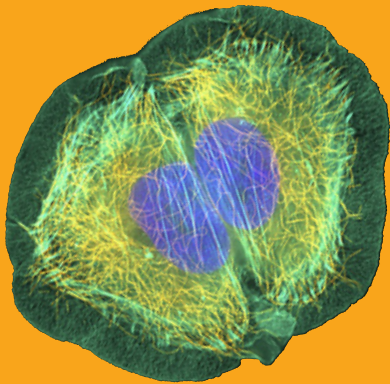


# CELL REPRODUCTION



# CELLS.



## 1 /// LIVING THINGS

### Activities 1-3

A **living thing** is a highly-organised and complex organism, able to perform three vital functions concerning nutrition, interaction and reproduction.

The hierarchical organisation of living things is governed by **emergence**. According to this principle, each higher level is made from pre-existing levels, but the new level will always have emerging properties that are not simply the sum of its parts.

### Interaction

To function properly and stay alive, keeping their internal conditions constant, living organisms must be able to suitably detect and respond to internal and external stimuli. This is known as **homeostasis**.

### Nutrition

Living things exchange materials and energy with their surroundings and use them in chemical reactions. All of these chemical reactions make up their **metabolism** and is what allows them to maintain their degree of complexity, organisation and their homeostasis, as well as grow and develop throughout their lives.

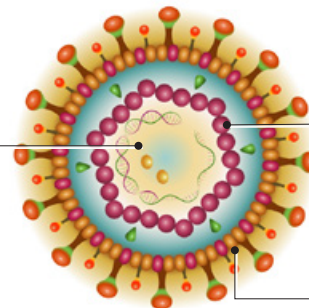
### Reproduction and inheritance

All living things possess the ability to reproduce and create copies of themselves. Reproduction can be asexual (without recombination of genetic material) or sexual (with recombination of genetic material). Nucleic acids are the physical containers for the information required for living things to function and develop and is what keeps them alive and is passed on to their offspring.

#### Acellular structures

These are organisms lacking in a cell structure which do not have a metabolism, and therefore, are not considered to be living. They can make changes to the organisms that they infect in order to reproduce. The most prominent and well-known are **viruses**. These are infectious agents only visible under an electron microscope. They reproduce by using the enzymes and structure of the cells that they infect to turn them into intracellular parasites.

**Genetic material.** Holds the hereditary information which can be DNA or RNA, but never both at once.



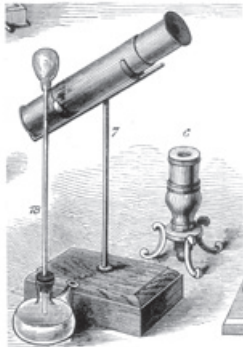
**Capsid.** Protein shell enclosing the genetic material.

**Envelope.** External lipoprotein coating. Only exists for certain types of viruses.

## 2 /// MICROSCOPES AND THE DISCOVERY OF CELLS

Activities 4-5

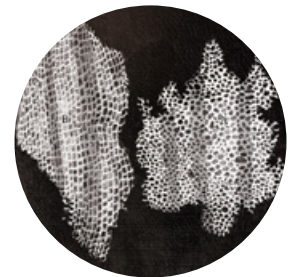
Cells are the basic units of living things. The discovery and study of cells is linked to the invention and perfection of optical systems for magnification: **microscopes**.



**1590** Dutch father-and-son spectacle makers **Hans and Zacharias Janssen** built the **first microscope**. It was formed of two brass tubes, each with a lens, which were slid inside a third tube for focus.

**1665**

English botanist **Robert Hooke** used the first microscope to discover the existence of small hollow rectangular shapes in cork, which he named **cells**. What Hooke observed were the cellulose walls of dead cork cells.



**1670** Dutch cloth merchant **Anton van Leeuwenhoek** designed a simple microscope that used a single lens and was able to magnify objects 270 times their size with surprising precision.

**1674**

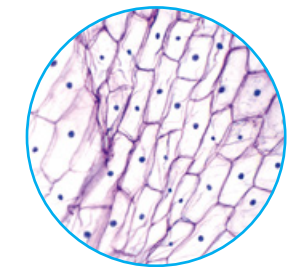
Thanks to this microscope, Van Leeuwenhoek discovered small organisms living in stagnant water, which he called '**animalcules**'. These animalcules were **bacteria and protozoa**.



**1820** English optician **Joseph Jackson Lister** built the **first modern compound optical microscope**, which was decisive in developing and expressing **cell theory**.

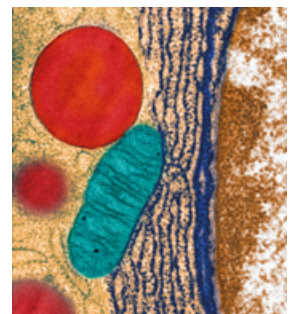
**1831**

With the first optical microscope, Scottish botanist **Robert Brown** discovered the existence of a clear central point inside cells, which he named the **nucleus**. He considered it an essential and constant cell component.



**1939** **Max Knoll** and **Ernst Ruska** invented the **electron microscope**, which uses beams of accelerated electrons in a vacuum tube instead of visible light. It can manage up to a million magnifications, with extraordinary resolution and sharpness.

Electron microscopes allowed for the detailed description of **cell organelles**. Electron micrographs are in black and white, although they are often coloured in by computer.



## 2.1 CELL THEORY

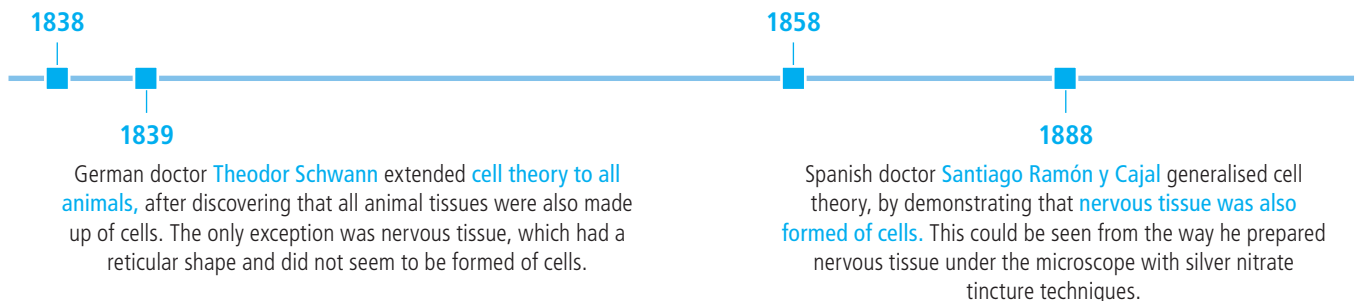
Cell theory defines cells as the structural, functional, reproductive and genetic units of living things.

Structural unit	Functional unit	Reproductive unit	Genetic unit
Cells are the basic units of living things. This means that all living things are made up of at least one cell.	Cells are the basic units able to support their own existence through nutrition and interaction.	Cells are the basic units of reproduction, given that all cells come from the division of pre-existing cells.	Cells are the basic units of inheritance, as they contain the hereditary information required to regulate their own functions, as well as transfer this information to their descendants.

### The scientists who developed cell theory

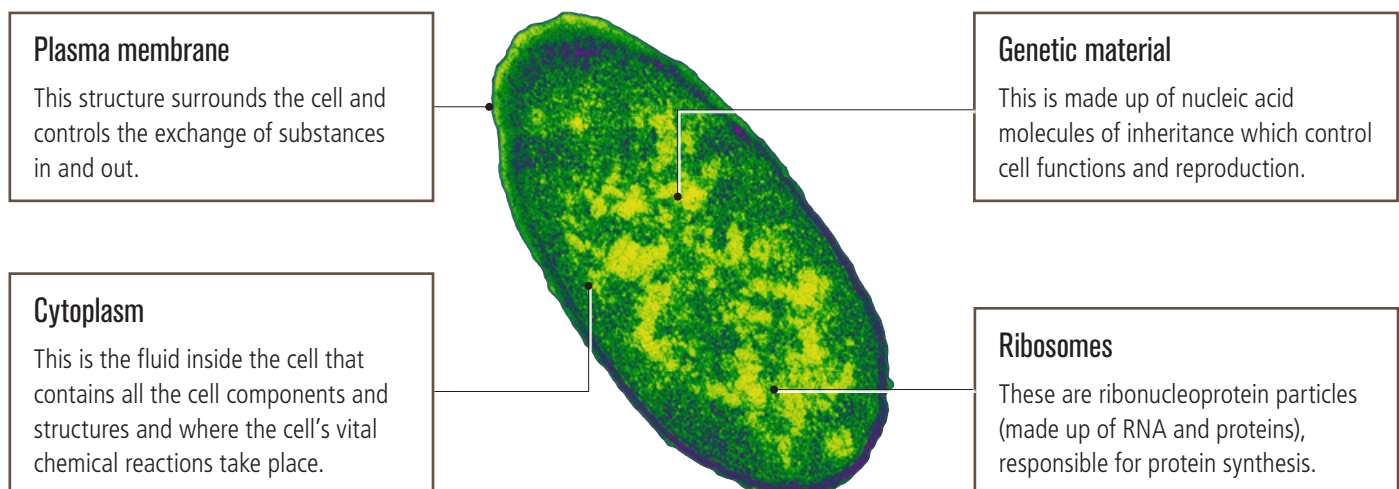
German botanist **Matthias Schleiden** started developing **cell theory in plants**. After observing large amounts of plant tissue under a microscope, he concluded that they were made up of individual units: cells.

Another German doctor **Rudolf Virchow** extended cell theory to the origin of cells. He proved that all cells come from the division of other pre-existing cells. He summarised this idea with the expression ***omnis cellula e cellula***.



## 2.2 BASIC CELL COMPONENTS

All living things are made up of cells, but not all cells are the same, nor do they have the same degree of organisation and complexity. However, in spite of the differences between the various types of cells, all cells share four essential components: **a plasma membrane, cytoplasm, genetic material and ribosomes**.



## 2.3 MODELS OF CELLULAR ORGANISATION

Depending on their degree of complexity and their evolutionary history, there are two types of cells: **prokaryotic and eukaryotic**.

### Prokaryotic cells

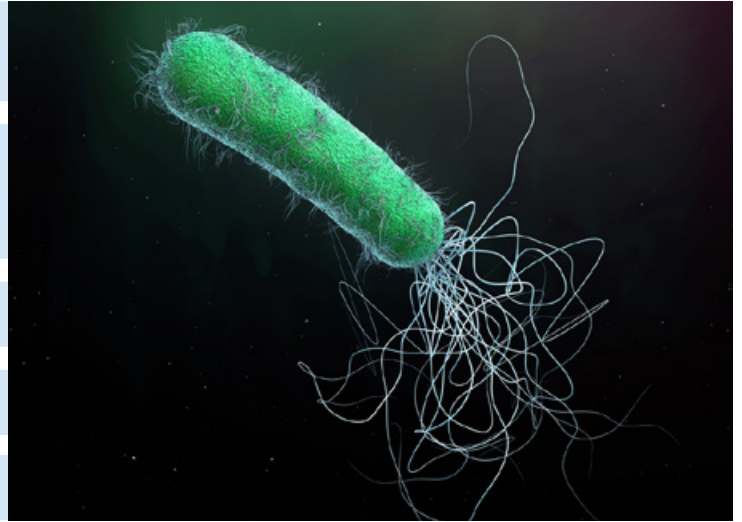
They have no internal membranes, and therefore lack any cytoplasmic organelles with membranes.

They have no nucleus. Their genetic material is located in the central region of the cytoplasm as a **nucleoid**, and not surrounded by any nuclear membrane.

They measure 0.5  $\mu\text{m}$  and 5  $\mu\text{m}$ .

Prokaryotes are unicellular organisms, such as bacteria.

They do not form multicellular organisms.



### Eukaryotic cells

- They have a nucleus containing the genetic material which is enclosed by a double nuclear membrane.
- They have internal membranes surrounding the cytoplasmic organelles.
- They are, on average, over ten times the size of prokaryotic cells.
- They form unicellular and multicellular organisms.
- Eukaryotic cells can belong to animals or plants.

#### Eukaryotic animal and plant cells

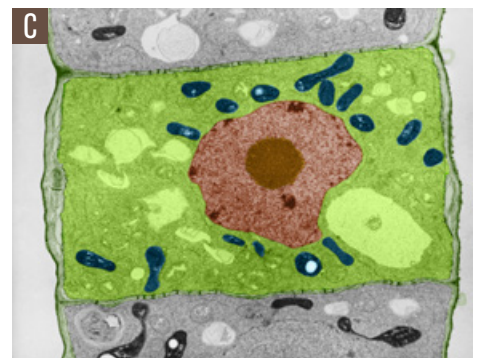
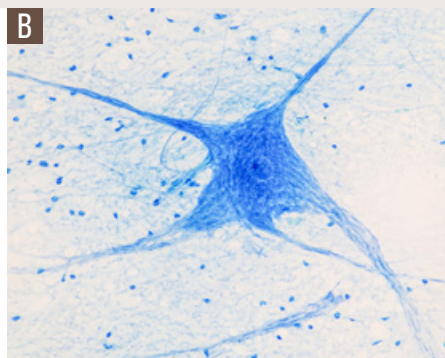
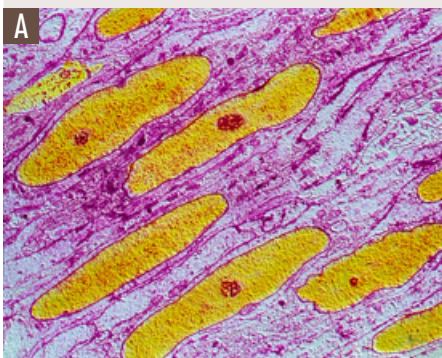
Eukaryotic animal cells are heterotrophic and are usually spherical in shape. Nevertheless, in multicellular organisms, in which the work is shared out among specialised cells, cell shape depends on its function. Muscle cells are elongated and nerve cells branch out for example.

In contrast, eukaryotic plant cells are autotrophic and polyhedral in shape.

Eukaryotic animal cells belong to organisms in the animal kingdom and protozoa in the protist kingdom.

Eukaryotic plant cells belong to organisms in the plant kingdom and algae in the protist kingdom.

The cells of organisms in the fungi kingdom don't have a clearly defined cell structure. They are eukaryotic and heterotrophic, like animal cells. They also have a cell wall, like plant cells.



A. Muscle cell. B. Nerve cell. C. Plant cell.

## 3 /// EUKARYOTIC CELLS

### Activities 6-11

Eukaryotic cells are contained within a **plasma membrane** and have a **nucleus** and **cytoplasm**. They may also have a **cell wall** with **cilia** and **flagella**.

The cytoplasm is made up of the **cytosol**, the **cytoskeleton** and **cytoplasmic organelles**.

Cytoplasmic organelles can be categorised according to whether they have surrounding membranes and whether these are single or double membranes.

The majority of the cytoplasmic organelles are found in eukaryotic cells belonging to both animals and plants, but some are only found in one or the other.

### 3.1 PLASMA MEMBRANE

The **plasma membrane** is a supramolecular complex made up of lipids and proteins that encases the cell.

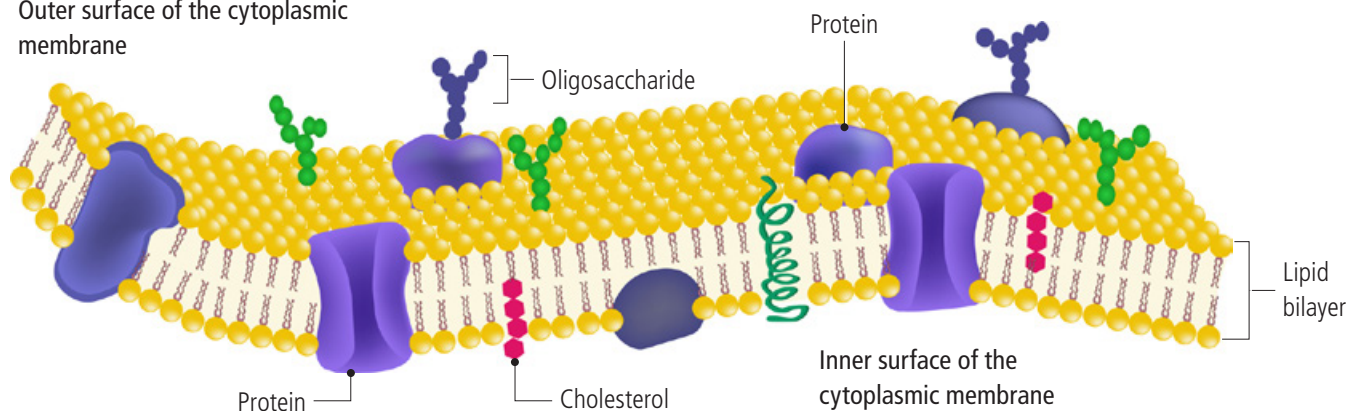
Structurally speaking, it is a fluid **phospholipid bilayer** in which proteins are arranged irregularly and asymmetrically.

In animal cells the plasma membrane also contains variable amounts of **cholesterol** as well as phospholipids. It also has short chains of carbohydrates (oligosaccharides) attached to its outer surface.

The main functions of the membrane are to:

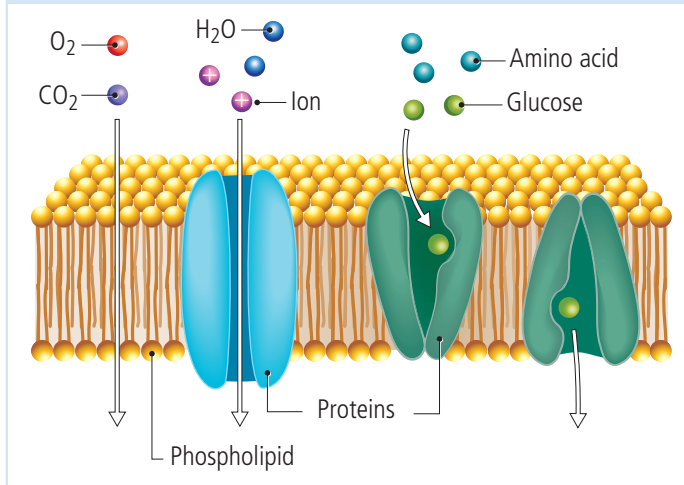
- Surround and protect the cell.
- Hold the cell's shape.
- Regulate the exchange of substances entering and leaving the cell.
- Transmit signals in and out of the cell.
- Allow the cell to be recognisable and identifiable.
- In multicellular organisms, encourage adherence or communication with adjacent cells through specialised intercellular unions.

Outer surface of the cytoplasmic membrane

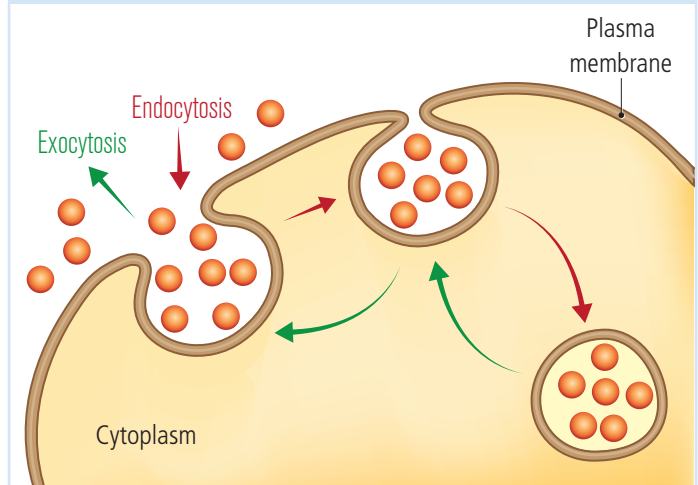


## Transport through the membrane

Small substances cross the membrane between the phospholipid bilayer (e.g. oxygen and carbon dioxide) or by using the channels made by the proteins (e.g. water, ions, glucose and amino acids).



Larger-sized particles enter by **endocytosis** and leave by **exocytosis**. These processes work through deformations in the membrane, thanks to small particles that are captured in vesicles to facilitate their transport.



## 3.2 CELL COVERINGS

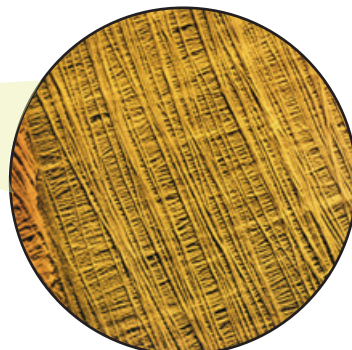
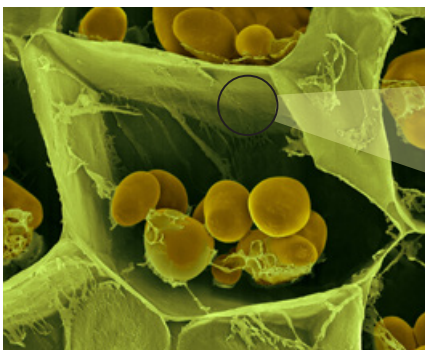
**Cell coverings** are thick and rigid cell walls around the plasma membrane that are attached to its outer side. They are mainly made up of carbohydrates.

Cell coverings come in various types: **cell walls in bacteria** (in prokaryotic cells) and **plant cells and fungi** (in eukaryotic cells).

- Cell walls in bacteria are formed of a complex carbohydrate, linked to short chains of amino acids, known as **peptidoglycans**, which are arranged in a mesh-like structure.
- Cell walls of plant and fungi cells are separated from the cell and formed of a fibrous component: the polysaccharide **cellulose** in plant cells and the polysaccharide **chitin** in fungi cells. The spaces between the fibres are filled with the **amorphous matrix**.

The main functions of the cell wall include:

- Giving shape, uniformity and structure to the cell and the multicellular organism.
- Limiting the entry of toxic molecules and pathogenic micro-organisms.



Cell wall of potato cells and its cellulose fibres seen under an electron microscope.

## 3.3 CYTOPLASM

The **cytoplasm** is the region of the cell between the plasma membrane and the nucleus. It contains the **cytosol**, the **cytoskeleton** and **cytoplasmic organelles**.

### Cytosol or hyaloplasm

The **cytosol** is the matrix formed of water, mineral salts, carbohydrates, lipids, amino acids, nucleotides, ribonucleic acids and proteins. Most of the chemical reactions related to cell metabolism take place here.

### Cytoskeleton

The **cytoskeleton** is a three-dimensional frame of protein filaments which extend through the hyaloplasm in all eukaryotic cells.

It is a dynamic structure which is continuously reassembled and reorganised depending on cell requirements.

The main functions of the cytoskeleton include:

- Supporting cell organelles.
- Giving the cell its shape.
- Allowing substances and vesicles to travel around the cytoplasm.

The cytoskeleton is made up of three types of protein filaments: **microfilaments**, **intermediate filaments** and **microtubules**.

#### Microfilaments

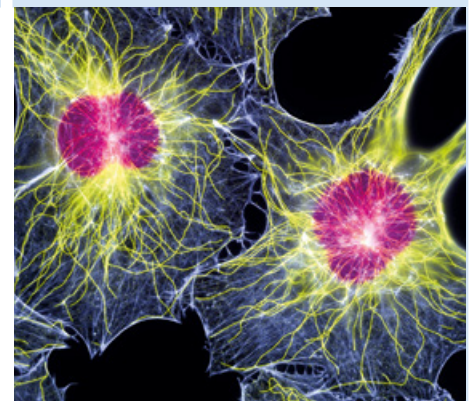
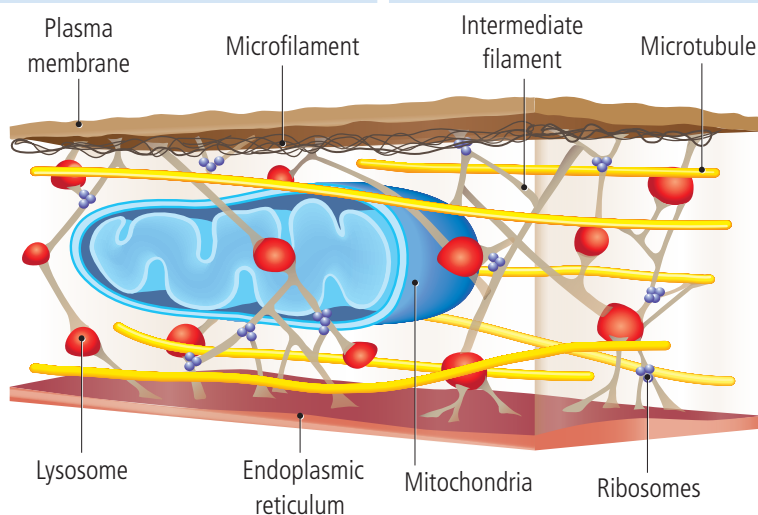
These are formed by polymerisation into double helices from monomers of **actin** protein. They are the slimmest and most fragile parts of the cytoskeleton. They are specifically involved in the deformation processes of the cell wall.

#### Intermediate filaments

These only exist in animal cells and look like ropes. They are formed of different types of protein, such as **cytokeratin**. These are the strongest parts of the cytoskeleton and their diameter lies between that of microfilaments and microtubules.

#### Microtubules

These hollow and rigid cylinders are made up of the polymerisation of **tubulin** protein monomers. They are the thickest parts of the cytoskeleton. They make up the internal structure of the achromatic spindle in cell division, the centrosome and cilia and flagella.



Optical micrograph of the cytoskeleton. The microtubules are shown in yellow and the microfilaments in blue.

## Cytoplasmic organelles

Cytoplasmic organelles include the **endoplasmic reticulum**, the **Golgi body**, the **lysosomes**, the **vacuoles**, the **mitochondria**, the **chloroplasts**, the **ribosomes** and the **centrosome**.

### Endoplasmic reticulum

The **endoplasmic reticulum** forms a system of membranous sacs and tube-like structures contained in a single membrane within the cytosol. They are connected to each other and the nuclear membrane.

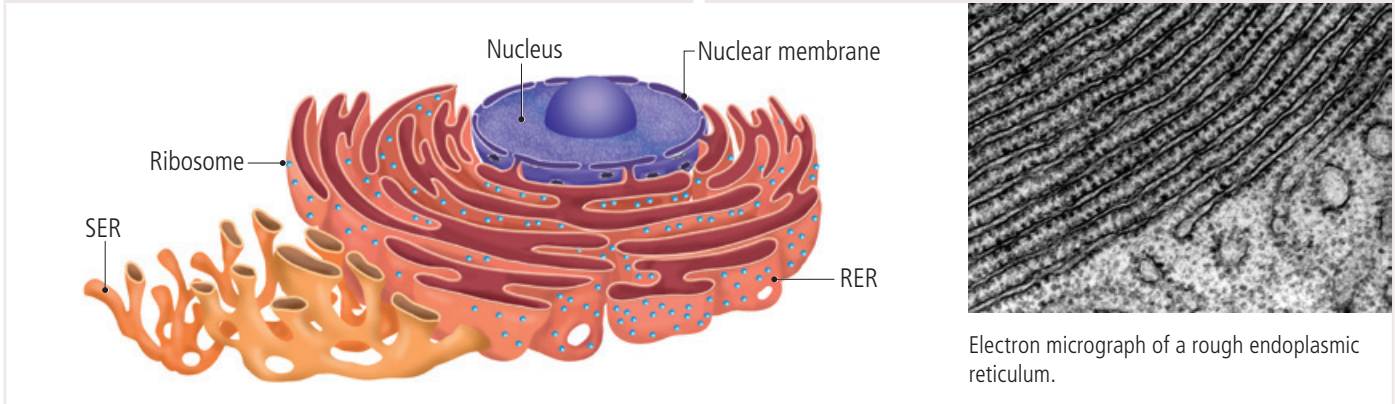
There are two different types: the **smooth endoplasmic reticulum (SER)** and the **rough endoplasmic reticulum (RER)**.

#### Smooth endoplasmic reticulum

Lacking ribosomes on its membranes, it works to synthesise membrane lipids and break down toxic substances.

#### Rough endoplasmic reticulum

With ribosomes attached to the surface of its membranes, its main function is to synthesise and secrete membrane proteins.

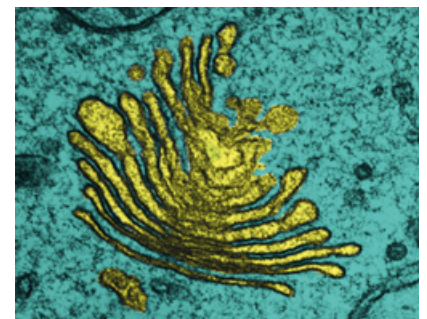


### Golgi body

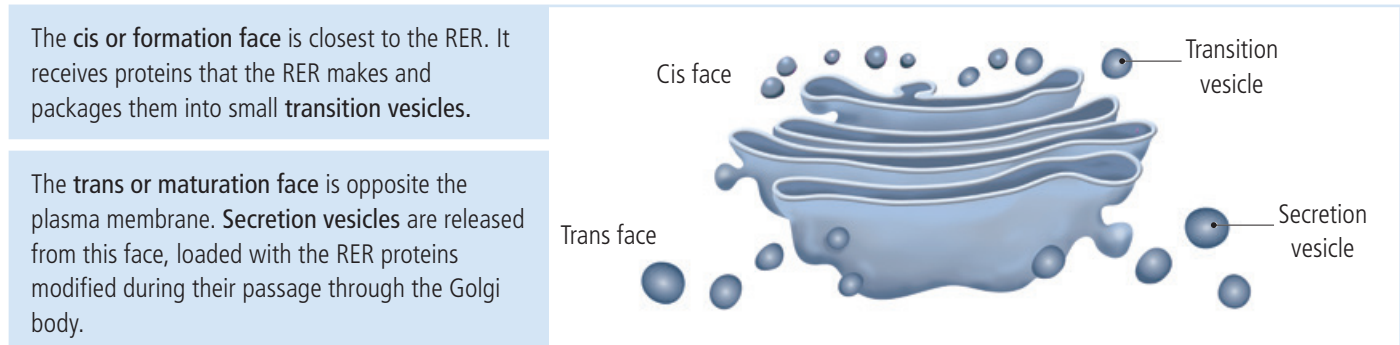
The **Golgi body** is made up of structural units called **dictyosomes**. Each dictyosome is a stack of disc-shaped sacs within a smooth membrane. The Golgi has two faces known as its **cis face** and its **trans face**.

The functions of the Golgi body include:

- Modifying proteins and lipids from the endoplasmic reticulum.
- Packaging and releasing substances carried in the vesicles for secretion by exocytosis.
- Forming cytoplasmic organelles, such as lysosomes.



Electron micrograph of a Golgi body.



## Lysosomes

Lysosomes are single-membrane vesicles formed by the Golgi body that contain hydrolytic enzymes.

Their function is to **digest** substances entering from outside the cell via endocytosis or materials inside the cell that need to be broken down, such as old organelles.

## Vacuoles

Vacuoles are single-membrane vesicles present in animal and plant cells, although they are especially developed in plant cells.

Their function is to:

- Store substances (water, waste products, reserves, aromatic substances and pigments).
- Maintain plant cell turgidity.

## Mitochondria

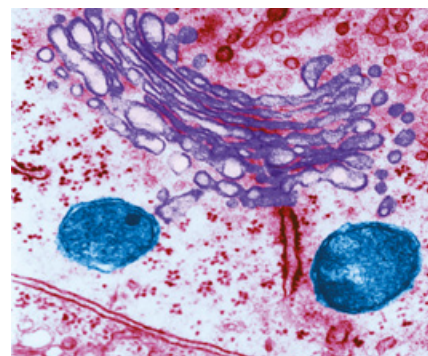
Mitochondria are organelles surrounded by a double membrane. They are cylindrical in shape and are able to divide by **binary fission**.

The main function of mitochondria is to generate chemical energy from nutrients (glucose) through a set of metabolic processes known as cellular respiration.

Cellular respiration is an aerobic process, as it requires oxygen, and can be summarised in the following general equation:



Mitochondria have a double membrane, an intermembrane space and a mitochondrial matrix.



Electron micrograph of lysosomes (in blue) close to the Golgi body.

### Lysosomes and lytic vacuoles

Lysosomes and lytic vacuoles perform the same function; lysosomes in animal cells and lytic vacuoles in plant cells.

### Double membrane

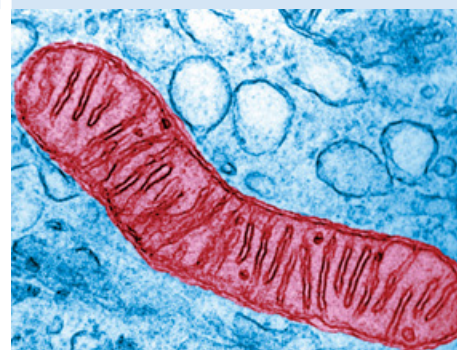
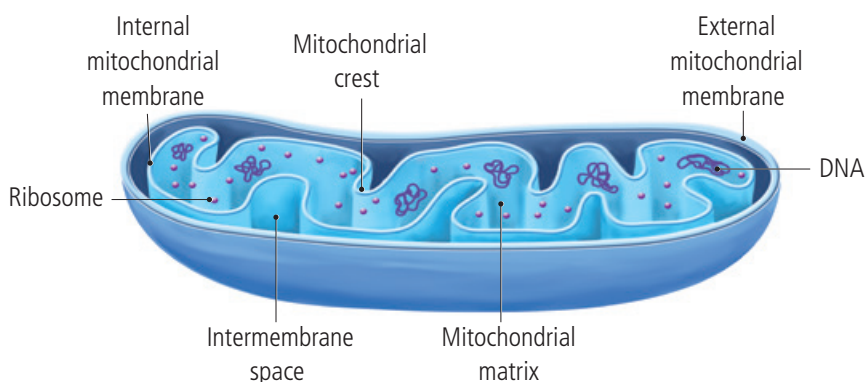
This is made up of a smooth **external mitochondrial membrane** and an **internal membrane** which is folded into **mitochondrial crests**.

### Intermembrane space

This is a small space between the outer and inner mitochondrial membranes.

### Mitochondrial matrix

This is surrounded by the inside membrane. It contains circular DNA and ribosomes similar to prokaryotic cells.



Electron micrograph of a mitochondrion.

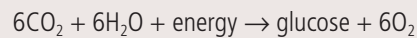
## Chloroplasts

**Chloroplasts** are organelles surrounded by a double membrane. They come in various shapes and are only found in eukaryotic plant cells. Just like mitochondria, they divide by **binary fission**.

They are organelles responsible for carrying out **photosynthesis**, which occurs in two stages:

1. **Light-dependent stage.** This takes place in the thylakoid membrane. Energy from the sun is converted into chemical energy.
2. **Light-independent stage.** This takes place in the stroma. The chemical energy that is generated in the light-dependent stage is used to transform  $\text{CO}_2$  into glucose.

The general equation for photosynthesis is:



Chloroplasts are made up of the following:

### Double membrane

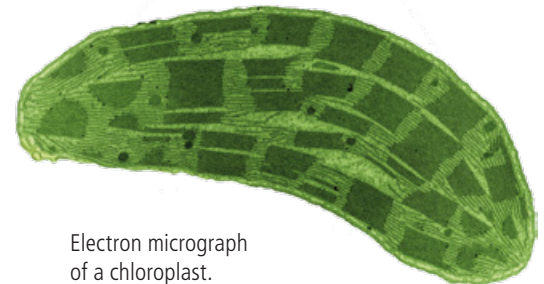
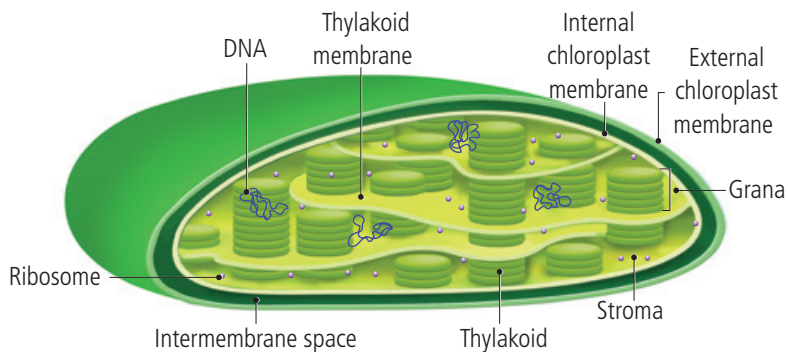
This is an **external chloroplast membrane** and an **internal membrane**, both of which are smooth.

### Intermembrane space

This is a small space located between the outer and inner chloroplast membranes.

### Stroma

This is bound by the internal membrane. It contains circular DNA and ribosomes similar to prokaryotic cells. The stroma is taken up by interconnected and flattened membranous sacs: the **thylakoids**. Stacks of thylakoids are called **grana**.

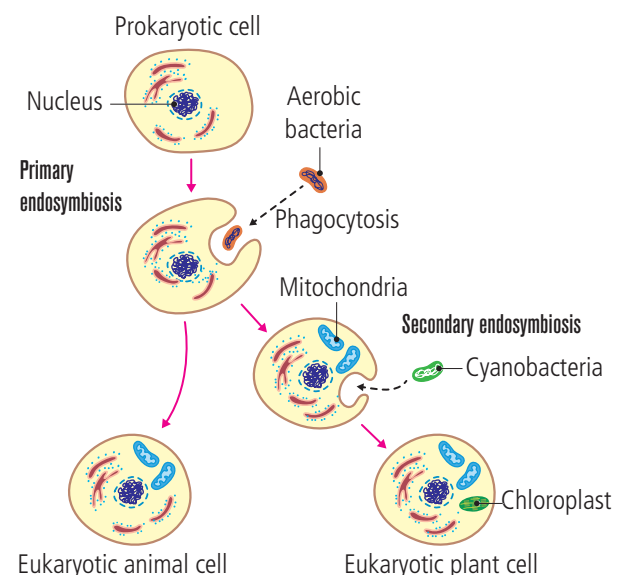


Electron micrograph of a chloroplast.

## The evolutionary origin of mitochondria and chloroplasts

The **endosymbiotic theory**, popularised by US biologist Lynn Margulis, states that mitochondria and chloroplasts originated from primitive prokaryotic cells via two consecutive endosymbiotic processes:

- **Primary endosymbiosis: mitochondria originate.** An anaerobic prokaryotic cell, with its DNA surrounded by a nuclear membrane, engulfed aerobic bacteria during phagocytosis which reproduced inside the prokaryotic cell and over time turned into mitochondria. This explains the origin of eukaryotic animal cells.
- **Secondary endosymbiosis: chloroplasts originate.** In a similar process to that of mitochondria, chloroplasts originate from photosynthetic bacteria (cyanobacteria) engulfed during phagocytosis which transformed into chloroplasts over time. This is how eukaryotic plant cells arose, and contain both mitochondria and chloroplasts.

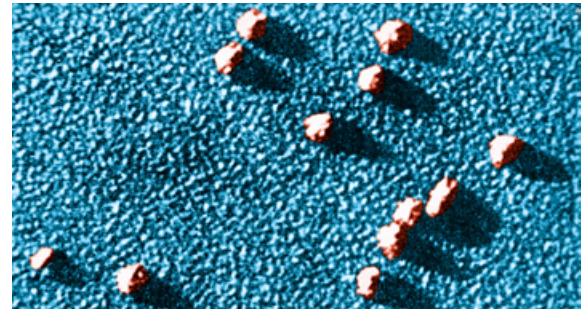
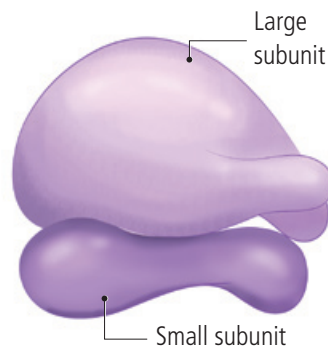


## Ribosomes

**Ribosomes** are compact particles not bound by any membrane. They are formed of ribosomal RNA and proteins in two subunits (large and small).

They are found in the cytoplasm of eukaryotic and prokaryotic cells, in the mitochondrial matrix and the stroma of chloroplasts. They also cover the cytoplasm-facing side of the RER and the external nuclear membrane.

Their function is to synthesise proteins from the information contained on the nucleic acids.



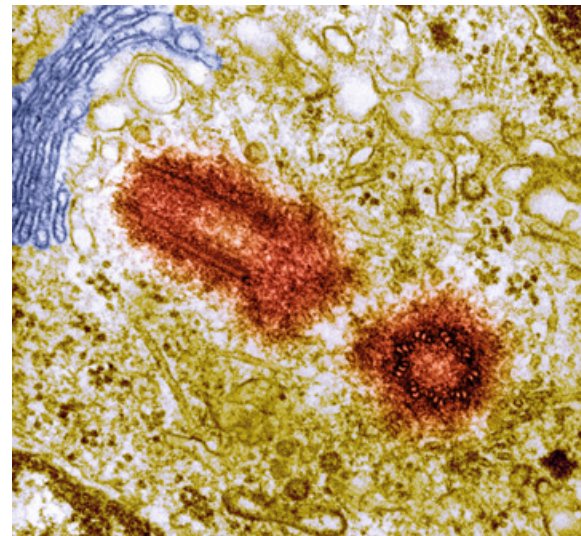
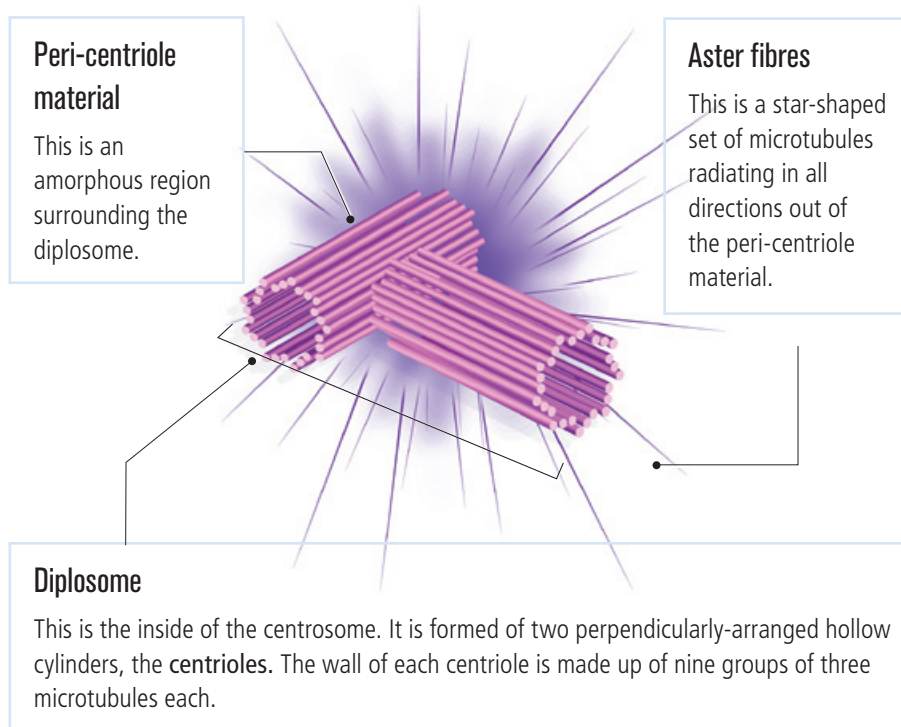
Electron micrograph showing various ribosomes.

## Centrosome

The **centrosome** is an organelle that is not surrounded by any membrane.

It is only found in animal cells close to the nucleus and is made up of microtubules of tubulin.

Centrosomes are made up of the following:



Electron micrograph of a pair of centrioles.

The centrosome is the organisation centre for microtubules. It is responsible for forming the following structures:

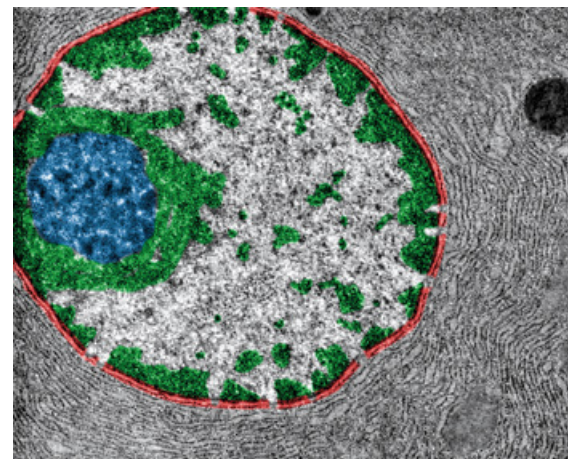
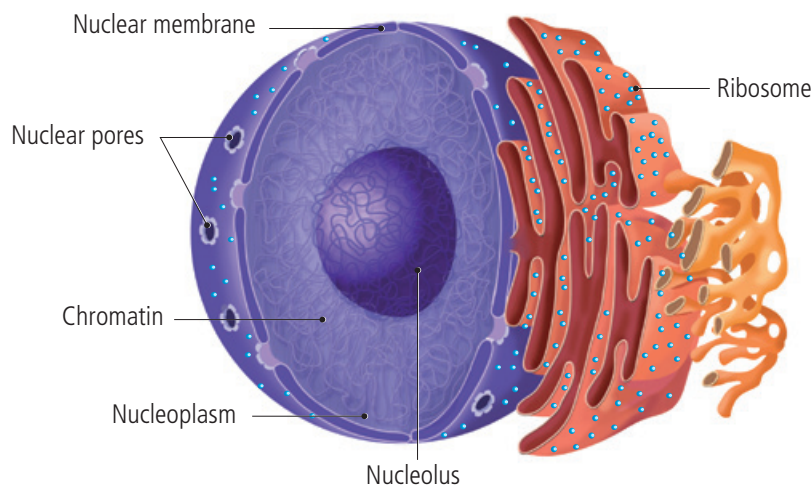
- The **microtubule components** of the cytoskeleton.
- A spindle of microtubules, known as the **mitotic spindle** or **achromatic spindle** during mitosis and meiosis.
- **Cilia** and **flagella**. These are mobile structures on the cell's surface that extend from the plasma membrane.

Their movement allows cells or the substances around them to move. Cilia are short and numerous, flagella on the other hand, are long but few.

## 3.4 THE NUCLEUS

The **nucleus** is a characteristic structure of eukaryotic cells. It is observed in the inside of the cell during **interphase**, i.e. when the cell is not dividing. In animal cells, the nucleus is spherical in shape and is usually positioned in the centre. In plant cells it is a flat-circular shape and frequently appears displaced towards one side due to the enormous vacuoles.

In the cell nucleus during interphase four components can be seen: the **nuclear membrane**, the **nucleoplasm**, the **nucleolus** and **chromatin**.



Electron micrograph of the nucleus.

### Nuclear membrane

This surrounds the contents of the nucleus. It is made up of two nuclear membranes: the **inner** and the **outer** membranes, between which there is a small **peri-nuclear space**.

The external nuclear membrane is actually an extension of the membrane of the rough endoplasmic reticulum and therefore, as such it has ribosomes attached to its inner face. The internal nuclear membrane however, does not have any ribosomes.

Both membranes are joined by **nuclear pores**: regulable channels that open to allow the exchange of substances between the nucleus and the cytoplasm.

### Nucleoplasm

This is the fluid inside formed of water, ions, nucleotides, RNA and proteins.

### Nucleolus

This is a roughly spherical region inside made up of DNA sequences responsible for ribosome synthesis. There may be more than one nucleolus. It is easily visible through an electron microscope due to its electron density.

### Chromatin

Chromatin is a mesh of fibres that extends out into the nucleoplasm, formed of DNA and proteins called **histones**. These help it to be more compact.

The nucleus has two main functions, namely to:

- Control cell functions from the genetic information contained in the DNA.
- Ensure the conservation of this genetic information through DNA replication.

## //// SPEAK <<<<

Work in pairs or small groups to write true or false sentences about the similarities and differences between plant and animal cells. Then, read your sentences to another group to check your knowledge.

### KEY STRUCTURES

How about including a sentence about ...?; Let's write that ...; Is it true that ...?; Would it be a good idea to ask about ...?; Is that correct?

## 4 /// CHROMOSOMES

Activities 12-15

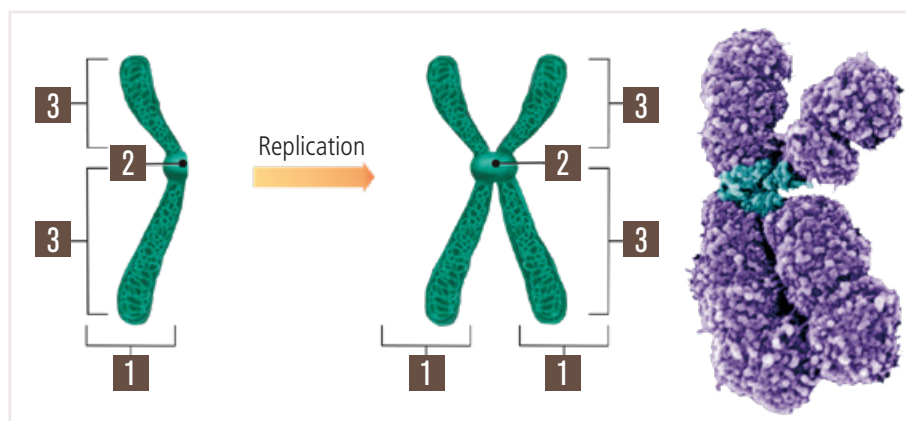
A **chromosome** is a large molecule formed of two linear strands of DNA in various lengths coiled into a double helix. It is very compact and can be observed under a microscope in eukaryotic cells when they are dividing in mitosis and meiosis.

The function of chromosomes is to ensure the genetic information contained in the DNA is preserved and passed on from the parent cell to the daughter cells.

Before cell division, each DNA molecule replicates itself to produce two identical copies. This guarantees that after the division, each cell receives a full copy of the DNA.

### 4.1 CHROMOSOME STRUCTURE

Chromosomes can be seen to have three parts: **chromatids**, **centromere** and **arms**.



#### 1 Chromatid

Chromatids are rod-shaped structures made up of a compacted molecule of DNA coiled into a double helix.

Before DNA replication, chromosomes only have one chromatid.

After DNA replication, the chromosome is formed of two identical sister chromatids. The rounded ends of the chromatids are called **telomeres** and are essential for chromosome stabilisation.

#### 2 Centromere or primary constriction

This is the constricted or narrow region that divides the chromosome into two arms. In chromosomes with two chromatids, this join is at the centromere.

#### 3 Arms

Centromeres divide the chromatids into halves known as arms.

### /// SPEAK <<<<

Work in pairs. Imagine you are a medical team, and you are going to give a talk about how paternity tests work. Find out and discuss how the tests are carried out, what steps are followed and how accurate the tests are.

#### KEY VOCABULARY

accuracy swab fragmented avoid  
contamination sample prove

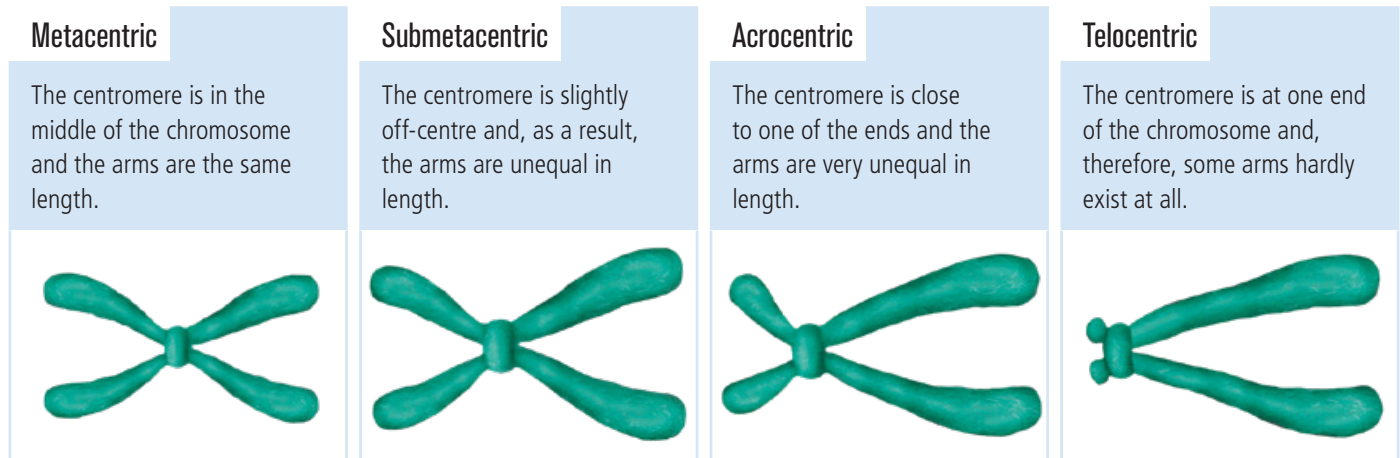
The molecular biologist and scientist from Alicante María Antonia Blasco has been pioneering in her studies into cell ageing and cancer and their relationship with chromosome ends or telomeres.

Her research and discoveries have garnered great prestige and international recognition in the fields of medicine and molecular biology. Since 2011 she has been the Director of the Spanish National Cancer Research Centre (CNIO).



## 4.2 CHROMOSOME TYPES

Chromosomes are classified depending on the position of their centromere.



## 4.3 KARYOTYPE AND CHROMOSOME NUMBERS

A **karyotype** is the set of chromosomes of a cell arranged in an established pattern, which categorises them according to the position of their centromere, their relative length (proportional to the base pairs that they contain) and their banding pattern when stained. Upon examination, the following conclusions can be drawn:

- The number of chromosomes is invariable for each species, unless there are genetic alterations.
- **Ploidy** is the number of complete sets of chromosomes in a cell. The number of chromosomes contained in a complete set is the **haploid** number and is given the letter  $n$ . The number of chromosomes corresponding to two complete sets is the **diploid** number and is represented as  $2n$ .

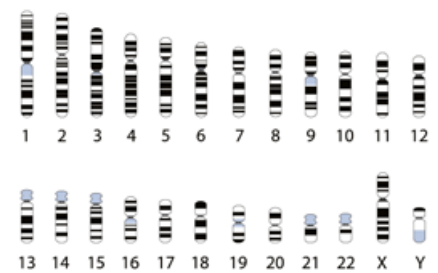
With this in mind, it can be concluded that: 1. The gametes of all species are haploids. 2. The zygotes of all species are diploids, as they combine both sets of chromosomes from the two gametes during the fertilisation process.

- Paired chromosomes from the diploid cells are called **homologous chromosomes**. These chromosomes are similar in shape, size and banding, although the information that they contain is not necessarily the same.

### Karyogram

A **karyogram** is a to-scale graphical depiction of the size, shape and banding pattern of all the chromosomes in a cell.

Karyograms represent just one chromosome of each pair of homologous chromosomes.



### Haploid cell ( $n = 3$ )

It has a set of 3 chromosomes. It has no homologous chromosomes; all of its chromosomes are different.



### Diploid cell ( $2n = 6$ )

It has 2 sets of three chromosomes and therefore, has three pairs of homologous chromosomes.



- In species in which sex is determined by the chromosomes, as occurs with the majority of animals, there are two different types of chromosomes: **autosomes** (which are not involved in determining sex) and **heterochromosomes** (also called sex chromosomes, which determine the sex of the organism). Heterochromosomes in mammals are called **X** and **Y**. Females are XX and males, XY.

## Human karyotypes

The number of chromosomes of non-sex (somatic) chromosomes in humans is  $2n = 46$ .

In the human karyotype, chromosomes are organised into seven groups. Humans do not have any telocentric chromosomes.

### Large chromosomes

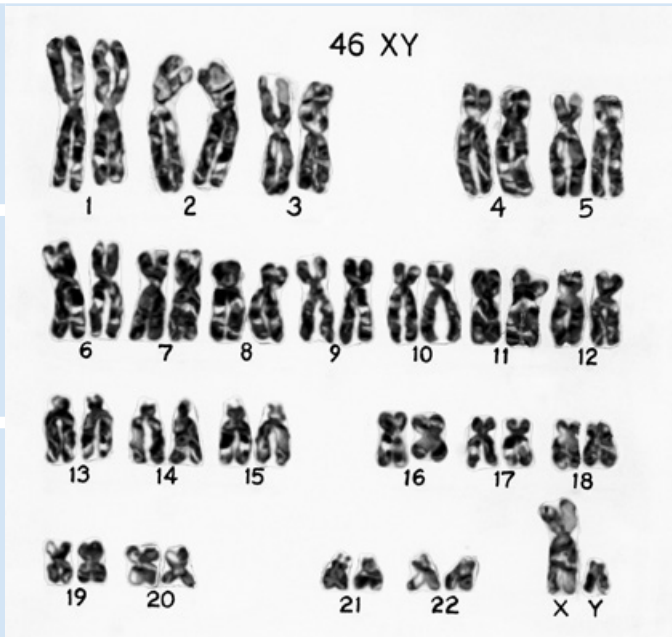
- Group A: chromosomes 1 (metacentric), 2 (submetacentric) and 3 (metacentric).
- Group B: chromosomes 4 and 5 (submetacentric).

### Medium chromosomes

- Group C: chromosomes 6, 7, 8, 9, 10, 11, 12 and chromosome X (submetacentric).
- Group D: chromosomes 13, 14 and 15 (acrocentric).

### Small chromosomes

- Group E: chromosomes 16, 17 and 18 (submetacentric).
- Group F: chromosomes 19 and 20 (metacentric).
- Group G: chromosomes 21, 22 and chromosome Y (acrocentric).



## Creation of a karyotype

### Materials

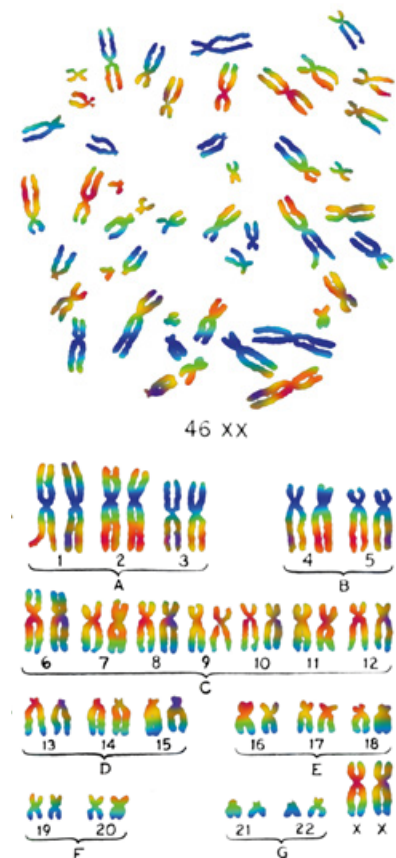
- Photograph or image of chromosomes seen under an optical microscope.
- Scissors, card and glue.

### Method

- 1 Count the number of chromosomes to confirm that the number matches the normal diploid number. This will also reveal whether the individual to whom it belongs has any chromosomal abnormality.
- 2 Cut out each of the 46 chromosomes and match them up into their homologous pairs. For ease of recognition, you can compare them to the chromosomes on the karyotype above or those on the karyogram.
- 3 Stick the homologous pairs onto the card in descending order with regard to their total length, with the centromeres positioned on the same horizontal line.
 

When the arms are of unequal length, turn each chromosome around so that the short arms point upwards and the long arms downward.
- 4 Number each pair of autosomes, arranged in decreasing length, consecutively from 1 to 22.
- 5 Classify the pairs into their corresponding group. To do this, highlight the pairs from each group and write the name of the group under the line.

- 6 Stick the sex chromosomes at the end of the karyotype. If they are different, first place the X and then the Y. You can now determine the sex of the individual.



## 5 /// CELL DIVISION

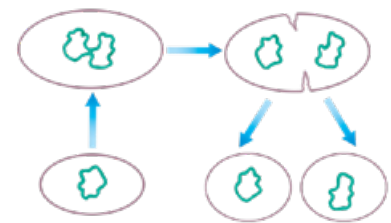
Activities 16-17

**Cell division** is a process by which each cell creates new cells. Prokaryotic cells and eukaryotic cells divide in different ways.

### 5.1 CELL DIVISION IN PROKARYOTIC CELLS

Cell division in prokaryotic cells occurs through **binary fission** or **amitosis**. The cell replicates its DNA to obtain two identical copies of the bacterial chromosome. Then the cytoplasm divides (cytokinesis) through a process of progressive contraction of its central part which culminates in its separation into two daughter cells, each with its own copy of the bacterial chromosome.

Binary fission is a type of **asexual reproduction** as two daughter cells arise from a single parent cell and are genetically identical to it.



Binary fission.

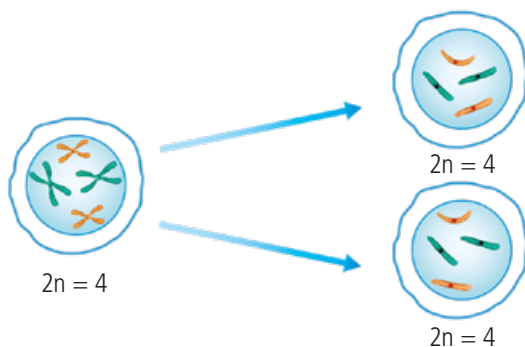
### 5.2 CELL DIVISION IN EUKARYOTIC CELLS

In eukaryotic cells, cell division involves the segregation (separation) and distribution of chromosomes before the cytoplasm divides. There are two ways in which this cell division can happen: by **mitosis** or by **meiosis**.

#### Mitosis

Mitosis is a process that follows the corresponding division of the cytoplasm (cytokinesis). It distributes and segregates the chromosomes into two daughter cells with the same number of chromosomes and identical genetic information as the parent cell. It is, therefore, the division mechanism involved in asexual reproduction.

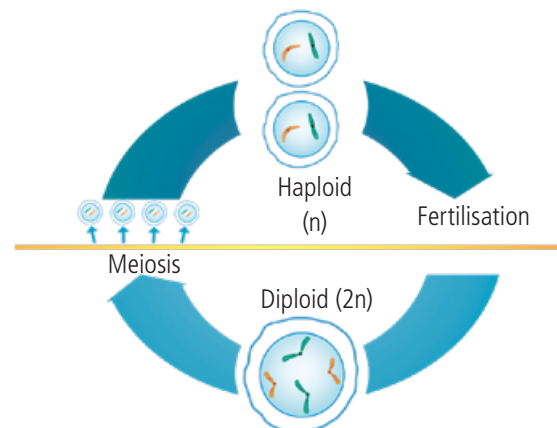
It is the main mechanism for division in eukaryotic cells. Mitosis produces unicellular eukaryotic organisms and divides the cells of multicellular eukaryotic organisms during embryonic development, growth and tissue repair.



#### Meiosis

Meiosis is a process of distributing and segregating chromosomes that has two consecutive cytoplasmic divisions. It produces four haploid cells, with half the number of chromosomes as the parent cell.

This mechanism is linked to sexual reproduction, which involves combining two of the reproductive cells of the chromosomes (the gametes) in fertilisation to make a zygote. Given that fertilisation doubles the number of chromosomes, meiosis is needed to produce haploid cells.



## 5.3 LIFE CYCLES

A **life cycle** is a series of changes that an organism of a sexually-reproducing species undergoes throughout its life. It starts with fertilisation and zygote formation and ends when the new organisms produce gametes, which then restart the cycle once they are fertilised.

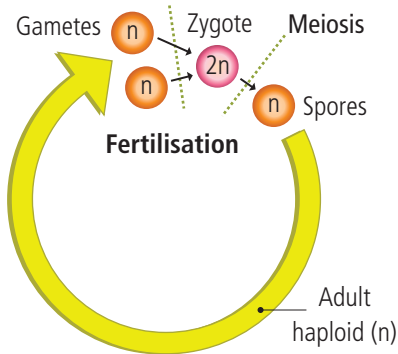
Alternating between the stages of fertilisation and meiosis requires alternating between a diploid phase ( $2n$ ) and a haploid phase ( $n$ ) throughout the life cycle.

Meiosis creates the haploid phase and, depending on the types of cells that are created, can establish three kinds of life cycles: **haploid**, **diploid** and **haploid-diploid** cycles.

### Haploid cycle

Meiosis is the first division of the zygote and generates **meiospores**, which develop by mitosis to become adults with haploid cells.

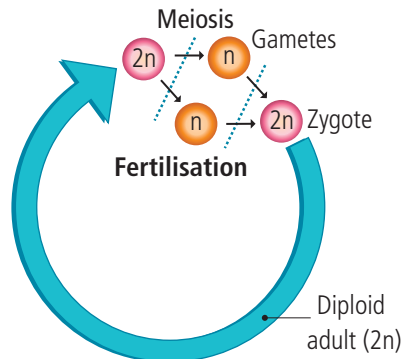
This is typical of many fungi and algae.



### Diploid cycle

Meiosis occurs in the sex cells to produce **gametes**, which fuse to create the zygote. This zygote then develops by mitosis to give rise to an adult with diploid cells.

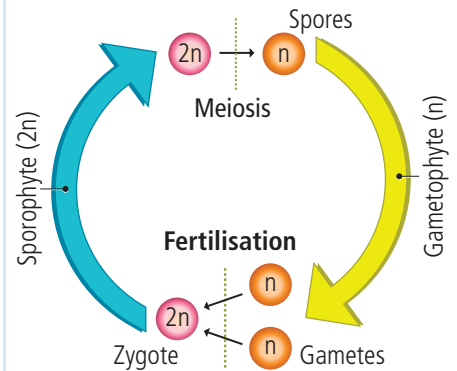
This is typical of animals.



### Haploid-diploid cycle

The zygote develops into a diploid adult (sporophyte). Meiosis occurs in special cells of the sporophyte and creates **meiospores** that develop into haploid adults (gametophytes), and produce **gametes**.

This is typical of plants.



### COMPARISON OF ASEQUAL AND SEXUAL REPRODUCTION

	Advantages	Disadvantages
Asexual reproduction	<ul style="list-style-type: none"> <li>Only one parent is involved, so no time or resources are spent searching for a mate.</li> <li>Does not require the formation of specialised reproduction cells, which saves energy.</li> <li>Produces offspring that is genetically identical to its parent and to each other. This ensures the survival of the species in populations adapted to its environment and in stable environments.</li> </ul>	<ul style="list-style-type: none"> <li>Does not introduce genetic variability in offspring. The only source of genetic variability comes from DNA replication errors: mutations.</li> <li>Genetically identical populations lower their chances of survival when faced with changes in their environment.</li> </ul>
Sexual reproduction	<ul style="list-style-type: none"> <li>Introduces genetic variability in offspring, due to the genetic contributions from both parents and the way in which meiosis works. Therefore, offspring are genetically different from their parents and each other.</li> <li>A population made up of genetically different individuals increases the probability that some of them are better adapted to new environmental conditions and as a result, the chances of survival of the species when faced with environmental changes. This is the basis of evolution.</li> </ul>	<ul style="list-style-type: none"> <li>It requires the involvement of two parents, who must invest time and resources into finding a partner.</li> <li>The process of forming specialised reproductive cells requires huge amounts of energy.</li> </ul>

## //// SPEAK <<<<

Prepare a presentation for your classmates about cell division in eukaryotes. Explain why each phase is important, what can go wrong and how that would affect cell division.

### KEY STRUCTURES

This phase is essential because ... ; The things that could go wrong are ... ; If this phase didn't occur, ...

## 6 /// EUKARYOTIC CELL CYCLE

### Activities 18-24

The **cell cycle** is a sequence of ordered, co-ordinated and regulated events that a cell goes through in its life: from the moment it is formed from the division of an existing cell to the moment it divides and produces two daughter cells that will start on their own cycles.

There are two stages to the cell cycle in eukaryotic cells: **interphase** and **M phase** or **division phase**.

### Interphase

This is the part of the cell cycle that occurs between two cell divisions and is also the longest stage in the cell cycle. During interphase, the cell expresses its genes, grows, duplicates its DNA and prepares itself for the M phase. It is divided into three substages: G1, S and G2.

#### G1 phase

This is the first stage of interphase. It begins after the M phase and before the S phase.

It is a period of intense metabolic activity in which the cell expresses its genes and increases in size and the number of its organelles.

#### S phase

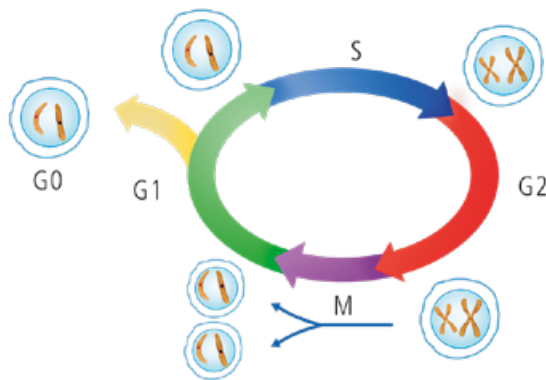
S phase occurs after the G1 phase. The cell replicates its DNA to contain two identical copies of the genetic material.

After the S phase, the nucleus contains double the amount of DNA than at the end of the G1 phase.

#### G2 phase

This occurs after the S phase and is when the cell synthesises the products it will need for the following M phase.

In animal cells, the centrosome duplicates itself.



### M phase

This is the cell cycle stage which divides the cell into two daughter cells.

Mitosis and cytokinesis occur during the M phase.

Mitosis is the stage of cell division which equally shares out the hereditary material between the daughter nuclei. It contains four stages: **prophase**, **metaphase**, **anaphase** and **telophase**.

Cytokinesis is the last stage of cell division and is when the cytoplasm divides. It overlaps with the final stages of mitosis.

## //// SPEAK <<<<

Work in pairs or small groups to write 6 sentences to play two rounds of “Two truths, One lie” about prokaryotic and eukaryotic cells. Then read your sentences to another group to guess which sentences are untrue.

### KEY STRUCTURES

Let’s include a sentence about...; Our false sentence can be about...; Could we talk about...?; I’m not sure that’s right.

### G0 phase

Certain very specialised cells, such as neurones, stop the progression of their cell cycle and enter into a period called G0, in which their DNA does not replicate and the cell does not divide, but remains in a permanent state of interphase.

## 6.1 MITOSIS

Cell division through **mitosis** is considered an **equal** type of division given that a parent cell produces **two daughter cells** with the same number of chromosomes and identical genetic information to that of the original parent cell.

Although it is a continuous and gradual process, to facilitate its description and examination, it is divided into the following four stages: **prophase**, **metaphase**, **anaphase** and **telophase**.

Some authors divide prophase again into two stages: early prophase and late prophase, before metaphase.

### Prophase

The chromatin duplicated in the S period condenses to form chromosomes with two chromatids.

In animal cells the centrosomes (previously duplicated in G<sub>2</sub>) migrate to opposite poles of the cell and form the mitotic or achromatic spindle.

In plant cells, which lack a centrosome, the mitotic spindle is organised from two dense cytoplasmic regions which act as microtubule control centres.

The microtubules of the mitotic spindle join up with the centromeres of the chromosomes.

The nucleolus and the nuclear membrane disappear.

### Metaphase

The chromosomes are fully condensed and arrange themselves along the cell's equator, forming the **equatorial plane**.

At the equatorial plane, sister chromatids of each chromosome are positioned pointing to either end of the spindle.

### Anaphase

The spindle's microtubules contract and pull the sister chromatids in opposite directions causing the chromosomes to break at their centromeres.

Each chromatid is slowly dragged towards a spindle pole.

The separated chromatids become individual daughter chromosomes formed of a single chromatid.

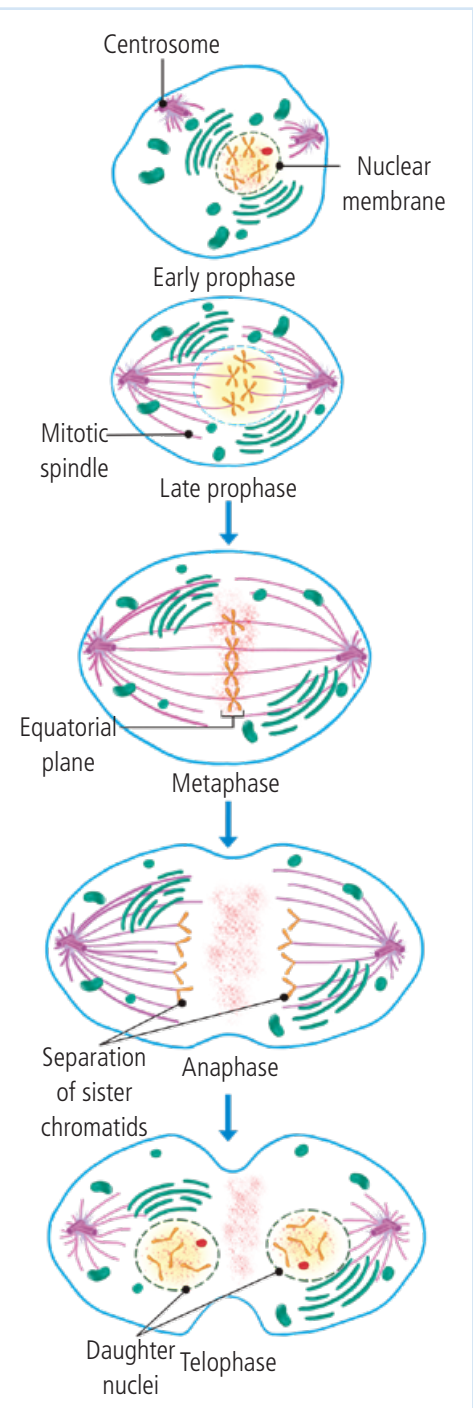
The mitotic spindle enlarges and increases the distance between the two poles of the cell.

### Telophase

Separated daughter chromosomes arrive at the poles. They slowly unravel, turn back into chromatin and the nucleoli reappear.

The nuclear membrane forms around each set of chromosomes and daughter nuclei have been formed.

Mitosis has come to an end, and daughter nuclei are once again at interphase.



## 6.2 CYTOKINESIS

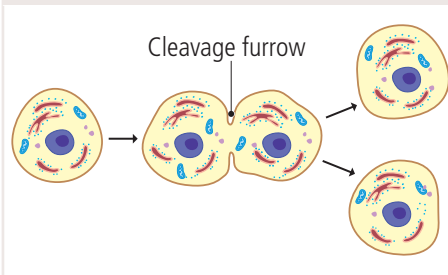
**Cytokinesis** or division of the cytoplasm occurs gradually as the chromosomes separate. The cytoplasm starts to divide at the end of anaphase or start of telophase and ends at the end of this latter stage. It happens differently in animal and plant cells.

### Cytokinesis in animal cells

This can occur in three ways: by **binary fission**, **budding** and **multiple fission** (e.g. sporulation).

#### Binary fission

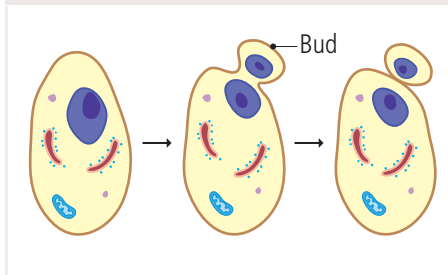
Binary fission is the most usual method of cytokinesis. It occurs in animal cells and for many protozoa, such as paramecia and amoeba. The cytoplasm constricts around the middle, creating two daughter cells of approximately the same size. The constriction is caused by the plasma membrane being pinched inwards to form a cleavage furrow.



#### Budding

The cytoplasm divides itself asymmetrically, and one of the daughter nuclei is introduced into a protrusion on the cell surface, known as a bud. This separates from the parent cell.

This is typical of yeast (unicellular fungi).

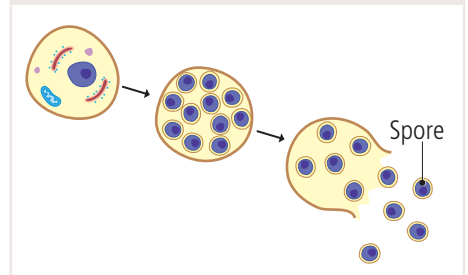


#### Multiple fission

This is the repeated division by mitosis.

Each resulting daughter nucleus is surrounded by a membrane and a portion of the cytoplasm. This is how spores are formed, which are released from the parent cell.

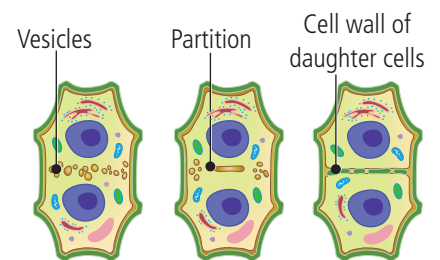
This is common among protozoa.



### Cytokinesis in plant cells

This occurs by **partitioning**, as it requires the formation of a cell wall between the two daughter cells.

This new cell wall is formed by the accretion of vesicles from the Golgi body which form a partition across the central region of the cytoplasm. The partition grows from the centre to the periphery until it divides into two daughter cells of approximately the same size.



### Microscopic interpretation of mitosis

To examine mitosis, cells in the process of division are used, such as those located on stem and root tips.

#### Stages of mitosis in onion root cells

##### Prophase

The chromatin condenses and the chromosomes become visible.



##### Metaphase

Chromosomes line up on along the equatorial plate.



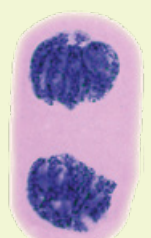
##### Anaphase

Sister chromatids are drawn to opposite poles of the cell.



##### Telophase

Daughter nuclei are formed, and the chromatin uncoils.



# 7 /// MEIOSIS

Activities 25-30

Cell division by **meiosis** is **reductive** as it generates four haploid ( $n$ ) cells from a diploid parent cell ( $2n$ ). To reduce the number of chromosomes, meiosis requires two consecutive cell divisions: **meiosis I** and **meiosis II**. There is no DNA replication phase in between these two stages.

## Meiosis I

### Prophase I

The chromatin condenses and the homologous chromosomes pair up, cross over with each other and exchange segments. This crossing-over results in genetic recombination, thanks to which new genetic combinations are produced and genetic variability is introduced in offspring. The achromatic spindle is formed and the nuclear membrane and nucleolus disappear.

### Metaphase I

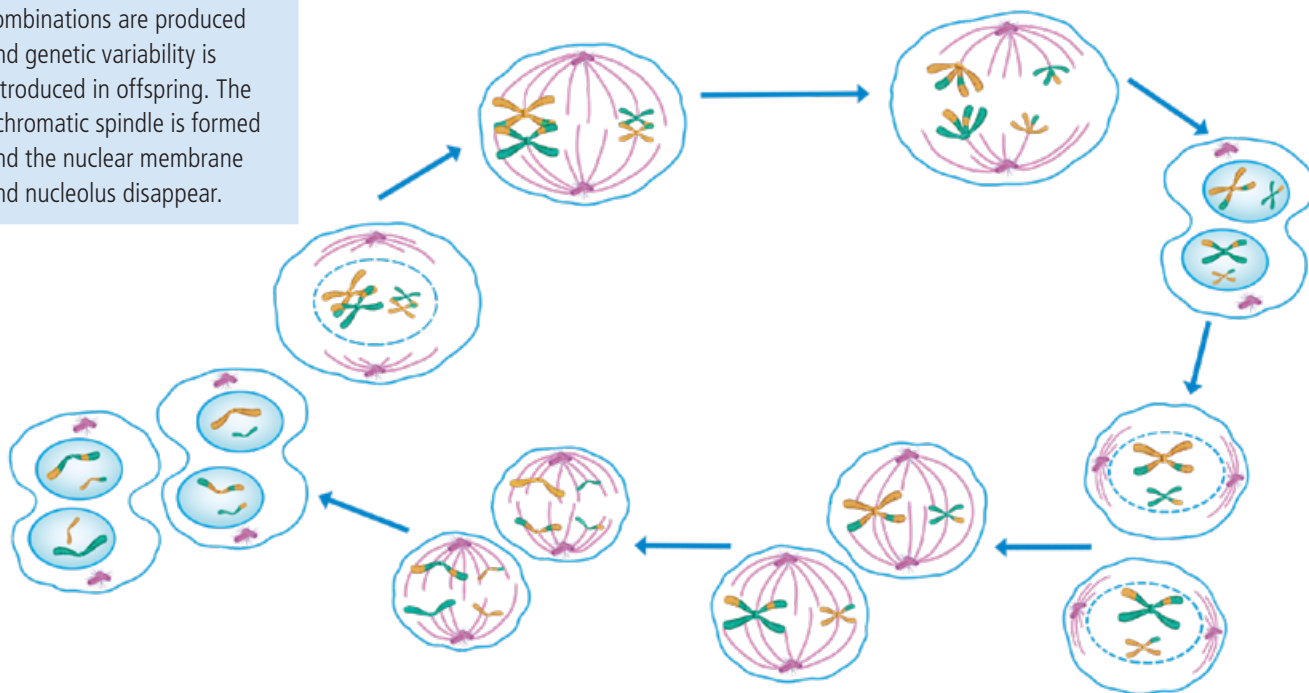
The equatorial plate is formed. Pairs of homologous chromosomes line up along the microtubules of the spindle by their centromeres in position to move towards opposite poles of the cell.

### Anaphase I

The homologous chromosomes (formed of two chromatids) are dragged to opposite poles as the spindle filaments shorten.

### Telophase I

Around each haploid ( $n$ ) set of homologous chromosomes is a temporary nuclear membrane. The cytoplasm starts to divide.



Meiosis II

### Telophase II

Nuclear membranes form around each haploid set of chromosomes of one chromatid. These unwind and the nucleoli reappear. Cytokinesis occurs at the same time, and so at the end of meiosis II the result is four haploid ( $n$ ) cells.

### Anaphase II

The sister chromatids (different due to genetic recombination) separate as they are dragged by the microtubules of the spindle to their respective poles.

### Metaphase II

The equatorial plate forms, made up of chromosomes joined to the spindle's microtubules, with its two sister chromatids pointing towards opposite poles of the cell.

### Prophase II

The nuclear membrane disintegrates and a new achromatic spindle forms in each daughter cell from meiosis I. The chromatin condenses resulting in chromosomes with two chromatids.

## 7.1 GENETIC VARIABILITY IN MEIOSIS

Meiosis is an extremely important biological process for two reasons:

- **It ensures the same number of chromosomes** in sexually-reproducing species.

This is because meiosis halves the number of chromosomes and therefore prevents it from doubling with each generation.

- **It introduces genetic variability in offspring**, due to the fact that the reproductive cells originating from meiosis present new genetic combinations thanks to two independent mechanisms linked to meiosis:

- Genetic recombination, in prophase I.
- Random distribution of homologous chromosomes and sister chromatids in anaphases I and II.

## //// SPEAK <<<<

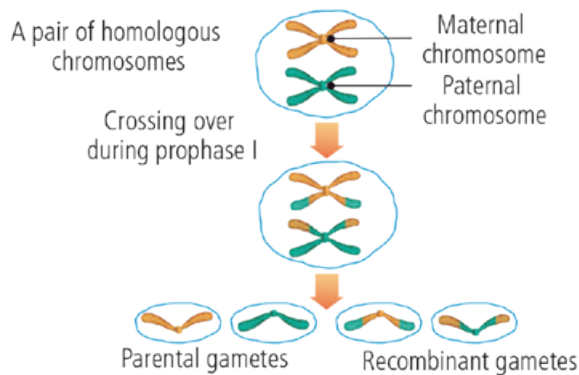
Nowadays there are many companies that offer personal DNA testing to learn about health, family history and ancestry. Work in small groups to find out how DNA testing kits work and discuss why people would want their DNA tested and if there are any disadvantages to these tests.

### KEY VOCABULARY

accurate saliva swab sample  
origin personalised report

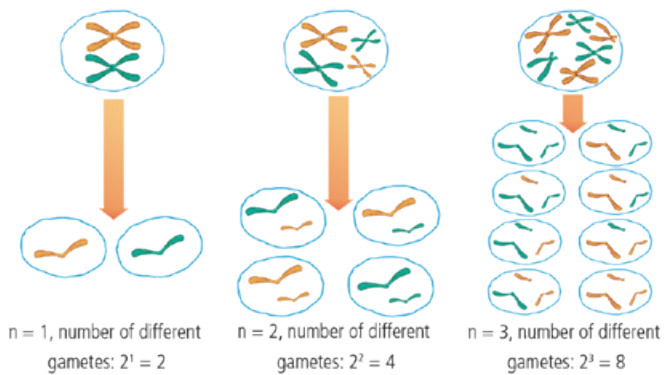
### Genetic recombination

Genetic recombination is the mixing of genes from both parents between homologous chromatids as they randomly cross over with each other during prophase I.



### Random distribution in anaphase stages


Maternal and paternal chromosomes line up at the top or at the bottom of the equatorial plate randomly. As a result, each meiosis can generate different  $2n$  gametes, where  $n$  is the haploid number of the species' chromosomes.




## 7.2 COMPARISON OF MITOSIS AND MEIOSIS


	Mitosis	Meiosis
Differences	<ul style="list-style-type: none"> <li>• Maintains the same number of chromosomes.</li> <li>• Produces two daughter cells identical to each other and the parent cell.</li> <li>• Can produce haploid and diploid cells.</li> <li>• Is linked to asexual reproduction.</li> <li>• Does not introduce genetic variability in offspring.</li> </ul>	<ul style="list-style-type: none"> <li>• Halves the number of chromosomes.</li> <li>• Produces four daughter cells, all different to each other and the parent cell.</li> <li>• Can only occur in diploid cells.</li> <li>• Is linked to sexual reproduction. Forms specialised reproductive cells that are haploid: gametes and meiospores.</li> <li>• Introduces genetic variability in offspring.</li> </ul>
Similarities	<ul style="list-style-type: none"> <li>• Requires a stage prior to DNA duplication (S phase), given that at the start of both meiosis and mitosis, the chromosomes must have two sister chromatids.</li> <li>• The chromosomes are positioned similarly in each of the equivalent stages.</li> <li>• They are mechanisms for nuclear division that only occur in eukaryotic cells.</li> </ul>	

# ACTIVITIES

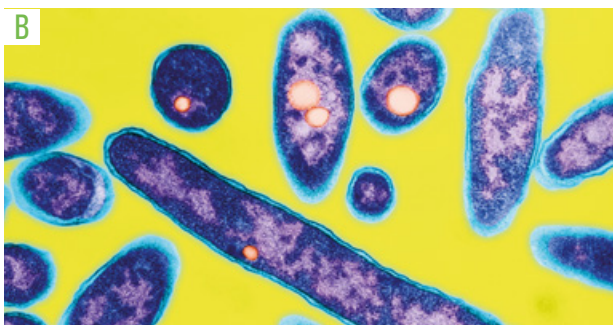
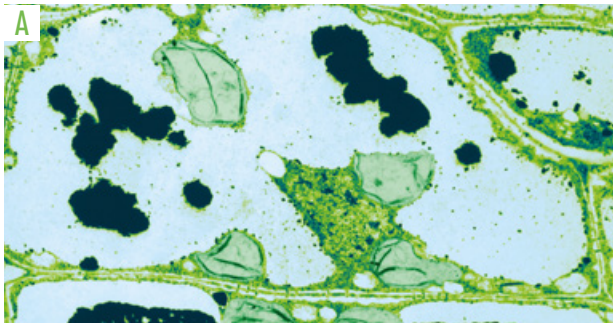
- 1  Listen and complete the sentences in your notebook.
  - a. The 1918 ..... influenza A virus is also known as .....
  - b. Two years after the first recorded case, the virus had spread to ..... people.
  - c. The number of deaths is estimated to be between .....

2  Discuss whether viruses are living things. How would you relate viruses with SDG 3?

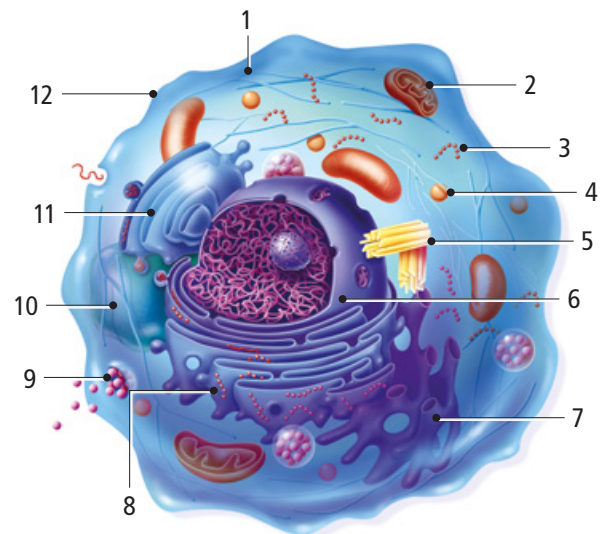
3 Is biological reproduction possible in any way if genetic material is not replicated? Justify your answer.

- 4  Listen and write in your notebook: T (true) or F (false).
  - a. Ramón y Cajal worked as a doctor in the military.
  - b. He grew up in Zaragoza.
  - c. He taught medicine all over the world.
  - d. He shared a Nobel Prize with an Italian biologist.

5 Identify the cell type of these cells and explain.



6 Analyse the following image of a cell.

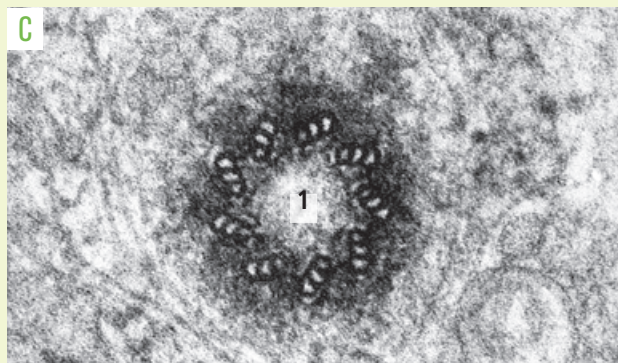
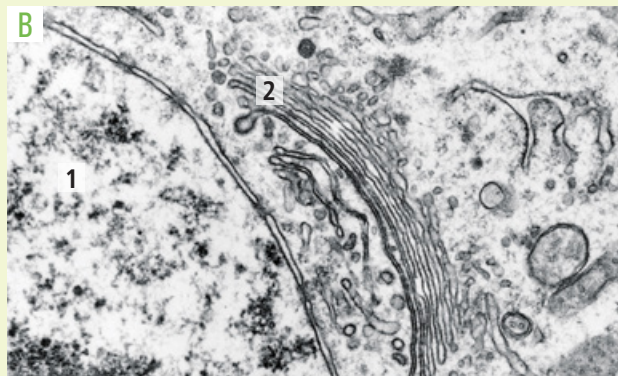
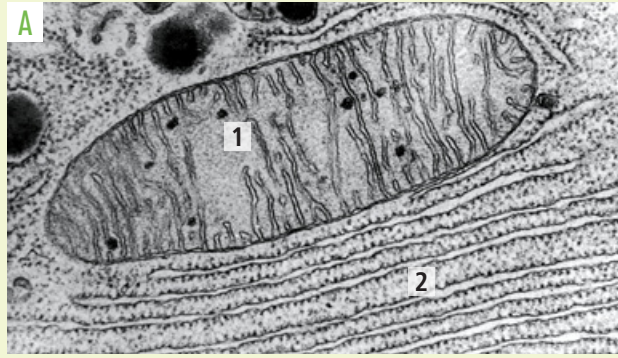


- a. How is this cell organised? Is it an animal or plant cell? Why?
- b. Name the numbered components.
- c. What is the name for the mechanism by which organelle 9 releases its contents to the outside? And the reverse process?
- d. Discuss whether these secretions to the outside can be performed by the cells in other kingdoms.

7 Explain which type of cell this is. Name the numbered components and indicate their function.



- 8 **C** Identify the organelles of the following electron micrographs and write down each of their functions.



- 9 **C** Explain the following quote:

"Life did not take over the globe by combat, but by networking"

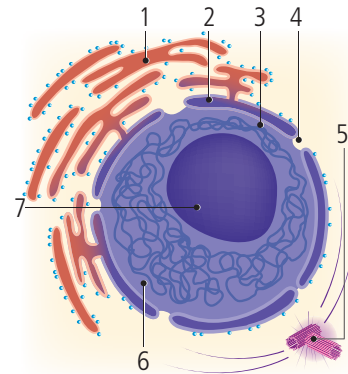
Lynn MARGULIS

- Prepare a presentation that summarises Lynn Margulis' work.
- Evaluate the life of the biologist by providing details of her work and her contribution as a female scientist. Evaluate the importance of the development of SDG 5.
- Indicate the relevance of her work to explain the early evolution of cells.
- Write down the advantages of cell networking for the survival of multicellular organisms.
- What connections can be made between this quote and SDG 17?

- 10 **T** Listen. In your notebook, number the topics in the order you hear them.

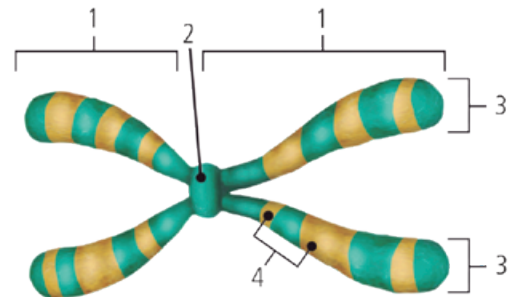
- A physical description of the scutoid.
- The origin of the shape's name.
- Scientists have discovered the scutoid.
- How scutoids fit together.

- 11 The image below shows an interphase nucleus.



- Name the numbered parts.
- What does the term 'interphase nucleus' refer to? Why do we say interphase nucleus and not mitotic nucleus?
- Discuss whether this cell is in G1 or G2 of interphase.

- 12 Look at the diagram below of a chromosome.



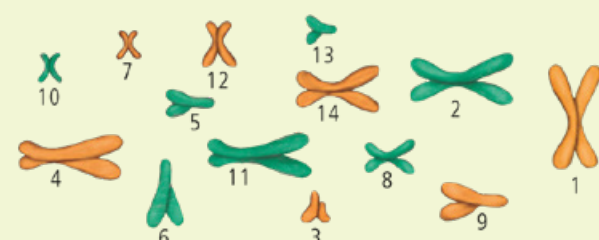
- What is the chemical composition of a chromosome?
- Name the numbered parts.
- By which process do the two parts numbered as (3) form? Why are they identical? Explain what happens if the parts are not identical. What process may have occurred if they are not identical?
- Classify this chromosome according to the position of its centromere.
- How are chromosomes before and after DNA replication structurally different? What functional difference is there after replication?

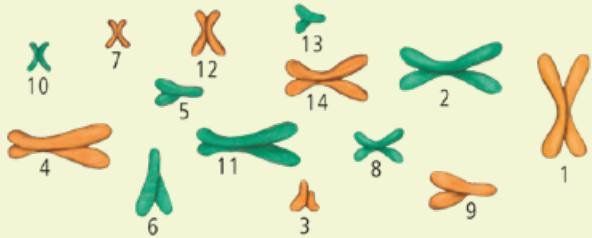
- 13 Answer the following questions and justify your answers:

- Is it possible for a diploid cell to have an uneven number of chromosomes?
- Is it possible for a haploid cell to have an even number of chromosomes? Would it have homologous chromosomes?

14 Answer and explain the following:

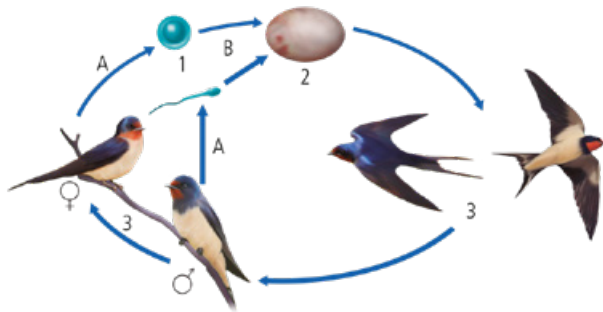
- Do the sister chromatids of a chromosome possess the same genetic information?
- Do homologous chromosomes contain the same genetic information?
- Do all the somatic cells of a multicellular organism contain the same genetic information?

15  The image below shows the chromosomes of a mammal's blood cell during mitosis.




- Say whether this cell is diploid or haploid. How many chromosomes does it have?
- How many chromosomes would a gamete of this species have?
- Photocopy the image and create the karyotype of this species.
- Determine the sex of this individual.

16 Look at the common swallow's life cycle and answer these questions:



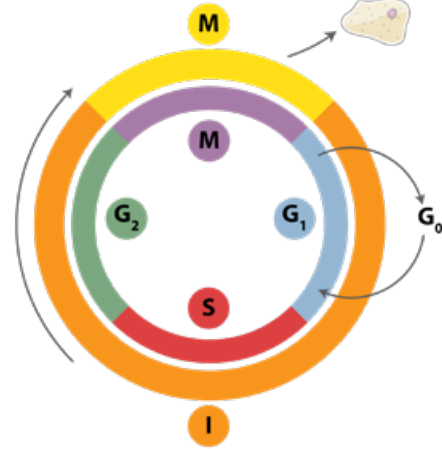
- What kind of life cycle is it?
- What name is given to cells 1 and 2? Are they haploid or diploid? Why?
- What are the names of processes A and B?
- By what means does cell 2 divide to generate adult swallows, indicated by number 3? Are these swallows  $n$  or  $2n$ ?


17  Listen and answer the questions in your notebook.

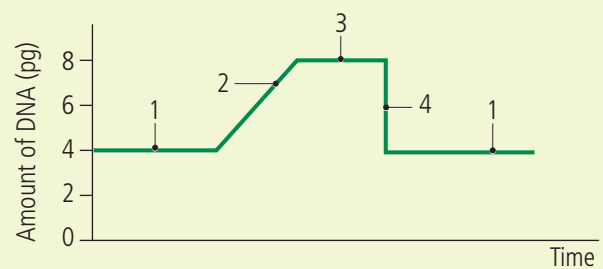
- How common is Down Syndrome?
- Where did the name come from?
- What is one of the main causes of Down Syndrome?
- How can Down Syndrome affect an individual?

18 Look at the cell cycle and write where the following cells are:

- A zygote
- A neuron
- An ovule
- A myocyte

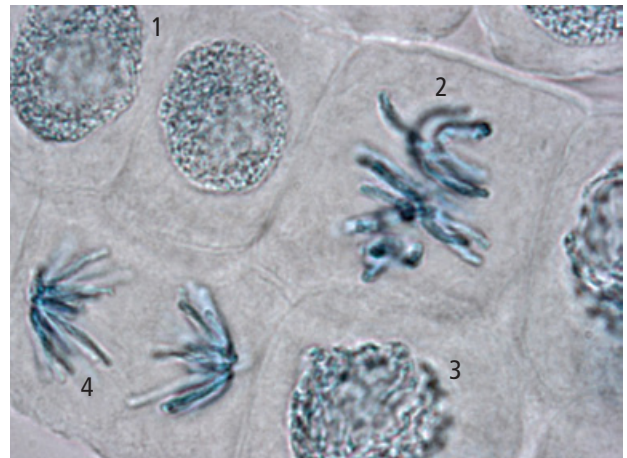


19  The graph below shows the variation in DNA content of a cell throughout its cell cycle.



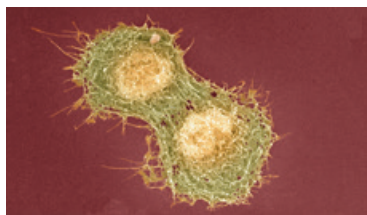
- Match each number on the graph to its corresponding stage in the cell cycle.
- Briefly explain what is happening at each of the numbers on the graph.

20 The micrograph below shows cells in various stages of mitosis.



- Identify the numbered stages. How did you recognise them?
- Justify whether they are plant or animal cells.
- Explain why cytokinesis occurs in this type of cell. Why can it not occur by budding?

- 21 At what stage of the cell cycle is the cell in this image? Explain how it is produced and whether it is an animal or a plant cell.

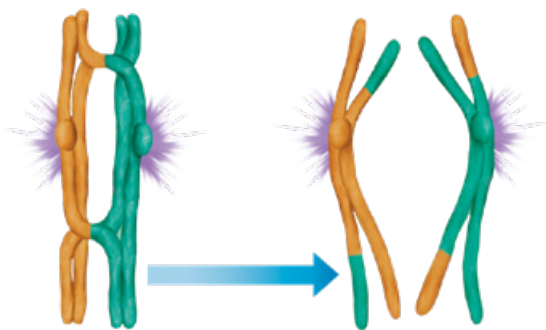


- 22 **(T)** Listen and write in your notebook: E (euchromatin) or H (heterochromatin).
- It is a tightly packed form of chromatin.
  - They make up 92% of the chromatin in our cells.
  - The chromatin where active genetic information can be found.
  - It acts as the "bookshelf" of cells.

- 23 **(C)** HeLa cells are a lineage of eukaryotic cells that are used in various laboratories around the world.
- Research the origin of HeLa cells.
  - Justify the importance of research into these cells and their reproductive qualities.
  - Discuss the advantages of these laboratories around the world collaborating to research these cells.
  - What does research into HeLa cells have to do with SDG 17?

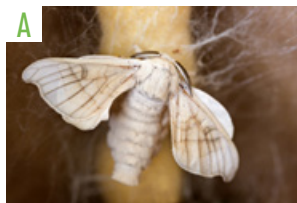
- 24 **(C)** An online blog states that insect cells, after a mitotic division with mutations, can stay alive for a long period without DNA fragments and even without a nucleus. Come up with a response to this news. Think of some questions to ask.

- 25 The following image represents a pair of chromosomes during meiosis.



- What is the name for these chromosomes that are arranged in pairs?
- In what stage of meiosis do they pair up?
- What process is happening between them? What is the biological significance of this process?
- Draw the four types of gametes that would be formed at the end of meiosis in your notes.

- 26 *Bombyx mori* and *Drosophila melanogaster* are insects which can be "achiasmatic" depending on their gender.



- Create a virtual presentation in which you indicate the species concerned, what is special about their genetics and how this affects their reproduction.
  - Provide at least three duly referenced bibliographical citations showing your information sources.
- 27 Indicate the corresponding stage of meiosis for each event in the list below.
- Pairs of homologous chromosomes separate.
  - Chromosomes line up, without their homologous pair, along the equatorial plane.
  - Homologous chromosomes pair up.
  - Sister chromatids separate.
  - The pairs of homologous chromosomes line up along the equatorial plane.
  - Each nucleus contains a haploid number of chromosomes made up of two chromatids.
  - Each nucleus contains a haploid number of chromosomes made up of one chromatid.

- 28 In your notebook, draw the mitotic metaphase and the two meiotic metaphases of an animal cell with  $2n = 4$ . One pair of the chromosomes is metacentric, and the other pair is telocentric.

- 29 A  $2n=6$  cell is involved in the process of mitosis, while each daughter cell is in meiosis.
- How many daughter cells will there be in total? Draw a diagram of the process which shows the original cell and its daughter cells in each case.
  - How many chromosomes do the daughter cells have?

- 30 A mule is a hybrid horse.
- If the diploid number of a horse is  $2n = 64$  chromosomes and the diploid number of a donkey is  $2n = 62$  chromosomes, work out how many chromosomes a mule will have.
  - Mules are sterile because they do not produce viable gametes. Try to explain why this process fails.

