Module 2: Foundations in biology

SPECIFICATION

2.1.1 Cell structure

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) The use of microscopy to observe and investigate different types of cell and cell structure in a range of eukaryotic organisms.

(b) The preparation and examination of microscope slides for use in light microscopy.

(c) The use of staining in light microscopy.

(d) The representation of cell structure as seen under the light microscope using drawings and annotated diagrams of whole cells or cells in sections of tissue.

(e) the use and manipulation of the magnification formula.

(f) The difference between magnification and resolution.

(g) The ultrastructure of eukaryotic cells and the functions of the different cellular components.

(h) Photomicrographs of cellular components in a range of eukaryotic cells.

(i) The interrelationship between the organelles involved in the production and secretion of proteins.

(j) The importance of the cytoskeleton.

(k) The similarities and differences in the structure and ultrastructure of prokaryotic and eukaryotic cells.

Use of microscopy in determination of cell structure

Optical and Electron Microscopes

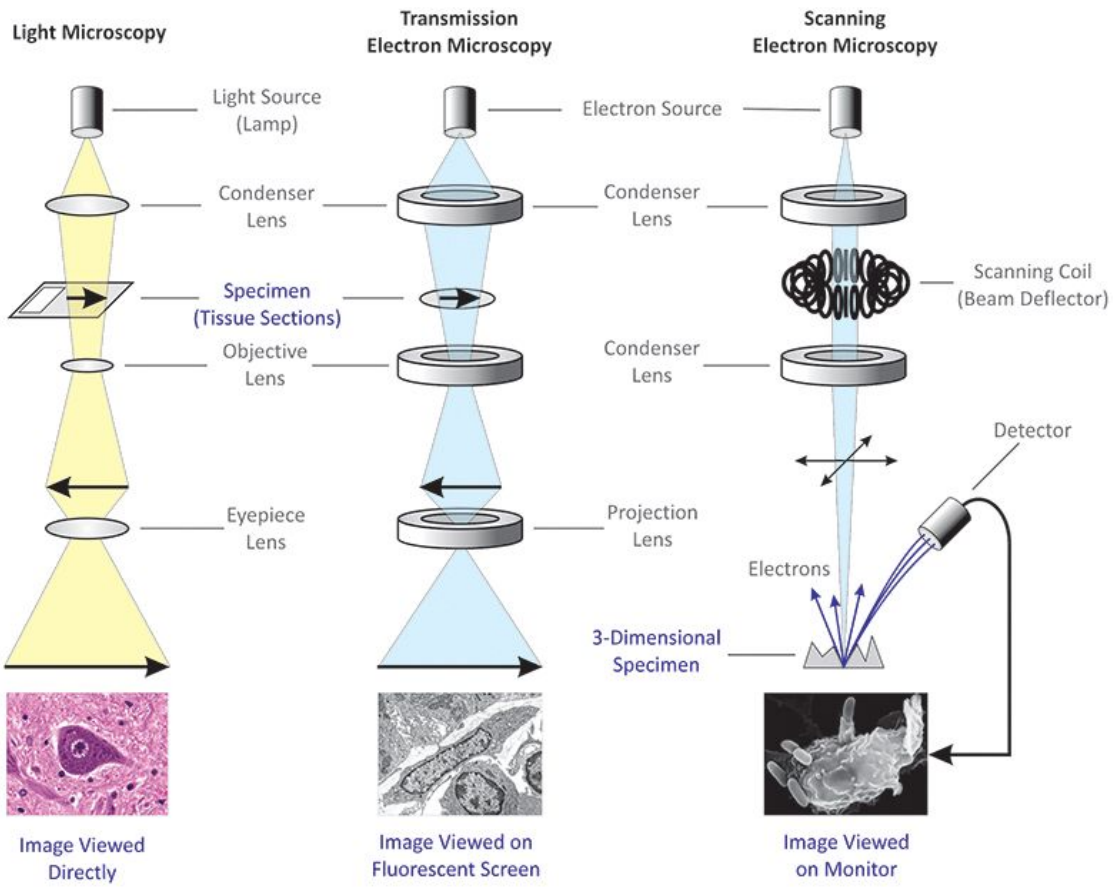
There are two types of microscopes used when studying cells: **Optical** (light) microscopes and **electron** microscopes.

Optical (light) microscopes

1. Uses a **light** to form the image
2. Has a maximum resolution of about **0.2 micrometres** (μm). You cannot view organelles that are smaller than 0.2μm - including **ribosomes**, the **endoplasmic reticulum** and **lysosomes**. **Mitochondria** may be visible but not clear. You can see the **nucleus**.
3. Maximum useful **magnification** of optical microscopes is about **x 1500.**

Electron microscopes

1. Uses **electrons** to form an image.
2. Has a **higher resolution** than optical microscopes to give a **more detailed image** (and can be used to view all organelles).
3. Maximum resolution of about **0.0002 micrometres** (μm) - about 1000 times higher than optical.
4. Maximum useful **magnification** of an electron microscope is about **x 1,500,000**.



Types of microscopes
Image Source: cnx.org

Scanning or Transmission Electron Microscopes

There are two basic types of electron microscopes: t**ransmission electron microscope** (TEM) and the **scanning electron microscope** (SEM).

Transmission electron microscopes (TEMs)

1. Uses electromagnets to focus a beam of electrons, which is transmitted through a specimen.
2. The densest parts of the specimen absorb more electrons, which makes them look darker.
3. TEMs produce a high resolution image to see internal structure of organelles.
4. They can only be used on thin specimens.

Scanning electron microscopes (SEMs)

1. Scans a beam of electrons over the specimen that knocks off electrons that are gathered in a cathode ray tube to form an image.
2. The images show the surface of the specimen and can be 3D.
3. Good for use on thick specimens.
4. SEMs give a lower resolution image than TEMs.

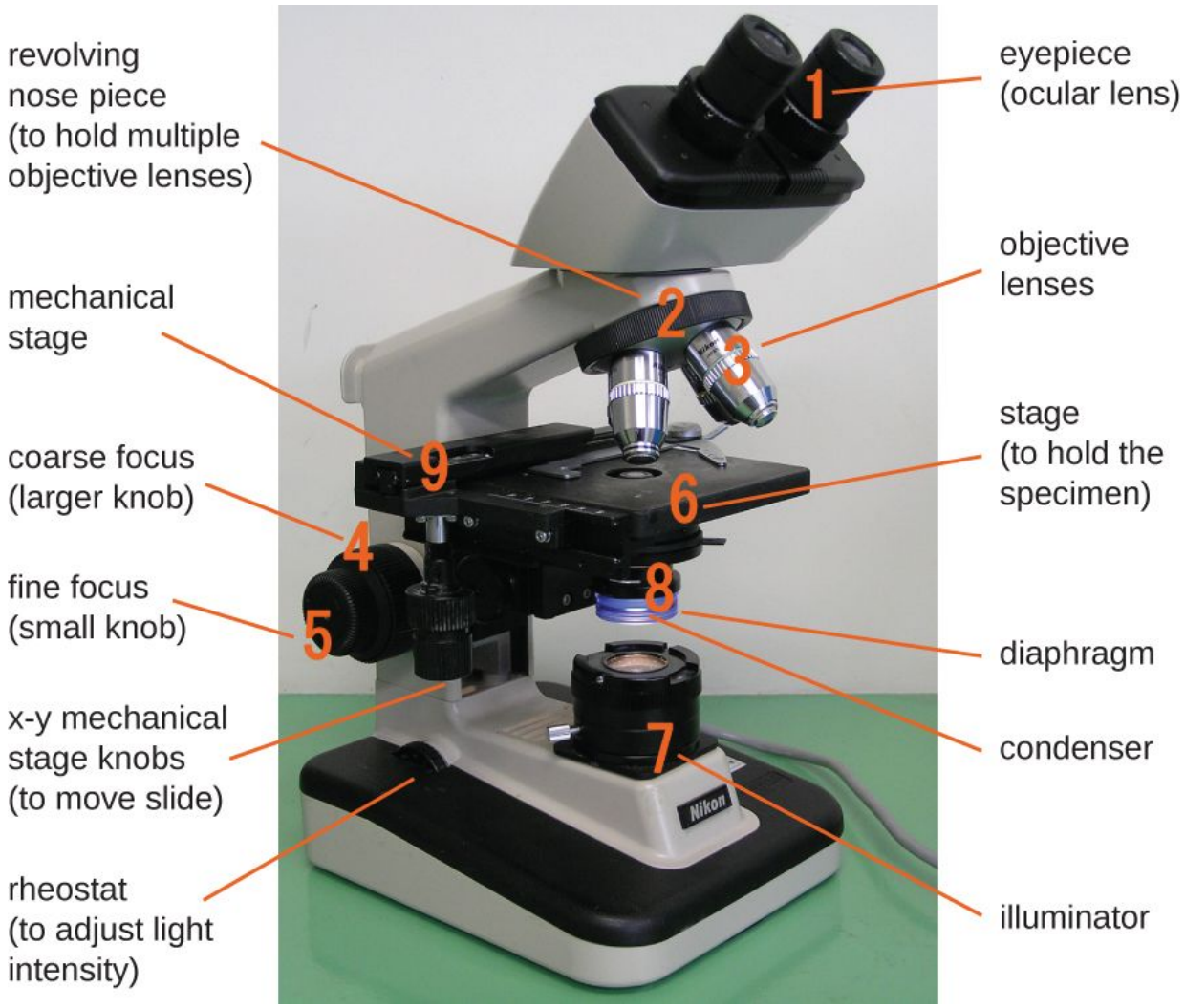
Viewing specimens under an optical microscope

Step-by-step instructions for preparing a temporary mount of a specimen on a slide:

1. Pipette a drop of water onto the slide and use tweezers to place a thin section of the specimen on the drop.
2. Add a drop of stain to highlight objects in the cell (e.g. eosin for cytoplasm, iodine in potassium iodine solution for starch grains in plant cells).
3. Add a cover slip (square of clear plastic) to protect the specimen. Stand the slip upright on the slide and tilt and lower it until the specimen is cover - making sure not to get any air bubbles under.

Preparing inputs for light microscopy

One of the most commonly used microscopes is the brightfield microscope for which the specimens are prepared by fixation and/or staining.



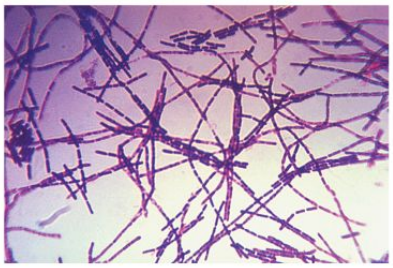
Components of a typical brightfield microscope
Image Source: cnx.org

The specimens can be fixed on the slide by the following methods:

1. Heat-fixation by using a slide warmer.
2. Heat-fixation by holding a specimen a slide with a smear over a microincinerator.
3. Chemical fixation by using chemical agents like acetic acid, ethanol, methanol, formaldehyde (formalin), and glutaraldehyde which denature proteins, stop biochemical reactions, and stabilise cell structures in tissue samples.

Preparing inputs for light microscopy

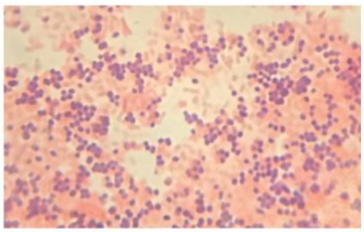
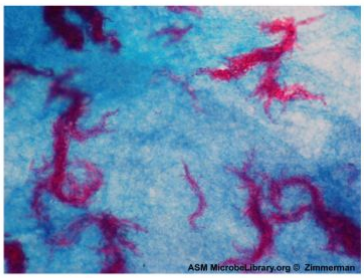
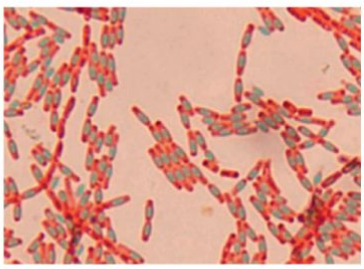
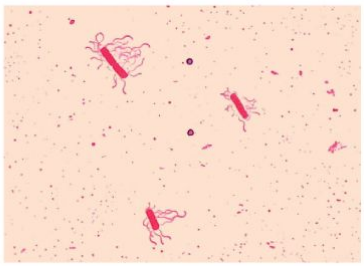
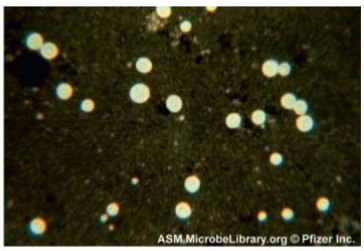
Staining of samples is often used in light microscopy to identify various components of a cell. In simple staining, a single dye is used to emphasise particular structures in the specimen which imparts the same color to all the organisms in a specimen.

SIMPLE STAINS				
Stain Type	**Specific Dyes**	**Purpose**	**Outcome**	**Sample Images**
Basic stains	Methylene blue, crystal violet, malachite green, basic fuchsin, carbolfuchsin, safranin	Stain negatively charged molecules and structures, such as nucleic acids and proteins	Positive stain	
Acidic stains	Eosin, acid fuchsin, rose bengal, Congo red	Stain positively charged molecules and structures, such as proteins	Can be either a positive or negative stain, depending on the cell's chemistry.	
Negative stains	India ink, nigrosin	Stains background, not specimen	Dark background with light specimen	

Types of simple staining
Image Source: cnx.org

Preparing inputs for light microscopy

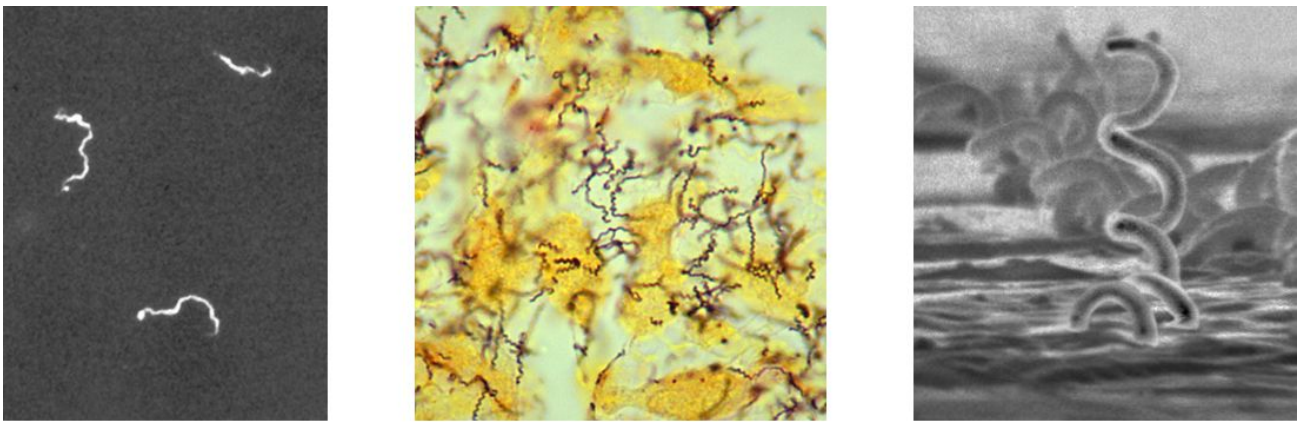
Staining of samples is often used in light microscopy to identify various components of a cell. Differential staining employs more than one dye to impart different colors to different organisms in a specimen.

DIFFERENTIAL STAINS				
Stain Type	**Specific Dyes**	**Purpose**	**Outcome**	**Sample Images**
Gram stain	Uses crystal violet, Gram's iodine, ethanol (decolorizer), and safranin	Used to distinguish cells by cell-wall type (gram-positive, gram-negative)	Gram-positive cells stain purple/violet. Gram-negative cells stain pink.	
Acid-fast stain	After staining with basic fuchsin, acid-fast bacteria resist decolorization by acid-alcohol. Non acid-fast bacteria are counterstained with methylene blue.	Used to distinguish acid-fast bacteria such as *M. tuberculosis*, from non–acid-fast cells	Acid-fast bacteria are red; non–acid-fast cells are blue.	
Endospore stain	Uses heat to stain endospores with malachite green (Schaeffer-Fulton procedure), then cell is washed and counterstained with safranin.	Used to distinguish organisms with endospores from those without; used to study the endospore.	Endospores appear bluish-green; other structures appear pink to red.	
Flagella stain	Flagella are coated with a tannic acid or potassium alum mordant, then stained using either pararosaline or basic fuchsin.	Used to view and study flagella in bacteria that have them.	Flagella are visible if present.	
Capsule stain	Negative staining with India ink or nigrosin is used to stain the background, leaving a clear area of the cell and the capsule. Counterstaining can be used to stain the cell while leaving the capsule clear.	Used to distinguish cells with capsules from those without.	Capsules appear clear or as halos if present.	

Types of differential staining
Image Source: cnx.org

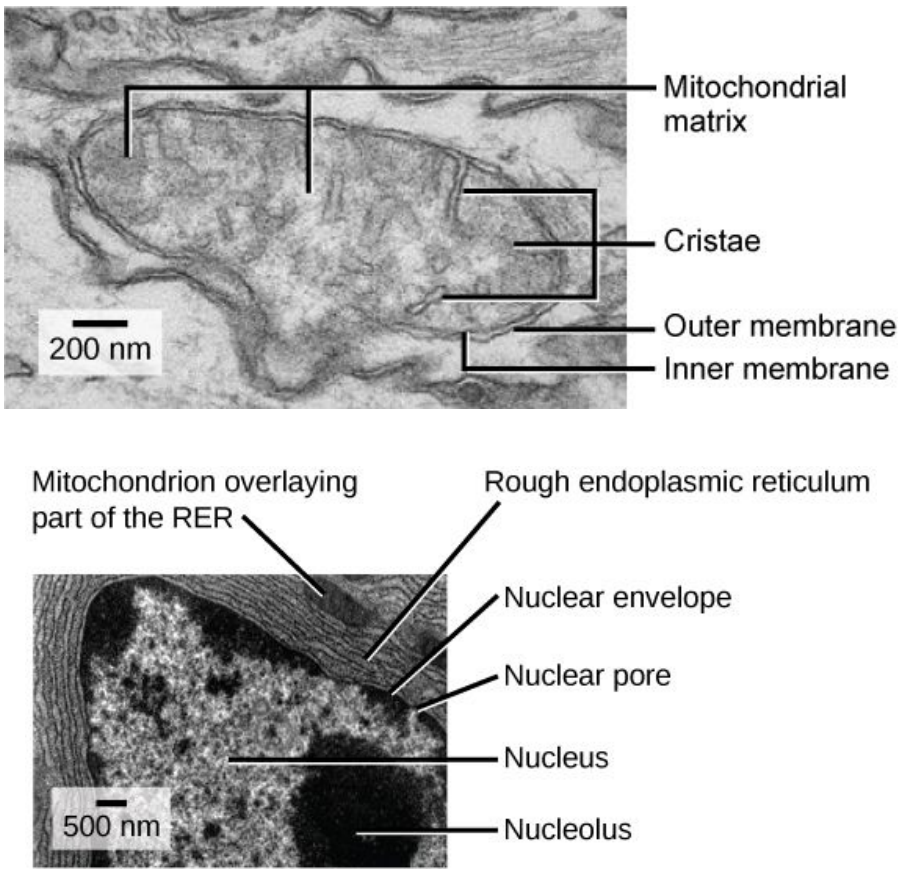
Outputs from a microscope

Light microscopy as well as electron microscopy produce images, which can be deciphered to the construction of the cellular level. Images produced by each of these vary and can be used as needed.



(a) (b) (c)

Treponema pallidum spirochetes as seen under dark field microscope, bright field microscope, and scanning electron microscope
Image Source: cnx.org



Components of cells (with labelling) as observed under microscope
Image Source: cnx.org

Magnification and Resolution

To see cells and the organelles found within them, you need to use a microscope. Microscopes produce a **magnified image** of a cell sample, but the **resolution** is equally important.

Magnification

Magnification is how much **bigger** the image appears than the specimen sample is. It's calculated using this formula:

$$\text{magnification} = \frac{\text{size of image}}{\text{size of real object}}$$

Resolution

The resolution is how **detailed** the image is. The better the resolution, the better the microscope is able to distinguish between two points that are close together.

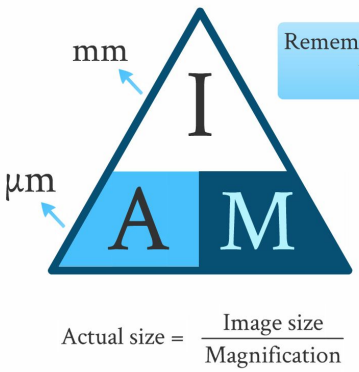
If a microscope cannot separate two objects, more magnification will not help to see them.

Magnification example

Your magnified image is 15mm wide and the actual size of the cell is 0.015mm. What is the magnification?

magnification = 15 ÷ 0.015 = ***x 1000 magnification***

- If no scale bar is given, use the formula *actual size = image ÷ size magnification*.
- If you are given the size of the image and the size of the sample in different units in your exam you will need to convert them into the same units before using the formula.
- You also need to be able to rearrange the formula and look for the units required in the answer.



Remember to convert mm into µm by dividing by 1000

Converting between units

cm *x10* mm *x1000* µm *x1000* nm

Eukaryotic Cells and Organelles

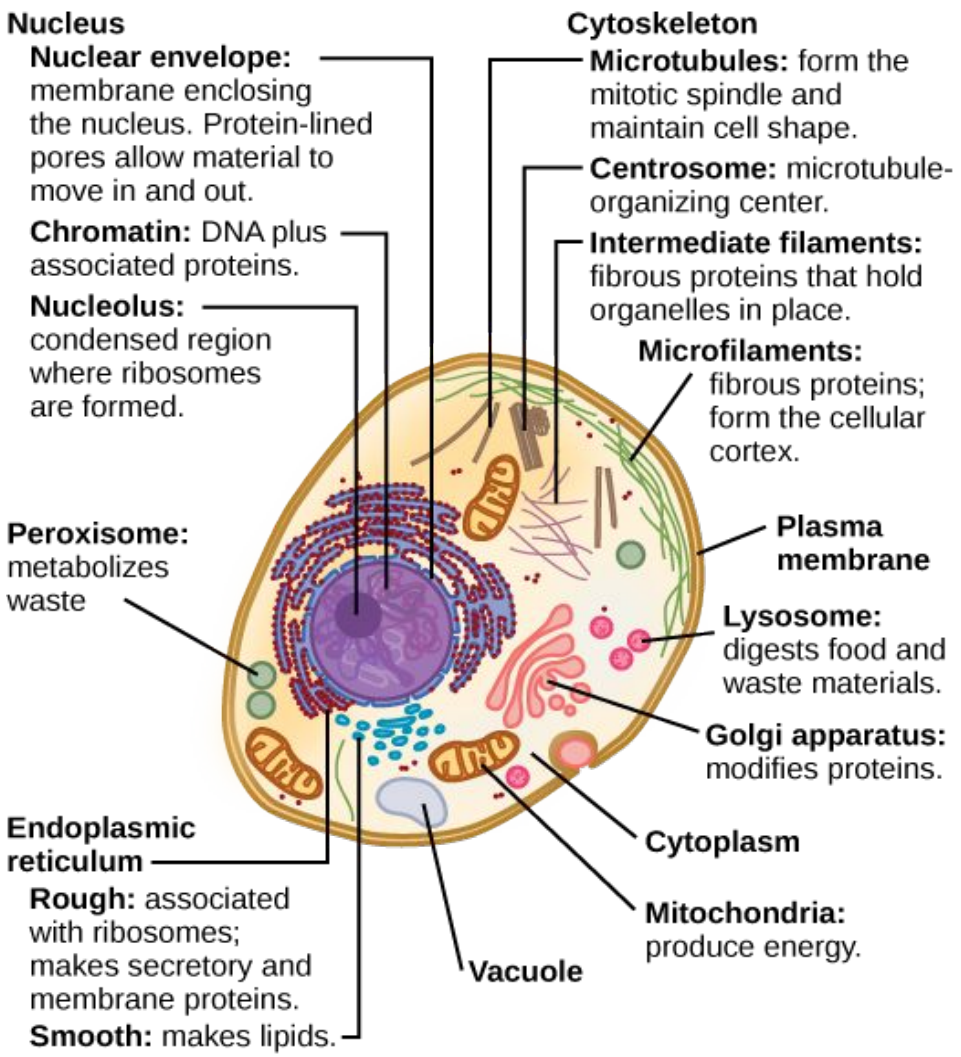
Cells are the **basic building block** of life. Living organisms are classified into one of five kingdoms. The biggest division is between the cells of the **prokaryote kingdom** (the bacteria) and those of the other four kingdoms (animals, plants, fungi and protoctists), which are all **eukaryotic cells**.

Prokaryotes or Eukaryotes

1. Prokaryotic organisms are **prokaryotic cells** (single-cell organisms) and eukaryotic organisms are made of **eukaryotic cells**.
2. Both cell types contain **organelles**, which are parts of cells, and each organelle **has a specific function**.

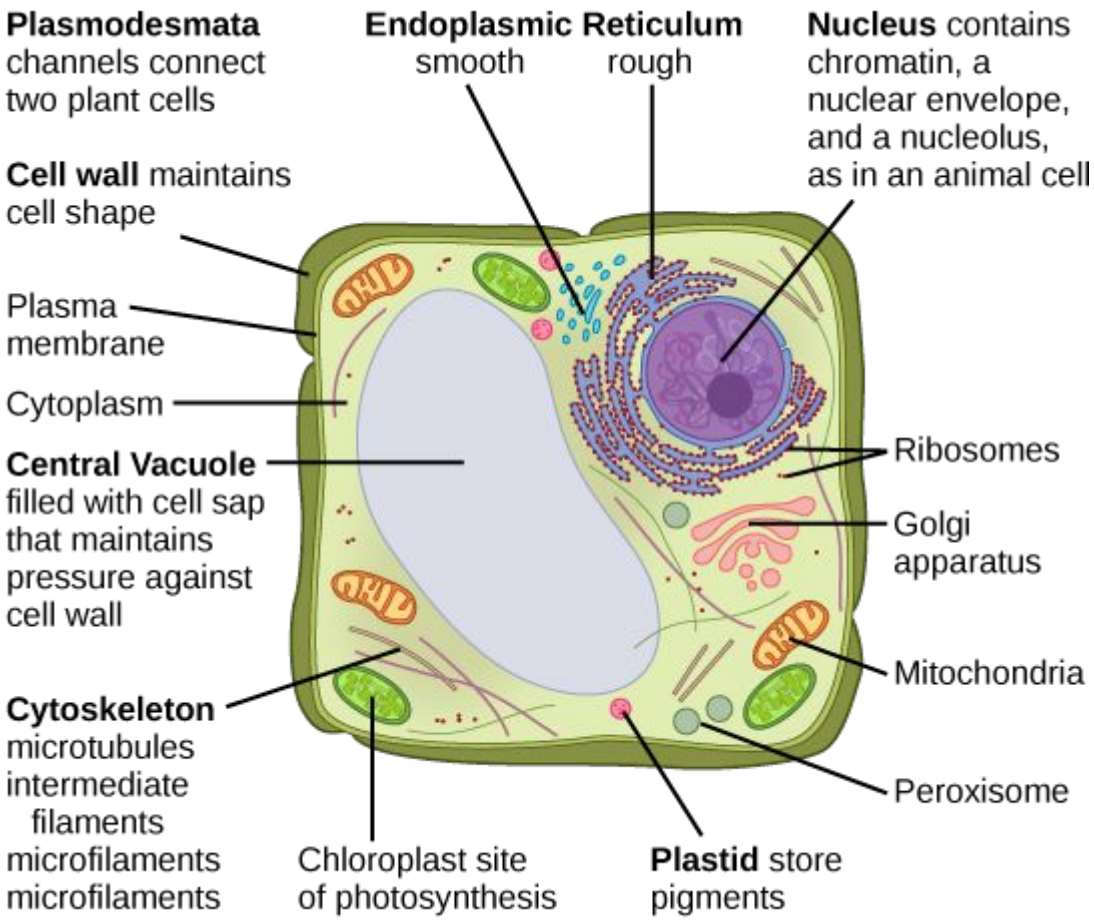
The structure of eukaryotic cells

Here are some general diagrammatic representations of plant and animal cells, and some of the structures (organelles) within them.
We need to learn how the structures outlined in the specification are adapted to do their job.



A typical animal cell
Image Source: cnx.org

The structure of eukaryotic cells



A typical plant cell
Image Source: cnx.org

Algal and fungal cells

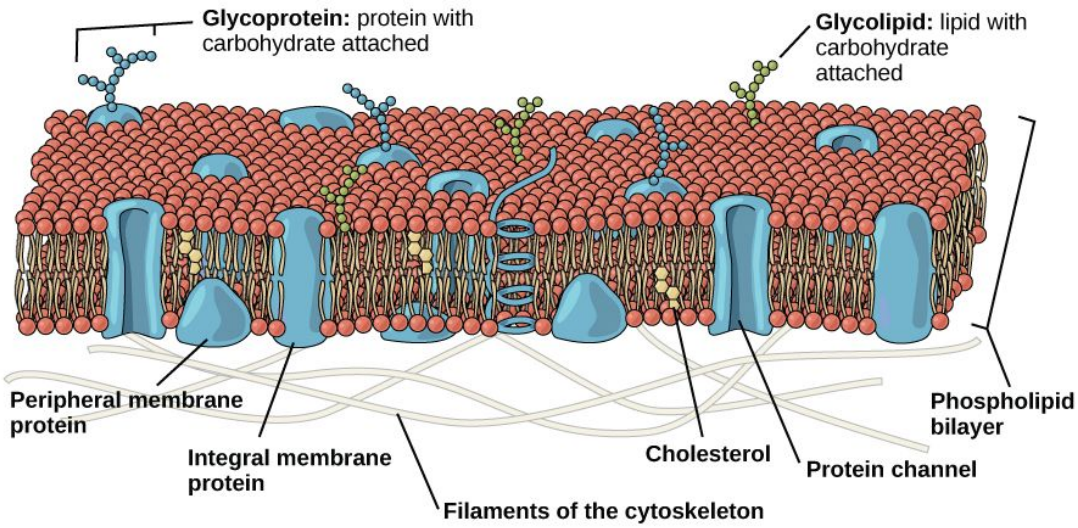
- Algal cells are similar to plant cells with the same organelles, including a cell wall and chloroplasts.
- Fungal cells are also very similar but have have two key differences:
    - Their cell walls are made of chitin and not cellulose.
    - They don't have chloroplasts because they don't photosynthesise.

Algae carry out photosynthesis like plants but they can be single-celled or multicellular. Fungi include yeast and mushrooms.

Organelles and Their Functions

Below is a big list of organelles, including their structure and function. **You will need to know all of these for your exams**. Most organelles are surrounded by **membranes** - don't confuse a diagram of an organelle as a diagram of a whole cell. They are only **parts of cells**.

Cell Membrane (Plasma Membrane)



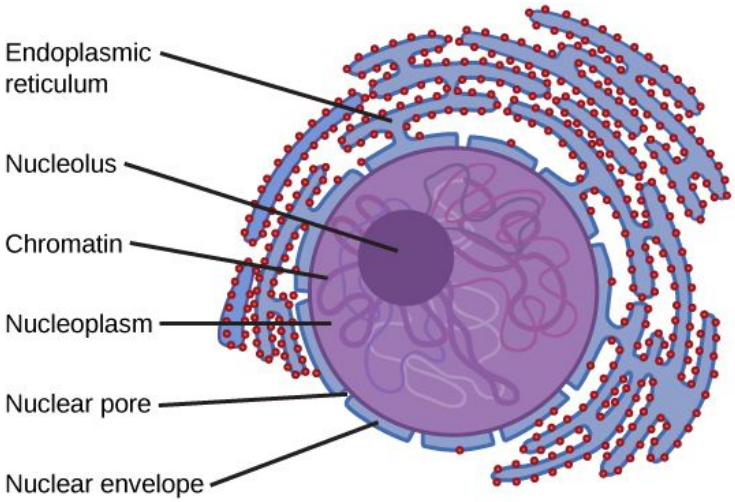
Structure of a cell membrane
Image Source: cnx.org

This membrane is found on the **surface** of animal cells and **just inside the cell wall** of other cells. It's made mostly of **lipids** and **protein**.
The cell membrane **regulates the movement** of substances into and out of the cell. **Receptor molecules** on the membrane allow it to respond to chemicals like hormones.

Nucleus

This is the **largest organelle** that is surrounded by a nuclear envelope, which contains many **pores**. The nucleus contains chromosomes made from **protein-bound linear DNA** and one or more structures called **nucleolus**.

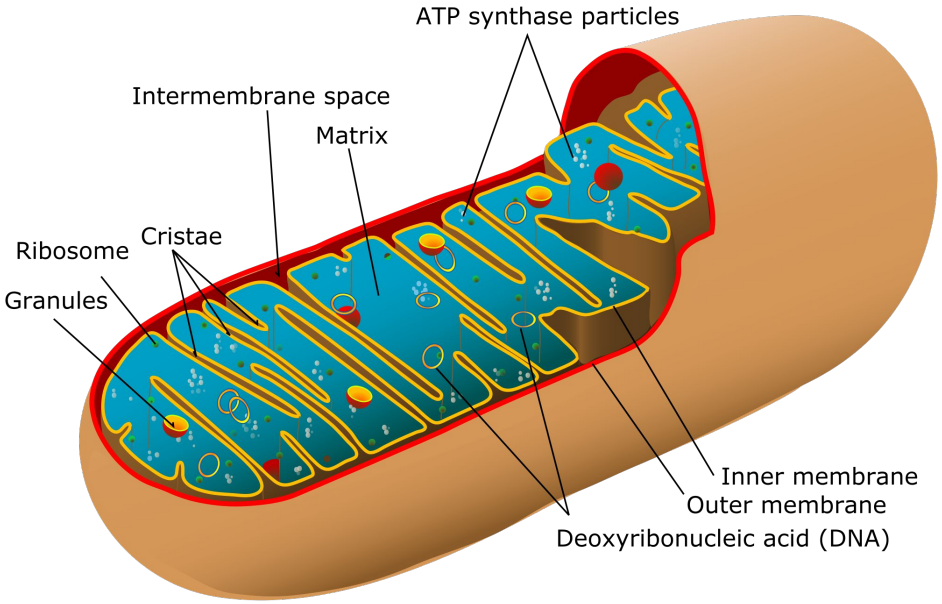
The nucleus **controls cell activity** through transcription of DNA, which contain instructions to make protein. The **pores** allow substances (i.e RNA) to move between the nucleus and the cytoplasm. The **nucleolus** makes **ribosomes**.



Structure of a nucleus
Image Source: cnx.org

Organelles and Their Functions

Mitochondrion



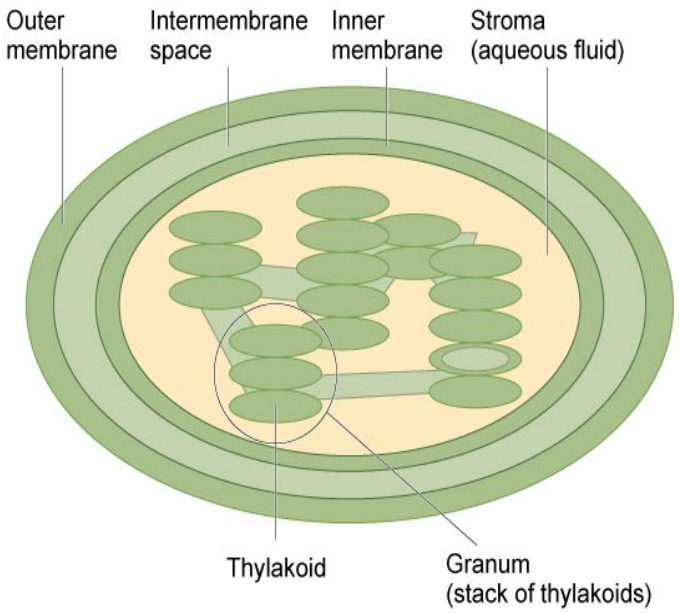
Structure of a cell membrane
Image Source: cnx.org

This is an **oval** or **rod-shaped** organelle that has a **double membrane**. The inner membrane is folded to form structures called **cristae**. Inside is the **matrix**, which contains **enzymes** involved in respiration.
Mitochondrion is the site of **aerobic respiration** where **ATP** is produced. They are found in large numbers in very **active** cells and require a **lot of energy**.

Chloroplast

Chloroplast is a **small**, **flattened** structure found in **plant** and **algal** cells. Surrounded by a double membrane with membranes inside called **thylakoid membranes**. These stack up to form **grana**. Grana are linked together by **lamellae** which are thin, flat pieces of **thylakoid membrane**.

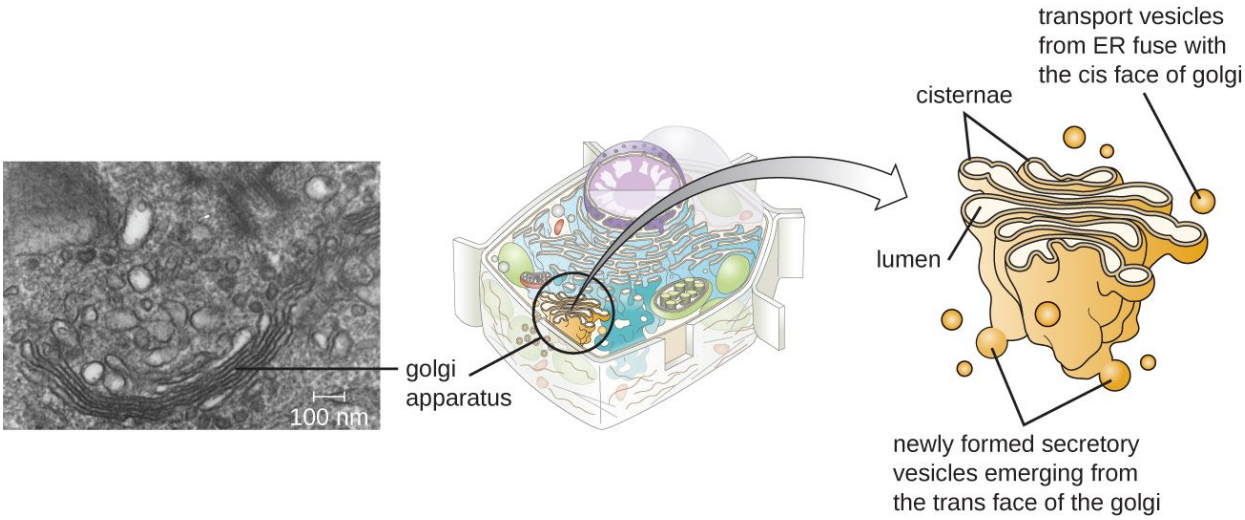
Chloroplast is the site where **photosynthesis** takes place. Some parts of that process happen in the **grana**, and others happen in the **stroma**, which is a **thick liquid** found in chloroplasts.



Structure of a chloroplast
Image Source: cnx.org

Organelles and Their Functions

Golgi Apparatus



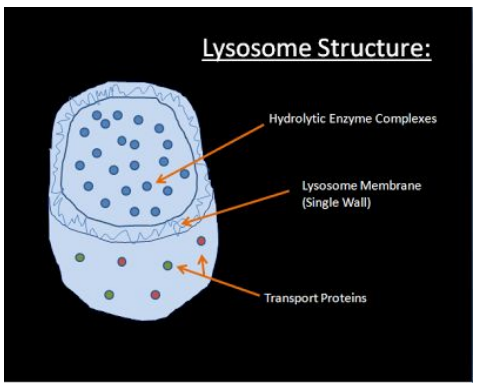
Structure of golgi apparatus
Image Source: cnx.org

A series of **fluid filled**, flattened **membrane sacs**. **Vesicles** are often seen at the edges of the sacs. The Golgi apparatus (or Golgi body) **processes** and **packages** new lipids and proteins. It also **makes lysosomes**.

Golgi Vesicle

This is a small fluid-filled sac (see diagram above) found in the **cytoplasm**. It is surrounded by a membrane and **is produced by the Golgi apparatus**.
The vesicle stored **lipids** and **proteins** made by the Golgi apparatus and then **transports** them out of the cell through the **cell-surface membrane**.

Lysosome



Structure of lysosome
Image Source: cnx.org

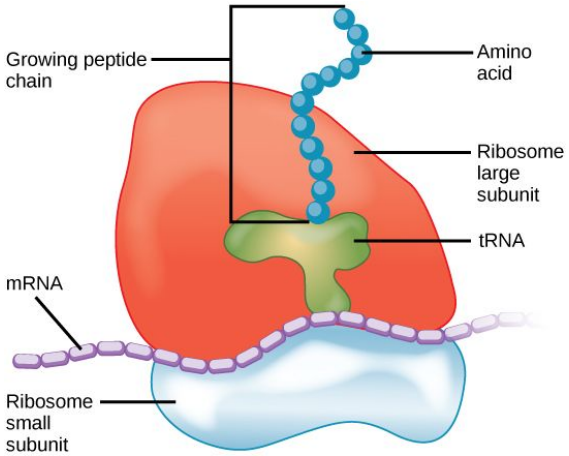
These are **small**, **round** organelles surrounded by a membrane and with **no clear internal structure.** Lysosome is a type of **Golgi vesicle**.
They contain the digestive enzymes **lysozymes**. The enzymes are kept separate from the **cytoplasm** by the membrane and can be used to **digest invading cells** or **break down** worn out components of the cell wall.

Organelles and Their Functions

Ribosome

The **smallest** and most **numerous** of the cell organelles, ribosomes either **float free** in the cytoplasm or are attached to the **rough endoplasmic reticulum**.

It's made up of **proteins** and **RNA**, is **not** surrounded by a membrane and is the **site** where **proteins** are made.



Structure of ribosome
Image Source: cnx.org

Rough Endoplasmic Reticulum (RER)

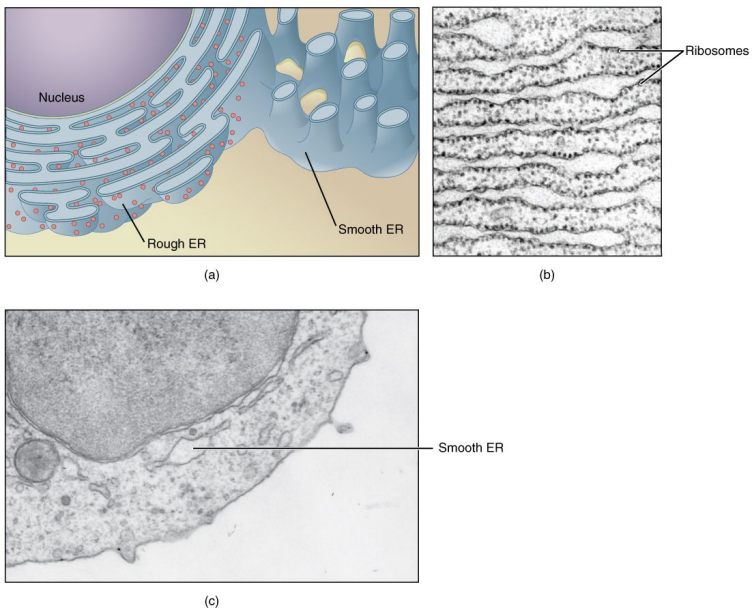
This is a system of membranes that enclose a fluid-filled space. The surface is covered with ribosomes.

RER folds and processes the proteins that have been produced at the ribosomes.

Smooth Endoplasmic Reticulum (SER)

Very similar to rough endoplasmic reticulum, except that no ribosomes are present.

SER synthesises and processes lipids.

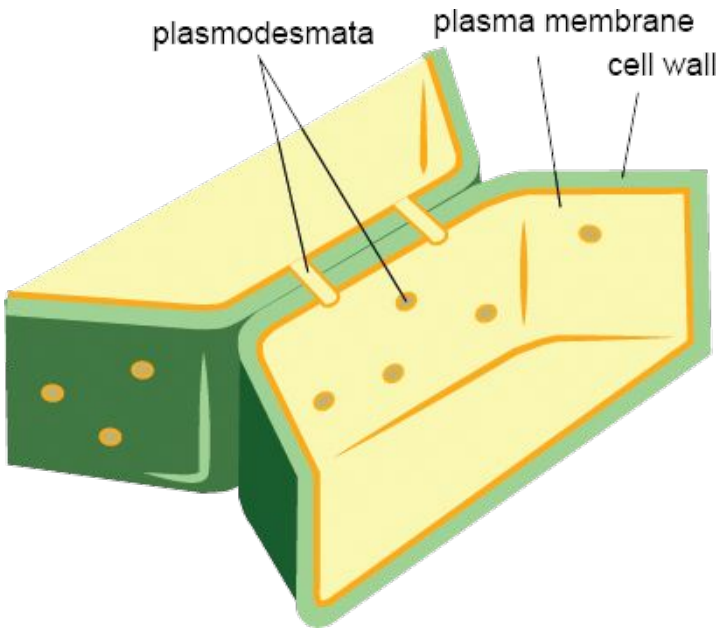


Structures of rough and smooth endoplasmic reticulum
Image Source: cnx.org

Organelles and Their Functions

Cell Wall

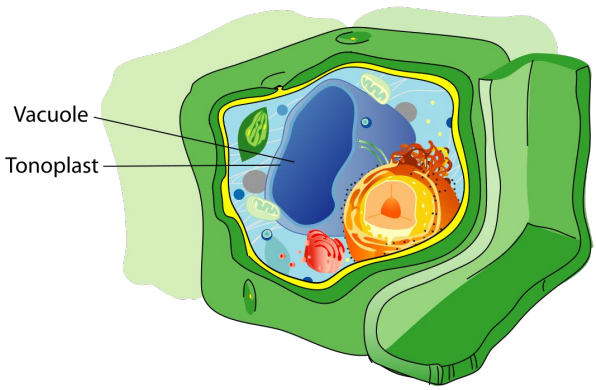
The cell wall is a rigid structure that surrounds cells in plants, algae and fungi. It's made mainly of the carbohydrate cellulose in plant and algae cells. In fungi, the cell wall is made of chitin. Its primary function is to support cells and prevent them from changing shape.



Structure of cell wall
Image Source: cnx.org

Cell Vacuole

A membrane bound organelle found in the cytoplasm of plant cells. It contains a weak solution of sugars and salts called cell sap. The membrane surrounding plant cell vacuoles is called the tonoplast.
They help to maintain pressure inside the cell and keep it rigid.
The vacuole is also involved in isolating unwanted chemicals in the cell.

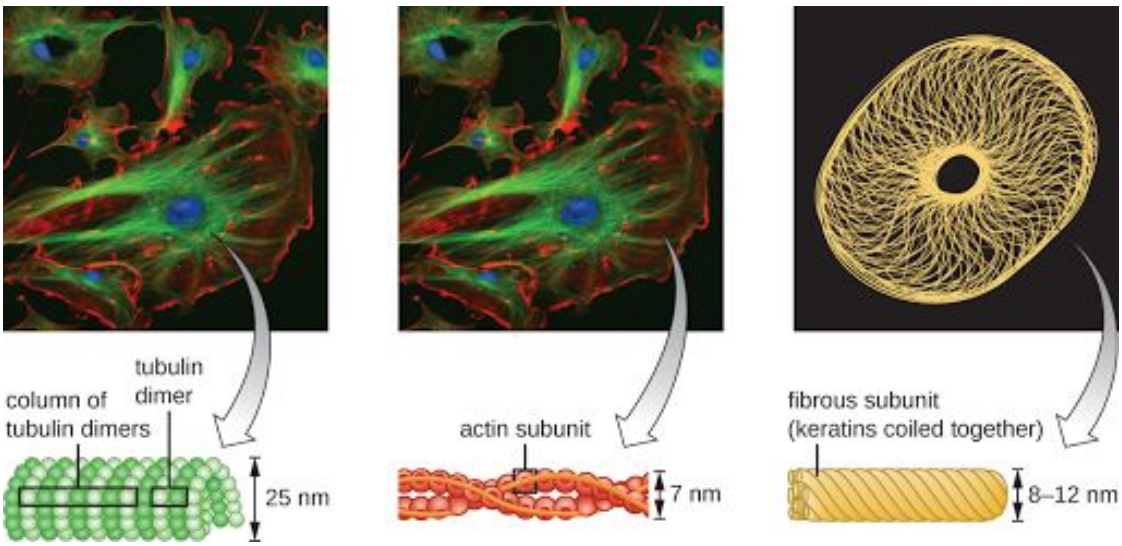


Structures of rough and smooth endoplasmic reticulum
Image Source: cnx.org

Organelles and Their Functions

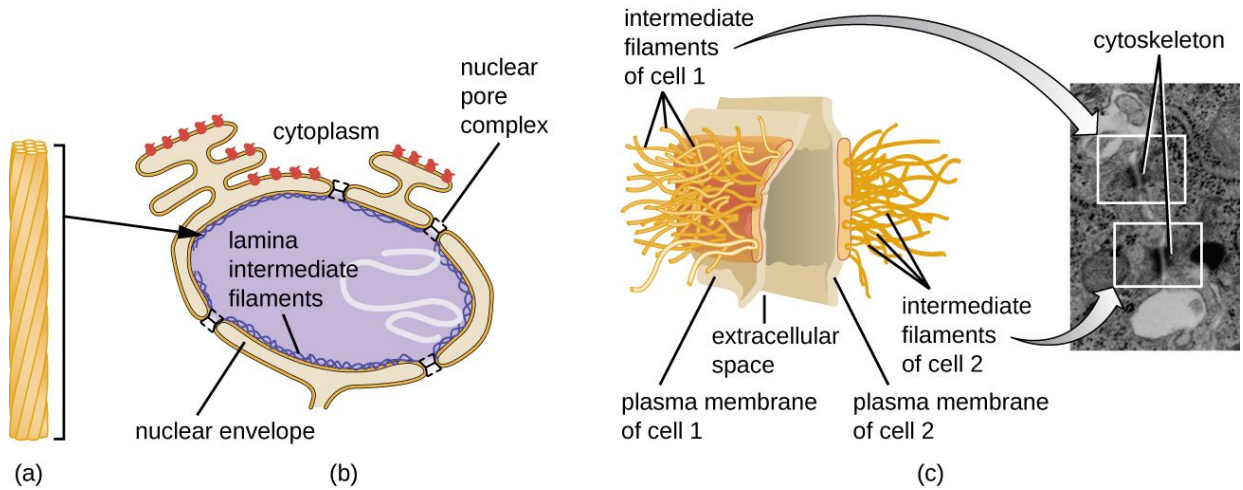
Cytoskeleton

Eukaryotic cells have an internal cytoskeleton made of microfilaments, intermediate filaments, and microtubules. This matrix of fibers and tubes provides structural support as well as a network over which materials can be transported within the cell and on which organelles can be anchored.



Structure of cytoskeleton
Image Source: cnx.org

Two short, identical microtubule structures called centrioles are found near the nucleus of cells. A centriole can serve as the cellular origin point for microtubules extending outward as cilia or flagella or can assist with the separation of DNA during cell division.
The microfilament is a thinner type of cytoskeletal filament responsible for muscle contraction.
An intermediate filament is a filament intermediate in thickness between the microtubules and microfilaments. Intermediate filaments, in conjunction with the microtubules, are important for maintaining cell shape and structure.



Structure of cytoskeletal ‘cables’ intermediate filaments
Image Source: cnx.org

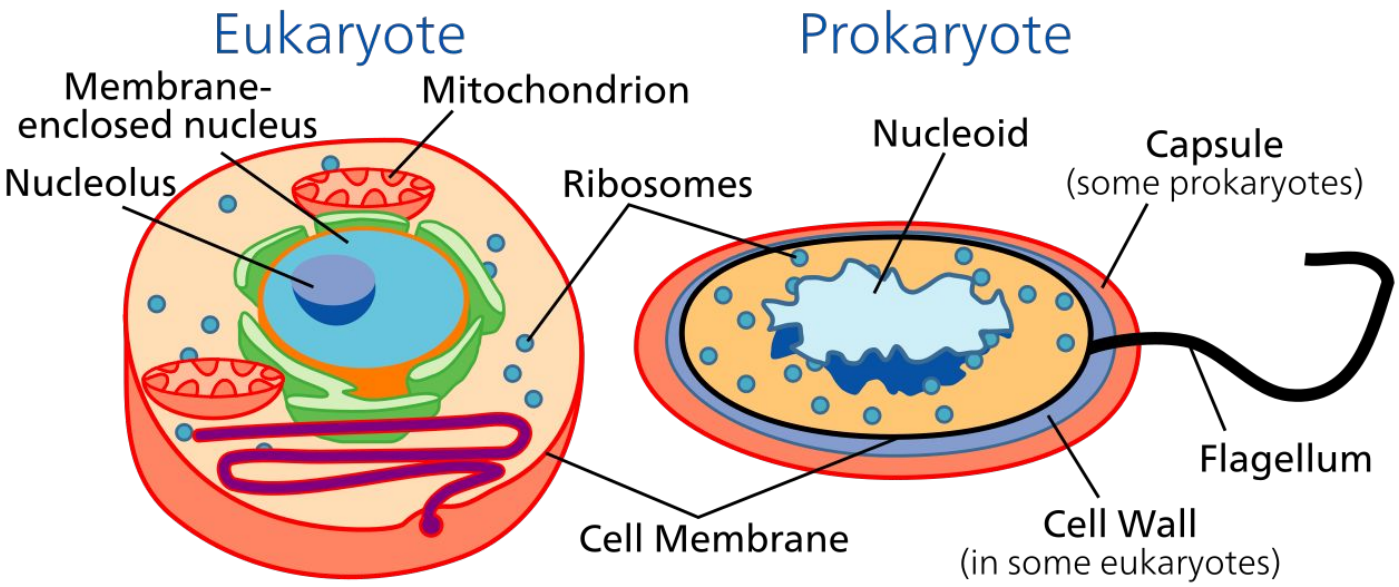
Organelles and Their Functions

Prokaryotes and Eukaryotes

Prokaryotic organisms are prokaryotic cells (single-cell organisms) and eukaryotic organisms are made of eukaryotic cells.

Both cell types contain organelles, which are parts of cells, and each organelle has a specific function.

Prokaryotic cells are smaller and simpler than eukaryotic cells. Bacteria are a good example of prokaryotic cells.



Difference between the structures of eukaryotic and prokaryotic cells
Image Source: cnx.org

Module 2: Foundations in biology

SPECIFICATION

2.1.2 Biological molecules

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) How hydrogen bonding occurs between water molecules, and relate this, and other properties of water, to the roles of water for living organisms.

(b) The concept of monomers and polymers and the importance of condensation and hydrolysis reactions in a range of biological molecules.

(c) The chemical elements that make up biological molecules.

(d) The ring structure and properties of glucose as an example of a hexose monosaccharide and the structure of ribose as an example of a pentose monosaccharide.

(e) The synthesis and breakdown of a disaccharide and polysaccharide by the formation and breakage of glycosidic bonds.

(f) The structure of starch (amylose and amylopectin), glycogen and cellulose molecules.

(g) How the structures and properties of glucose, starch, glycogen and cellulose molecules relate to their functions in living organisms.

(h) The structure of a triglyceride and a phospholipid as examples of macromolecules.

(i) The synthesis and breakdown of triglycerides by the formation (esterification) and breakage of ester bonds between fatty acids and glycerol.

(j) How the properties of triglyceride, phospholipid and cholesterol molecules relate to their functions in living organisms.

(k) The general structure of an amino acid.

(l) The synthesis and breakdown of dipeptides and polypeptides, by the formation and breakage of peptide bonds.

(m) The levels of protein structure.

(n) The structure and function of globular proteins including a conjugated protein.

(o) The properties and functions of fibrous proteins.

(p) The key inorganic ions that are involved in biological processes.

Module 2: Foundations in biology

SPECIFICATION

2.1.2 Biological molecules

Learners should be able to demonstrate and apply their knowledge and understanding of:

(q) How to carry out and interpret the results of the following chemical tests:

- Biuret test for proteins.
- Benedict's test for reducing and non-reducing sugars.
- Reagent test strips for reducing sugars.
- Iodine test for starch.
- Emulsion test for lipids.

(r) Quantitative methods to determine the concentration of a chemical substance in a solution.

(s) i) The principles and uses of paper and thin layer chromatography to separate biological molecules / compounds.

ii) Practical investigations to analyse biological solutions using paper or thin layer chromatography.

Water

Water is an important constituent of the tissues. Typically about 60% of the water we take in comes from drinks, 30% from food and the remaining 10% is metabolic water (a byproduct of respiration).

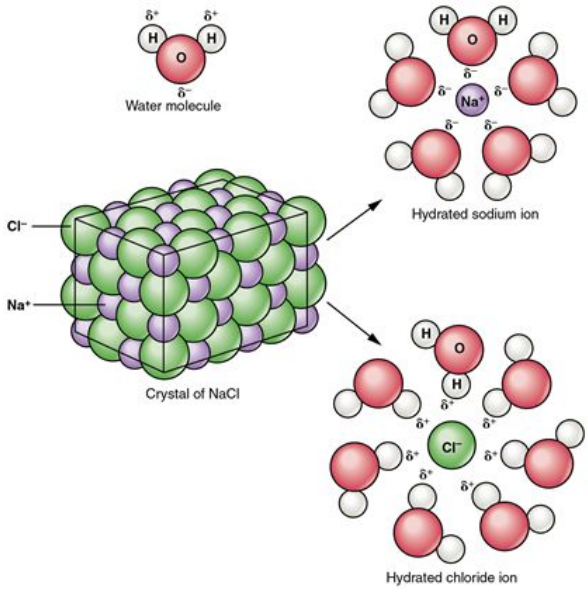
Water as a Solvent

Water is made up of hydrogen ion and hydroxyl ions. It is dipolar in nature thus it attracts both positively and negatively charged ions towards it.
It is a universal and a very important solvent in all living organisms.
70% of the human body weight is water.
Ions can dissolve in water present in the blood and can be transported to various parts of the body.
Water molecules are charged, with the oxygen atom being slightly negative and the hydrogen atoms being slightly positive.
These opposite charges attract to each other, forming hydrogen bonds than bind water molecules loosely together.

Charged or polar molecules such as salts, sugars, amino acids dissolve readily in water and so are called hydrophilic ("water loving").
Uncharged or nonpolar molecules such as lipids do not dissolve so well in water and are called hydrophobic ("water hating").

Hydrogen bonds are formed between an atom (usually hydrogen) with a slight positive charge (denoted d+) and another atom (usually oxygen or nitrogen) with a slight negative charge (denoted d−).

Because hydrogen bonds are weak they can break and form spontaneously at the temperatures found in living cells without needing enzymes.



When table salt (NaCl) is mixed in water, spheres of hydration are formed around the ions.
Image Source: cnx.org

Water Can Resist Changes in Temperature

- Hydrogen bonds between water molecules can absorb a lot of energy.
- This means that water has a high specific heat capacity - it takes a lot of energy to heat it up.
- Water has a specific heat capacity of 4.2 J g^{-1} $°C^{-1}$, which means that it takes 4.2 joules of energy to heat 1g of water by 1°C.
- This unusually high heat capacity means that water does not change temperature very easily.
- The constant temperature is useful for living organisms because it means water doesn't experience rapid temperature changes.
- Water is a good habitat as the temperature underwater is likely to be more stable than on land.
- Water inside organisms is also fairly stable - which helps them to maintain a constant internal body temperature.

Strong cohesion between water molecules

- Cohesion is the tendency of molecules within a substance to "stick together".
- Water molecules are very cohesive because they are polar hydrogen bonds.
- A strong cohesion helps water to flow, which is useful for transporting substances - for example the xylem (tube-like transport cells) in plants relies on water being pulled up.
- Cohesion also gives the water a high surface tension, allowing small organisms like pond skaters and other insects to "walk" on the surface of a pond.

Density and freezing properties

- Water is unusual because its solid form is less dense than its liquid form. Below 4°C the density of water starts to decrease.
- Ice floats on water and insulates the water below it, reducing the chances of large bodies of water completely freezing and increasing the chances of life.
- Changes in density of water with temperature set up ocean currents, which circulate nutrients.

Photosynthesis

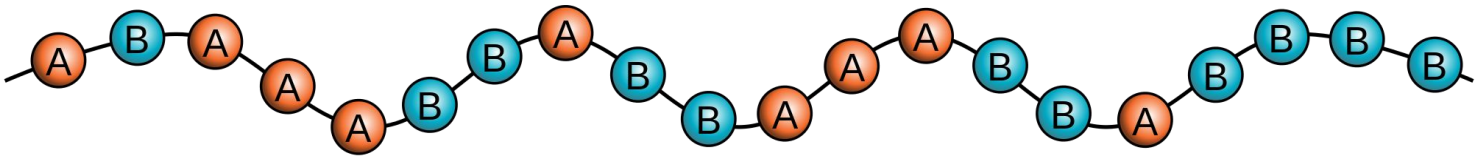
- Water is used in photosynthesis, so it is responsible for the production of glucose. This in turn is used in the synthesis of many chemicals.

What are monomers?

Monomers are small, identical or similar molecules, that can be joined together to make larger molecules **called polymers**.

What are polymers?

Polymers are large molecules which are formed by joining many identical or very similar monomers together.



A polymer with monomer units A and B
Image Source: Wikipedia

Monomers: Key monomers to learn

Nucleic acids, amino acids, α&β glucose, fructose, fatty acids and glycerol are all examples of monomers. *Isomers* are molecules with the same molecular formula but different molecular arrangement.

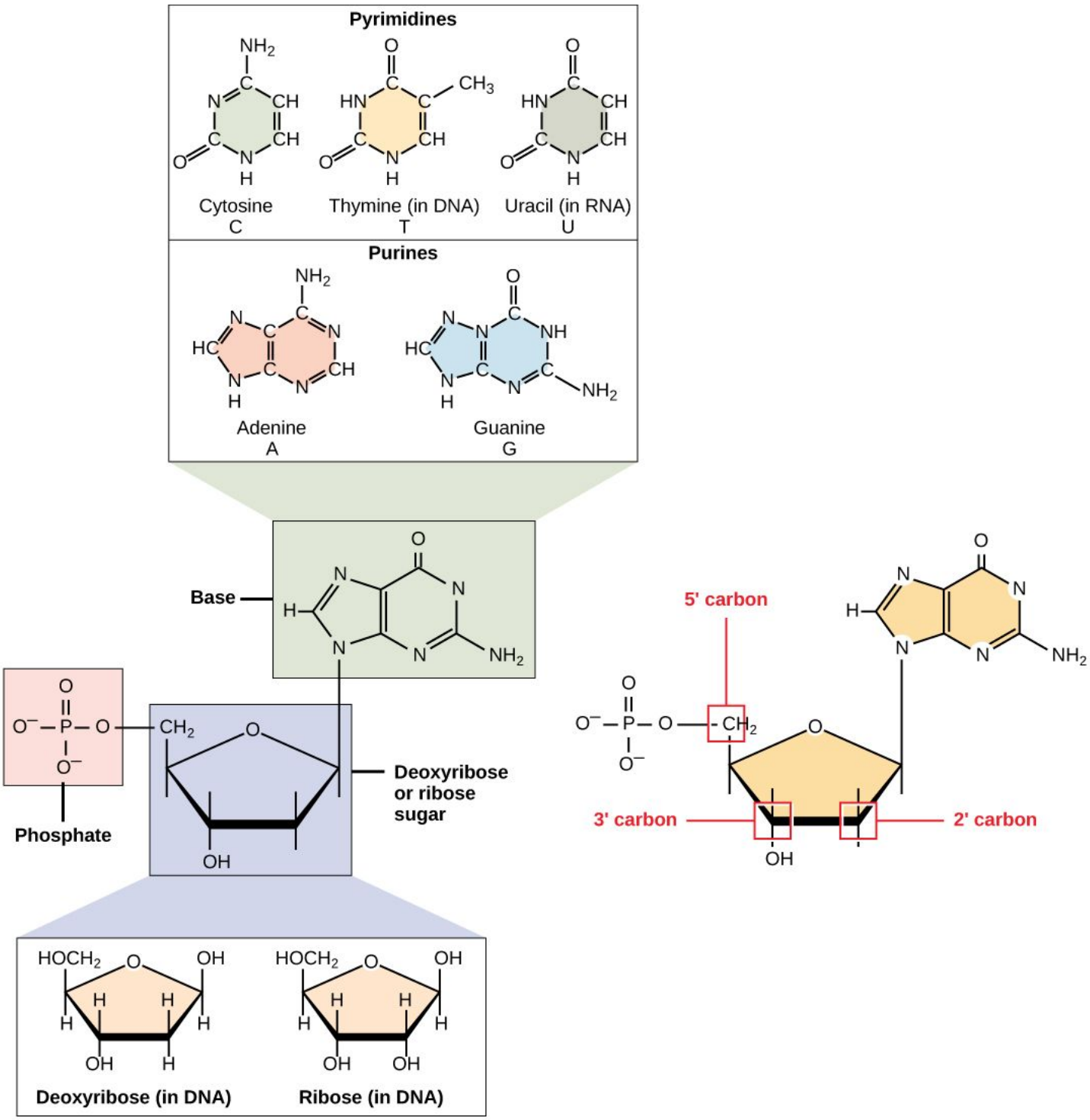
DNA and RNA nucleotides

A nucleotide is made up of three components:

1. A nitrogenous base
2. A pentose sugar
3. One or more phosphate groups

Two types of pentose sugar are found in nucleotides: Deoxyribose (found in DNA) and ribose (found in RNA). Deoxyribose is similar in structure to ribose but it has an H instead of an OH at the 2' positions.

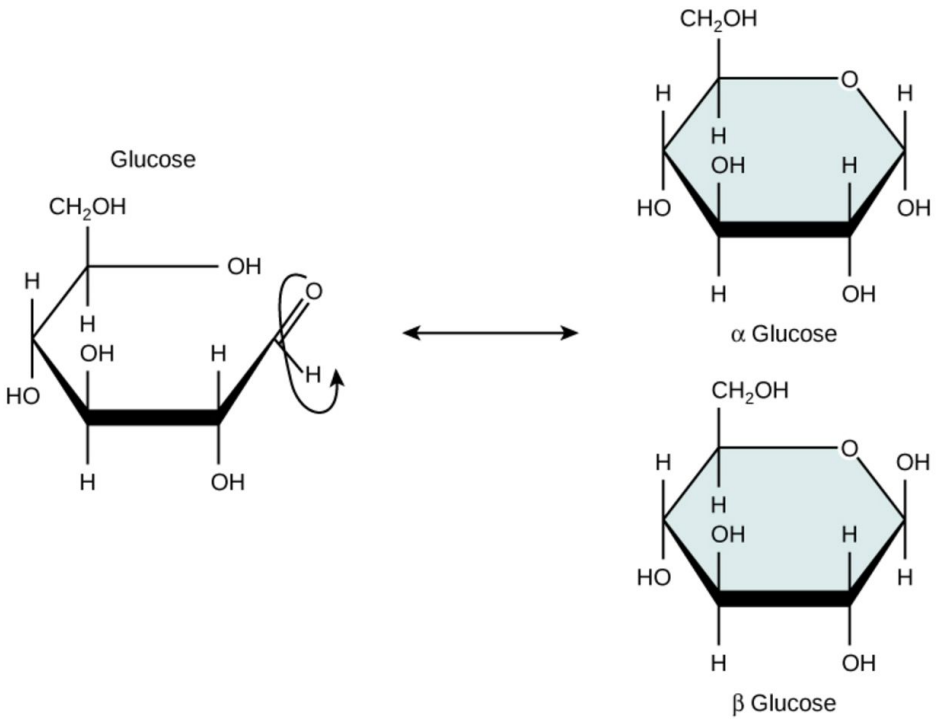
Nucleotide (DNA and RNA) monomers



Nucleotide (DNA and RNA) monomers
Image Source: Wikipedia

Glucose

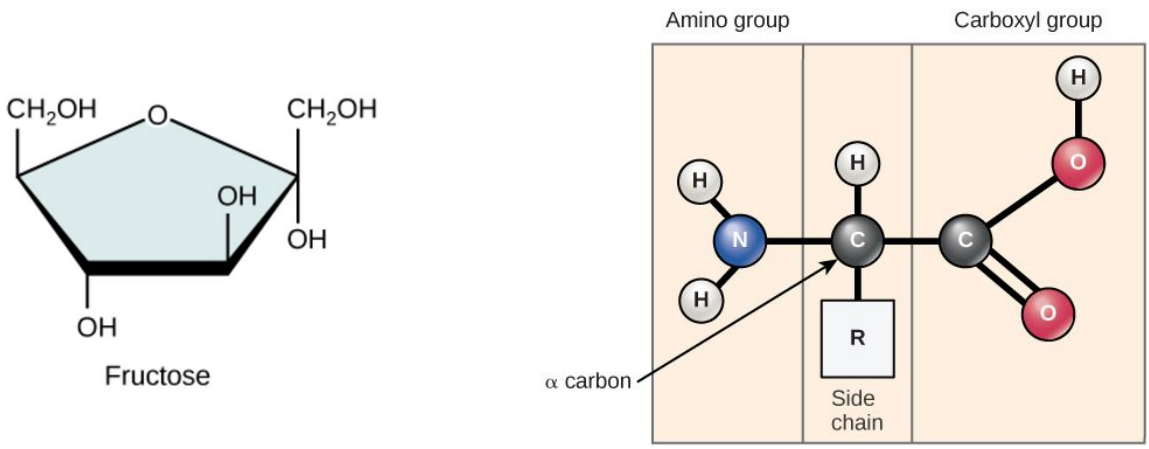
Glucose is a hexose sugar (a monosaccharide) which has six carbon atoms in each molecule. The two types of glucose are alpha (α) and beta (β). They are isomers, which means they have the same molecular formula, but the atoms are connected in a different way.



The two types of glucose have the functional group reversed, as shown in the diagrams on the right
Image Source: cnx.org

Other important monomers

Below are examples of fructose and amino acids - two important monomers.

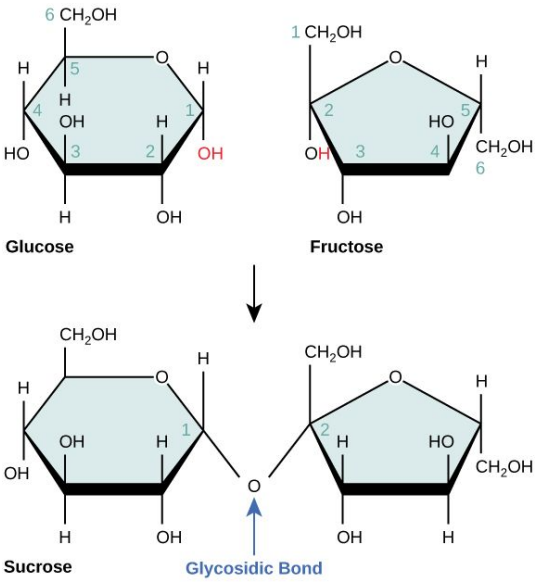


Structures of fructose (left) and a functional unit of amino acid (right)
Image Source: cnx.org

Polymers: Key polymers to learn

The three main polymers you need to know:
Carbohydrates: monomers are joined by glycosidic bonds.
Proteins: monomers are joined by peptide bonds.
Lipids: monomers are joined by ester bonds.

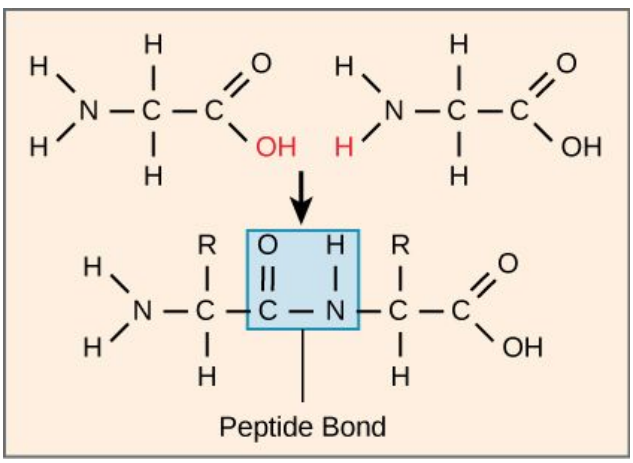
Glycosidic bond



Glycosidic bond in sucrose
Image Source: cnx.org

Peptide bond

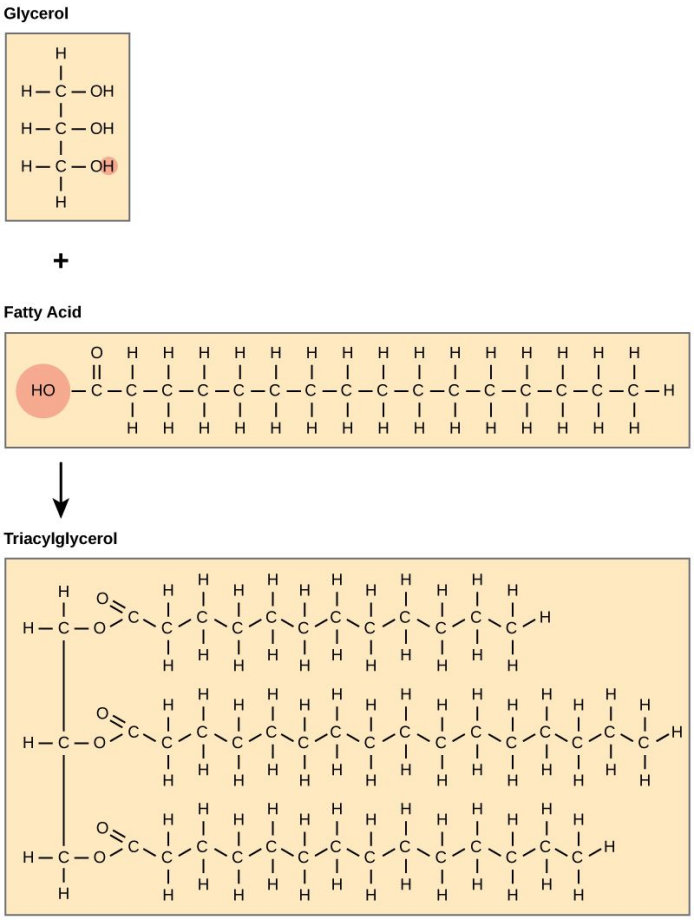
Peptide bond formation is a dehydration synthesis reaction. The carboxyl group of one amino acid is linked to the amino group of the incoming amino acid. In the process, a molecule of water is released.



Structure of peptide bond
Image Source: cnx.org

Ester bond

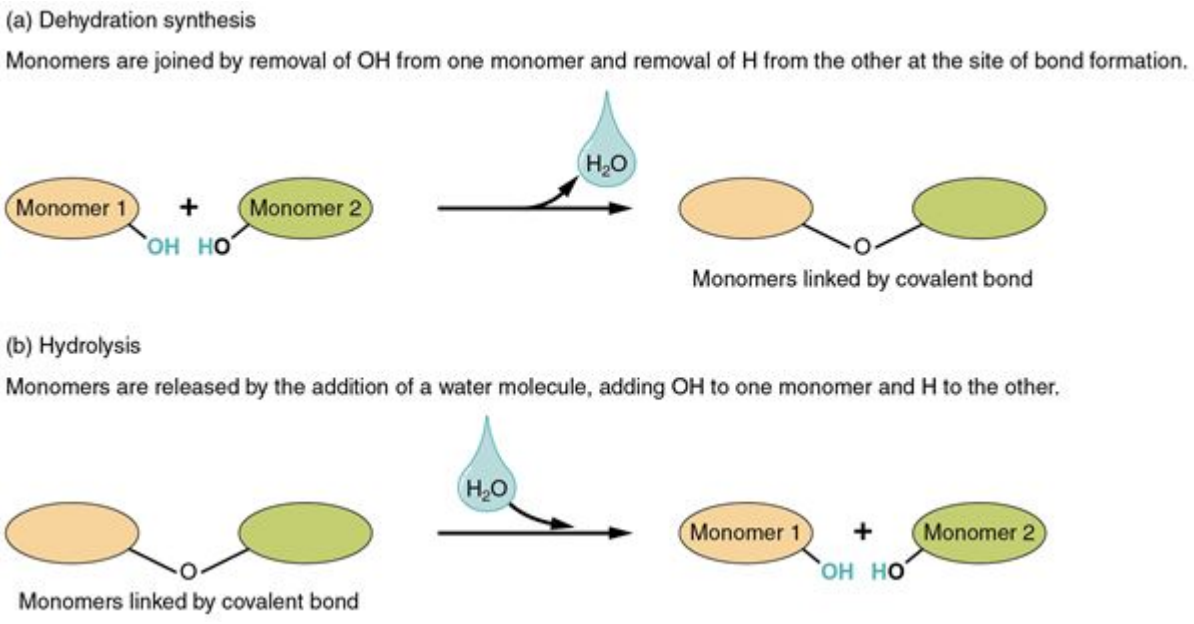
Triacylglycerol is formed with an ester bond by the joining of three fatty acids to a glycerol backbone in a dehydration reaction. Three molecules of water are released in the process.



Formation of ester bond
Image Source: cnx.org

Types of reactions in biological molecules

Two most common types are: (a) Dehydration (condensation), (b) Hydrolysis.



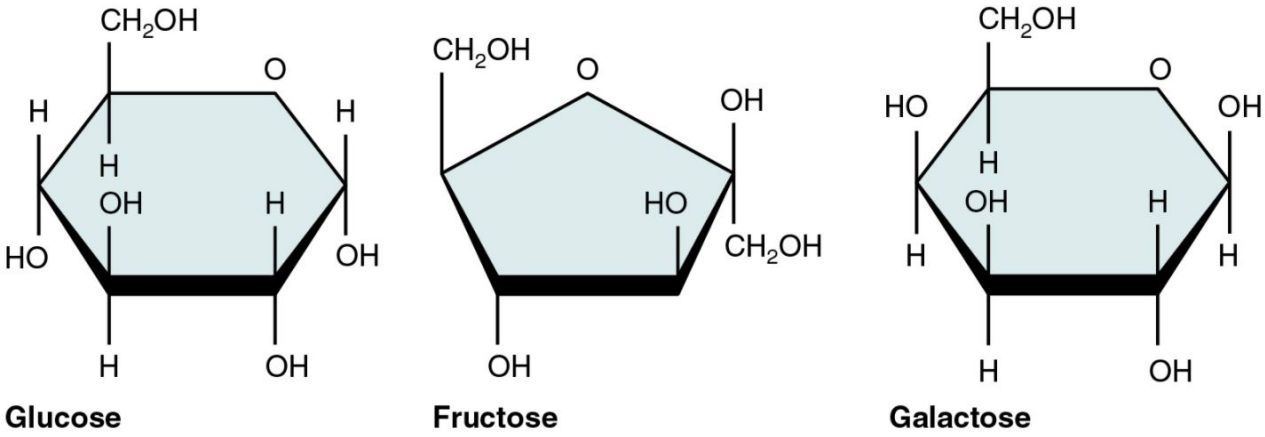
Monosaccharides and Disaccharides

Carbohydrates only contain the elements carbon, hydrogen and oxygen. They provide energy to the body, particularly through glucose - a simple sugar.

Carbohydrates have the formula $(CH_2O)_n$ where n is the number of carbons in the molecule.

Monosaccharides

You need to know the structure of the three main monosaccharides: glucose, fructose, and galactose.



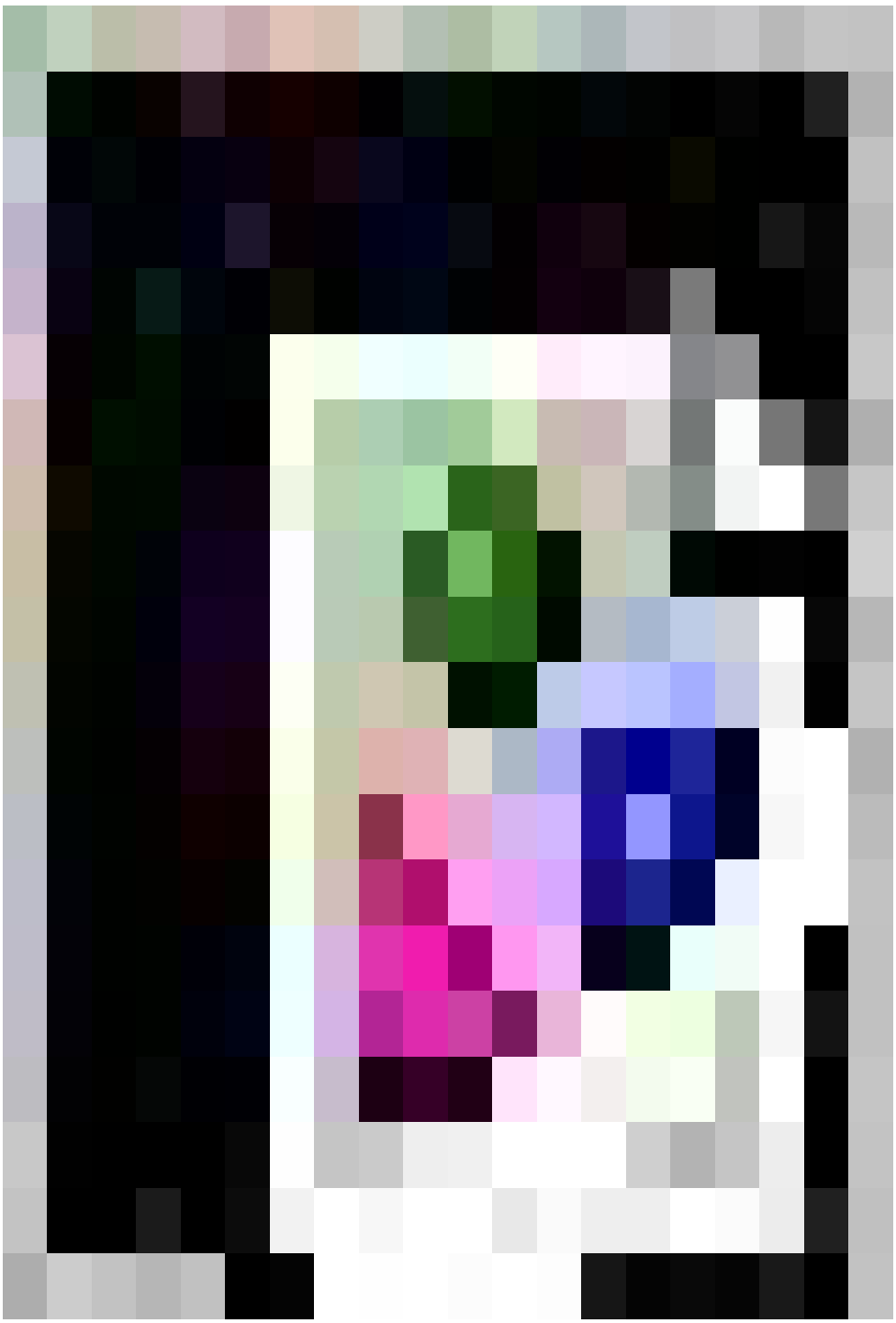
Structures of some monosaccharides
Image Source: cnx.org

Disaccharides

Disaccharides are formed when two monosaccharides are joined together by a glycosidic bond. This is a condensation reaction, which involves the removal of a molecule of water (H_2O).

Glucose molecules join together to form the disaccharide maltose. Because this bond is between carbon 1 of one molecule and carbon 4 of the other molecule, it is called a 1-4 glycosidic bond. Bonds between other carbon atoms are possible, leading to different shapes, and branched chains.
Three common disaccharides: Sucrose (glucose + fructose), lactose (glucose + galactose), maltose (glucose + glucose).

Disaccharides



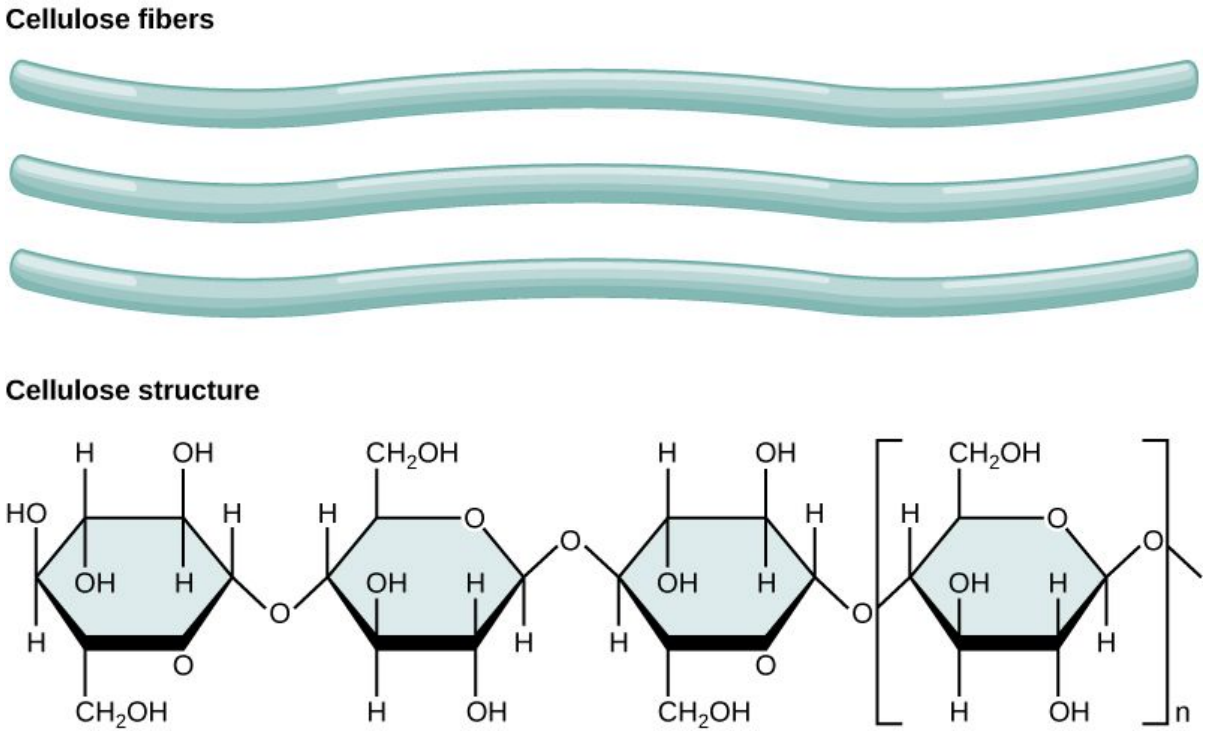
Structures of some disaccharides
Image Source: cnx.org

Polysaccharides: Cellulose, starch and glycogen

A long chain of monosaccharides that are linked by glycosidic bonds are known as a polysaccharide - *poly* meaning many.

Cellulose structure

- Cellulose is a polymer of β glucose - it's made of **long, unbranched** chains of **beta-glucose**.
- Condensation reactions link carbon atom 1 to carbon atom 4 on the next β glucose.
- The glucose subunits in the chain are oriented alternately upwards and downwards.
- The consequence of this is that the cellulose molecule is a **straight chain** rather than curved.



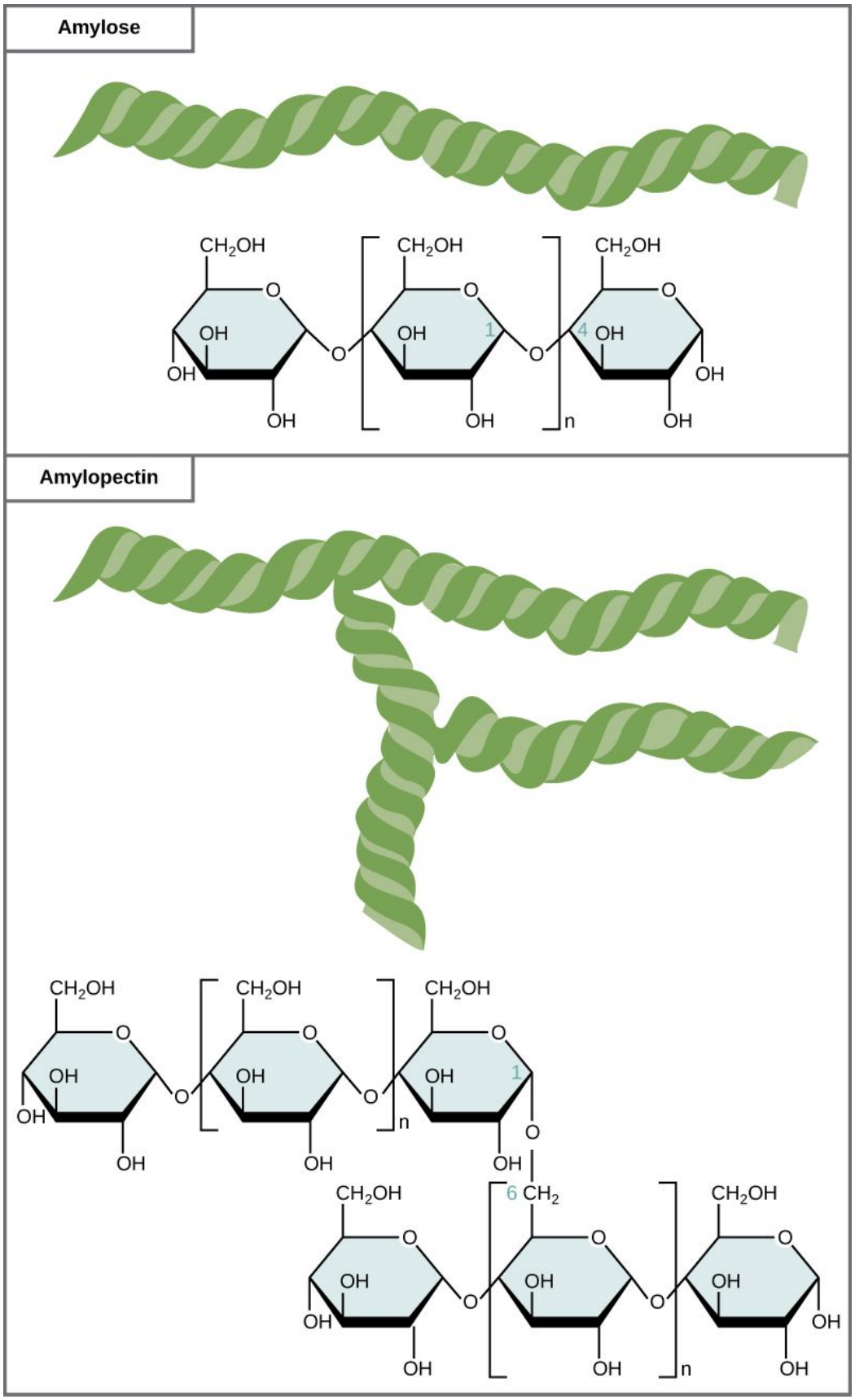
Structure of cellulose
Image Source: cnx.org

- The cellulose chains are linked together by hydrogen bonds to form strong fibres called cellulose microfibrils.
- Because of those fibres, the tensile strength of cellulose provides structural support for the cells (e.g. the cell walls) and prevents plant cells from bursting - even under very high (water) pressure.

Starch structure

- Cells get their energy from **glucose**. Plants store excess glucose as **starch**.
- When a plant needs more glucose for energy, it will **break down** that starch to release the glucose.
- Starch is a mixture of two polysaccharides of alpha-glucose - **amylose** and **amylopectin**.
- Amylose is a long, **unbranched** chain of α-glucose. The angle of the glycosidic bonds give it a **coiled**, cylinder-like structure. This compact structure is good for storage because more glucose can be **stored in a small space**.
- Amylopectin is a long, **branched** chain of α-glucose. It has **side branches** which allow the enzymes that break the molecule down to access glycosidic bonds easily - meaning the glucose can be **released quickly**.
- Since starch is insoluble, water cannot enter the cells by **osmosis** - which makes it very good for **storage**.
- Condensation reactions link carbon atom 1 to carbon atom 4 on the next α-glucose.
- All the glucose molecules in starch can be orientated in the same way.
- The consequence of this is that the starch molecule is curved, rather than straight and the size of the molecule is not fixed.

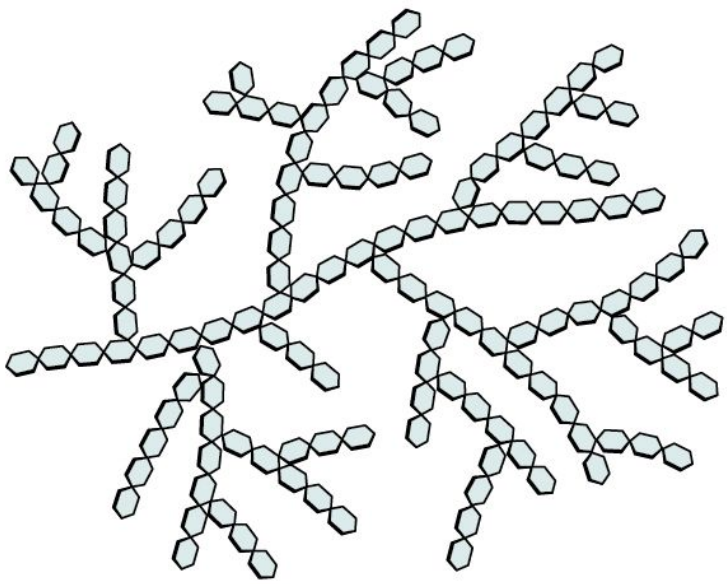
Amylose and Amylopectin



Structure of amylose and amylopectin
Image Source: cnx.org

Glycogen structure

- Glycogen is the main energy storage material in animals and is made by some fungi too.
- It's a polymer made from repeating glucose sub-units and varies in size, typically consisting of 30,000 units.
- Animals store excess glucose as glycogen - another polysaccharide of alpha-glucose. In humans, it is stored in the liver and some muscles.
- It's used in cells where large stores of dissolved glucose would cause osmotic problems.
- Glycogen has a similar structure to amylopectin but it has a lot more side branches. These extra branches mean the stored glucose can be released very quickly - something that is very important in animals.
- As a result of the branches, glycogen is very compact which makes it very good for energy storage.
- Glycogen does not affect the osmotic balance of cells - i.e. cause too much water to enter them.



Structure of glycogen
Image Source: cnx.org

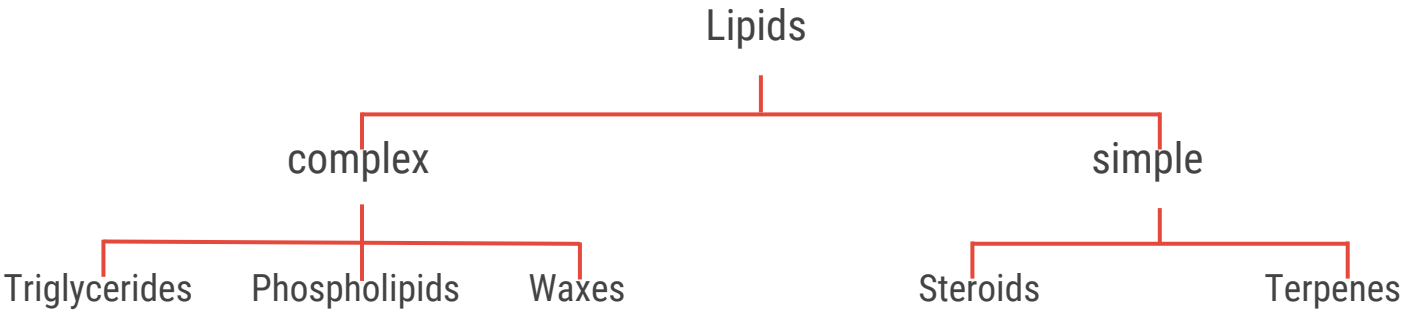
Lipids

Lipids are a mixed group of hydrophobic compounds composed of the elements carbon, hydrogen and oxygen. The main complex lipid types are triglycerides and phospholipids.

Hydrophobic: water fearing, non-polar molecules, lipid soluble.

Hydrophilic: water loving, polar molecules, water soluble (not soluble in lipids).

Lipid Classification



Triglyceride Formation

Triglycerides are commonly called fats or oils. Triglycerides are insoluble in water.

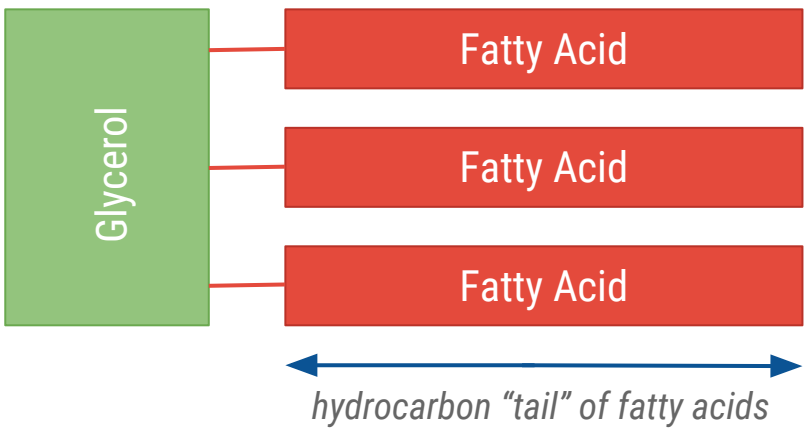
They are made of one molecule of glycerol and 3 fatty acids attached to it.

Glycerol is a small, 3-carbon molecule with three alcohol groups. ($C_3H_8O_3$).

Glycerol is common to all triglycerides and so the properties of the fats depend on the nature of the fatty acids.

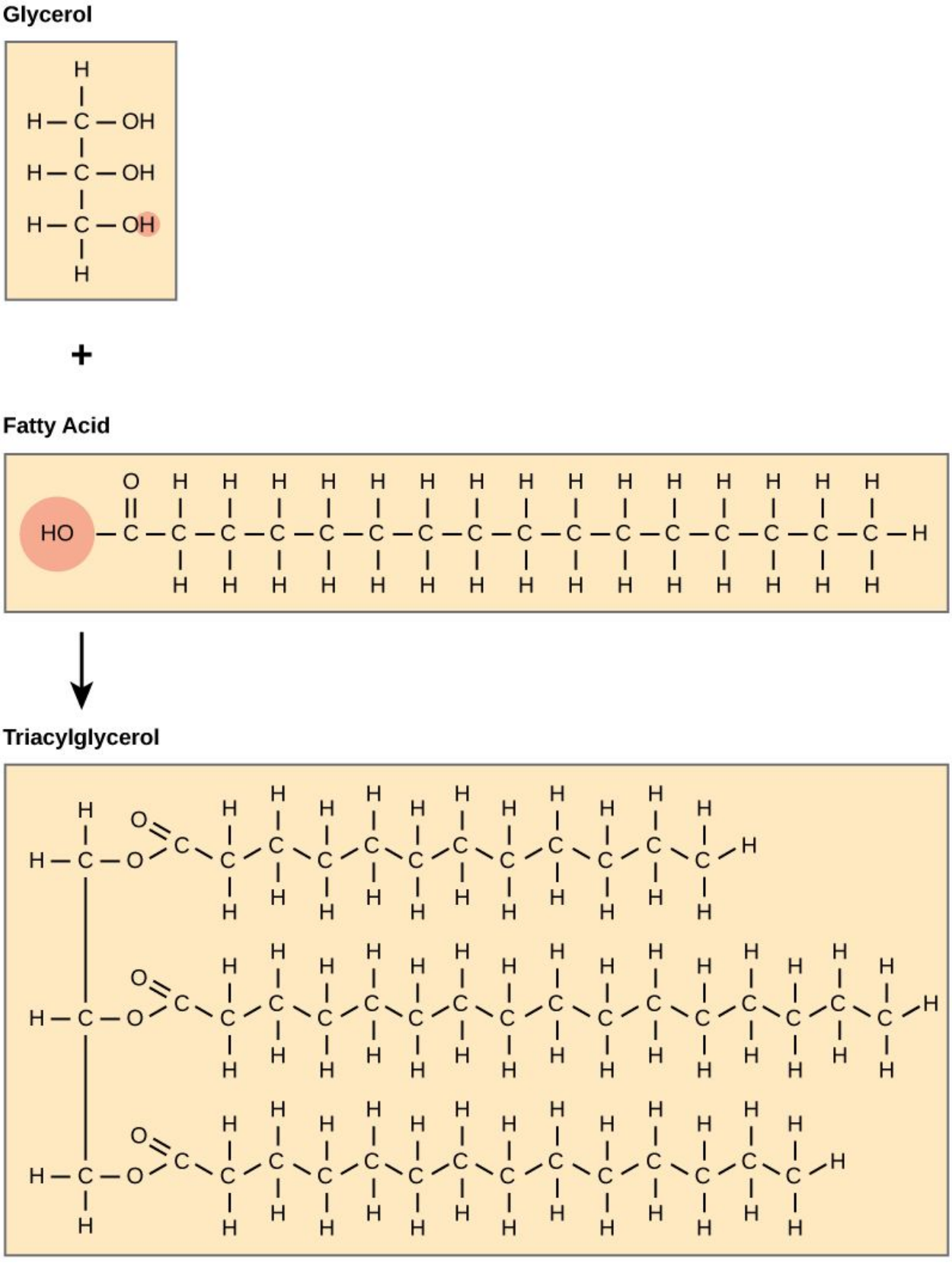
They are used for storage, insulation and protection in fatty tissue (or adipose tissue) found under the skin (subcutaneous) or surrounding organs.

They yield more energy per unit mass than other compounds so are good for energy storage.



Formation of Triacylglycerols (triglycerides)

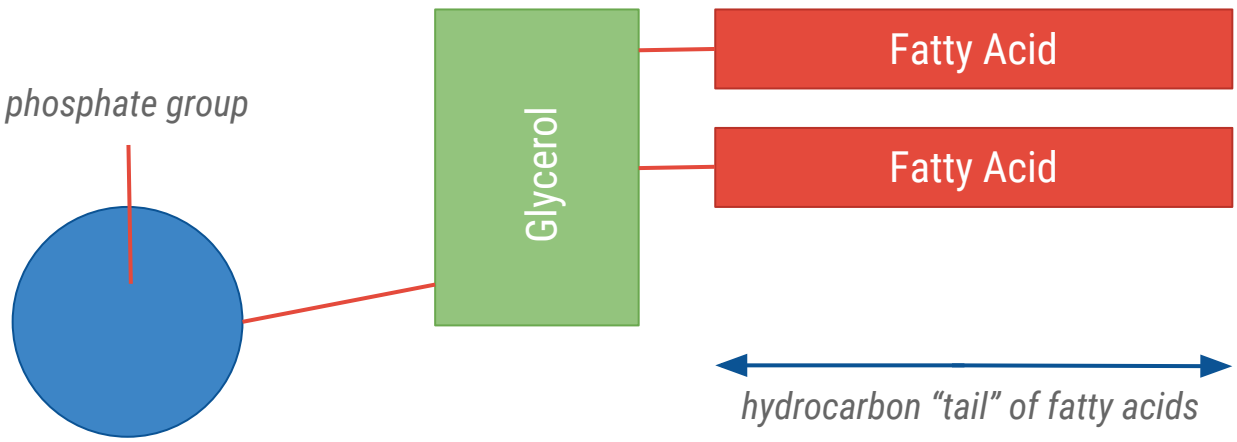
Fats are also called triacylglycerols or triglycerides because of their chemical structure.



Formation of Triglycerides (triglycerol)
Image Source: cnx.org

Phospholipids

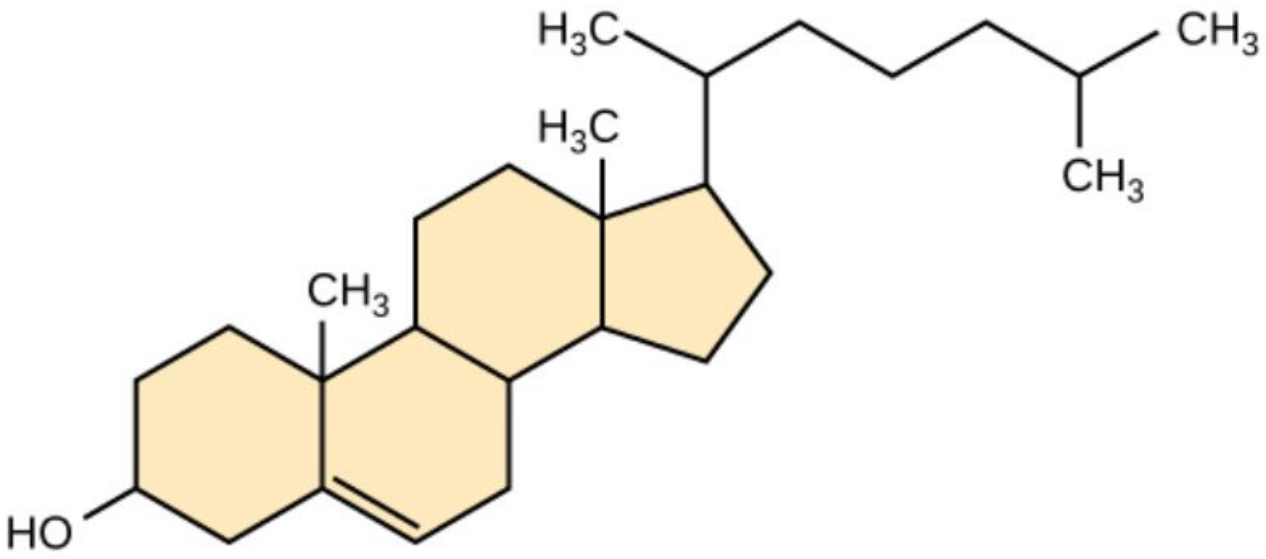
- Similar to triglycerides, but a phosphate group in place of one fatty acid chain.
- The phosphate head is hydrophilic and polar (water soluble).
- Two non-polar hydrophobic "tails" (the fatty acid chains).
- They are the main components of the cell membranes also known as plasma membranes.
- When mixed with water, phospholipids form droplet spheres with the hydrophilic heads facing the water and the hydrophobic tails facing each other. This is called a micelle.
- Alternatively, they may form a double-layered phospholipid bilayer. This traps a compartment of water in the middle separated from the external water by the hydrophobic sphere.
- This naturally-occurring structure is called a liposome, and is similar to a membrane surrounding a cell.



Formation of Phospholipid
Image Source: cnx.org

Steroids

- Steroids have a fused ring structure.
- They are also hydrophobic and insoluble in water. Hence these are clubbed with lipids.
- All steroids have 4 linked carbon rings and several of them, like cholesterol, have a short tail.
- Many steroids like cholesterol also have the OH functional group, which puts them in the alcohol classification.
- Cholesterol is the most common steroid.
- Cholesterol is mainly synthesized in the liver and is the precursor to many steroid hormones such as testosterone and estradiol.
- It is also the precursor to vitamin D.
- Cholesterol is also the precursor of bile salts, which help in the emulsification of fats and their subsequent absorption by cells.
- It is necessary for proper functioning of the body. It is involved in cell-to-cell communication.

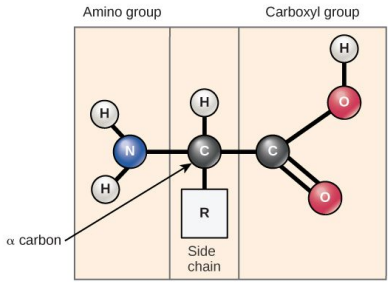


Structure of cholesterol
Image Source: cnx.org

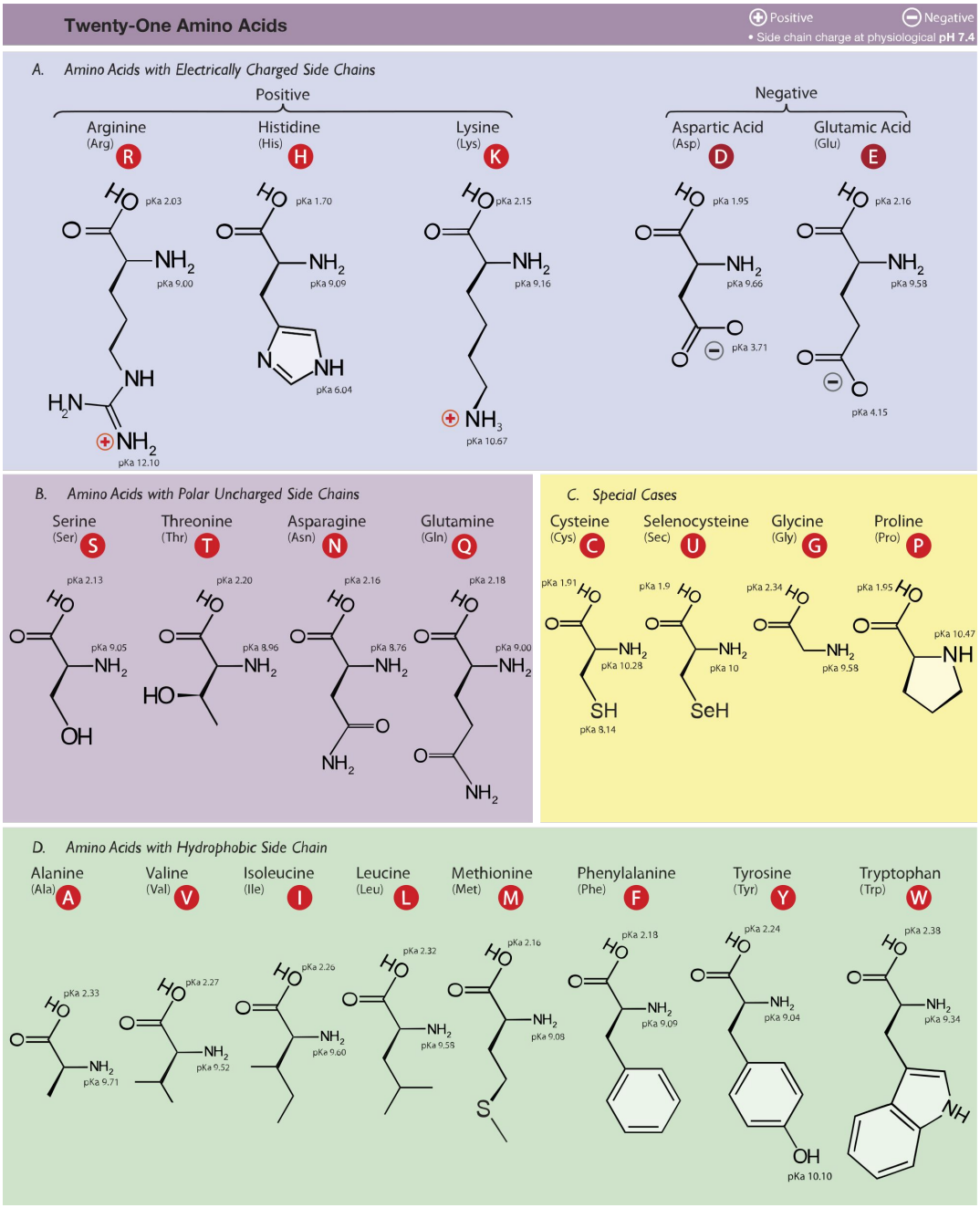
Amino acids and proteins

Amino Acid General Structure

Amino acids have a central asymmetric carbon to which an amino group, a carboxyl group, a hydrogen atom, and a side chain (R group) are attached.



Structure of amino acid
Image Source: cnx.org



Proteins

Proteins are one of the most abundant organic molecules in living systems. Amino acids are the monomers that make up proteins.

Amino acids are so-called because they have both amino groups and acid groups, which have opposite charges.

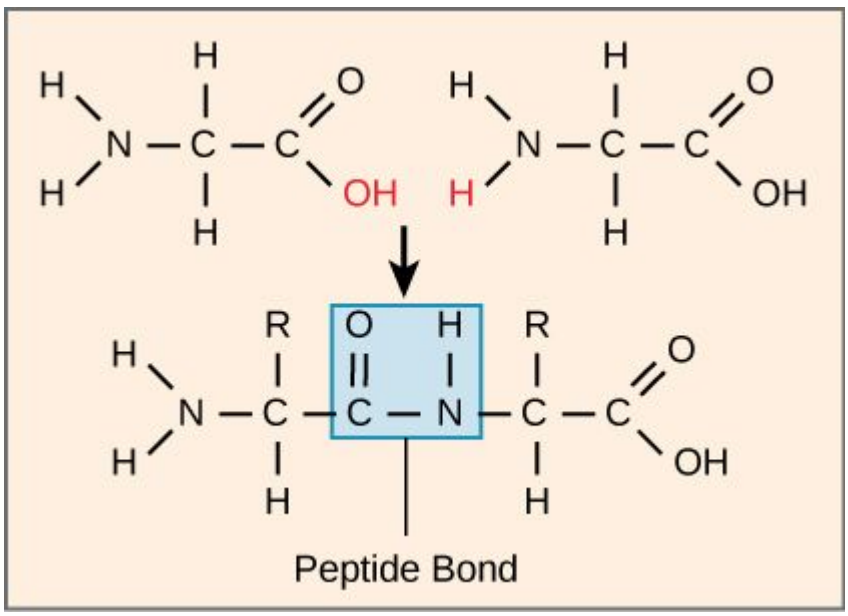
All living things share a bank of only 21 amino acids. Each amino acid has different properties, and this in turn means that proteins can have a wide range of properties.

Peptide formation between two amino acids

Polypeptides are formed via condensation reactions between the amine group of one amino acid and the carboxyl group of another.

A molecule of water is released during reaction. The bonds formed between amino acids are called peptide bonds. The reverse reaction happens during digestion.

The sequence of amino acids in a polypeptide is determined by the sequence of the genetic code on mRNA being translated in the ribosomes.



Peptide formation between two amino acids
Image Source: cnx.org

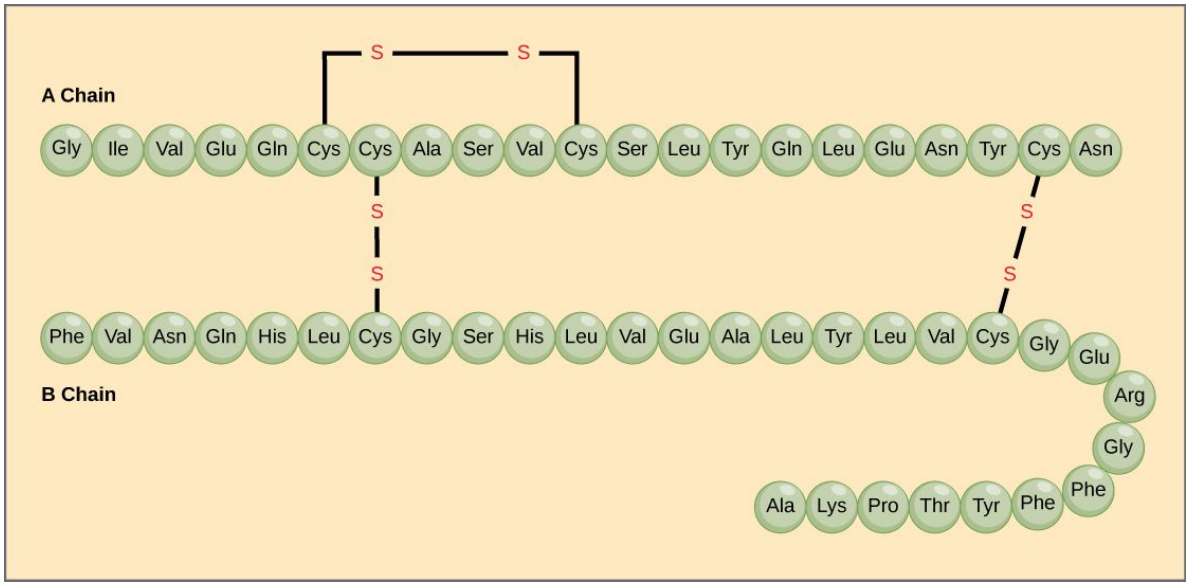
Formation of Proteins

The shape of a protein is critical to its function. An enzyme, for example, can bind to a specific substrate at site known as the active site. If that active site is altered because of changes to the protein structure, the enzyme may be unable to bind to the substrate.

To understand how the protein gets its final shape, you need to know the four levels of protein structure: Primary, secondary, tertiary and quaternary.

Primary Structure

The unique sequence of amino acids in the polypeptide chain is its primary structure.



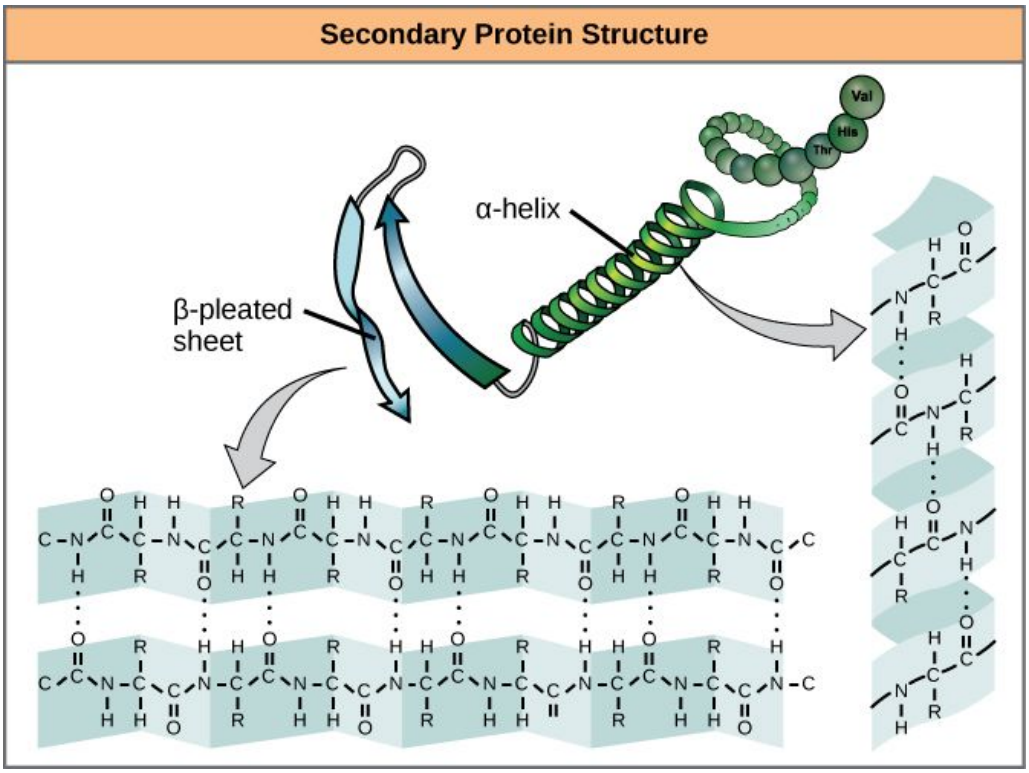
Primary structure of proteins
Image Source: cnx.org

Secondary Structure

This is a result of protein folding, and consists of a few basic motifs that are found in all proteins. The secondary structure is held together by hydrogen bonds between the carboxyl groups and the amino groups in the polypeptide backbone. The two most common secondary structure motifs are the α-helix and the β-pleated sheet, but it does not have to be either of these

The α-helix is held together by hydrogen bonds running parallel with the long helical axis. There are so many hydrogen bonds that this is a very stable and strong structure.

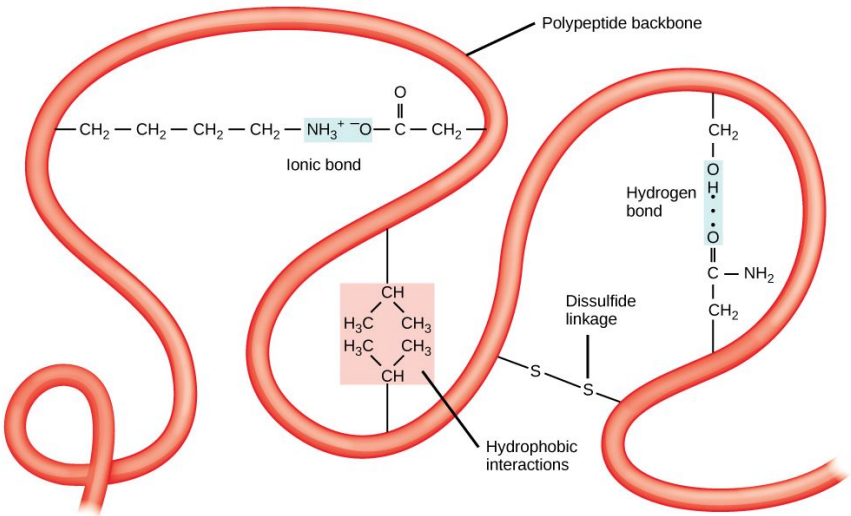
Formation of Proteins



Secondary structure of proteins
Image Source: cnx.org

Tertiary Structure

Further folding of the secondary structure. The tertiary structure is held together by bonds between the R groups of the amino acids in the protein, and so depends on what the sequence of amino acids is. There are three kinds of bonds involved:
Hydrogen bonds, which are weak.
Ionic bonds between R-groups with positive or negative charges, which are quite strong.
Sulphur bridges - covalent S-S bonds between two cysteine amino acids, which are strong.



Tertiary structure of proteins
Image Source: cnx.org

Formation of Proteins

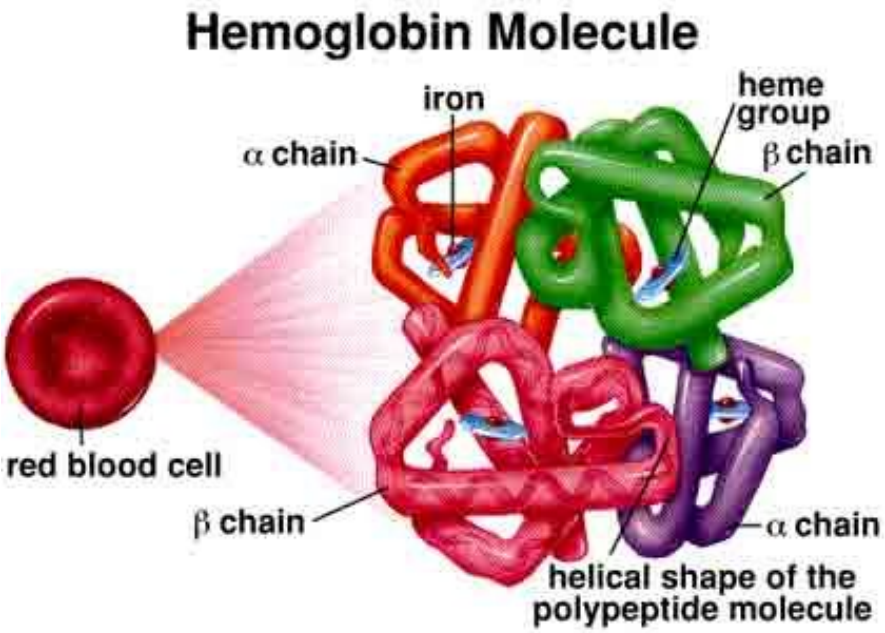
Quaternary Structure

In nature, some proteins are formed from several polypeptides, also known as subunits, and the interaction of these subunits forms the quaternary structure. Examples of this association of several polypeptides include:

Collagen - a fibrous protein of three polypeptides (trimetric) that are supercoiled like a rope.

Hemoglobin - a globular protein with four polypeptide chains (tetrameric).

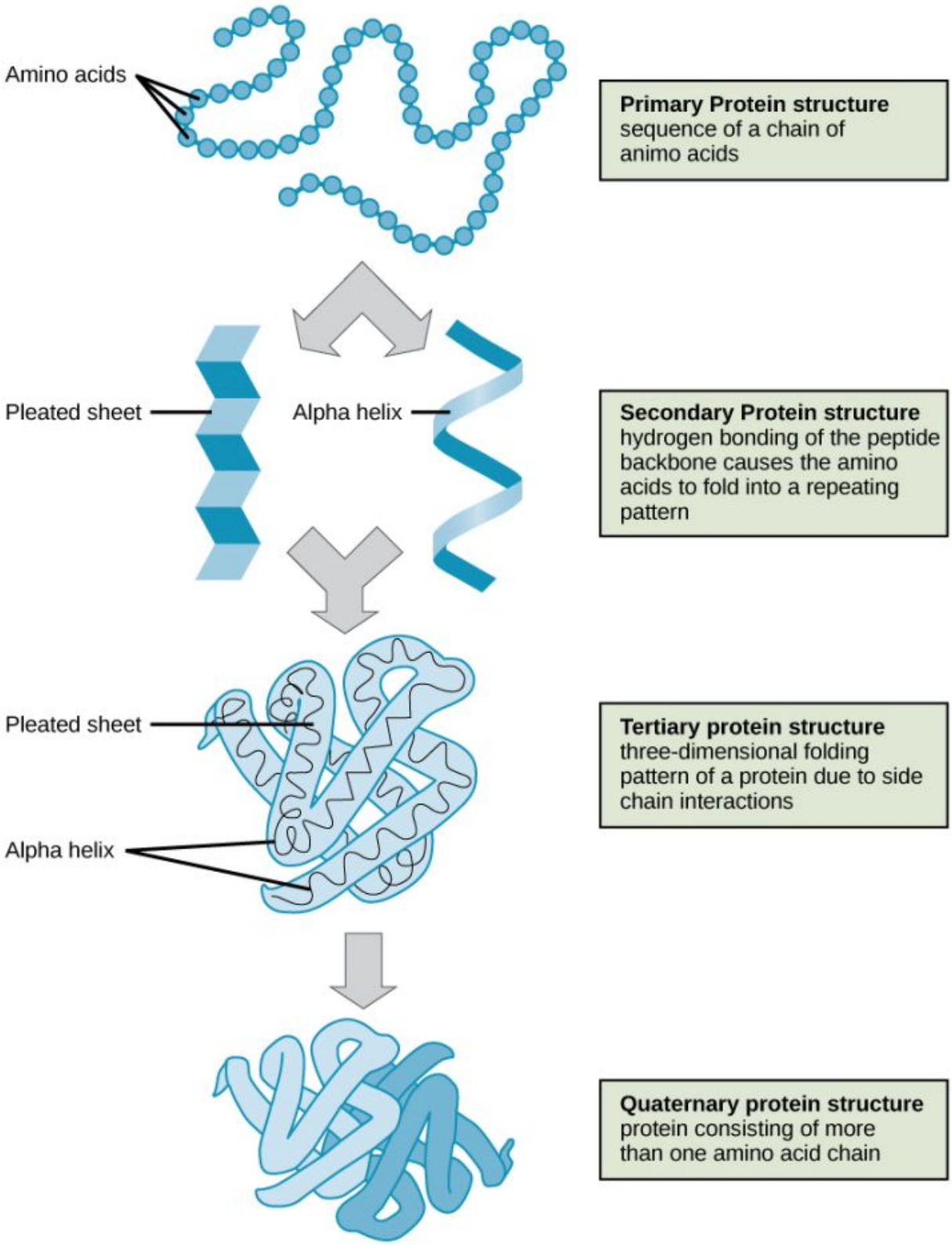
Insulin - two polypeptide chains (dimeric) held together by disulfide bond.



Quaternary structure of proteins
Image Source: cnx.org

Formation of Proteins

The four levels of protein structure summarised



The four levels of protein structure
Image Source: cnx.org

Inorganic ions in biological processes

An inorganic ion is one which does not contain carbon (with a few exceptions)
There are inorganic ions in cells and each has a specific role.

Hydrogen (H^+)
- pH is calculated based on the concentration of hydrogen ions (H^+). The more H^+ present the lower the pH level and the more acidic the environment is.
- Enzyme-controlled reactions are affected by pH.

Iron (Fe^{2+})
- Haemoglobin is a large protein that carries oxygen around the body in red blood cells
- It's made of four polypeptide chains - each with an iron ion in the centre.
- The iron ion is a key component that binds to the oxygen in haemoglobin.
- When oxygen is bound, the Fe^{2+} ion temporarily becomes an Fe^{3+} ion until oxygen is released.

Calcium (Ca^{2+})
- As calcium phosphate it provides a hard, strong, insoluble matrix in bones and teeth in mammals.
- Required for blood clotting in mammals.
- As calcium pectate in plant cell walls, it forms a matrix in which cellulose fibres lie.
- Involved in the transmission of action potentials from one neuron to another in muscle contraction.

Sodium (Na^+)
- Helps glucose and amino acids cross cell membranes.
- A molecule of glucose or an amino acid can be transported into a cell across the cell-surface membrane alongside sodium ions (Na^+).
- This is known as co-transport.

Potassium (K^+)
- Constantly pumped into cells by active transport in exchange for sodium ions.
- Important in the transmission of nerve impulses.

Magnesium (Mg^{2+})
- Forms part of the chlorophyll molecules in plants.
- Important for the absorption of light energy to drive the reactions of photosynthesis

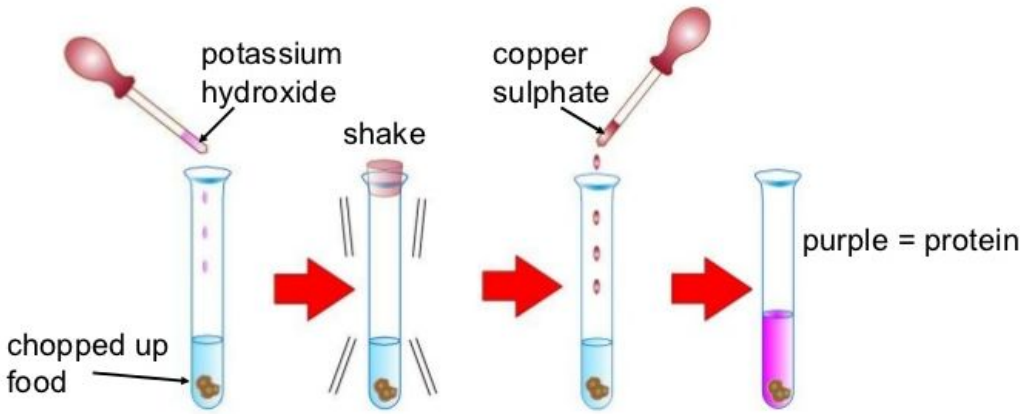
Chloride (Cl^-).
- Moved out of cells lining the lungs and digestive system to provide a low water. potential outside the cell causing water to follow so mucus is not thick and stiff (failure of this mechanism causes cystic fibrosis).

Nitrate (NO_3^-)
- Used to produce amino acids and proteins from the carbohydrates made in plants by photosynthesis.

Phosphate (PO_4^{3-})
- Used in production of nucleic acids (DNA and RNA) production of ATP (energy currency of cells) and phospholipids, which are essential in cell membranes.

Chemical tests to detect biological molecules

Biuret test for proteins



Biuret test for proteins
Image Source: cnx.org

The test solution needs to be alkaline, so you first need to add sodium or potassium hydroxide solution.
Next you add a few drops of copper sulfate solution.
If protein is present, the solution turns purple. If there is no protein, it will remain blue.

Benedict's test for reducing and non-reducing sugars

Sugar is a general term used to describe monosaccharides and disaccharides. All sugars can be classified as either reducing or non-reducing.

Testing for reducing sugars

Reducing sugars include all monosaccharides (e.g. glucose) and some disaccharides (e.g. maltose and lactose).
Add Benedict's reagent (which is blue) to a sample and heat it in a water bath that boils the mixture for 5 minutes.
If the test is positive, it will form a coloured precipitate (solid particles suspended in the solution).
The higher the concentration of reducing sugar, the further the change of colour goes. You can use this to compare the amount of reducing sugars in different solutions.
A more accurate way, though, is to filter the solution and weigh the precipitate.

The colour of the precipitate changes from:

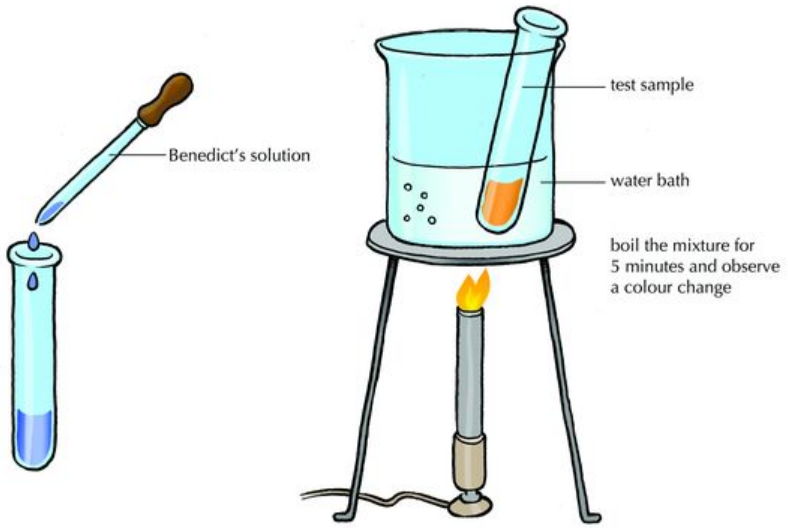
None → Trace → Low → Moderate → High

Chemical tests to detect biological molecules

Benedict's test for reducing and non-reducing sugars

Sugar is a general term used to describe monosaccharides and disaccharides. All sugars can be classified as either reducing or non-reducing.

Testing for reducing sugars



Benedict's test
Image Source: cnx.org

Testing for non-reducing sugars

If the result of reducing sugars is negative, there may still be non-reducing sugar present in the solution.
To test for a non-reducing sugar (like sucrose) you first need to break them down into monosaccharides.
Take a fresh sample of the solution and either heat it with diluted hydrochloric acid or hydrolyze using enzymes.
You can then neutralise it with sodium hydrogencarbonate.
Once you have done these, you can continue the Benedict's test in the same way you would for a reducing sugar.
If the test is positive, it will form the coloured precipitate just the same as for a reducing sugar. If the test is negative, the solution stays blue and it means the solution does not contain any sugar (either reducing or non-reducing).

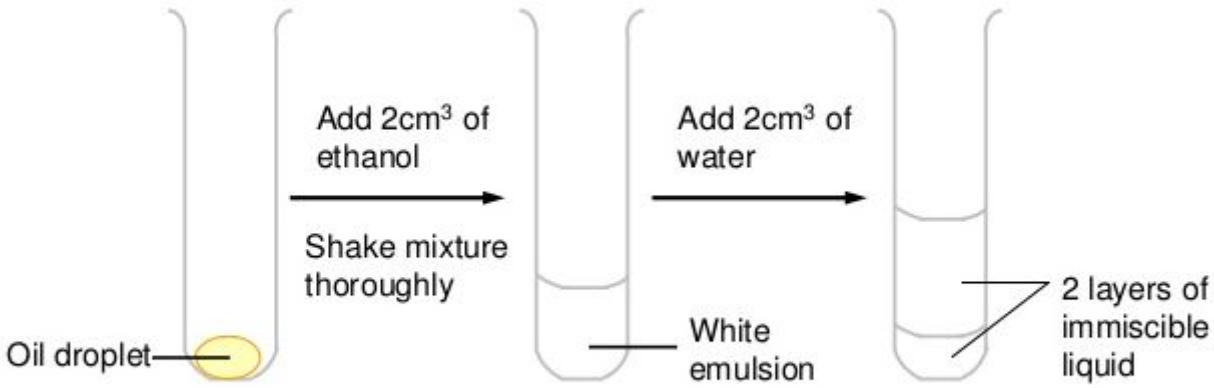
Chemical tests to detect biological molecules

Iodine Test for Starch

Whenever you want to experiment on the digestion of starch and need to know if there is any left, you need the iodine test.
The test is very simple. Just add iodine dissolved in potassium iodide solution to the test sample.
If there is starch present, the sample changes from brown-orange to a dark blue-black colour.

"Iodine is dissolved in potassium iodide" and not just iodine alone.

Emulsion Test for Lipids



Emulsion Test for Lipids
Image Source: cnx.org

Chromatography in separation of biological molecules

Thin Layer Chromatography

A common and effective use of TLC in in the isolation of amino acids. Amino acids have different R groups, which means they will have different solubilities in different solvents and can be separated by thin layer paper chromatography.

- A container is filled to a depth of 2cm with a suitable chromatography solvent. The container is sealed and left to allow the solvent to saturate the atmosphere. This is important because solvent must not evaporate from the chromatogram as it is running.
- A strip of chromatography paper has a pencil line drawn on it slightly more than 2cm from the bottom and small crosses are drawn on it to indicate where to add the amino acids. It is important not to touch the paper as there are amino acids on your fingers.
- A spot of amino acid is applied to a cross on the line using a capillary tube; the spot must not exceed 2mm in diameter.
- The spot is dried with a hairdryer and another is applied over the top. This is done until a small but concentrated dot of amino acid has been built up on the cross.
  The nature of the amino acid is indicated by writing in pencil below the spot.
  This is repeated until each amino acid dot has been added.
- The strip of chromatography paper is placed in the container, making sure that the solvent doesn't splash above the line.
- The solvent is drawn up the paper by capillary action but does not evaporate from it due to the saturated air around it. The amino acid was be carried by the solvent and each will travel at different speeds.
- When the solvent has nearly reached the top the paper is removed and a line is drawn to show where the solvent has reached, this is the solvent front.
- The chromatogram is dried in a fume cupboard and then sprayed with ninhydrin spray. When the chromatogram dries, the amino acids will appear as purple spots at different distances up the chromatogram.
- The distance each spot has traveled from the center of the cross to the center of the spot is measured, call this D1.
- The distance the solvent front has traveled from the cross is measured, call this S.
- The Rf value can then be calculated as R_f = D1/ S
- Each amino acid will have a unique Rf value and as the R_f values for all amino acids are known they can be identified knowing the R_f value.

Module 2: Foundations in biology

SPECIFICATION

2.1.3 Nucleotides and nucleic acids

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) The structure of a nucleotide as the monomer from which nucleic acids are made.

(b) The synthesis and breakdown of polynucleotides by the formation and breakage of phosphodiester bonds.

(c) The structure of ADP and ATP as phosphorylated nucleotides.

(d) i) The structure of DNA (deoxyribonucleic acid).

ii) Practical investigations into the purification of DNA by precipitation.

(e) Semi-conservative DNA replication.

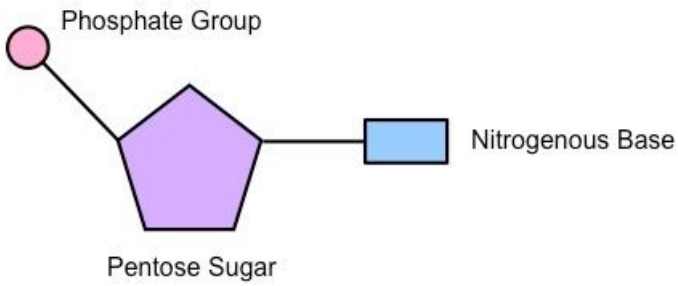
(f) The nature of the genetic code.

(g) Transcription and translation of genes resulting in the synthesis of polypeptides.

The structure of a nucleotide

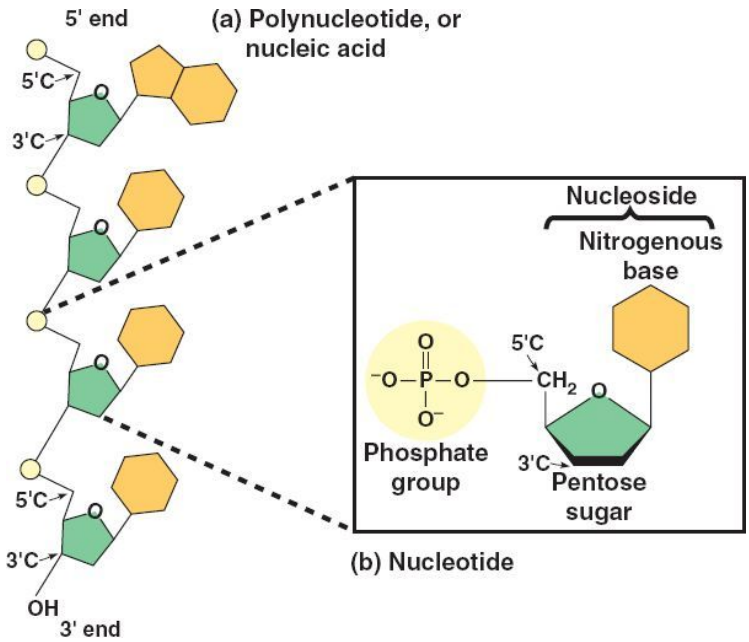
The basic structure of a nucleotide is made up of three components:

1. A pentose sugar (made with 5 carbon atoms)
2. A nitrogenous base
3. A phosphate group



The basic structure of a nucleotide
Image Source: cnx.org

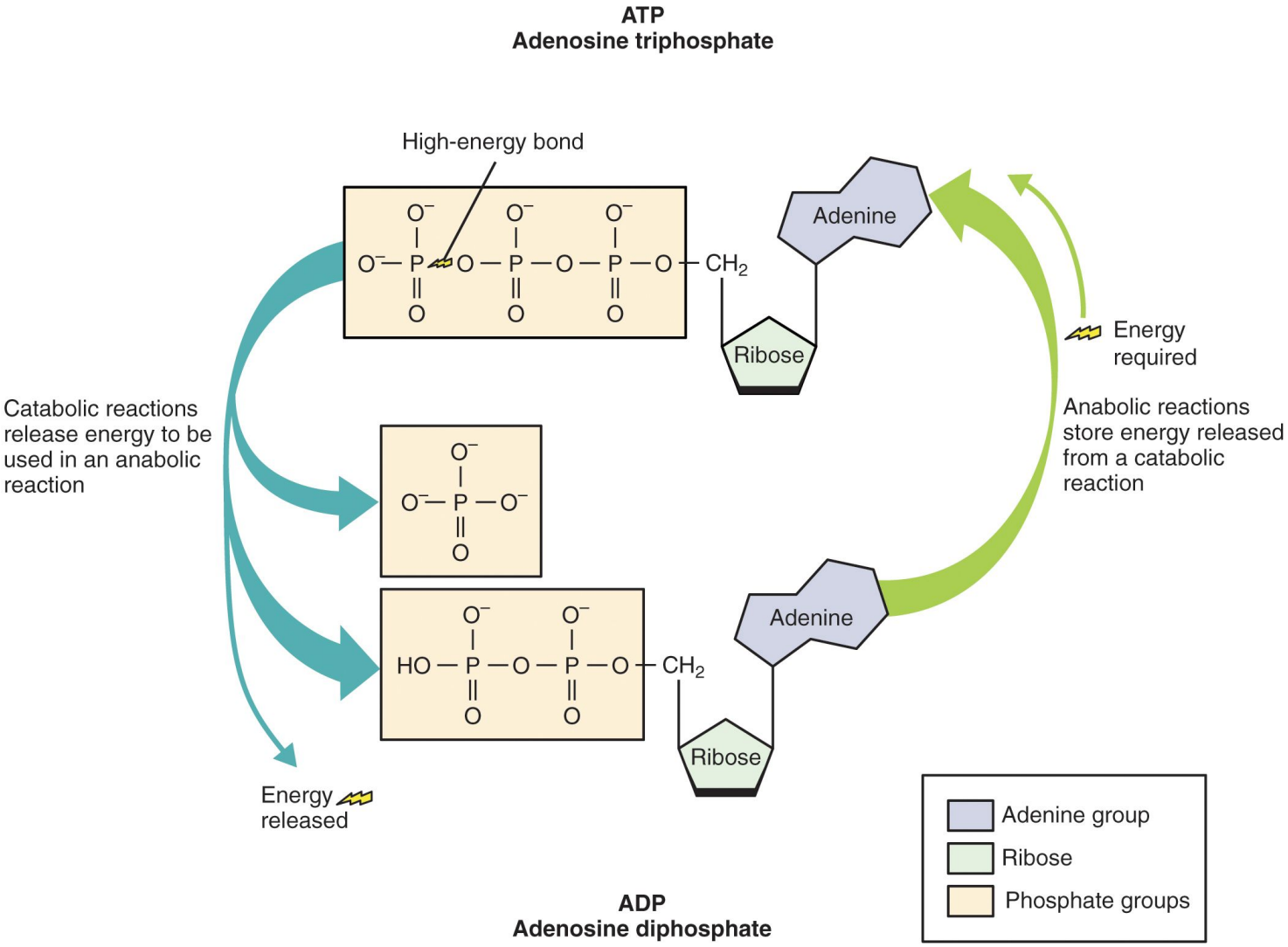
Nucleotides Join Together and Form Polynucleotides



Formation of a polynucleotide
Image Source: cnx.org

A polynucleotide is a polymer of nucleotides. Both DNA and RNA form polynucleotides.
Nucleotides join via a condensation reaction between the phosphate group of one nucleotide and the sugar of another.
This forms a strong, covalent, phosphodiester bond (which consists of the phosphate group and two ester bonds).
This chain of sugars and phosphates is known as the sugar-phosphate backbone.
When a polynucleotide is formed, the 5' phosphate of the incoming nucleotide attaches to the 3' hydroxyl group at the end of the growing chain.

The structure of ATP and ADP

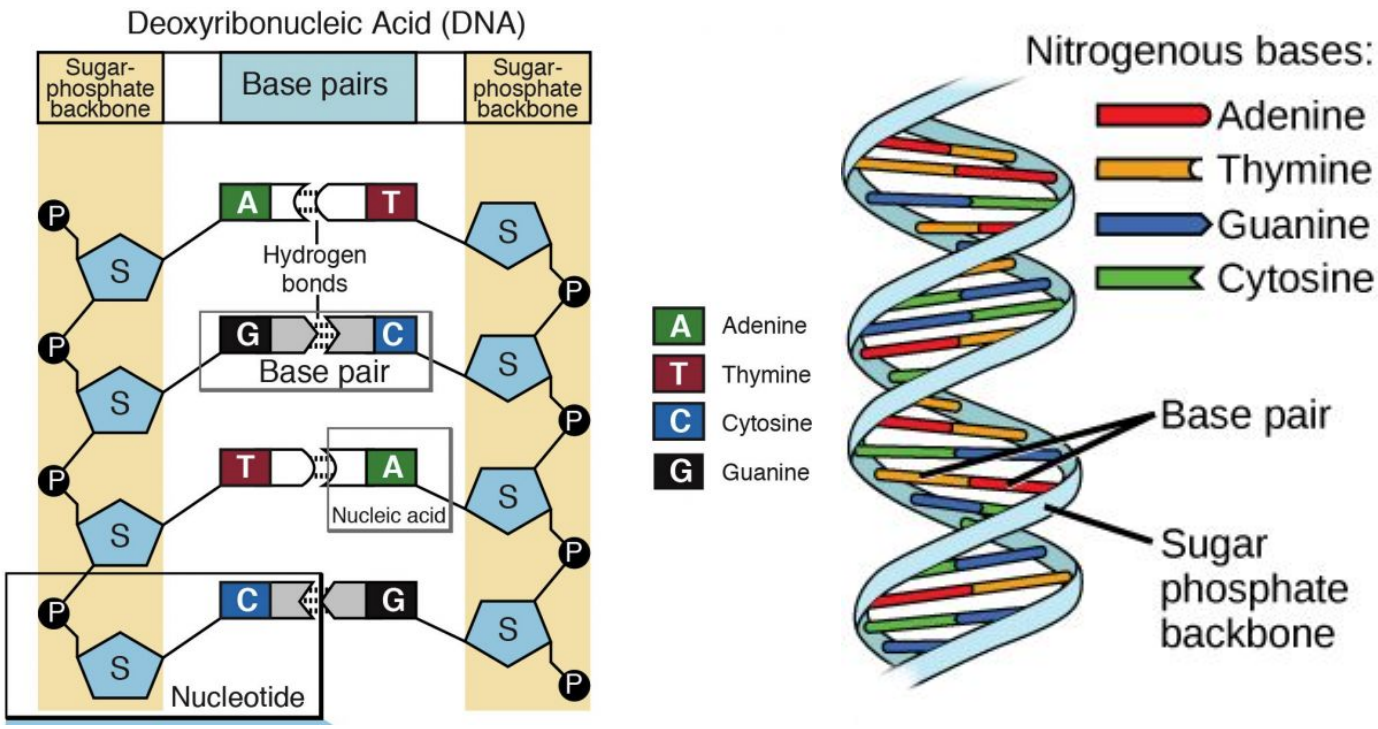


ADP and ATP as phosphorylated nucleotides
Image Source: cnx.org

The structure of DNA

DNA is made of **two polynucleotide** chains in a **double-helix** structure.

- **Two DNA** polynucleotide strands join together by **hydrogen bonding** between bases.
- Each base can only join with one particular partner - this is called **complementary base pairing.**
- **Adenine** always pairs with **thymine (A-T)** and **cytosine** always pairs with **guanine (C-G)**, which means there are always **equal amounts** of adenine and thymine in a DNA molecule and equal amounts of cytosine and guanine.
- **Two** hydrogen bonds form between **A and T** and **three** hydrogen bonds form between **C and G.**
- This complementary base pairing ensures that **replication of DNA is accurate** (it will also ensure accurate transcription of the genes for protein synthesis).
- Individually these H bonds are **weak** and allow the DNA to be separated so replication and transcription can occur.
- Two **antiparallel** polynucleotide strands **twist** in opposite directions to form the **DNA double-helix.**
- This double strand is important as each strand can act as a t**emplate in replication**, a semi conservative process, meaning that the DNA is copied accurately.



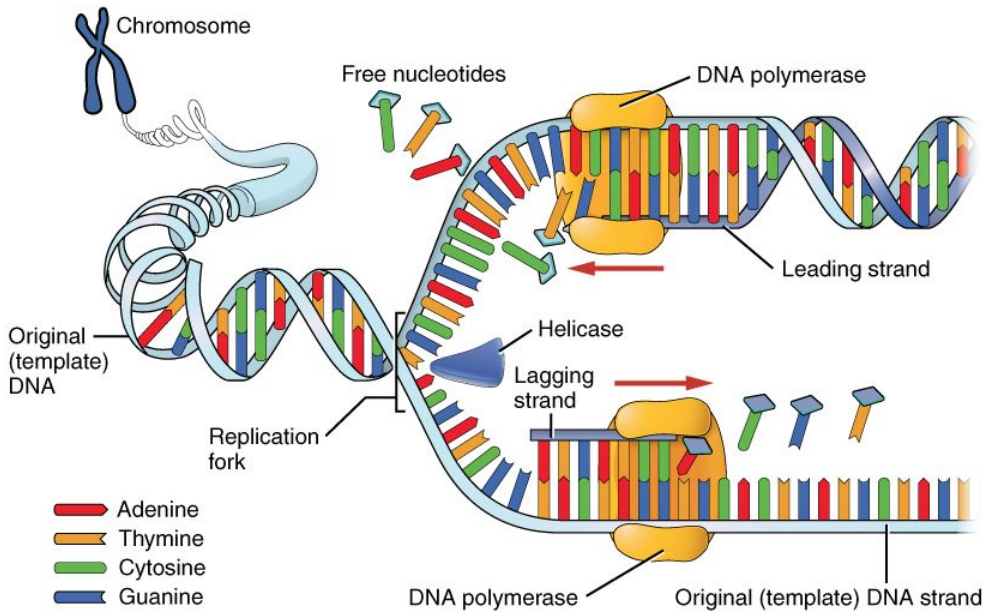
The structure of DNA
Image Source: cnx.org

DNA Replication

DNA has an incredible ability to **replicate** itself. It copies itself **before** cell division, so that each new cell has the **full amount of DNA**.
This is called **semi-conservative replication** because **half** the strands in each new DNA molecule come from the **original** DNA molecule. By doing this, it ensures **genetic continuity** between generations of cells (the cells produced by cell division will inherit their genes from parent cells).

The DNA replication process

1. The enzyme **DNA helicase** breaks the **hydrogen bonds** between the base pairs on the two **polynucleotide** DNA strands. This unwinds the helix to form two single strands.
2. Each **original single strand** acts as a template for the new strand. **Complementary base pairing** means that free-floating DNA nucleotides are attracted to their base pair - A with T and C with G.
3. **Condensation reactions** join the nucleotides of the new strands together using the enzyme **DNA polymerase** as the catalyst. Hydrogen bonds **form** between bases on the original and new strands.
4. Each new DNA molecule contains **one strand** from the **original** DNA molecule and one **new strand.**



The DNA replication process
Image Source: cnx.org

Meselson and Stahl showed that DNA is replicated using the semi-conservative method by using two isotopes of nitrogen (DNA containing nitrogen) - heavy nitrogen (^{15}N) and light nitrogen (^{14}N).

Nature of the genetic code

Due to the degenerate nature of the genetic code, not all base substitutions cause a change in the sequence of encoded amino acids.

▸The genetic code is **degenerate.**
▸It means more possible combinations of codons are present than number of amino acids (20 amino acids and 64 possible triplets or codons).

▸As a result, some amino acids are coded by more than one codon, e.g. tyrosine can be coded for by UAU or UAC.

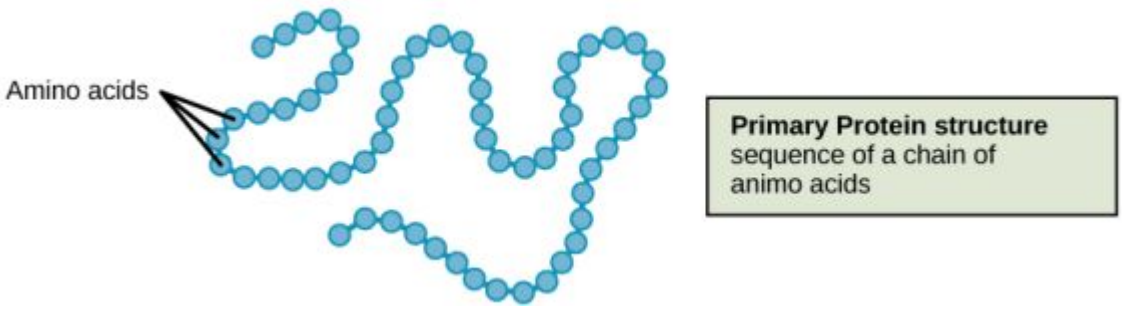
▸So, all base substitutions do not change the sequence of encoded amino acids.

First letter	Second letter: U	Second letter: C	Second letter: A	Second letter: G	Third letter
U	UUU, UUC: Phe UUA, UUG: Leu	UCU, UCC, UCA, UCG: Ser	UAU, UAC: Tyr **UAA Stop** **UAG Stop**	UGU, UGC: Cys **UGA Stop** UGG Trp	U C A G
C	CUU, CUC, CUA, CUG: Leu	CCU, CCC, CCA, CCG: Pro	CAU, CAC: His CAA, CAG: Gln	CGU, CGC, CGA, CGG: Arg	U C A G
A	AUU, AUC, AUA: Ile **AUG Met**	ACU, ACC, ACA, ACG: Thr	AAU, AAC: Asn AAA, AAG: Lys	AGU, AGC: Ser AGA, AGG: Arg	U C A G
G	GUU, GUC, GUA, GUG: Val	GCU, GCC, GCA, GCG: Ala	GAU, GAC: Asp GAA, GAG: Glu	GGU, GGC, GGA, GGG: Gly	U C A G

Genetic code for translating mRNA codons to amino acid
Image Source: cnx.org

Primary Structure of Protein

The unique sequence of amino acids in the polypeptide chain is its primary structure.



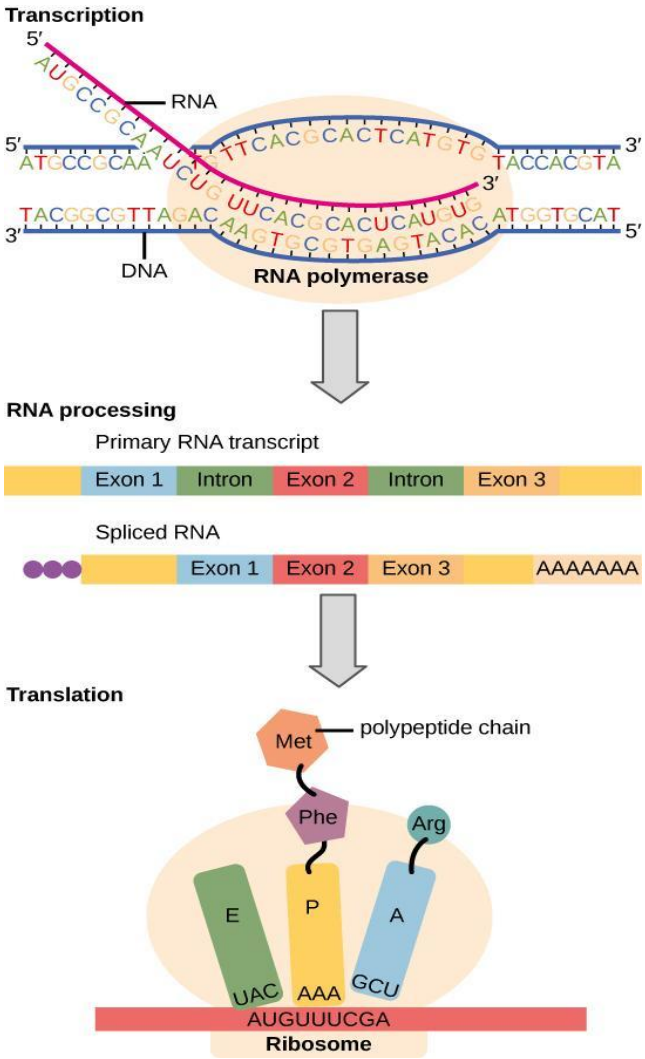
Primary protein structure
Image Source: cnx.org

Transcription and translation of genes

Gene expression is a complex series of processes in which the information coded in the gene is translated into a useful and functional product such as proteins that dictates the function of the cells. In the process of gene expression DNA is converted to RNA and then RNA is converted to protein. This is also known as central dogma of life.

Three main processes in gene expression are:

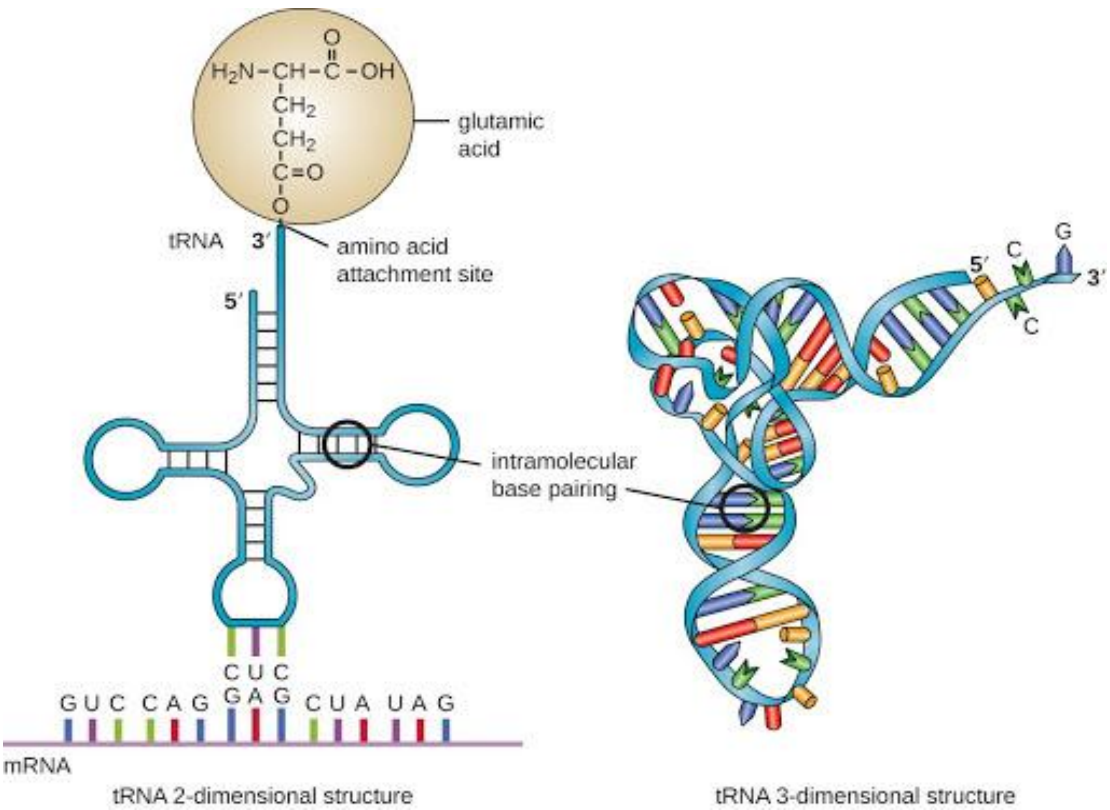
1. **Transcription** – The conversion of DNA to mRNA with the help of RNA polymerase and transcriptional factors is known as transcription.
2. **Post-transcriptional Modifications** – In this process, mRNA is modified to produce mature RNA. It involves:
   i. Splicing
   ii. Addition of a cap at 5' site
   iii. Addition of a poly A tail at 3' site
3. **Translation** – Conversion of mature RNA into protein is known as translation.



Central Dogma
Image Source: cnx.org

The structure of molecules of messenger RNA (mRNA) and of transfer RNA (tRNA).

- RNA is ribonucleic acid. It is single stranded and have uracil as base instead of thymine present in DNA.
- It is formed from ribose sugar, bases and phosphates.
- There are various types of RNA such as, mRNA, tRNA, rRNA, siRNA, snRNA and many more.
- **Messenger RNA (mRNA):** It is made during transcription from DNA. It has single polynucleotide strand.
- Three adjacent bases form a group in mRNA, which is known as codons or triplets.
- **Transfer RNA (tRNA):** It is involved in translation.
- It is also single polynucleotide stranded but bends to form cloverleaf-like structure.
- This special shape is maintained by the hydrogen bonds between specific base pairs.
- They have specific triplets made at one end by specific bases, known as anticodon, which actually recognises the codon on mRNA.
- At another end they carry amino acids binding site where it carries amino acids through ribosomes according to the codons on mRNA.

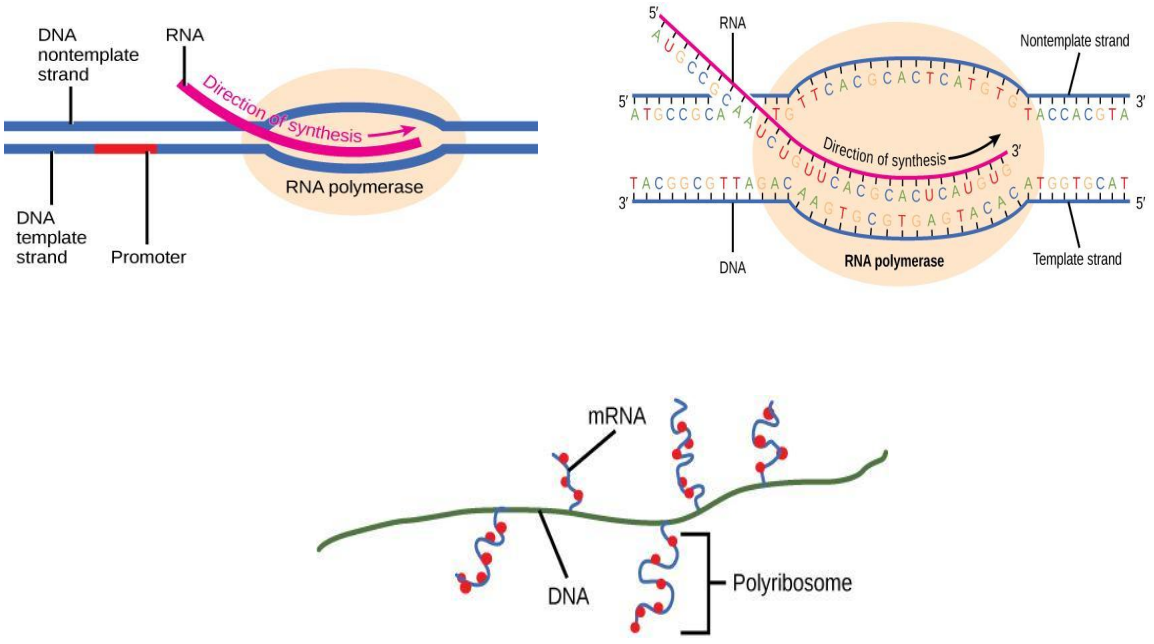


Structure of mRNA and tRNA
Image Source: OpenStax CNX

Transcription as the production of mRNA from DNA and the role of RNA polymerase in joining mRNA nucleotides.

Transcription is the first stage of protein synthesis.

1. At the initial point of a gene, **RNA polymerase** attaches to the DNA double-helix.
2. Hydrogen bonds between bases of DNA breaks to uncoil a segment of DNA thus exposing some of the bases.
3. Among the two strands of DNA, one is used as **template** for making mRNA copy.
4. Free RNA nucleotides are **arranged** beside **exposed bases of DNA** by RNA polymerase.
5. The **base pairs of DNA pairs up with free RNA nucleotides** following complementary base pairing.
6. Then these **RNA nucleotides are joined by RNA polymerase** forming RNA molecule.
7. Now RNA polymerase moves along the length of DNA to make a whole mRNA.
8. Once RNA polymerase completes its moving through DNA, it again **recoils** by forming the lost H-bonds.
9. RNA polymerase stops at a certain place in DNA called stop signal and finally detaches from DNA.
10. mRNA will come out of the nucleus through nuclear pores in eukaryotes and further steps of protein synthesis take place in cytoplasm.

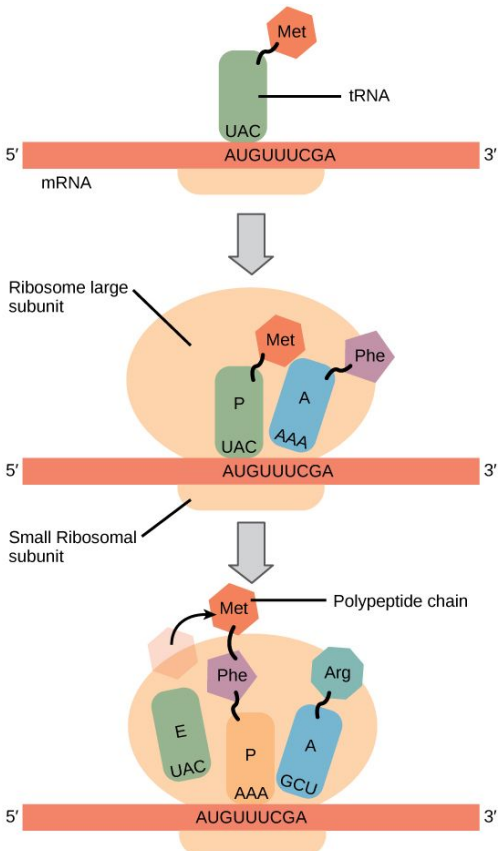


Steps in transcription
Image Source: OpenStax CNX

Translation as the production of polypeptides from the sequence of codons carried by mRNA.

Translation is the second phase of protein synthesis which takes place in cytoplasm with the help of ribosomes both in prokaryotes and eukaryotes.

1. The mRNA, ribosome and tRNA all come together.
2. Ribosome attaches to mRNA and amino acids are carried by transfer RNA (tRNA) near to ribosomes.
3. tRNA molecule carrying amino acids and anticodon pairs with the first codon of mRNA .
4. Then second tRNA molecule attaches itself to mRNA in same manner.
5. A peptide bond is formed between amino acids on two different tRNA molecules. The first tRNA molecule leave its amino acid at this point.
6. This process continues till ribosome reaches the stop codon on mRNA, thus producing a chain of amino acids (polypeptide or protein).
7. The polypeptide chain moves away and leaves behind ribosome and thus translation completes.



Translation
Image Source: OpenStax CNX

Role of ribosomes, tRNA and ATP

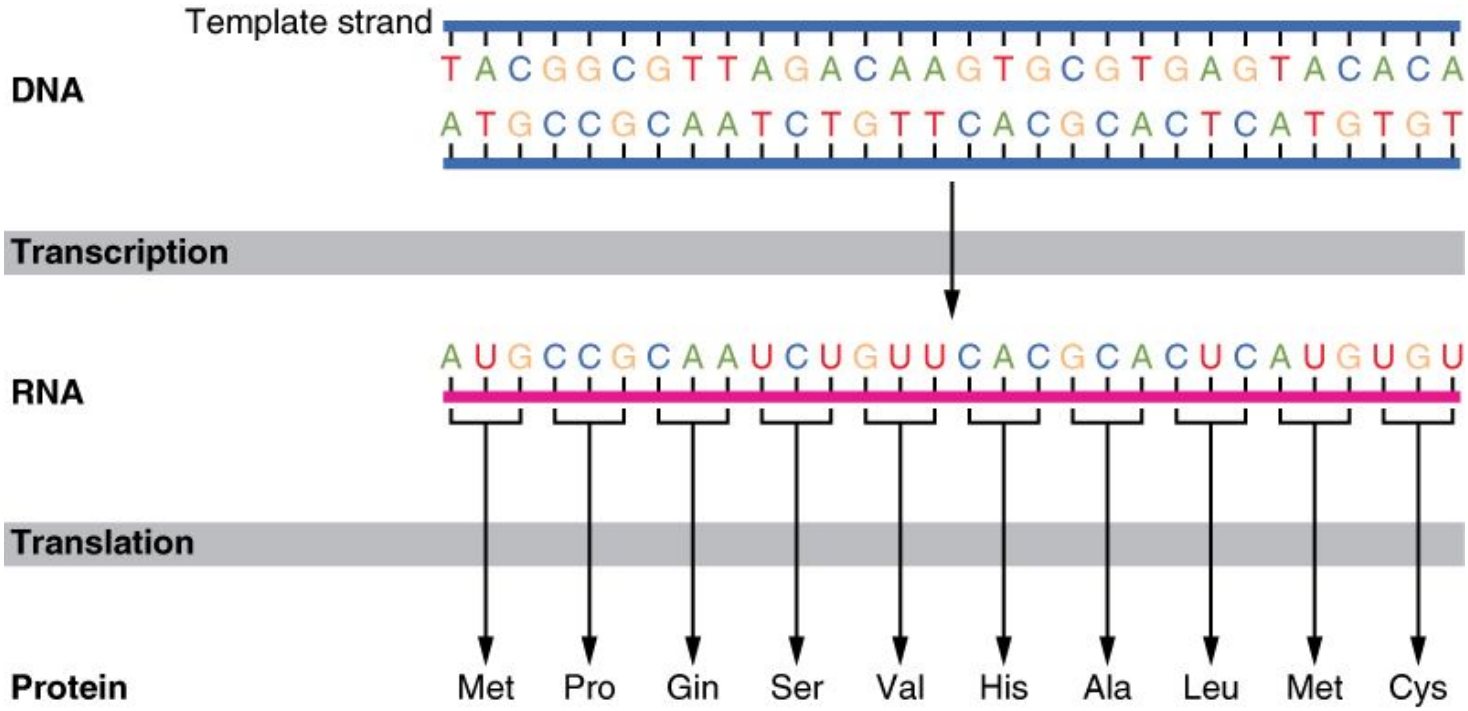
1. **Ribosomes:** The two units of ribosome joined to form a cleft like structure where mRNA attaches itself. Also it moves along the length of mRNA facilitating the base pairing of mRNA and tRNA.

2. **tRNA:** It has two roles. It base pairs with codons of mRNA complementarily with its anticodon. Also it carries amino acids specific to the codons on mRNA.

3. **ATP:** It provides energy for the bond formation between tRNA and amino acid.

Relation of base sequence of nucleic acids to amino acid sequence in polypeptides

1. Three bases of DNA form complementary three bases of one mRNA.
2. Those three bases (base triplet) of one mRNA is a codon and that codon codes for one amino acid.
3. Therefore, if base sequence of a nucleic acid (DNA or mRNA) is known, then amino acid sequence can be taken out.
4. If amino acid sequence of a protein is provided, then from that, base sequence of nucleic acid can be taken out.



Genetic code sequence diagram
Image Source: OpenStax CNX

Module 2: Foundations in biology

SPECIFICATION

2.1.4 Enzymes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) The role of enzymes in catalysing reactions that affect metabolism at a cellular and whole organism level.

(b) The role of enzymes in catalysing both intracellular and extracellular reactions.

(c) The mechanism of enzyme action:

(d) i) The effects of pH, temperature, enzyme concentration and substrate concentration on enzyme activity.

ii) Practical investigations into the effects of pH, temperature, enzyme concentration and substrate concentration on enzyme activity.

(e) The need for coenzymes, cofactors and prosthetic groups in some enzyme-controlled reactions.

(f) The effects of inhibitors on the rate of enzyme controlled reactions.

Enzymes

Enzymes are biological catalysts.
Enzymes come up a lot in biology because they make reactions work quickly. They increase the rate of reactions by lowering the activation energy.

Enzymes catalyse metabolic reactions at both a **cellular** level (for example, respiration) and for the **organism** as a **whole** (for example, digestion in mammals).

They can affect **structures** in an organism. For example, enzymes are involved in the production of collagen - an important protein in the connective tissue of animals.

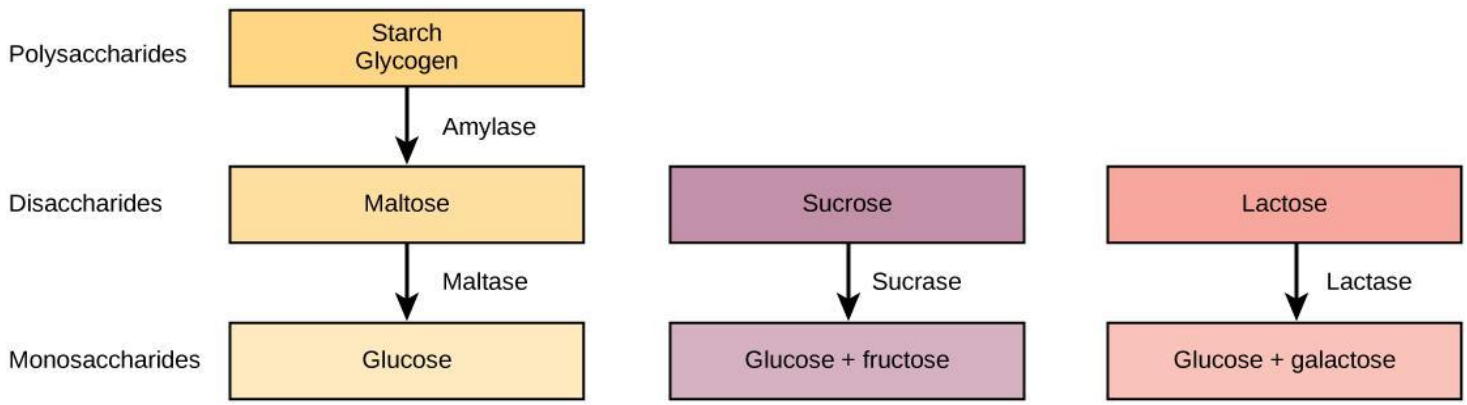
Enzymes can also affect organism **functions**, like **respiration**.

An enzyme action can be **intracellular** (within the cells) or **extracellular** (outside the cells).

Enzymes have an **active** site, which is a specific shape. It's part of the enzyme where the substrate molecules bind to.

Role of enzymes in catalysing both intracellular and extracellular reactions

The macromolecules or large molecules are broken down or hydrolysed by the enzyme called hydrolases. Hydrolases are enzymes which help in splitting up of a molecule by adding water and the process is hydrolysis. Examples of Hydrolases: digestive enzymes like amylase, lipase, protease etc.



Digestion of carbohydrates through a series of enzymatic reactions
Image Source: OpenStax CNX

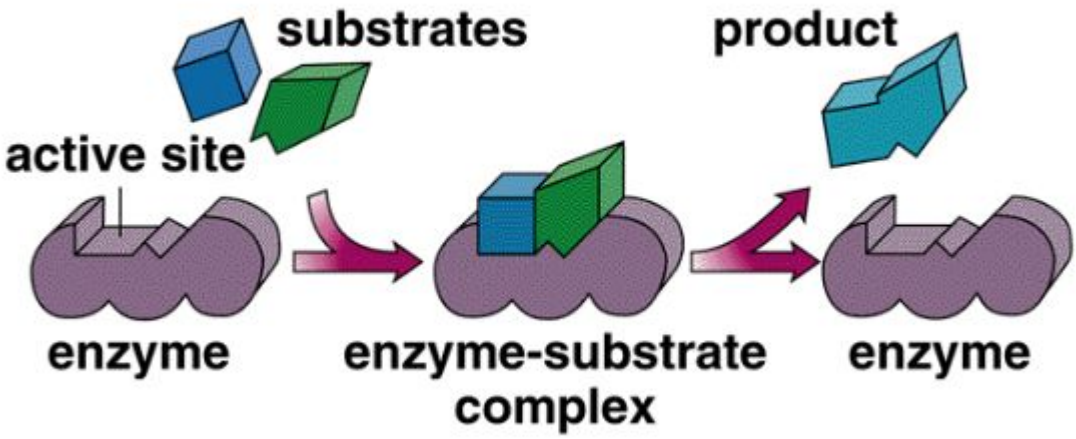
Aerobic respiration constantly generates reactive oxygen species (ROS), byproducts that must be detoxified. The enzyme catalase converts one such ROS hydrogen peroxide to water and oxygen according to the reaction: $2H_2O_2 \rightarrow 2H_2O+O_2$

The mechanism of enzyme action

Lock and Key Model

For many years, scientists thought that enzyme-substrate binding took place in a simple "**lock-and-key**" fashion.

This model suggested that the active site has a rigid shape and that only a substrate with the correct complementary shape can bind to the active site. However, this has its limitations.



Lock and Key Model of enzyme action
Image Source: OpenStax CNX

Scientists soon realised that this lock and key had limitations. In particular:

- It does not easily explain how activation energy is lowered.
- It does not easily explain the role of competitive inhibitors.
- It does not easily explain the role of non-competitive inhibitors.

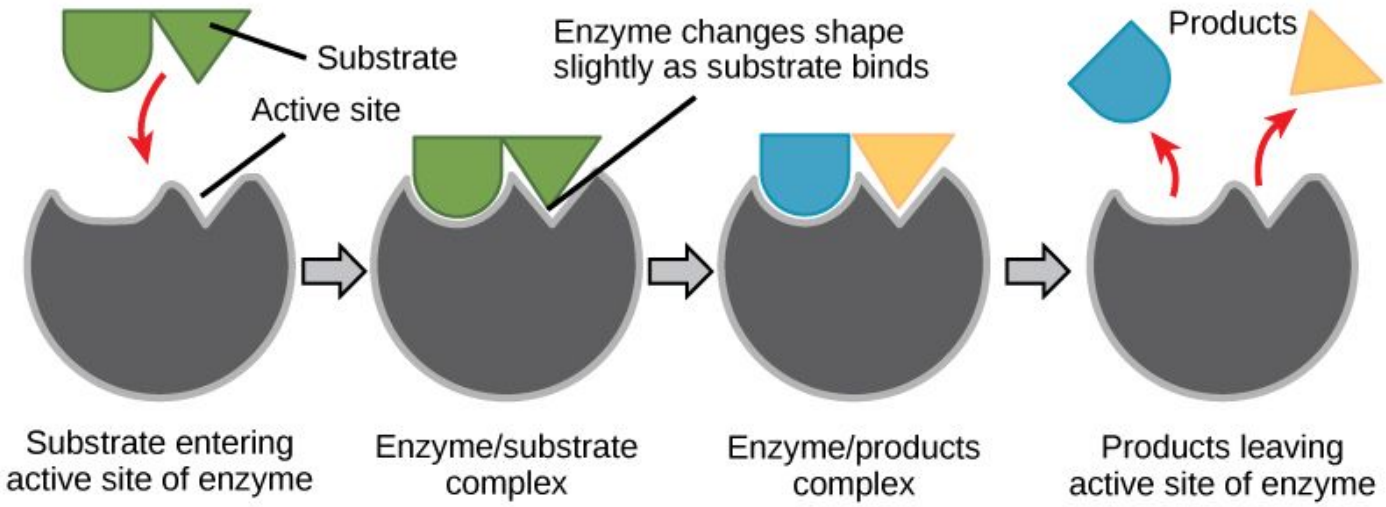
Current research supports a more refined view called induced fit. The induced fit model is a better mechanism to explain enzyme activity.

Induced Fit and Enzyme Function

The induced-fit model expands upon the lock-and-key model by describing a more dynamic interaction between enzyme and substrate.

As the enzyme and substrate come together, their interaction causes a mild shift in the enzyme's structure that confirms an ideal binding arrangement between the enzyme and the transition state of the substrate.

This ideal binding maximises the enzyme's ability to catalyze its reaction.



Induced-fit model of enzyme action
Image Source: OpenStax CNX

According to the induced-fit model, both enzyme and substrate undergo dynamic conformational changes upon binding. The enzyme contorts the substrate into its transition state, thereby increasing the rate of the reaction.

Advantages of the induced fit model

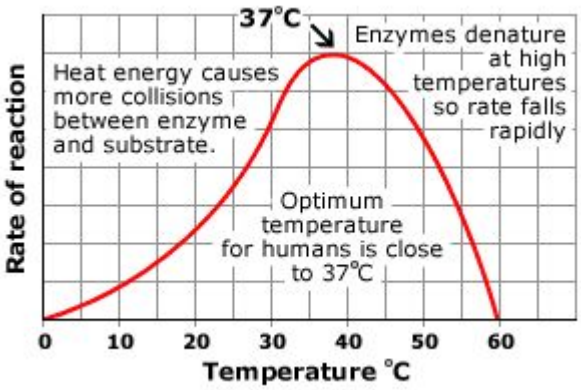
- Can explain how the activation energy is lowered, the stretching and distorting of bonds or causing the closer orientation of reactive groups.
- Explain how non-competitive inhibitors can bind to a region away from the active site and change its shape so that substrate can no longer bind to the active site.
- Explains how competitive inhibitors can bind to the active site or other molecules with similar shapes to the substrate.

Factors Affecting the Rate of Enzyme Activity

Now you know what enzymes are and how they work, you need to understand the factors that affect their activity.

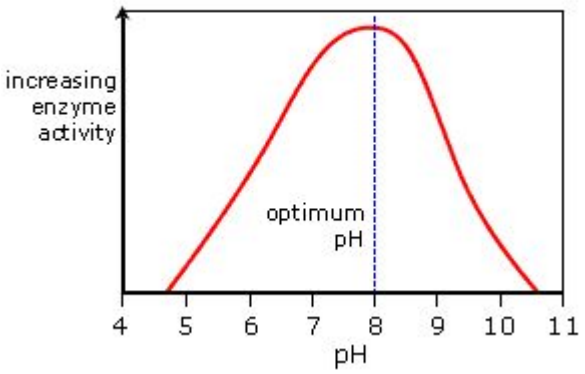
Temperature

- Increase in temperature increases kinetic energy.
- so more enzyme substrate complexes form.
- High temperatures cause denaturation, due to the breaking of breaking of bonds holding the tertiary structure together (H bonds/disulphide bridges/ionic bonds).
- Active site altered (changes shape) substrate cannot bind, no enzyme substrate complexes form.



pH

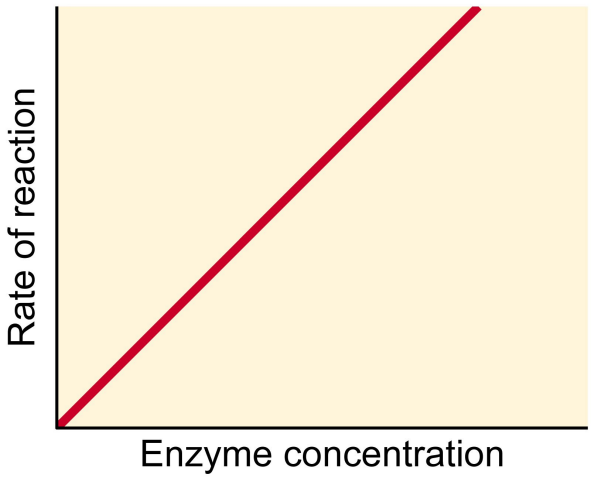
- Deviations from the optimum pH cause a decrease in enzyme activity.
- Small deviations change the charge at the active site and affect the binding of the substrate.
- Larger deviations can cause the hydrogen and ionic bonds holding the tertiary structure together to change and the enzyme denatures, meaning enzyme substrate complexes can no longer form.



Factors Affecting the Rate of Enzyme Activity

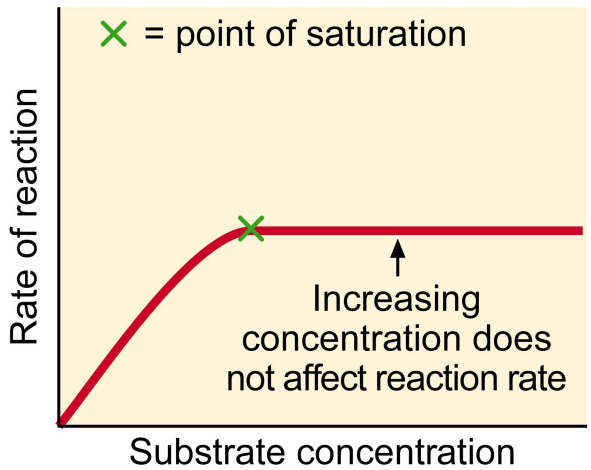
Enzyme Concentration

- As enzyme concentration increases so will the rate: As there are more enzyme substrate complexes forming.
- At very high concentrations of enzyme the rate remains constant as substrate becomes the limiting factor Add more enzyme will cause rate to increase again.



Substrate Concentration

- As the substrate concentration increases, the rate increases because more substrate molecules can collide with enzyme molecules, so more reactions will take place.
- At higher concentrations the enzyme molecules become saturated with substrate, so there are few free enzyme molecules, so adding more substrate doesn't make much difference.



Factors Affecting the Rate of Enzyme Activity

Enzyme Activity can be **inhibited**

Enzyme activity can be prevented by **enzyme inhibitors**. These are molecules that bind to the enzyme that they inhibit. Inhibition can be either **competitive** or **noncompetitive**.

Inhibitors prevent the binding of substrate to active site; therefore fewer enzyme-substrate complexes formed, reducing the rate of their reactions.

They are found naturally, but are also used artificially as drugs, pesticides and research tools.

COMPETITIVE INHIBITORS

- They have a similar shape to that of the substrate molecules.
- They compete with the substrate molecules to bind to the active site, but no reaction takes place.
- Instead of a reaction, they block the active site so no substrate molecules can fit in it.
- The level of activity inhibited depends on the relative concentrations of the inhibitor and the substrate.
- High concentration of the inhibitor means it will take up nearly all of the active sites and hardly any substrate will get to the enzyme.
- With a lower concentration, the chances of the substrate getting to an active site before the inhibitor increase.
- So, increasing the concentration of a substrate will increase the rate of reaction - up to a point.

NON-COMPETITIVE INHIBITORS

- They bind to the enzyme **away from its active site**.
- This causes the active site to change shape so the substrate molecules cannot bind to it.
- They don't "compete" with the substrate molecules to bind to the active site because they are different shapes.
- Increasing the concentration of substrate doesn't affect the reaction rate - enzyme activity is still inhibited.

Competitive and Noncompetitive Enzyme Inhibitors

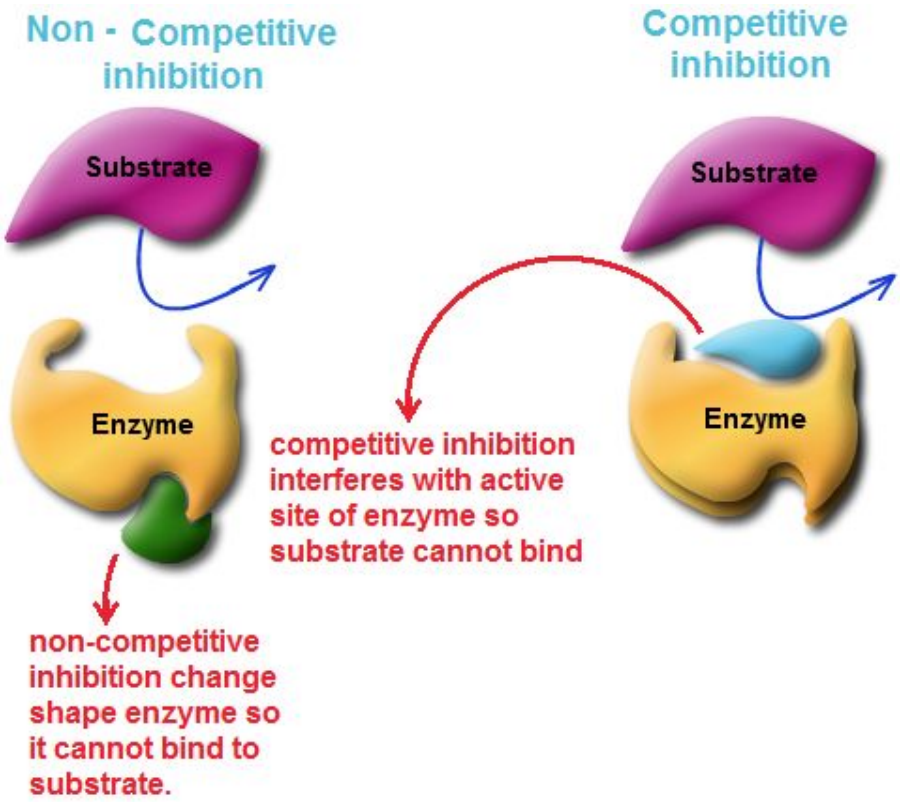
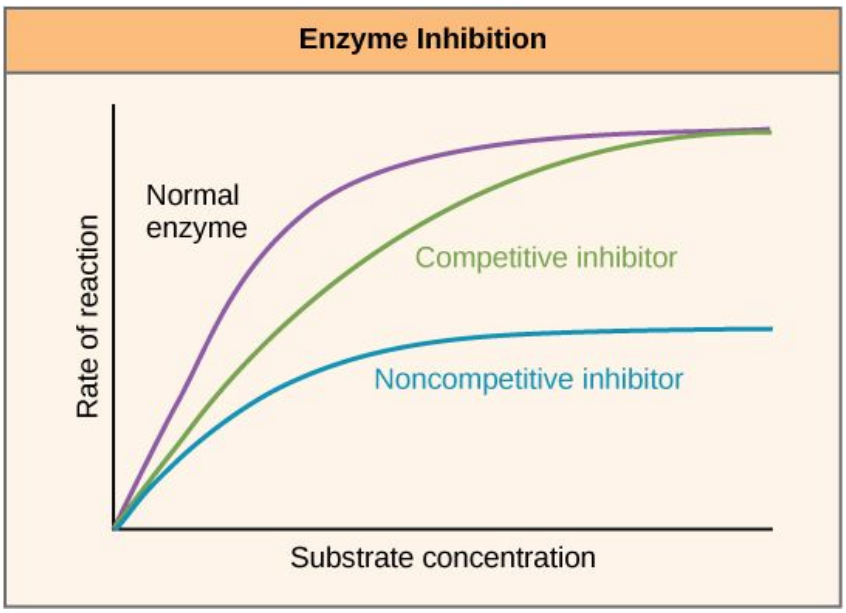


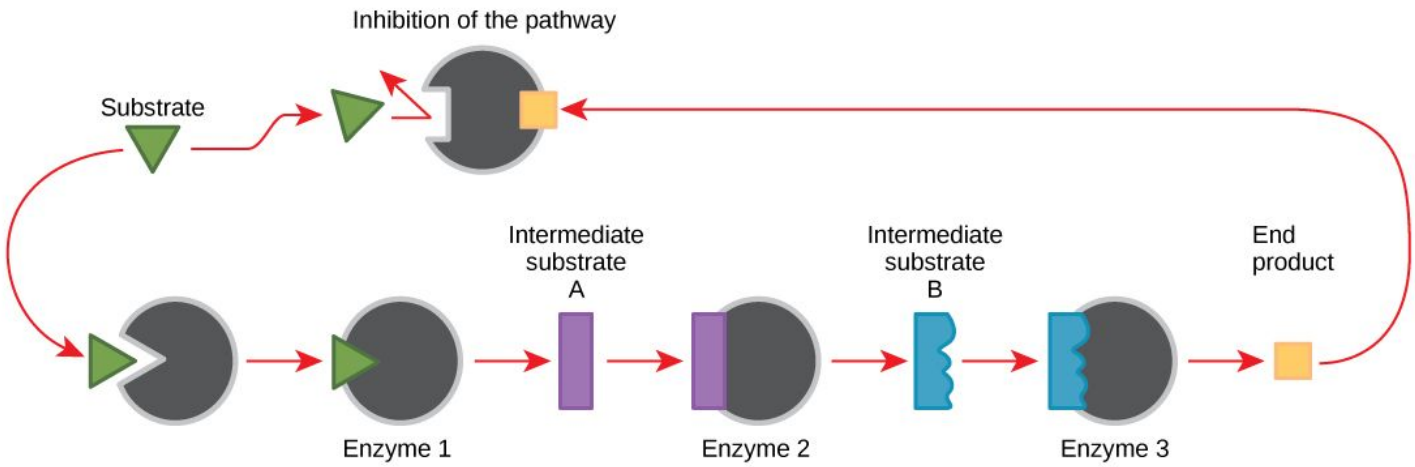
Diagram showing the difference between competitive and noncompetitive enzyme inhibition
Image Source: cnx.org



Competitive and noncompetitive inhibition affect the rate of reaction differently. Competitive inhibitors affect the initial rate but do not affect the maximal rate, whereas noncompetitive inhibitors affect the maximal rate.

Competitive and Noncompetitive Enzyme Inhibitors

Metabolic pathways are a series of reactions catalyzed by multiple enzymes. Feedback inhibition, where the end product of the pathway inhibits an upstream step, is an important regulatory mechanism in cells.



Inhibition of pathway
Image Source: cnx.org

End product inhibition/allosteric effectors

The activity of some enzymes is controlled by certain molecules binding to a specific regulatory (or allosteric) site on the enzyme, distinct from the active site.

Different molecules can inhibit or activate the enzyme, allowing sophisticated control of the rate. Only a few enzymes can do this, and they are often at the start of a long biochemical pathway.

They are generally activated by the substrate of the pathway and inhibited by the product of the pathway, thus only turning the pathway on when it is needed.

Module 2: Foundations in biology

SPECIFICATION

2.1.5 Biological membranes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) The roles of membranes within cells and at the surface of cells.

(b) The fluid mosaic model of membrane structure and the roles of its components:

(c) i) Factors affecting membrane structure and permeability.

ii) Practical investigations into factors affecting membrane structure and permeability.

(d) i) The movement of molecules across membranes.

ii) Practical investigations into the factors affecting diffusion rates in model cells

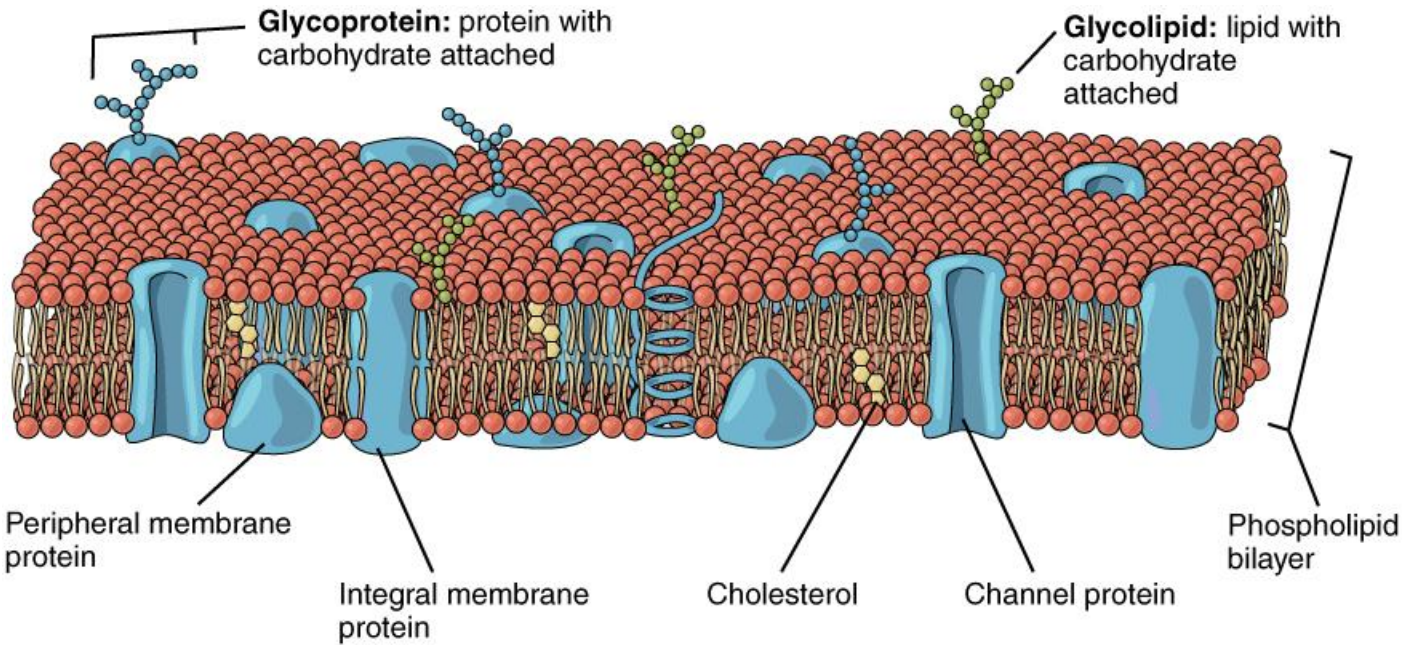
(e) i) The movement of water across membranes by osmosis and the effects that solutions of different water potential can have on plant and animal cells.

ii) Practical investigations into the effects of solutions of different water potential on plant and animal cells.

Cell Membrane

Also known as the **plasma membrane**, the cell membrane is a **semi-permeable** area in a cell that separates the interior components of the cell from the extracellular matrix. Ions and organic molecules can selectively pass through the membrane. Transport of material across the cell membrane is important in the operation of the cell.

The cell membrane is composed of a **lipid bilayer** with some proteins embedded in it. The hydrophobic tails of the lipid components of the membrane is placed in the middle of the bilayer, protected from the polar extracellular and interstitial fluids. Aside from the proteins, **cholesterol** molecules are also embedded in the cell membranes. It maintains the fluidity of the membrane and increases its stability.



Cell Membrane
Image Source: OpenStax CNX

Functions of Cell Membrane

1. Separation between the extracellular fluid and the internal components of the cell.
2. Communication with other cells.
3. Recognition of external substances.
4. Structural support.
5. Transport of materials.

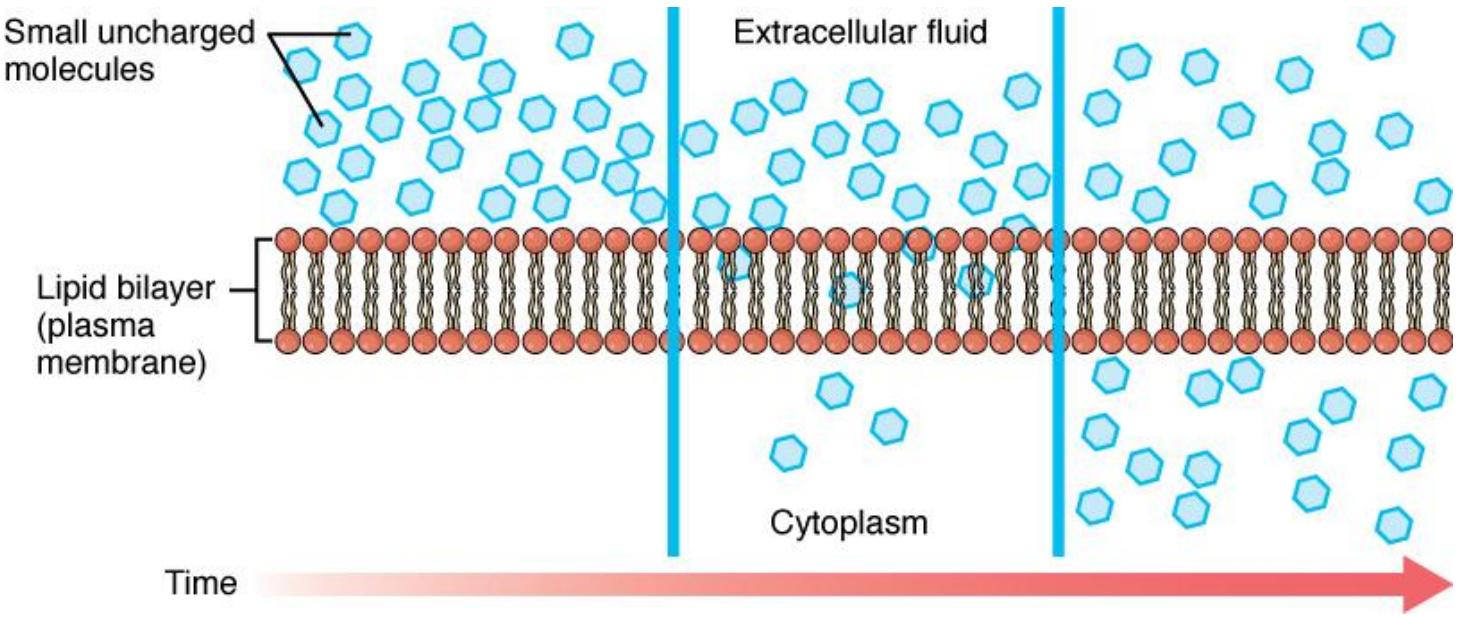
One of the important functions of the cell membrane is facilitating the transport of materials from the outside to the inside of the cells, or vice-versa. Transport of materials is accomplished via a number of possible mechanisms. These include:

- Simple diffusion.
- Facilitated diffusion.
- Osmosis.
- Active Transport.
- Co-transport.

The type of transport is dependent on the concentration difference of the extracellular matrix and the interstitial fluids, the type of compound being transported, and energy requirement for the transport.

Simple diffusion

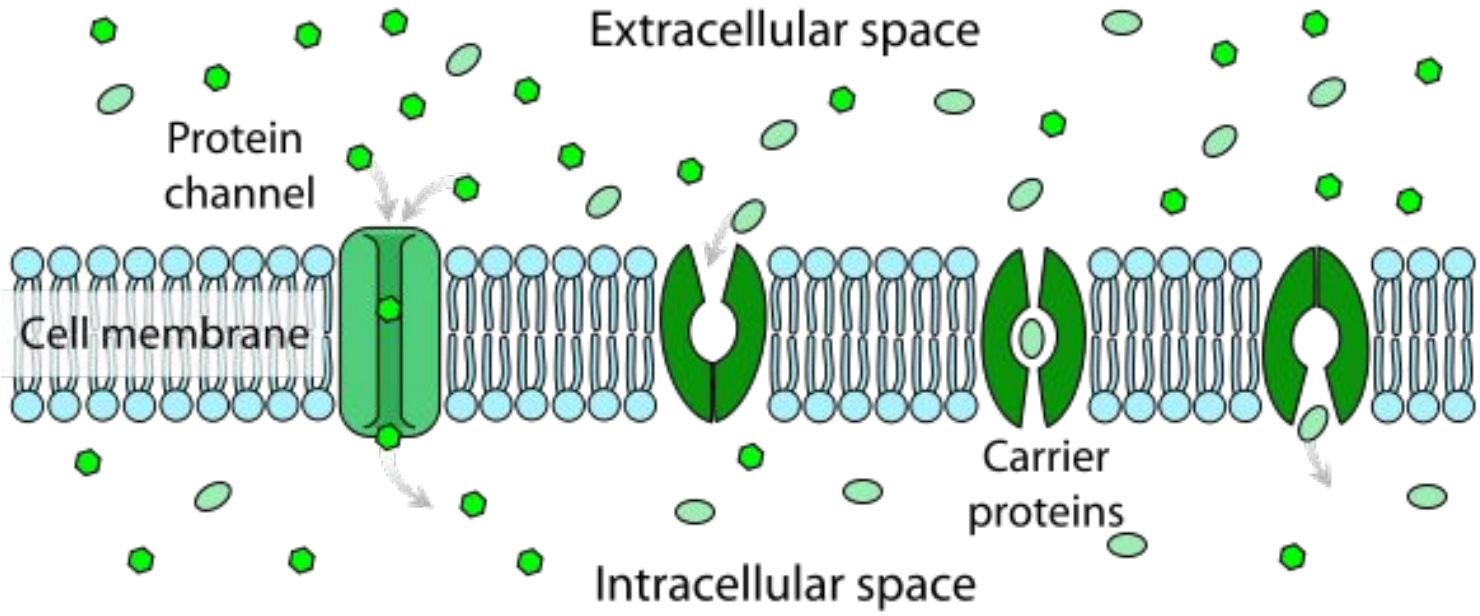
- **Diffusion,** also called **passive transport,** is the movement of particles from an area with higher concentration to an area of lower concentration.
- This is the primary mode of transport for small molecules and gases like oxygen and carbon dioxide. It is important that these two gases readily diffuse through the membrane because oxygen is needed by the cells for metabolism, and carbon dioxide need to be expelled by the cell for eventual release to the environment.



Simple diffusion
Image Source: OpenStax CNX

Facilitated diffusion

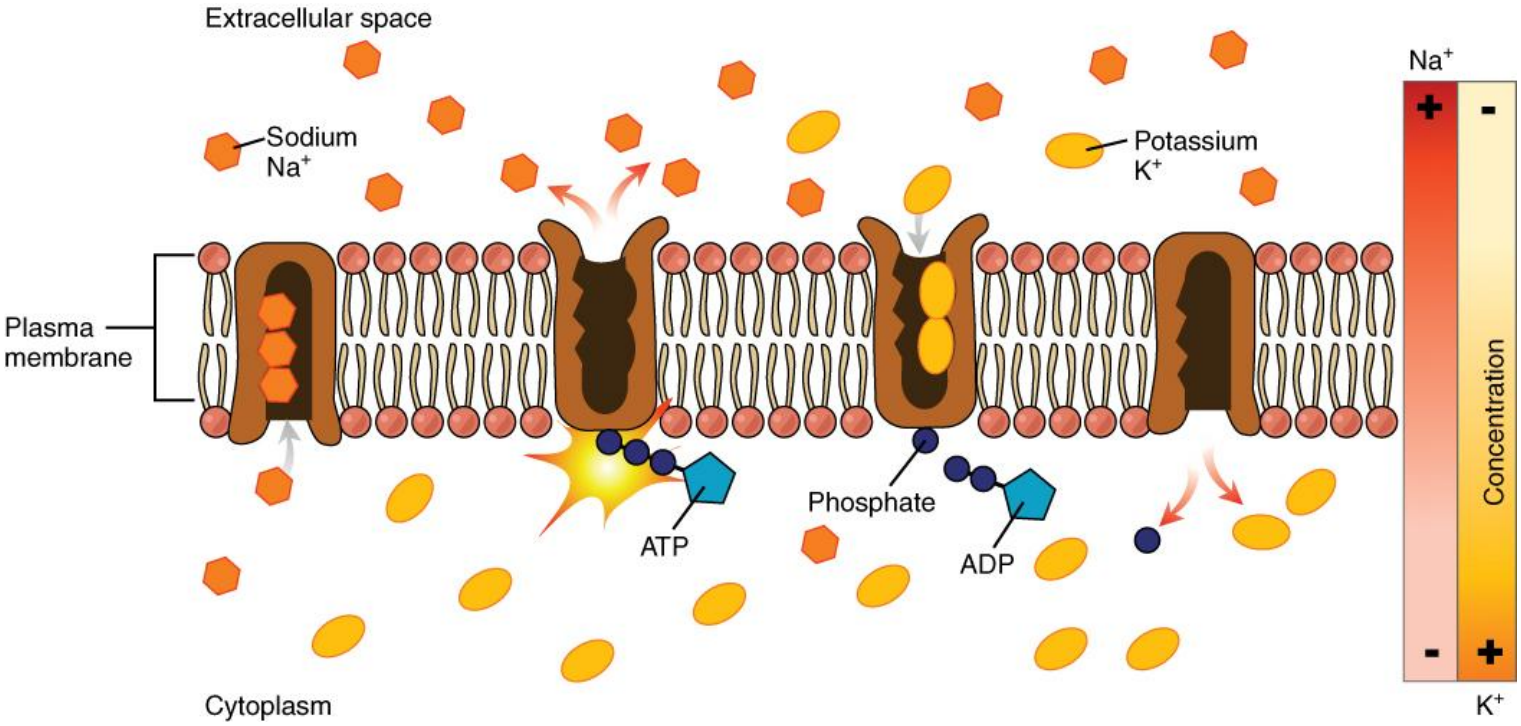
- Facilitated diffusion is the spontaneous transport of material across the cell membrane via membrane proteins embedded in it.
- The transport is dependent on the interaction of material and the channel or carrier protein.
- This type of transport is particularly important in moving large polar molecules and ions that cannot readily diffuse via simple diffusion.
- The main difference between carrier and channel proteins is carrier proteins are not open readily to both intracellular and extracellular environments, while a channel protein is open to both.
- In **carrier proteins**, binding sites are present where molecules to be transported can bind. The protein then undergoes conformational change eventually opening the protein molecule to the other side of the cell membrane. Eventually, the solute molecule is released to the other side of the membrane.
- **Channel proteins** interact weakly with the material to be transported. If the channel is open, specific solutes can freely pass through them.



Facilitated diffusion
Image Source: Wikimedia commons

Active transport

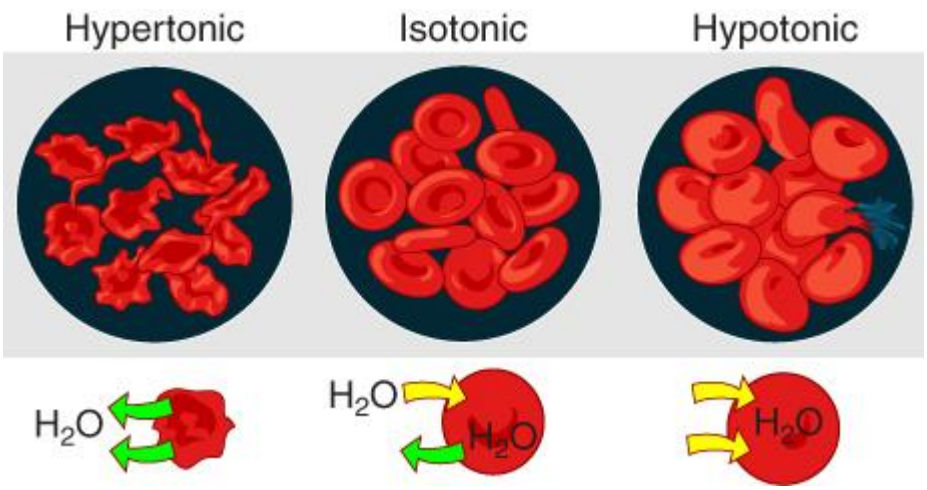
- This is the type of transport where solute is transported from an area of **lower concentration to an area of higher concentration**.
- This type of transport is needed to accumulate solute in a specific area where cellular metabolic process may occur.
- Active transport may be classified as either primary or secondary active transport. Primary active transport requires energy in the form of **ATP** for the transport of material. Secondary active transport, on the other hand, uses an **electrochemical gradient** for the transport of material to occur.
- An example of active transport is the transport of potassium and sodium ions through the **sodium potassium pump**. An electrochemical gradient is present because of the imbalance in the concentration of positive charges across the membrane. ATP provides the energy needed to produce conformational change for the eventual release of the ions to the other side of the membrane.



Sodium - Potassium Pump
Image Source: OpenStax CNX

Osmosis

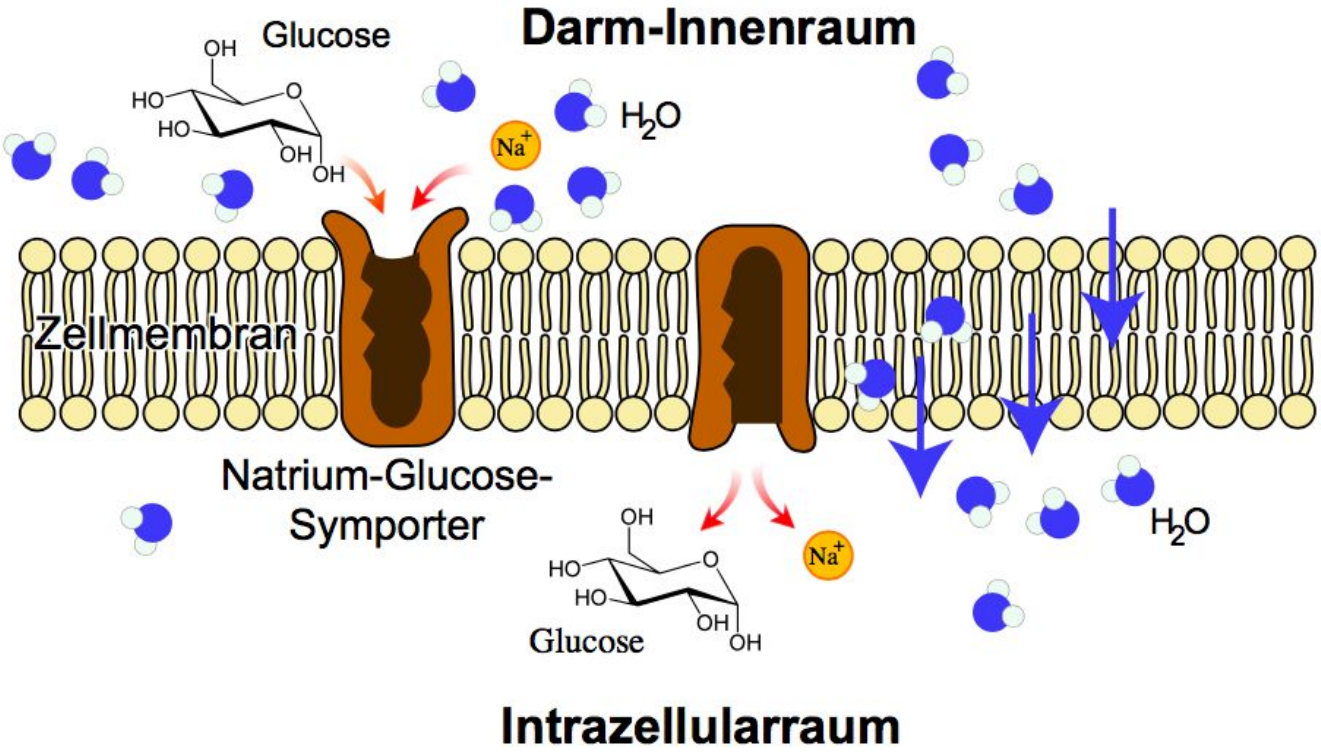
- This is the type of transport where water molecules (solvent) diffuse through the membrane down its concentration gradient.
- In the process of transport, the concentration in both sides of the membrane is equalised.
- This type of transport occurs when there the solute concentrations are not equal, and water molecules have higher tendency to diffuse than the solute molecules.
- Depending on the condition of the extracellular environment, different things can happen to the cell. If the cell is exposed to an **isotonic** environment (same concentration inside and outside the cell), the movement of water into and out of the cell occur at the same rate. If the cell is exposed to a **hypertonic** environment (outside of the cell has higher solute concentration than the inside), the cell will shrivel because of loss of water. If the cell is exposed to a **hypotonic** environment (inside of the cell has higher concentration than outside), the cell take up more water and becomes bloated and will eventually burst.



Osmosis in Red Blood Cells
Image Source: OpenStax CNX

Co-transport

- This is the type of transport where two substances are simultaneously transported across a membrane.
- This is a specific type of secondary active transport.
- This is facilitated by **symporters**, which can transfer two substances in the same direction. An example of a symporter is the sodium-glucose symporter. It uses the sodium ions to move glucose into the cell. The flow of sodium ions through the symporter provides the needed energy for the glucose to move also through the symporter.



Co-transport
Image Source: Wikimedia Commons

Module 2: Foundations in biology

SPECIFICATION

2.1.6 Cell division, cell diversity and cellular organisation.

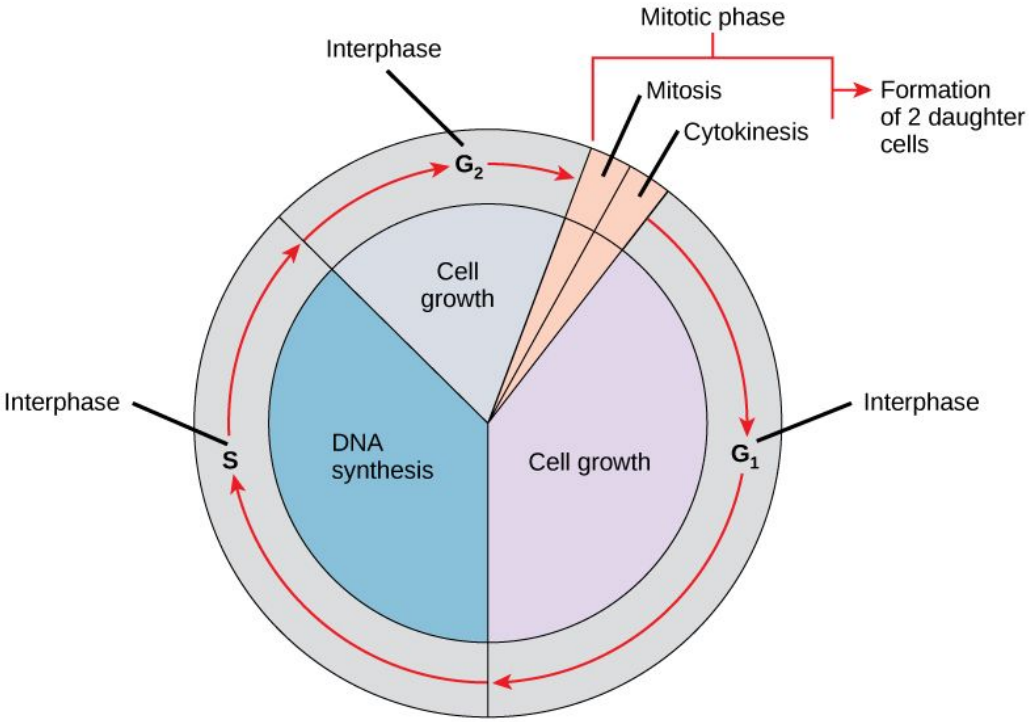
Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) The cell cycle.
(b) How the cell cycle is regulated.
(c) The main stages of mitosis.
(d) Sections of plant tissue showing the cell cycle and stages of mitosis.
(e) The significance of mitosis in life cycles.
(f) The significance of meiosis in life cycles.
(g) The main stages of meiosis.
(h) How cells of multicellular organisms are specialised for particular functions.
(i) The organisation of cells into tissues, organs and organ systems.
(j) The features and differentaton of stem cells.
(k) The production of erythrocytes and neutrophils derived from stem cells in bone marrow.
(l) The production of xylem vessels and phloem sieve tubes from meristems.
(m) The potential uses of stem cells in research and medicine.

The Cell Cycle

The cell cycle is an ordered series of events involving cell growth and cell division that produces two new daughter cells.

A series of precisely timed and carefully regulated stages of growth, DNA replication, and division that produces two identical (clone) cells.



The cell cycle
Image Source: OpenStax CNX

Mitosis vs Meiosis

1. **Mitosis** is the type of cell division which produces two **daughter cells** that are identical from the parent cell.
2. **Meiosis** is the type of cell division which produces daughter cells that is **not identical** to the parent cell, and contains half the amount genetic material as the parent cell. (This will be covered in more detail later)

Regulation of the Cell Cycle

By External Events

Both the initiation and inhibition of cell division are triggered by events external to the cell.

The reason may be a simple factor like death of a nearby cell.

It can also be a major factor like release of growth-promoting hormones, such as human growth hormone (HGH). A lack of HGH can inhibit cell division, resulting in dwarfism, whereas too much HGH can result in gigantism.

Crowding of cells can also inhibit cell division.

Another factor that can initiate cell division is the size of the cell. Due to the growing size, a cell becomes inefficient due to its decreasing surface-to-volume ratio. Hence, the division occurs.

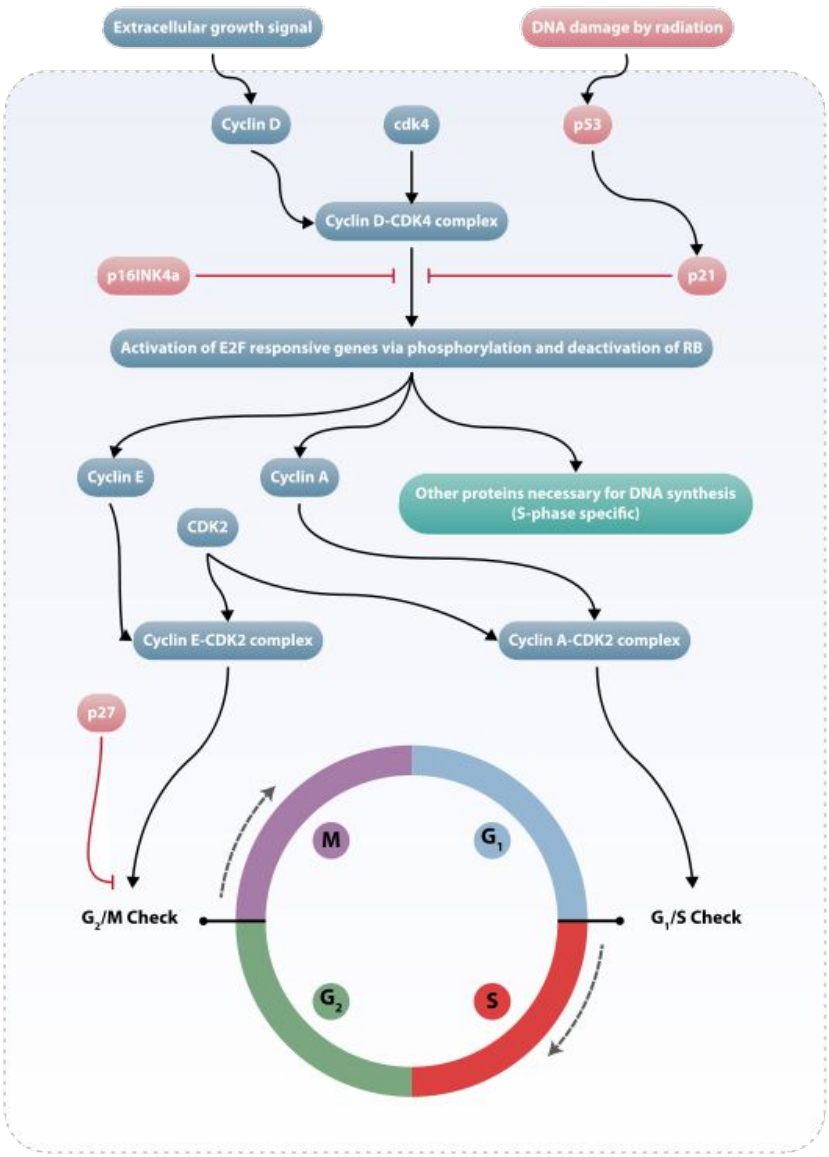
Regulation of the Cell Cycle

Regulation at Internal Checkpoints

The G_1 Checkpoint: At the G_1 checkpoint, cell size and protein reserves are assessed. Determines whether all conditions are favourable for cell division to proceed. Growth factors, play a large role in carrying the cell past the G_1 checkpoint. Additionally, check for genomic DNA damage is done at the G_1 checkpoint.

The G_2 Checkpoint: The most important role of the G_2 checkpoint is to ensure that all of the chromosomes have been replicated and that the replicated DNA is not damaged. On detection of damage, the cell cycle is halted, and the cell attempts to either complete DNA replication or repair the damaged DNA.

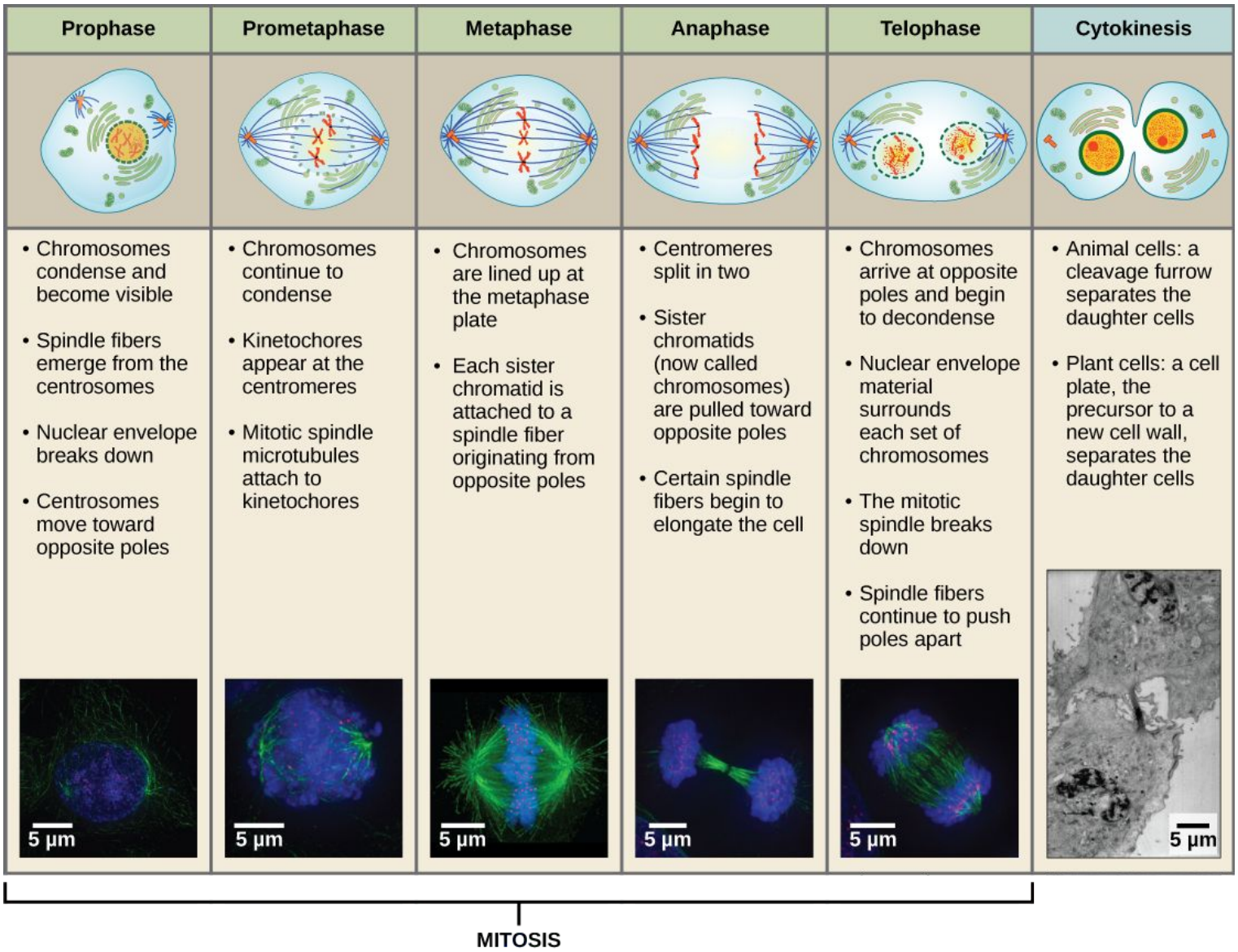
The M Checkpoint: It determines whether all the sister chromatids are correctly attached to the spindle microtubules.



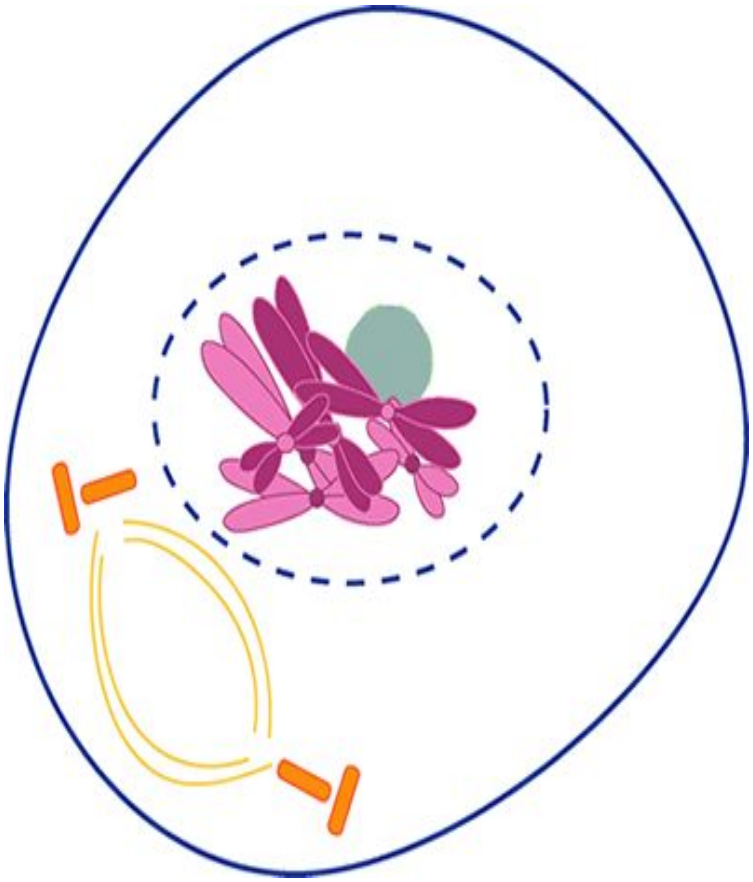
Regulation of the cell cycle
Image Source: Wikimedia commons

Stages of Mitosis

The diagram below shows the processes involved in mitosis. You need to learn what happens in each step and how daughter cells that are identical to the parent cells are produced.



Stages of Mitosis
Image Source: Openstax cnx



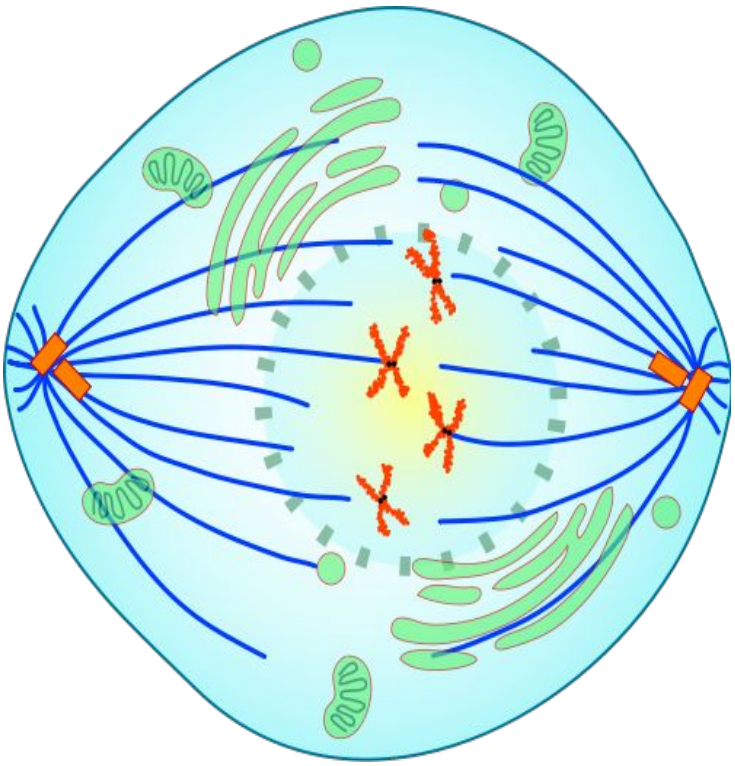
Prophase
Image Source: The Biology Corner

Prophase

- During the prophase, the nuclear membrane of the cell breaks down forming small vesicles. In the process, the nucleolus disintegrates.
- The **centrosome** that have been duplicated in the G2-phase separates. They start to move towards opposite poles of the cells.
- **Mitotic spindles** extend between the centrosomes, pushing them further apart when the microtubules lengthen.
- Chromosomes become visible, which is composed of **two chromatids** joined together at the **centromere**.

Prometaphase

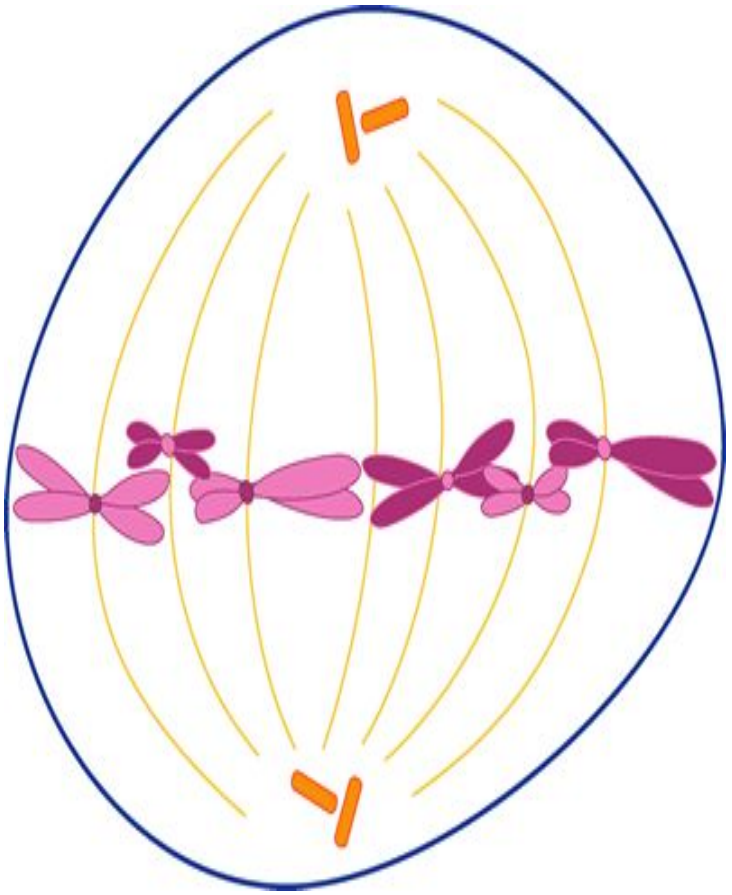
- This the second stage of the mitotic cycle where remnants of the nuclear envelope disappears.
- Protein structures called **kinetochores** appear.
- Microtubules that emerges from the centrosome lengthen to reach the chromosomes and attach to the kinetochore.
- **Proton motors** associated to microtubules arrange the chromosomes towards the center of the cell.
- Prometaphase ends when all the **kinetochore microtubules** have attached to their kinetochore.



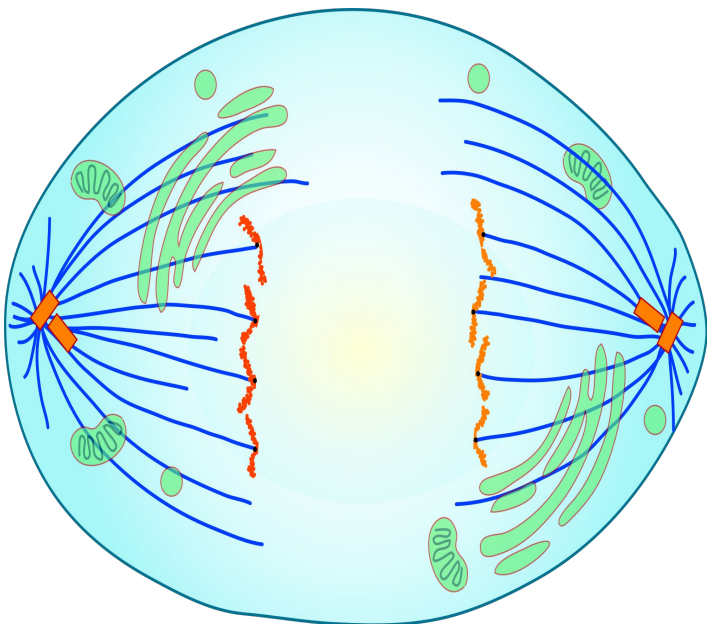
Prometaphase
Image Source: Wikimedia Commons

Metaphase

- This is the **third** stage of the mitotic cycle.
- This is when the centromeres of the chromosomes line up in an imaginary line equidistant (at equal distances) to the two centrosome poles called the **metaphase plate**.
- This is facilitated by the counter effect of the pull of the two opposing kinetochore microtubules.



Metaphase
Image Source: The Biology Corner



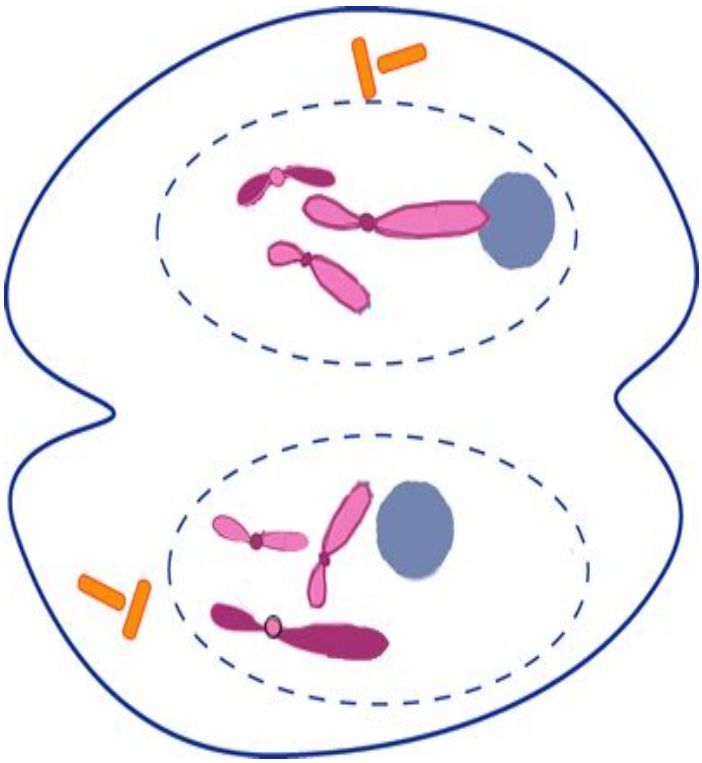
Anaphase
Image Source: Wikimedia Commons

Anaphase

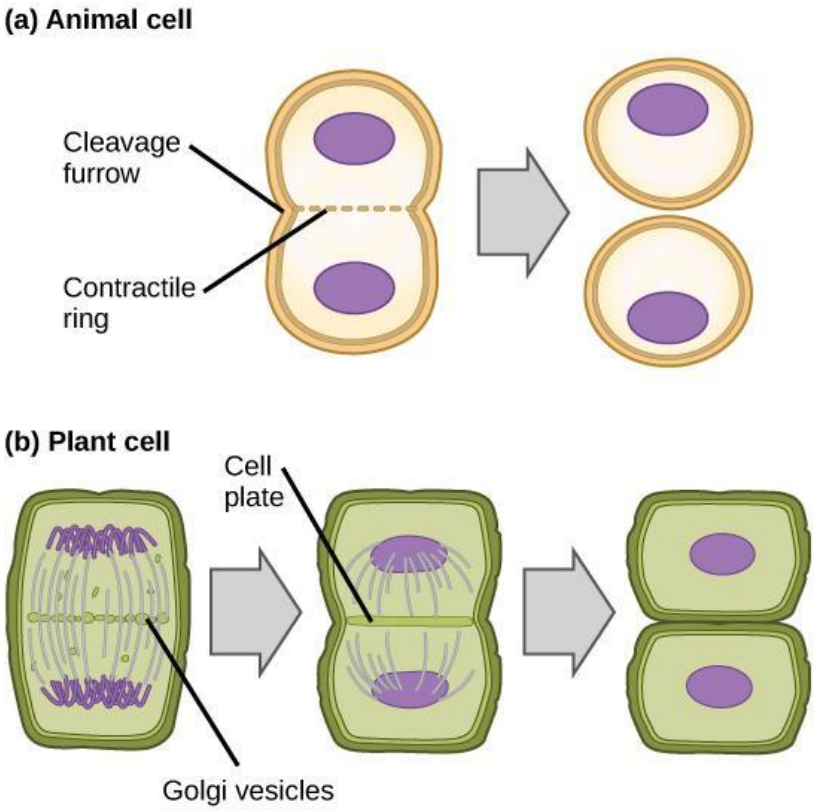
- This is the **fourth** stage of the mitotic cycle.
- This is when the the centromere splits, dividing the chromosome into two **sister chromatids**.
- Each chromatid moves to opposite poles of cells when the mitotic spindle shortens.

Telophase

- This is the **fifth** stage of the mitotic cycle.
- The mitotic spindle disappears during telophase and the chromosomes uncoil to form **diffuse chromatin**.
- A nuclear membrane forms around the daughter chromosomes present in both ends of the cell.



Telophase
Image Source: The Biology Corner



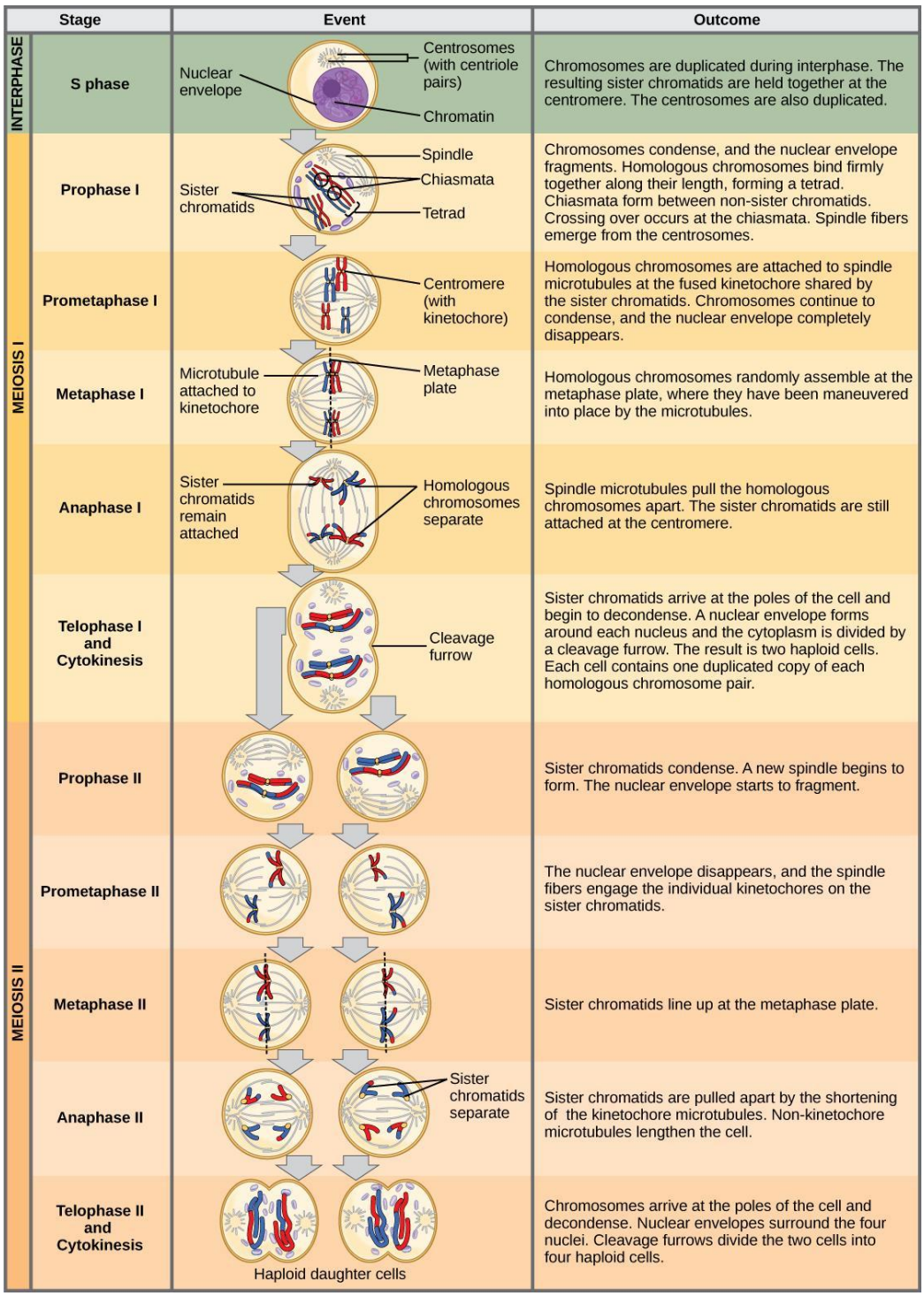
Cytokinesis
Image Source: OpenStax CNX

Cytokinesis

- This is the **final step** in cellular division.
- This is when physical separation of cytoplasmic materials occur in the parent cell.
- For animal cells, a **cleavage furrow** is produced by having the actin filaments pull the equator of the cell inwards, forming the fissure called a cleavage furrow. The cleavage furrow continually develops eventually dividing the cell in two.
- For plant cells, a cell plate is produced by having Golgi vesicles come together at the position of the original metaphase plate separating the two sets of chromosomes. The **cell plate** continually grows until it reach the cell walls. New cell walls are then produced from the contents of the vesicle.

The process of meiosis

1. Two nuclear divisions result usually in the formation of four haploid daughter cells from a single diploid parent cell.
2. Genetically different daughter cells result from the independent segregation of homologous chromosomes.
3. Crossing over between homologous chromosomes results in further genetic variation among daughter cells.



Total process of meiosis
Image Source: OpenStax CNX

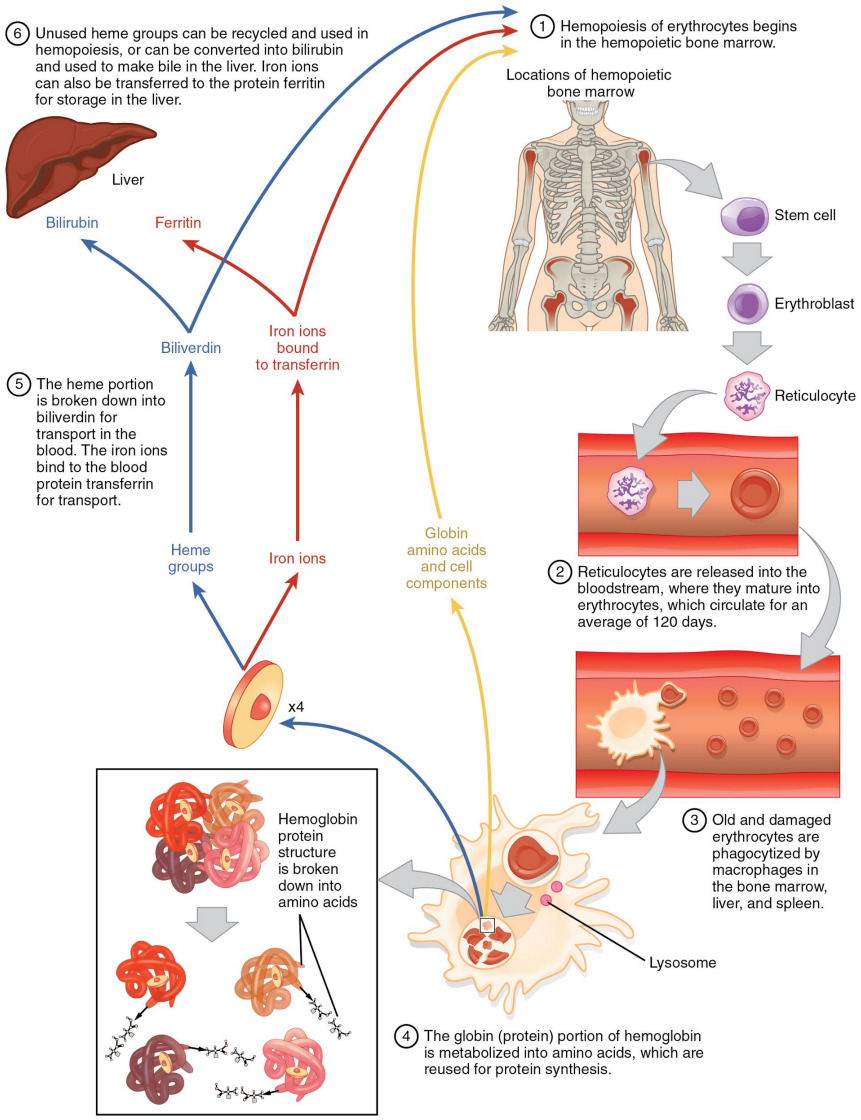
Stem Cells

1) Different cell types, each having a specialised function, make up the multicellular organisms. These include muscle cells, liver cells, WBC, RBC etc.
2) The origin of these specialised cell types is from a reservoir called stem cells.
3) Stem cells are like a reservoir, i.e. they are unspecialised cells which can develop into different specialised cells.
4) Every multicellular organism has stem cells.
5) Human stem cells are located in early embryos (which can develop into all the types of cells in a human) and also in some parts in adults (which have a limited range of development).

Cell Differentiation

The division of stem cells is followed by specialisation - a process called differentiation.

From bone marrow to blood cells - the process of cell differentiation in erythrocytes



The erythrocyte lifecycle
Image Source: OpenStax CNX

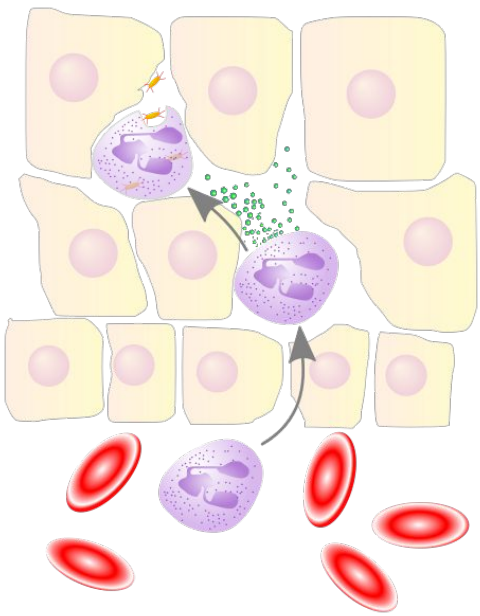
Stem cells in medical research for curing diseases

A range of diseases arise from deformities in specialised cells. Hence, the scientists are researching the possibility of utilising the stem cells to generate the specialised cells that can replace damaged cells. Neurological disorders like Alzheimer's and Parkinson's both of which are related to the death of nerve cells in the brain, can be cured by newly generated cells.

Stem cell research also paves the way for understanding developmental biology and stages of development and also in understanding the nature of cancer cells and finding the cure.

Specialised cells - Neutrophil

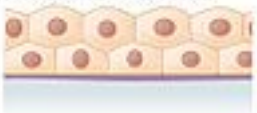
A neutrophil is a phagocytic cell that is attracted via chemical messenger from the bloodstream to infected tissues.
These are like military reinforcements that are called into a battle to hasten the destruction of the enemy.
The neutrophil is the primary pathogen-killing cell of the inflammatory process of the innate immune response.



Neutrophil granulocyte migrates from the blood vessel to the matrix, secreting proteolytic enzymes, and envelop bacteria through phagocytosis
Image Source: Wikimedia commons

Specialised cells - Epithelial cells

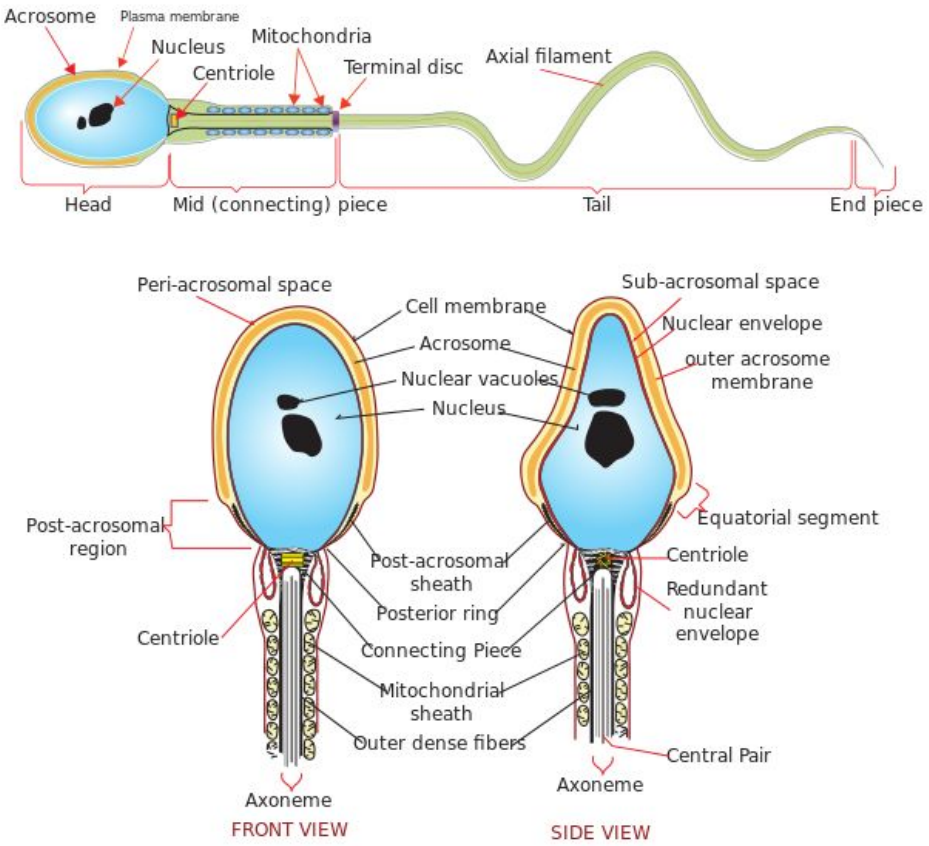
Epithelial cells are the cells forming the outermost layer on the surfaces of organs.
These have a membrane at their base and joined by interlinking cell membranes.
Ciliated epithelia are the ones having cilia to brush away the particles.
Squamous epithelia are extremely thin, which allows diffusion of gases in a smooth manner.

Cells	Location	Function
Simple squamous epithelium 	Air sacs of lungs and the lining of the heart, blood vessels, and lymphatic vessels	Allows materials to pass through by diffusion and filtration, and secretes lubricating substance
Simple cuboidal epithelium 	In ducts and secretory portions of small glands and in kidney tubules	Secretes and absorbs
Simple columnar epithelium 	Ciliated tissues are in bronchi, uterine tubes, and uterus; smooth (nonciliated tissues) are in the digestive tract, bladder	Absorbs; it also secretes mucous and enzymes
Pseudostratified columnar epithelium 	Ciliated tissue lines the trachea and much of the upper respiratory tract	Secretes mucus; ciliated tissue moves mucus
Stratified squamous epithelium 	Lines the esophagus, mouth, and vagina	Protects against abrasion
Stratified cuboidal epithelium 	Sweat glands, salivary glands, and the mammary glands	Protective tissue
Stratified columnar epithelium 	The male urethra and the ducts of some glands	Secretes and protects
Transitional epithelium 	Lines the bladder, uretha, and the ureters	Allows the urinary organs to expand and stretch

Types and functions of epithelial cells
Image Source: Wikimedia commons

Specialised cells - Sperm cells

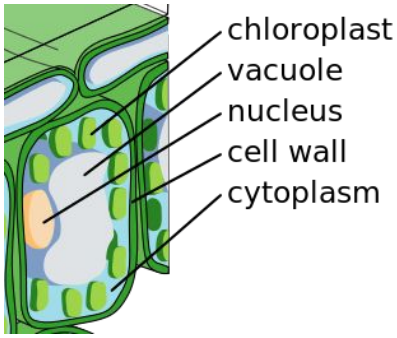
Sperm cells are the cells in males to carry forward the sexual reproduction. The flagella help these to swim towards the egg (female sex cell), mitochondria supplies the required energy while the acrosome contains the enzymes which help to penetrate the surface of the egg.



Structure of a sperm cell
Image Source: Wikimedia commons

Specialised cells - Palisade cells

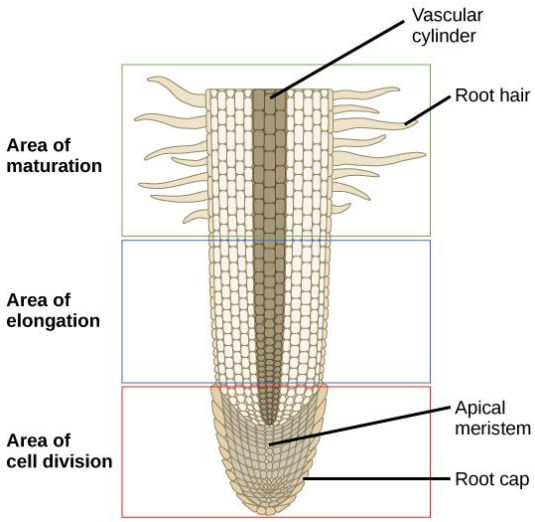
These are the main site for photosynthesis on a leaf surface. These contain the most number of chloroplasts, absorb a lot of sunlight and let the carbon dioxide easily diffuse into the active site for photosynthesis.



Structure of a palisade cell
Image Source: Wikimedia commons

Specialised cells - Root hair cells

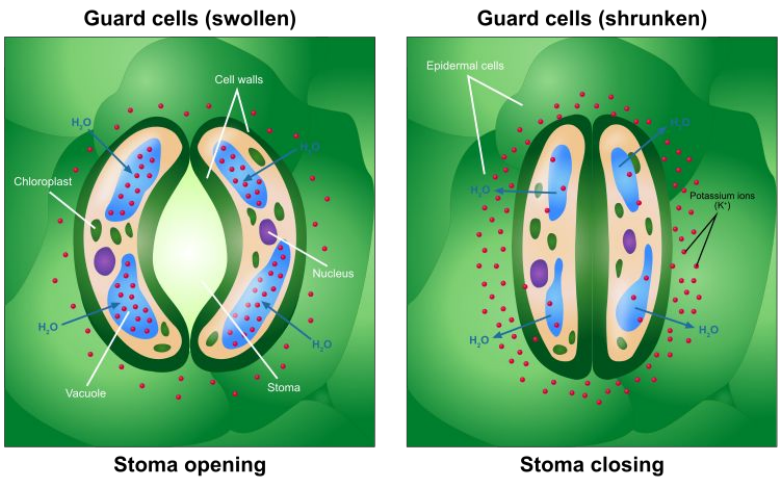
These are designed to absorb water and minerals from the soil. A very thin and permeable cell wall and the large surface area allows the inflow of water and necessary ions. Extra mitochondria is housed in cytoplasm to provide the extra energy for the process of absorption.



Tip of the root with root hair cells
Image Source: cnx.org

Specialised cells - Guard cells

Since plants need to open their stomata to allow gas exchange, there should be a mechanism by which the plants can control the loss of water. This is solved by the presence of guard cells. Guard cells become swollen when water enters them. This swelling causes the stomata to open. When the plant gets dehydrated, the guard cells lose the water and as it becomes flaccid, the stomatal pore closes.



Guard cells in action
Image Source: Wikimedia commons

Organisation of cells into tissues, organs and organ systems

The constitution of multicellular organisms comprises of different types of cells combined in form of tissues which in turn combine to form specialised organs to carry out the life processes.

Tissue: A group of the same category of cells and other extracellular matter to carry out a specific task.
Some examples of **animal tissues** carrying out very specialised functions are shown below:

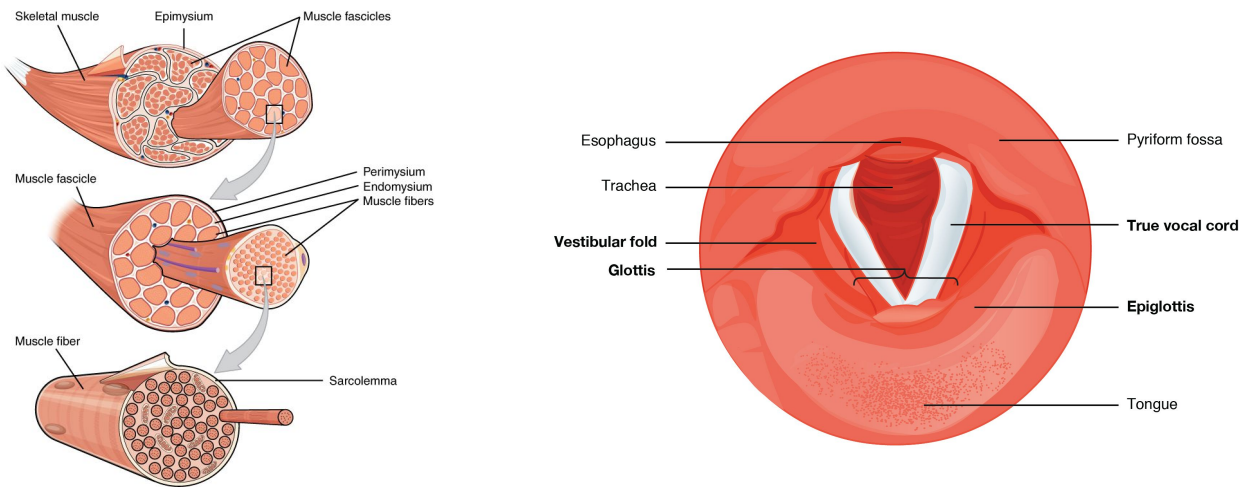
Squamous and Ciliated epithelium

A single layer of epithelial cells which are in contact with the basal lamina and allows the quick transport of small molecules across the membranes is called squamous epithelium.
A layer of cells having cilia which helps in the movement of particles by brushing them along the path is called ciliated epithelium.

Squamous (left) and Ciliated (right) epithelium
Image Source: cnx.org

Muscle tissues and cartilages

Muscle tissues are composed of long cells called muscle fibres. These are of 3 types - smooth, cardiac and skeletal. Cartilages are connective tissues found in joints and as support in nose and windpipe.



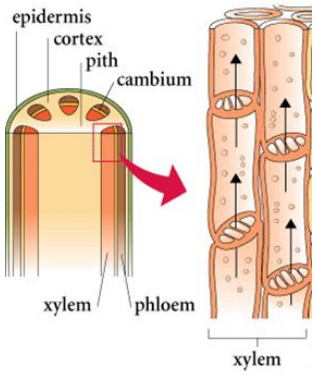
Muscle tissues (left) and cartilages (right)
Image Source: Wikimedia commons

Organisation of cells into tissues, organs and organ systems

Some examples of **plant tissues** carrying out very specialised functions are shown below:

Xylem

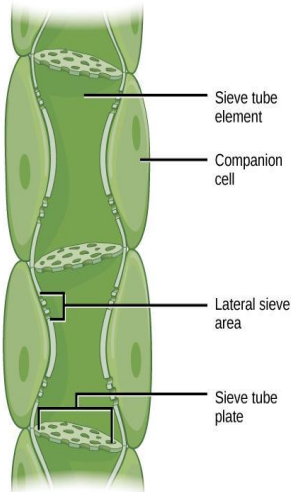
Water and mineral ions are transported by xylem tissue.
These substances move against the gravity in a plant from the roots to the leaves.
Xylem vessels transports the water and ions.
These are very long, tube-like structures and are dead.
These are also known as vessel elements and joined end to end.
End walls are absent on these cells, as a result uninterrupted flow of water occurs.



Xylem tissue structure
Image Source: OpenStax CNX

Phloem

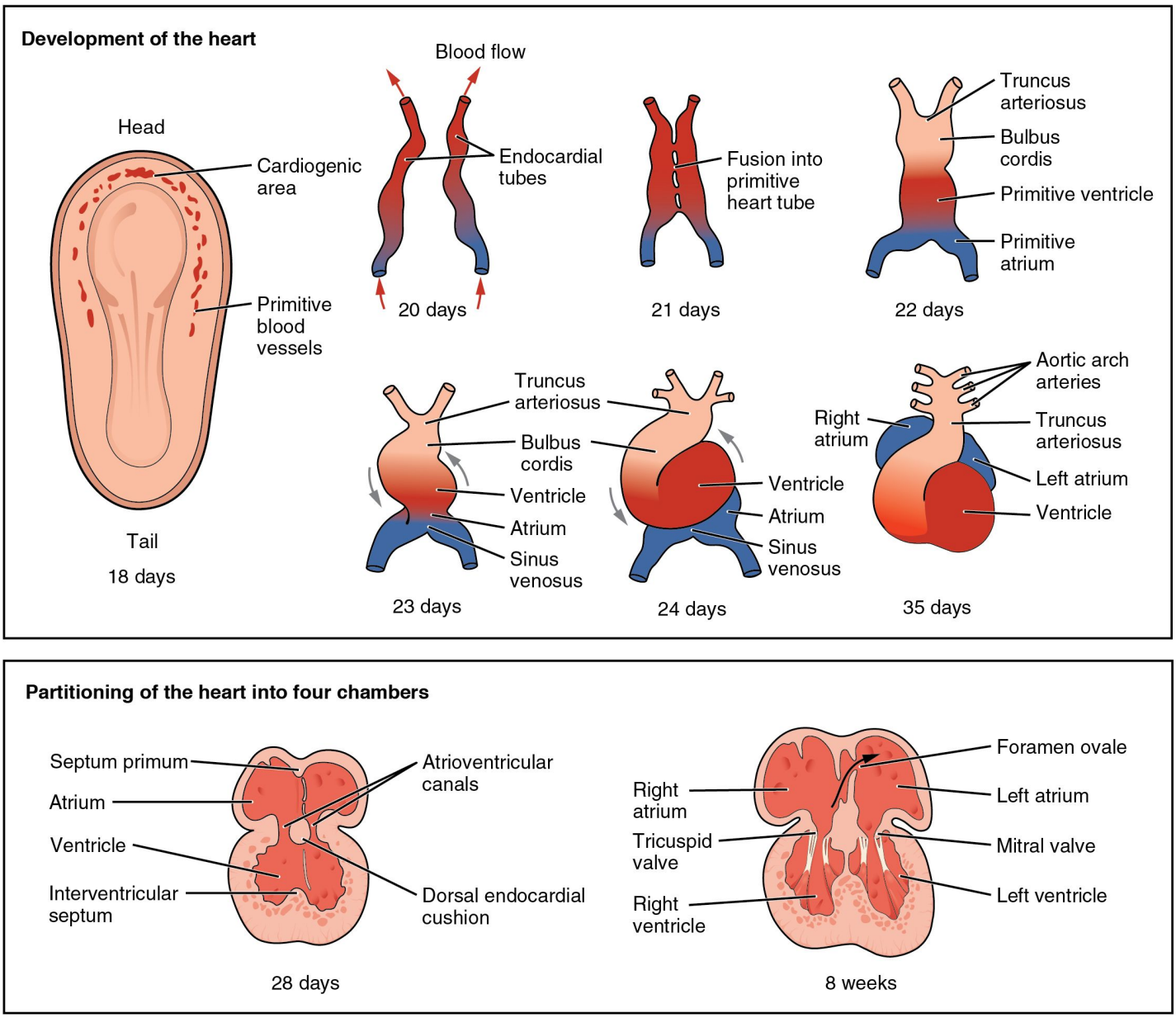
Phloem transports solutes, mainly sugars like sucrose, starch etc., all around the plants.
Sieve tube elements are living cells without nucleus that form the tube like structures for transport of solutes.
For each sieve tube element, companion cells with nucleus are there.
Companion cells carry out all metabolic activities for sieve cells.



Phloem tissue structure
Image Source: OpenStax CNX

Organisation of cells into tissues, organs and organ systems

Formation of organs from cells and tissues is a complex process. An example is shown below which represents the formation of the heart during the first eight weeks of a human life and the formation of the heart chambers.



Development of heart - formation of an organ from cells
Image Source: OpenStax CNX