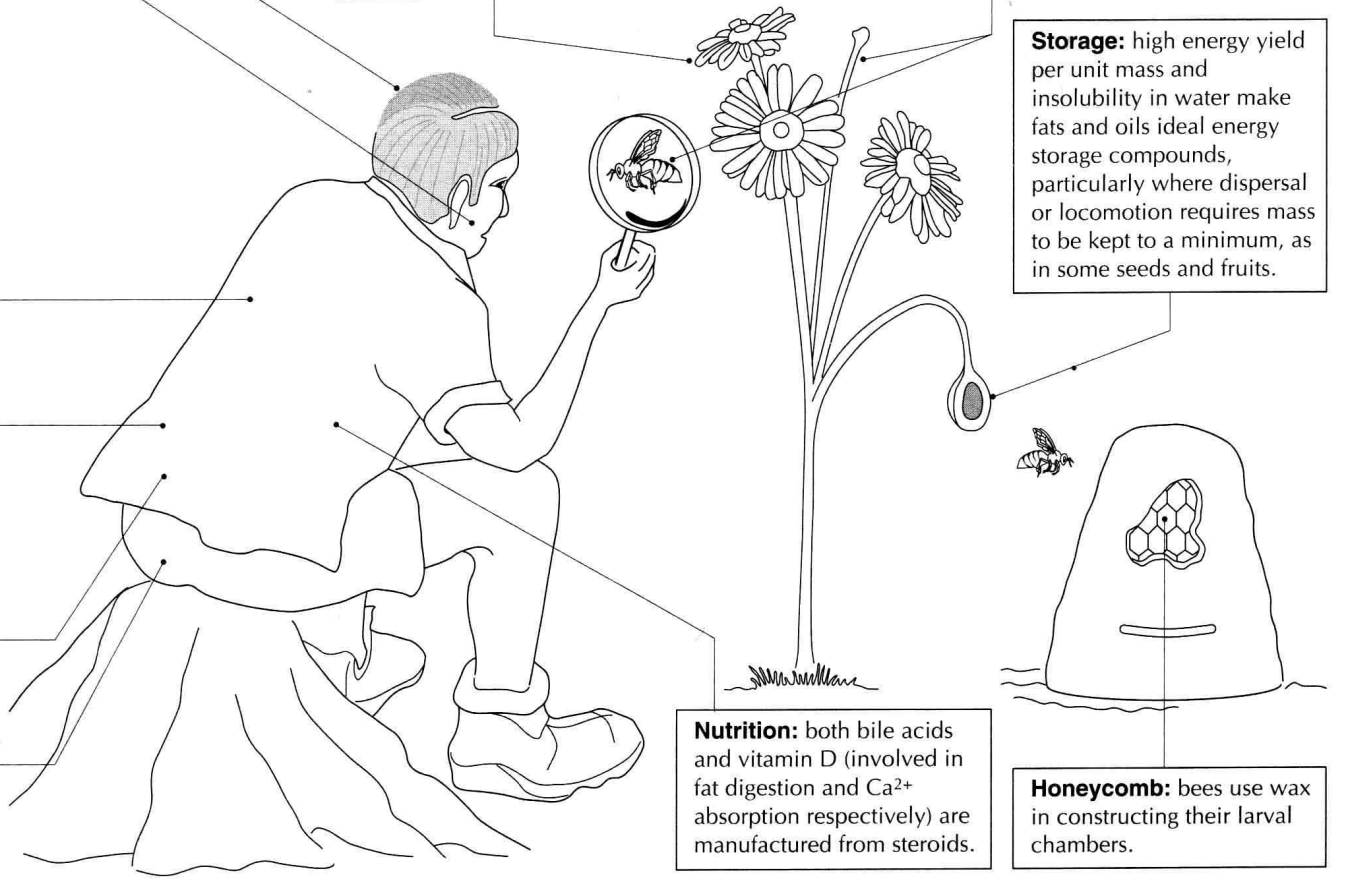
Hormones: an important group of hormones, including cortisone, testosterone and oestrogen, are *steroids*. Steroids are not true esters but have the same solubility properties as them.

Physical protection: the shock-absorbing ability of subcutaneous fat stores protects delicate organs such as the kidneys from mechanical damage.

Thermal insulation: fats conduct heat very poorly - subcutaneous fat stores help heat retention in endothermic animals. Incompressible blubber is an important insulator in diving mammals.

Attraction: plant scents are derivatives of fatty acids. They are attractive to insects and thus aid pollination.

Waterproofing: the waxy cuticle of insects and plants reduces water losses by evaporation since water cannot cross the insoluble lipid layer. Waxes are esters of higher fatty acids with long chain alcohols (i.e. *not* with glycerol).



Storage: high energy yield per unit mass and insolubility in water make fats and oils ideal energy storage compounds, particularly where dispersal or locomotion requires mass to be kept to a minimum, as in some seeds and fruits.

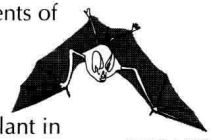
Nutrition: both bile acids and vitamin D (involved in fat digestion and Ca^{2+} absorption respectively) are manufactured from steroids.

Honeycomb: bees use wax in constructing their larval chambers.

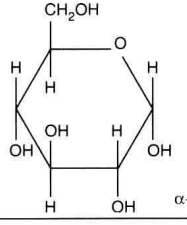
Functions of soluble carbohydrates include transport, protection, recognition and energy release.

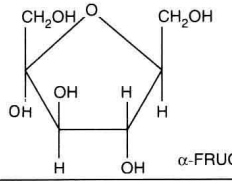
Glucose is the most common substrate for respiration (energy release).
Fructose is a constituent of nectar and sweetens fruits to attract animals and aid seed dispersal.

Sugar derivatives include *sugar alcohols*, e.g. glycerol, *sugar acids*, e.g. ascorbic acid, and *mucopolysaccharides*, which are important components of connective tissues, synovial fluid, cartilage and bone. Heparin (anticoagulant in blood) is derived from mucopolysaccharides and has a protective function.

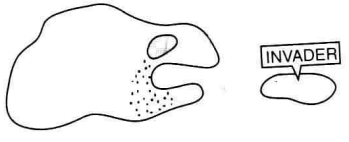


Glucose and fructose are both *monosaccharides* (single sugar units) with the typical formula $C_nH_{2n}O_n$. They each have *six carbon atoms* and are thus called *hexoses* (*pentoses* have 5 carbon atoms and *trioses* have 3).
Glucose and *fructose* are isomers of $C_6H_{12}O_6$.

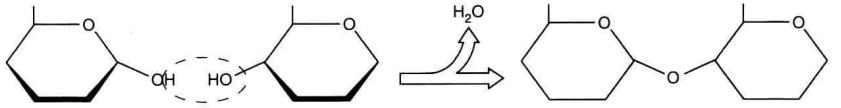




Oligosaccharides are short (often 6-12 units) condensation products which combine with protein (*glycoprotein*) or lipid (*glycolipid*) and form the outer coat (*glycocalyx*) of animal cells. They are important in *cell-cell recognition* and the *immune response*.

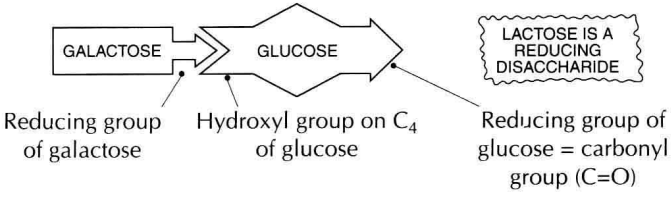


In naturally occurring **disaccharides** monosaccharide rings are joined together by *glycosidic bonds*.



This most usually occurs between *aldehyde* or *keto group* (i.e. the reducing group) of one monosaccharide and an *hydroxyl group* of another monosaccharide,

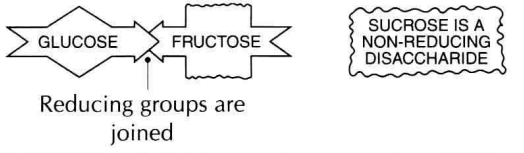
e.g. *lactose*



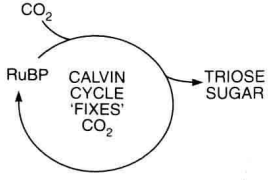
(*Maltose* is a reducing disaccharide formed from two molecules of α-glucose.)

or, more rarely, between *reducing groups of adjacent monosaccharides*,

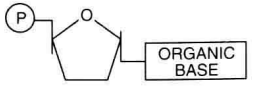
e.g. *sucrose*



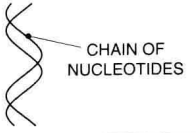
Ribulose bis phosphate is the *acceptor of CO_2* in the Calvin Cycle.



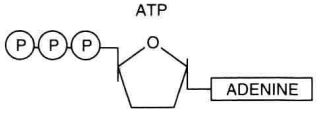
Ribose and **deoxyribose** are constituents of *nucleotides*



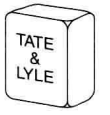
which are the subunits of *nucleic acids* (e.g. DNA).



Other important roles are in the *electron carriers* NAD, FAD and NADP and as the 'energy currency'.



Sucrose (*glucose-fructose*) is the main transport compound in plants. Commonly extracted from sugar cane and sugar beet and used as a sweetener.



Lactose (*glucose-galactose*) is the carbohydrate source for suckling mammals - milk is about 5% lactose.

Maltose (*glucose-glucose*) is a respiratory substrate in germinating seeds.