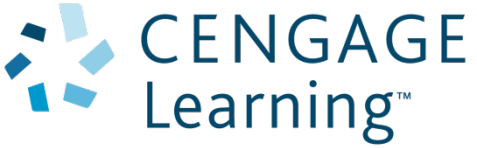
Chapter 2:
Processes for the continuity of life



The continuity of life

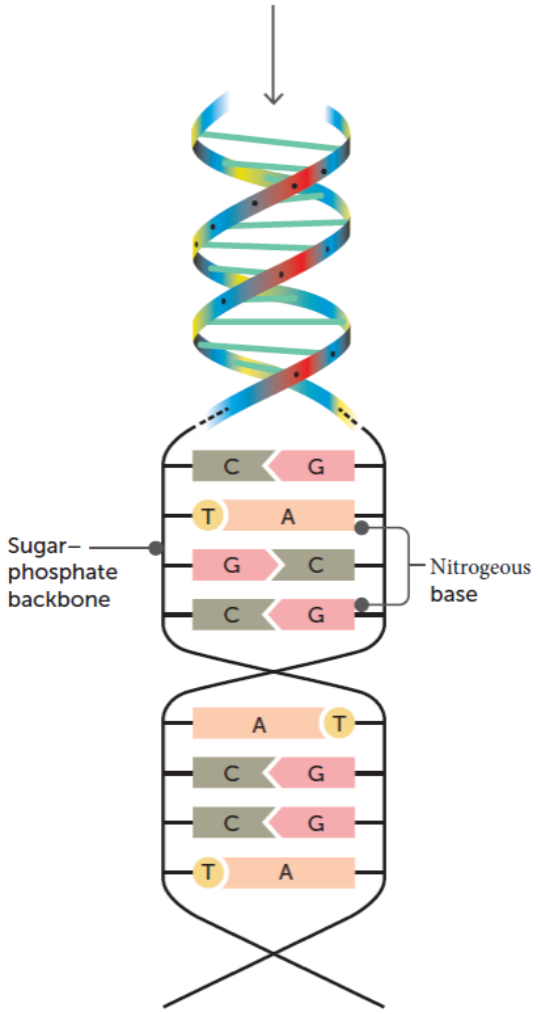
Heredity is the study of inheritance and of the processes involved in transmitting genetic material to the next generation of cells or offspring.

When black swans breed to produce a cygnet, the process of meiosis is required when creating the cells that will fuse (during fertilisation) to form the cygnet's first cell. After meiosis and fertilisation, mitosis plays a major role in the growth of the cygnet.

Shutterstock.com/Jessica Dale

DNA

DNA (deoxyribonucleic acid) is the genetic material that is passed on to offspring for the continuity of life. DNA determines the characteristics that define the species. In all living things, DNA is the molecule that contains the instructions, written in a chemical code, for the production of proteins by the cell; the information it contains is sufficient for the making and maintaining of an organism.



Eukaryotes

Eukaryotic cells are complex cells containing membrane-bound organelles, including a nucleus.

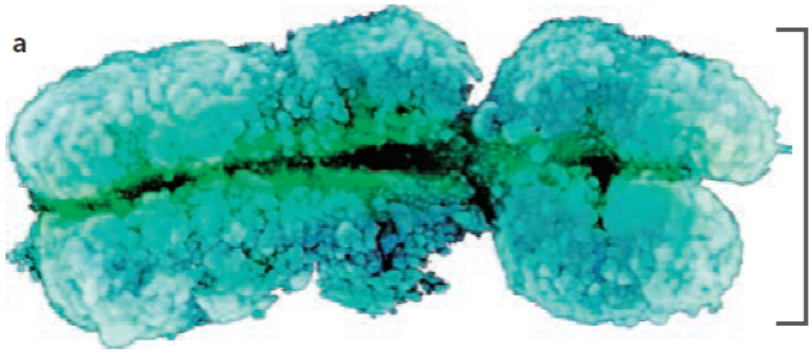
In eukaryotic cells, DNA is found in the nucleus, in chloroplasts and in mitochondria. In the nucleus of a eukaryotic non-dividing cell, DNA is in the form of chromatin.

Chromatin is a complex consisting of DNA and histone proteins organised into a relatively loosely coiled form. When the cell prepares to divide, the chromatin coils more tightly and becomes visible as chromosomes. Each chromosome consists of one DNA molecule and its associated histone proteins.

Chromosomes of eukaryotes

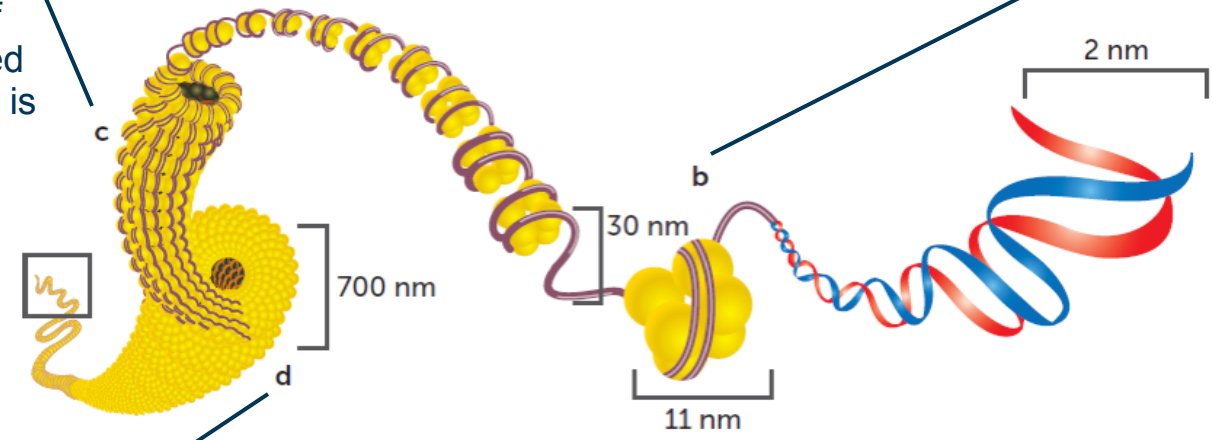
Eukaryotes

A tightly coiled and condensed human chromosome (only visible during cell division and when stained)



A nucleosome consists of a section of a DNA molecule looped twice around a core of eight histone proteins.

Interacting proteins package loops of coiled DNA, called chromatin, which is organised as a cylindrical fibre.



Chromatin is further condensed to make chromosomes.

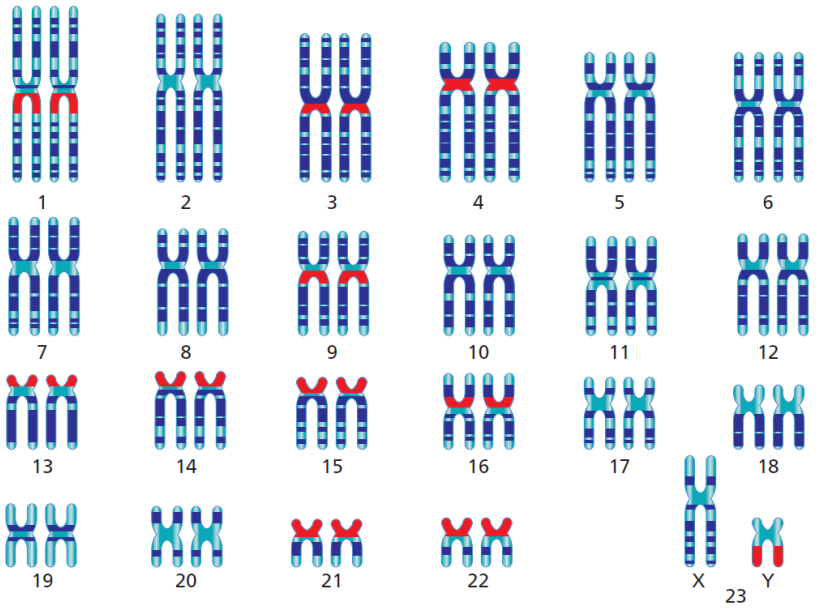
CENGAGE Learning

Chromosomes of eukaryotes

Karyotype

In human body (**somatic**) cells, there are 23 pairs of chromosomes. When these are paired and ordered they can be shown as a **karyotype**, the standard graphical form used to display and analyse chromosomes.

Each pair of chromosomes contains one paternal and one maternal chromosome.



Matched pairs of chromosomes are called **autosomes** and are **homologous**.

One pair of chromosomes is the sex chromosomes.

Chromosomes of eukaryotes

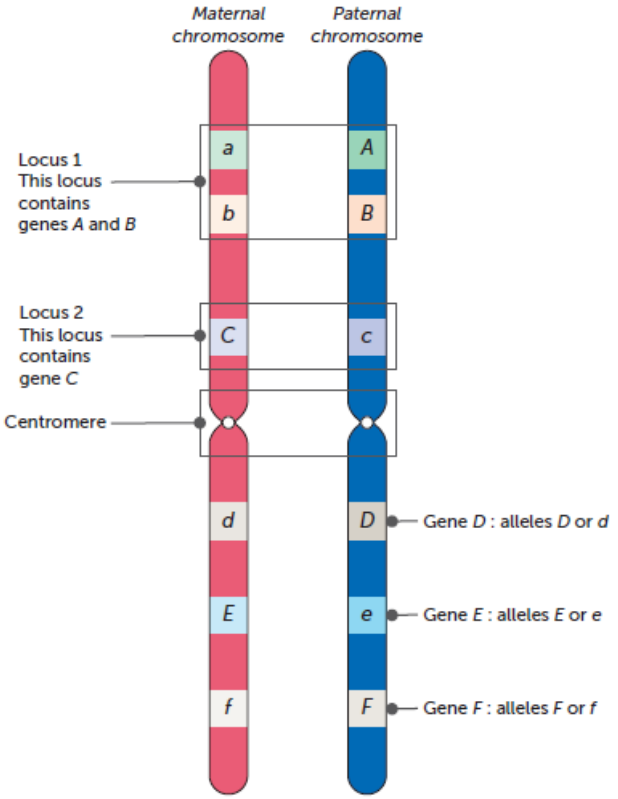
Loci

A genetic location is called a **locus**.

A locus is the position of a gene, a cluster of genes or even a single nucleotide on a chromosome.

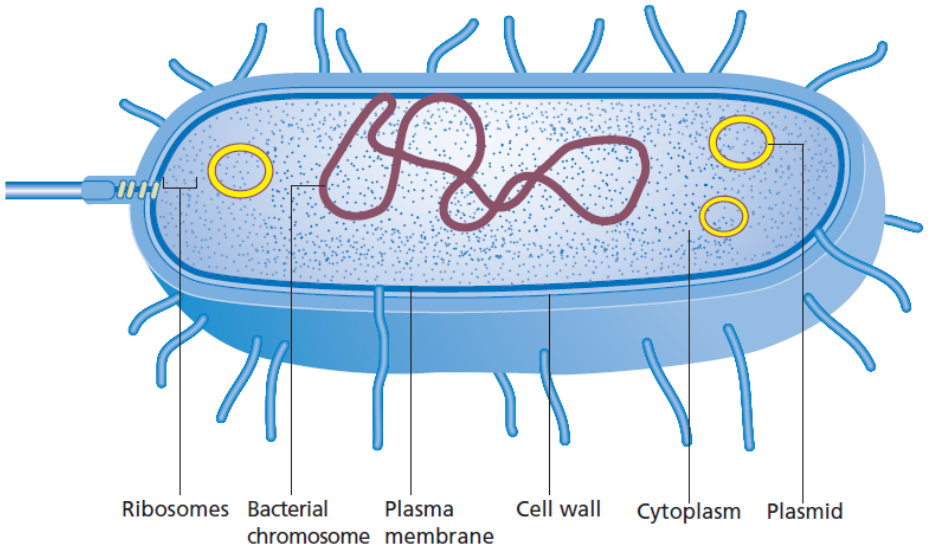
Since there are two of each chromosome in a somatic cell, there are two copies of each gene.

Individual gene copies are called **alleles**, and can be given names such as *D* and *d* depending on the allele's characteristics.



Chromosomes of prokaryotes

Prokaryotes



Membrane-bound organelles, such as a nucleus, are not present in the single-celled organisms known as **prokaryotes**.

DNA is usually in the form of a single circular chromosome.

The chromosome can be in a distinct region of the cell called a nucleoid.

Additional small rings of DNA, called plasmids, may also be present in the cytoplasm.

Comparing eukaryotes and prokaryotes

Factor	Prokaryotic cell	Eukaryotic cell
Typical diameter	1−5 micrometres	10−100 micrometres
Location of DNA	In cytoplasm (in nucleoid)	In nucleus
Membrane-bound organelles	No membrane-bound organelles (such as mitochondria, endoplasmic reticulum, Golgi apparatus, or nucleus)	Membrane-bound organelles, including a nucleus
Ribosomes	Yes, but they float freely in the cytosol	Yes, they can float freely in the cytosol or be attached to the endoplasmic reticulum
Chromosome(s)	A single circular DNA strand (typically, without histones)	DNA is wrapped around proteins (called histones), creating units called nucleosomes. This loosely coiled form of DNA is called chromatin. The chromatin coils more tightly (‘condenses’) to form chromosomes in preparation for mitosis or meiosis.

Cell division

Eukaryotic cell division involves a number of phases, including nuclear division (mitosis or meiosis) and cytoplasmic division (cytokinesis).

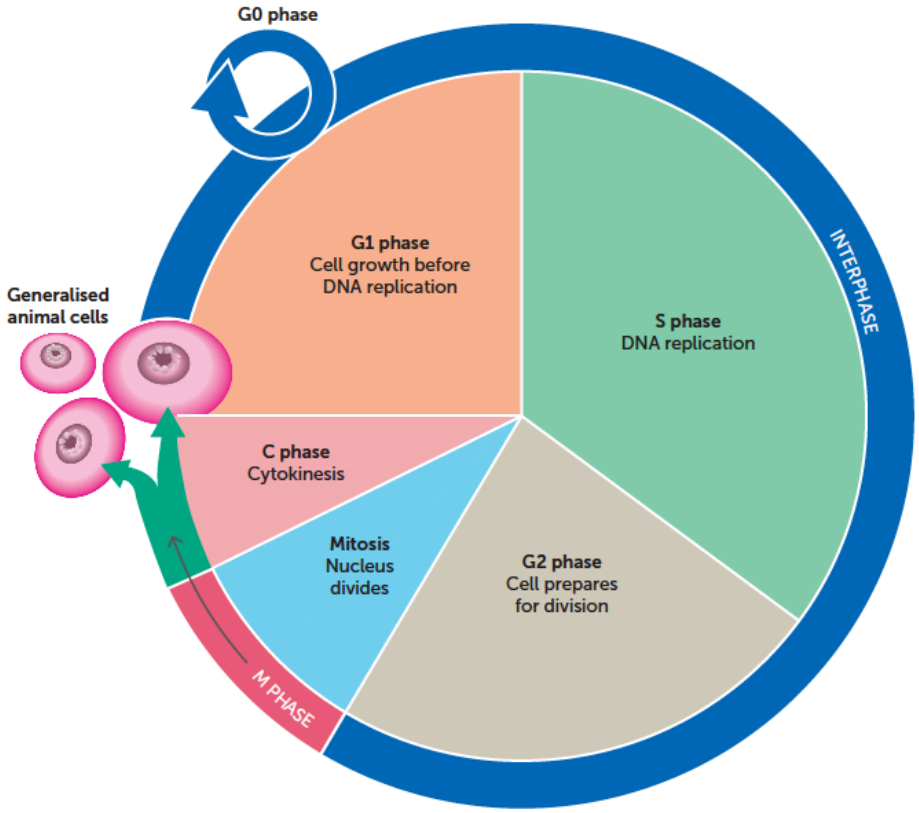
Mitosis is a type of nuclear division occurring in somatic cells that maintains the parental diploid number of chromosomes in the daughter cells; for bodily growth and asexual reproduction.

Meiosis is the form of eukaryotic cell division concerned with the production of gametes (sex cells) in sexually reproducing organisms. Meiosis, a type of cellular division involving one cycle of DNA replication and two rounds of cell division, results in the production of four haploid daughter cells from each original diploid cell.

At fertilisation, two haploid gametes, a male and a female, combine to form a diploid zygote.

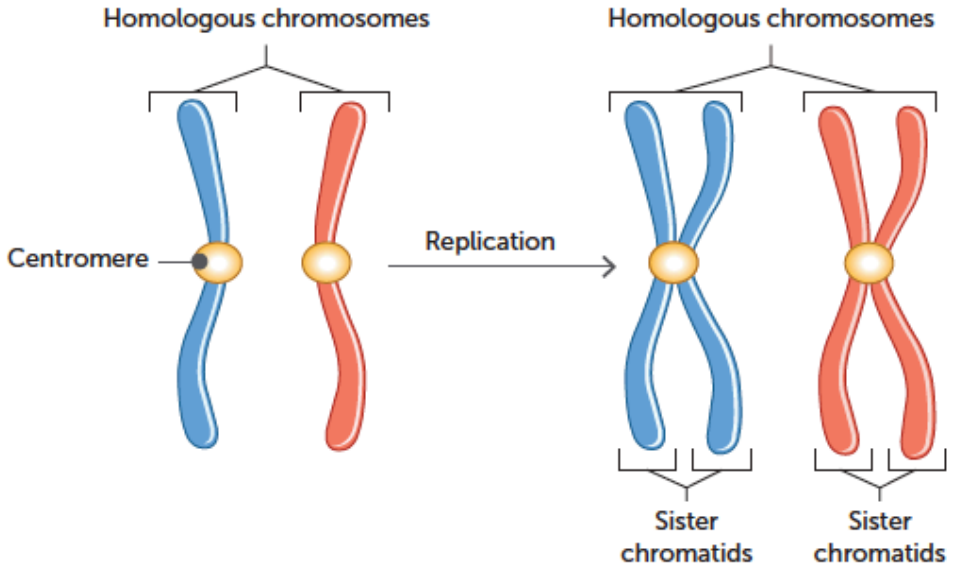
The cell cycle

The sequence of events from one cell division to another is called the **cell cycle**. The cell cycle is a continuous but ordered sequence of events in the life of a cell from when it was formed from a parent cell until its own division



Interphase

Prior to any cell division, a doubling of the genetic material needs to take place. This happens during **interphase**.



Mitosis

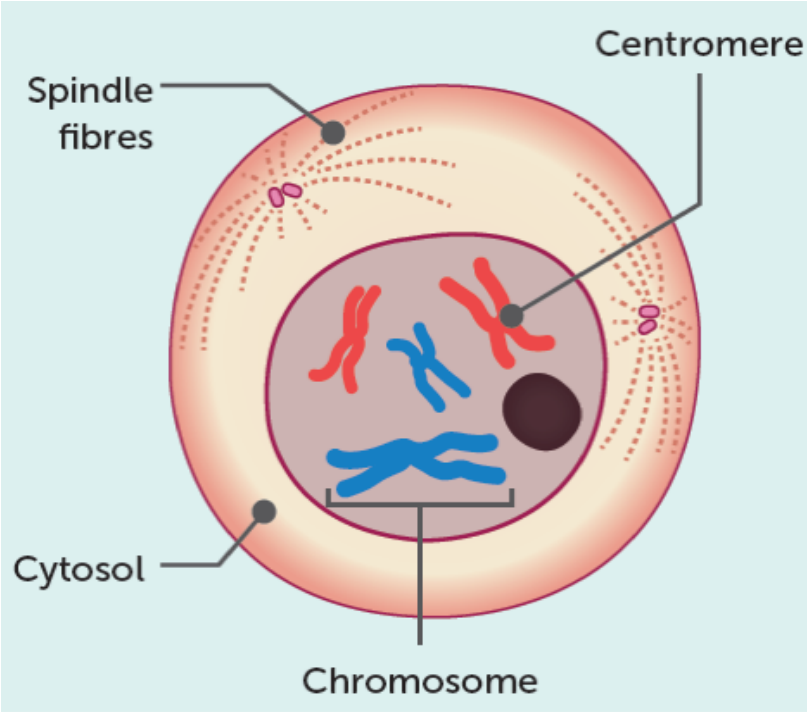
Mitosis, a relatively short part of the cell cycle, is itself broken down into four phases: **prophase**, **metaphase**, **anaphase** and **telophase**.

For the completion of cell division, **cytokinesis**, separation of the cytoplasm, follows mitosis (nuclear division).

Mitosis produces two separate, identical, diploid daughter cells.

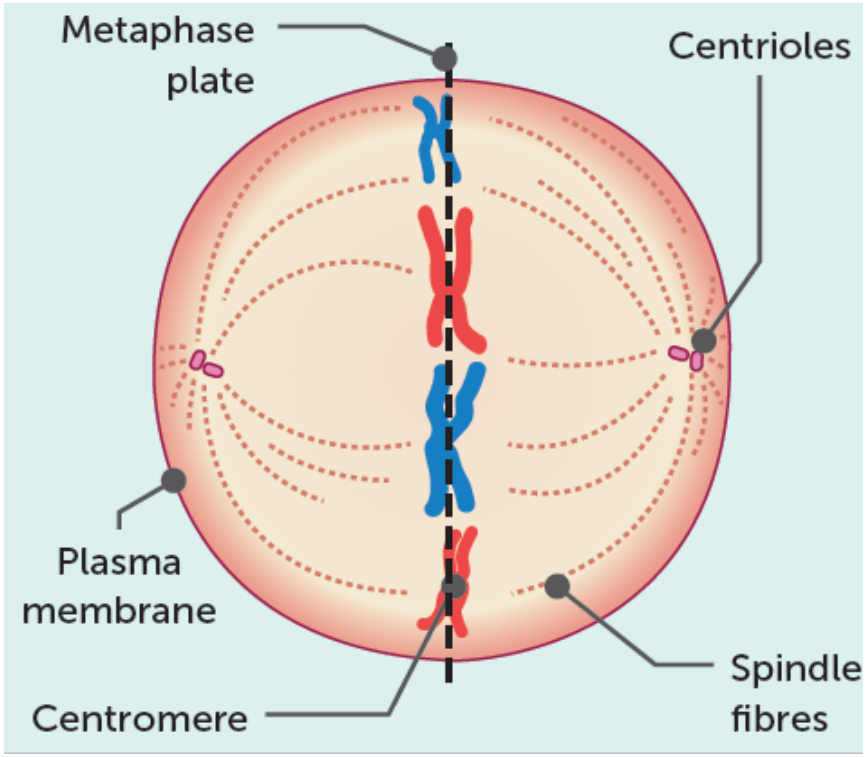
Prophase

1 Chromatin threads condense to form chromosomes.
2 Chromosomes: two sister chromatids held together by a centromere.
3 Nuclear membrane disintegrates and nucleolus disappears.
4 Mitotic spindle begins to form and is completed by the end of prophase. Spindle fibres attach to each chromosome at its centromere.
5 The two centrosomes (each containing two centrioles) move toward opposite poles of the cell.



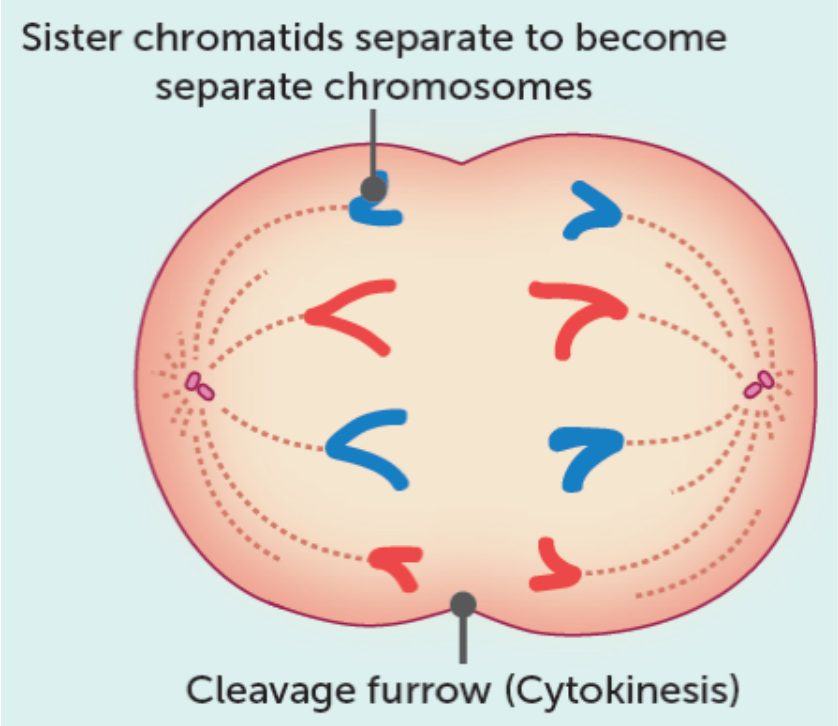
Metaphase

1 Chromosomes move to centre of cell and line up along the equator (also referred to as the metaphase plate).
2 Centromeres of the chromosomes are aligned on equator.
3 The centrioles are located at opposite poles of the cell.



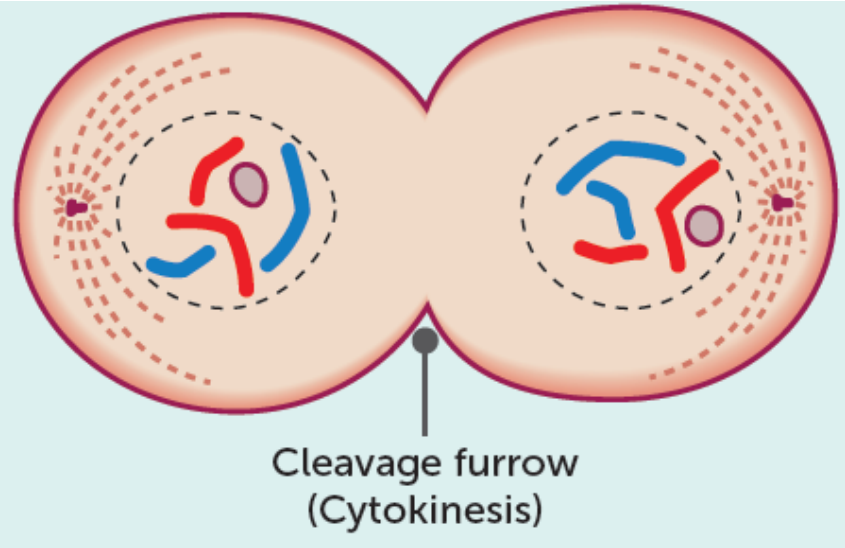
Anaphase

1 Spindle microtubules shorten and pull on the centromere; sister chromatids separate.
2 Spindle microtubules pull sister chromatids to opposite poles of cell.
3 Centromere is the part of each chromosome to be pulled toward poles; ‘arms’ of each chromatid follow as it is pulled along by the centromere.
4 At end of phase, each pole has a complete identical set of maternal and paternal chromosomes.
5 Sister chromatids now referred to as chromosomes.



Telophase

1 Chromosomes decondense to form chromatin; can no longer be seen under microscope.
2 Two new nuclear membranes form, one for each new daughter cell.
3 Nucleoli reappear and spindle apparatus disappears.
4 Cell elongates to become ready for cytokinesis.



Prokaryote cell division

As prokaryotes lack a nucleus and have only a single chromosome with no centromere, they cannot be properly said to undergo mitosis. They reproduce by binary fission.

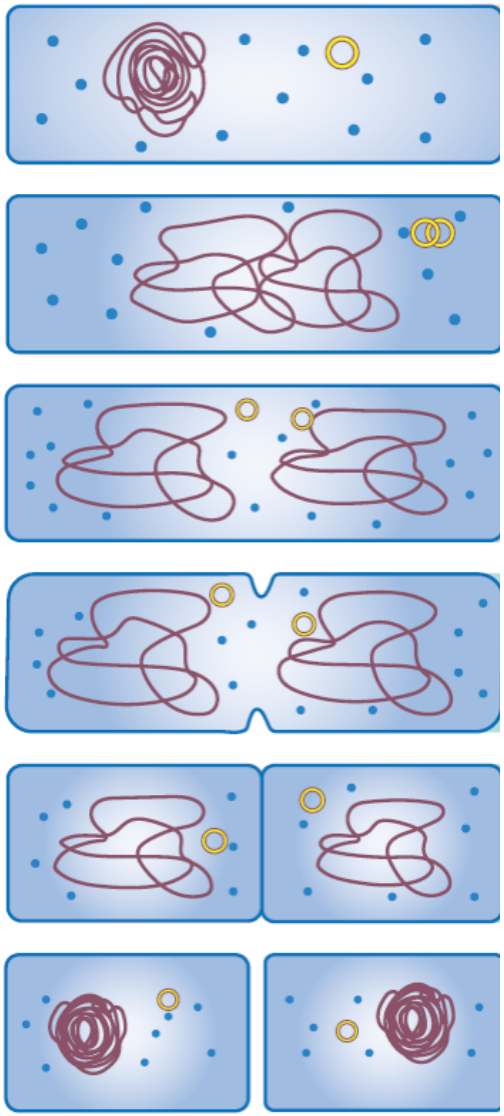
Binary fission can be defined as a process of asexual reproduction whereby a prokaryotic cell divides into two identical daughter cells.

The process includes DNA replication, chromosome segregation, and cytokinesis.

There is limited variation in prokaryotic populations other than that due to mutation.

However, binary fission is a process that happens relatively fast compared with other cell division processes, which means the mutation rate is much higher.

Binary fission



1 Prior to binary fission, single chromosome is tightly coiled.

2 Genetic material in the chromosome and the plasmid replicates and separates.

3 Original and replicate chromosomes attach to cell membrane; are pulled to separate poles as cell elongates.

4 New cell wall starts to grow; cleavage furrow develops in cell membrane.

5 New cell wall fully develops.

6 Two cells separate, forming two identical daughter cells: cytokinesis. Chromosomes become tightly coiled again.

Meiosis

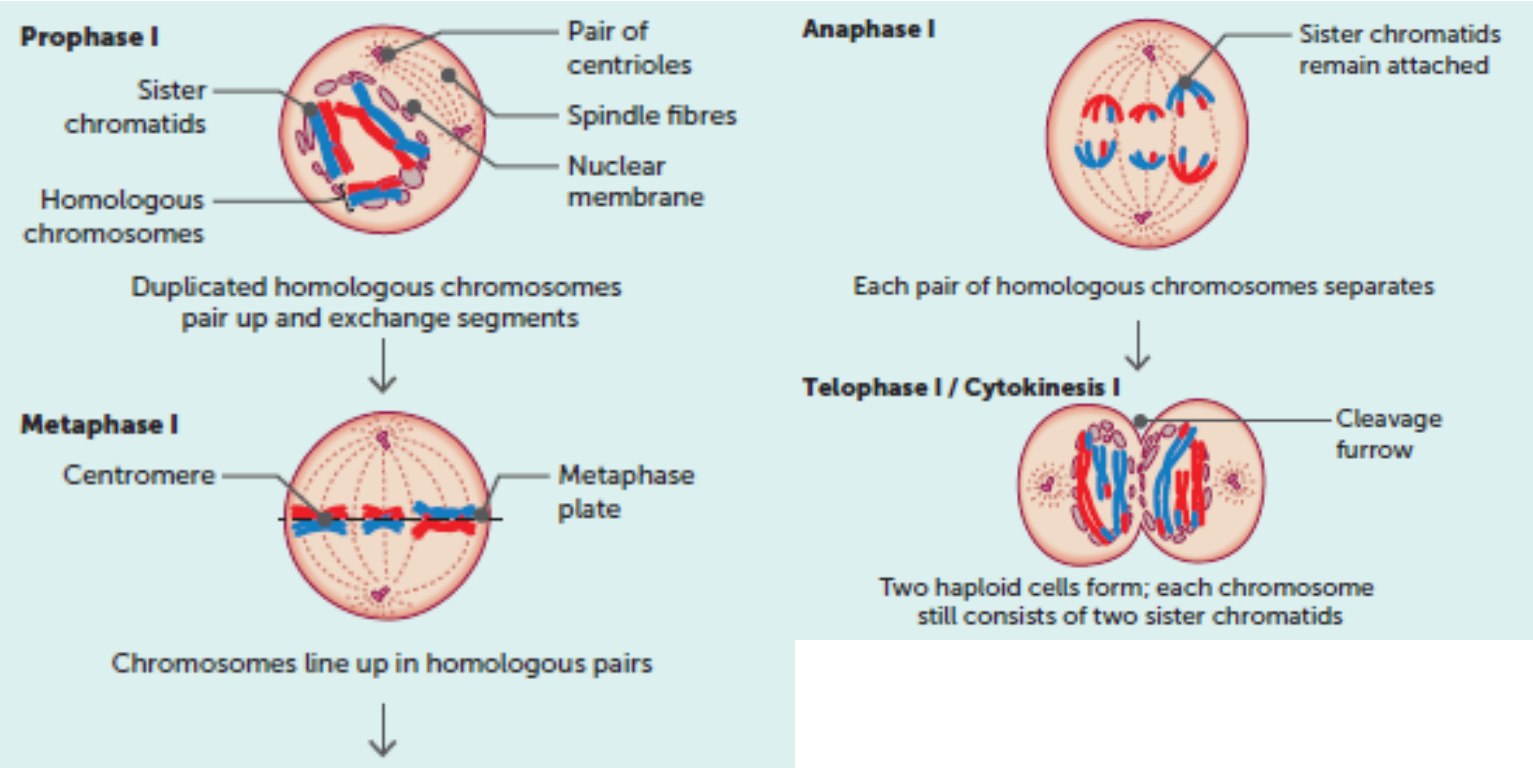
Meiosis occurs in specialised organs in sexually reproducing animals and plants. It results in the production of gametes, also known as sex cells.

Meiosis is a unique type of cell division in that the daughter cells produced have only half the number of chromosomes that the parent cell has. This prevents the doubling up of the diploid number of chromosomes at fertilisation.

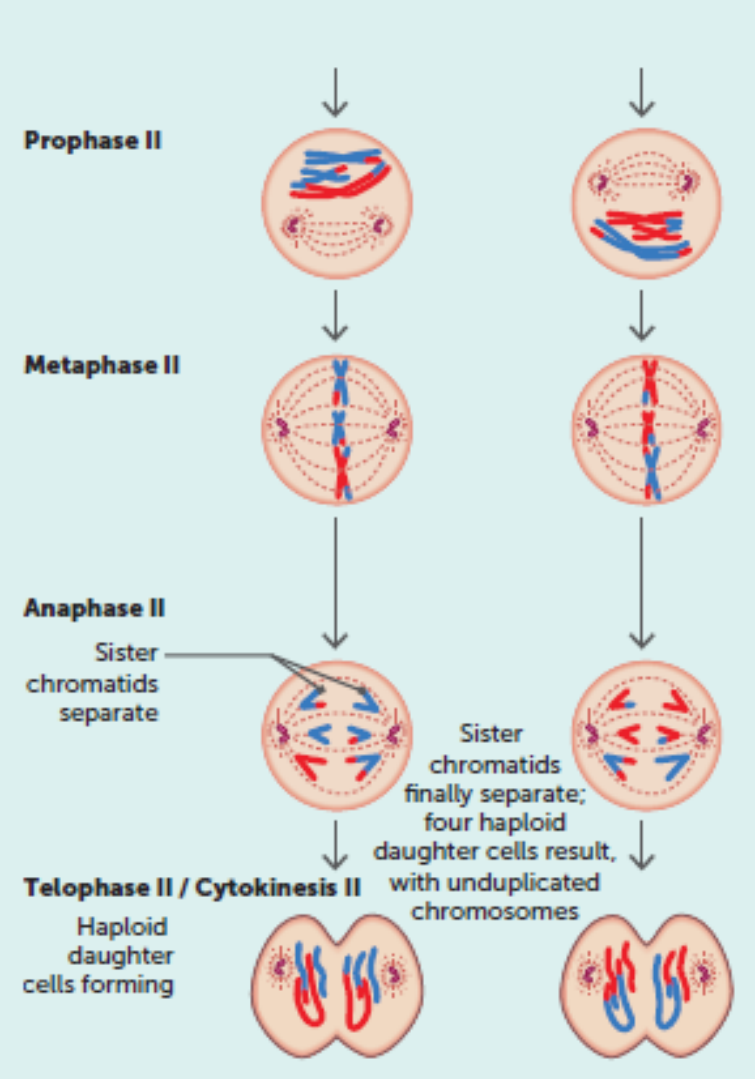
In meiosis, two divisions of the nucleus of the parent cell take place.

Four non-identical haploid gametes are produced with half the original number of chromosomes = (*n*).

Meiosis I

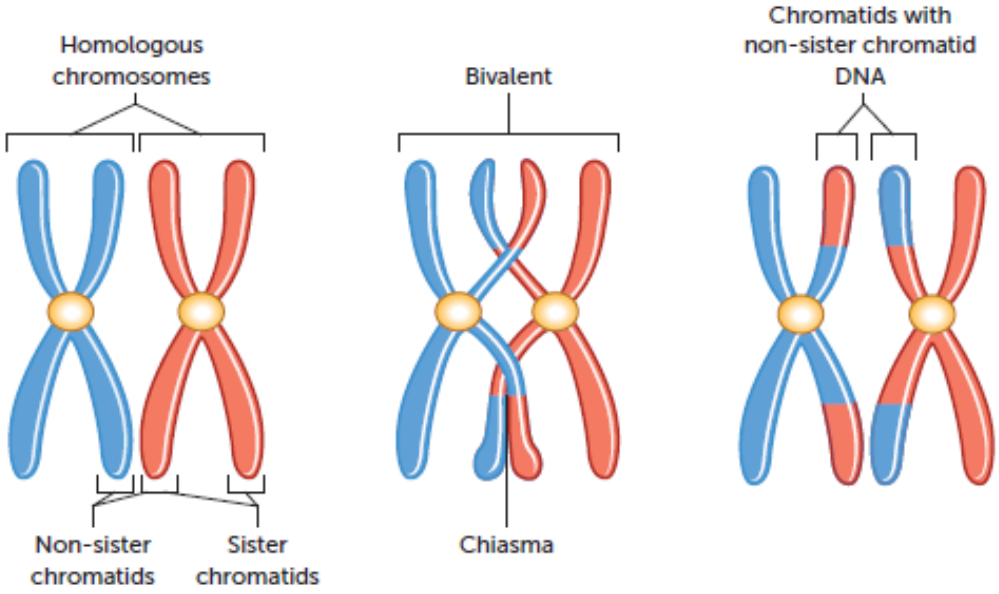


Meiosis II



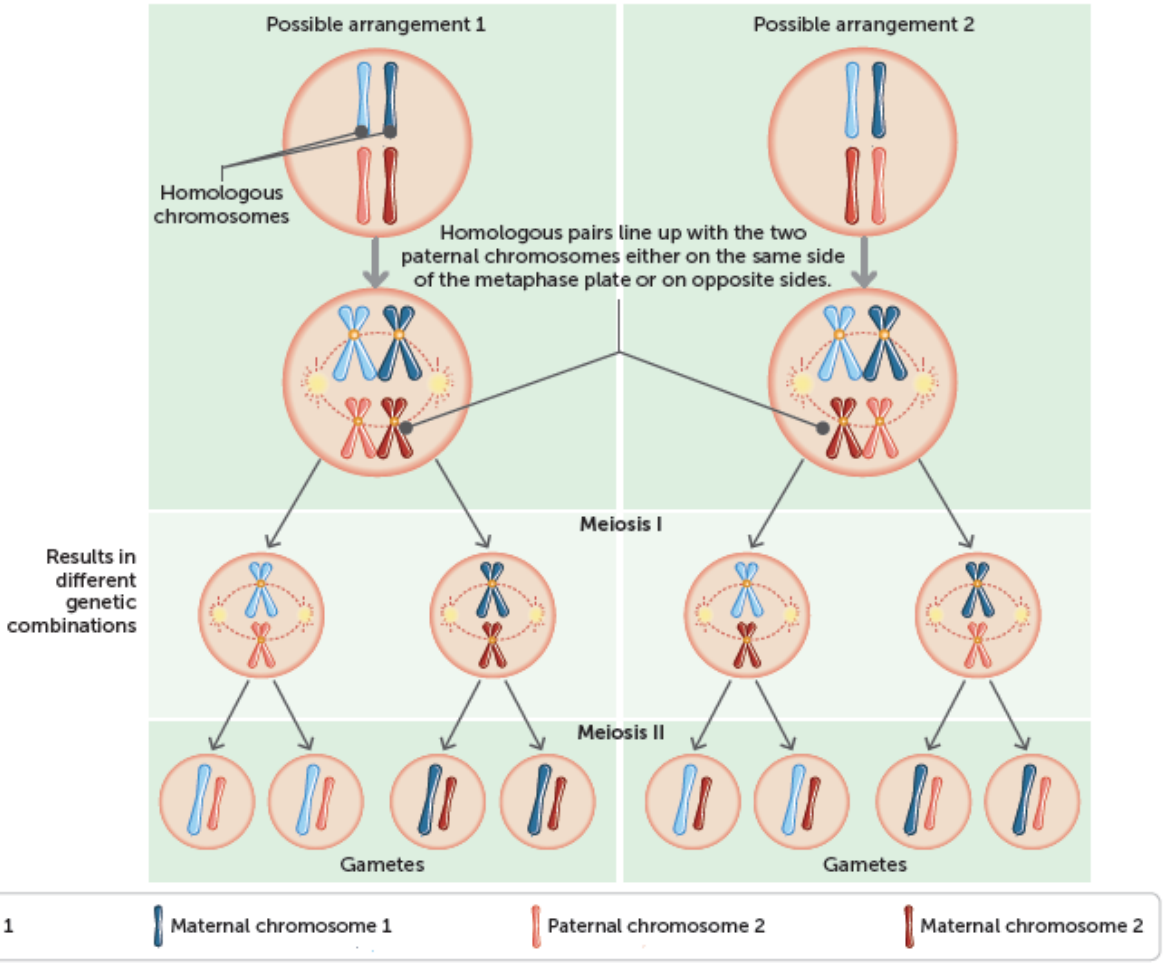
Crossing over during prophase I

A major difference between mitosis and meiosis: during the first step of meiosis, prophase I, there is an exchange of genetic material between maternal and paternal homologous chromosomes (i.e. between non-sister chromatids of the homologous chromosomes). This process is called **crossing over**.



Independent assortment starts in metaphase I

In eukaryotic cells, **independent assortment** occurs due to random orientation of maternal and paternal homologous chromosomes during metaphase. When gametes are formed, the assortment of one pair of chromosomes between the daughter cells is independent of that of another pair.



Comparing mitosis and meiosis

Features	Mitosis	Meiosis
Purpose	Nuclear and cellular division for growth, repair and replacement of tissues.	Nuclear and cellular division for producing sex cells (gametes).
Number of divisions	One cell division completes the process.	Two cell divisions complete the process.
Number of chromosomes in daughter cells	Each of the two identical daughter cells contains the diploid number of chromosomes ($2n$).	Each of the four, non-identical daughter cells contains the haploid number of chromosomes (n).

Comparing mitosis and meiosis *(continued)*

Features	Mitosis	Meiosis
Variation	New cells or offspring produced by this kind of reproduction do not show variation between them unless there are environmental influences or mutations; they are genetically identical to one another (i.e. clones).	Offspring produced show variation between them due to crossing over in prophase I and independent assortment in metaphase I.
Variation increase or decrease	Variation and diversity of offspring are narrowed.	Variation and diversity of offspring are increased.
Types of cells in which it occurs	Somatic cells	Germ-line or sex cells

Fertilisation

Fertilisation occurs in sexually reproducing organisms and is the joining of a male and female gamete. It results in a zygote that has gained one of each of its pairs of chromosomes from each parent.