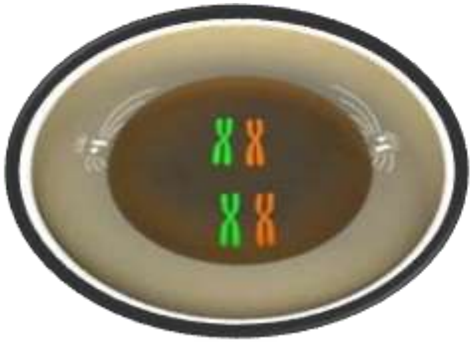
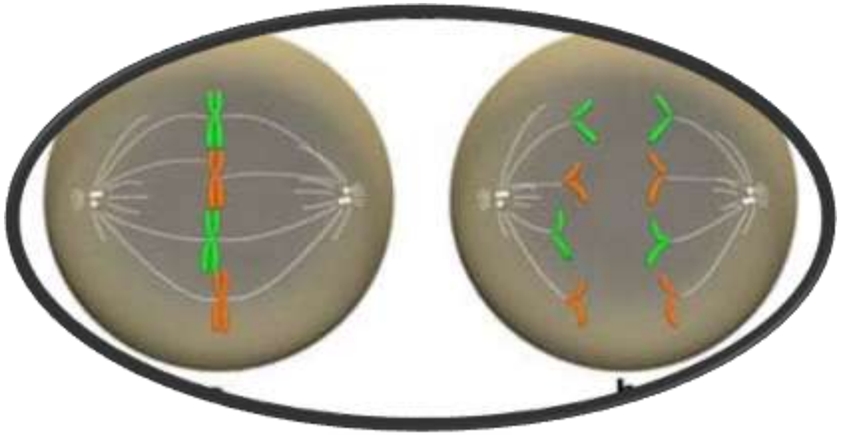


Cellular Division



Most cells grow, perform the activities needed to survive, and divide to create new cells. These basic processes, known collectively as **the cell cycle**, are repeated throughout the life of a cell.

In many situations, division also ensures that new cells are available to replace the older cells within an organism whenever those cells die.

- **Prokaryotic cells**, which include bacteria, undergo a type of cell division known as **binary fission**. This process involves replication of the cell's chromosomes, segregation of the copied DNA, and splitting of the parent cell's cytoplasm. The outcome of binary fission **is two new cells that are identical to the original cell**.

- In contrast to prokaryotic cells, **eukaryotic cells** may divide via either **mitosis or meiosis**. Of these two processes, **mitosis is more common**.
- In fact, whereas only **sexually** reproducing eukaryotes can engage in meiosis, all eukaryotes — regardless of size or number of cells — can engage in **mitosis**. **But how does this process proceed, and what sorts of cells does it produce?**

What happens during mitosis?

- **During mitosis**, a eukaryotic cell undergoes a carefully coordinated nuclear division that results in the formation of two genetically identical daughter cells.
- **Mitosis** itself **consists of five active steps**, or phases:

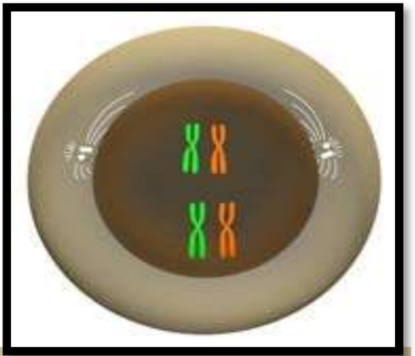
prophase, prometaphase, metaphase, anaphase, and telophase.

- Before a cell can enter the active phases of mitosis, however, it must go through a period known as **interphase**, during which **it grows and produces the various proteins necessary for division.**

- Then, at a critical point during interphase (called the **S phase**), the **cell duplicates its chromosomes and ensures its systems are ready for cell division.**
- If all conditions are ideal, the cell is now ready to move into the first phase of mitosis.

Prophase

- **Prophase** is the first phase of mitosis. During this phase, the chromosomes inside the cell's nucleus condense and form tight structures.
- In fact, the chromosomes become so dense that they appear as **curvy, dark lines** when viewed under a microscope (Figure 1).
- Because each chromosome was duplicated during S phase, it now consists of two identical copies called **sister chromatids** that are attached at a common center point called the **centromere**.

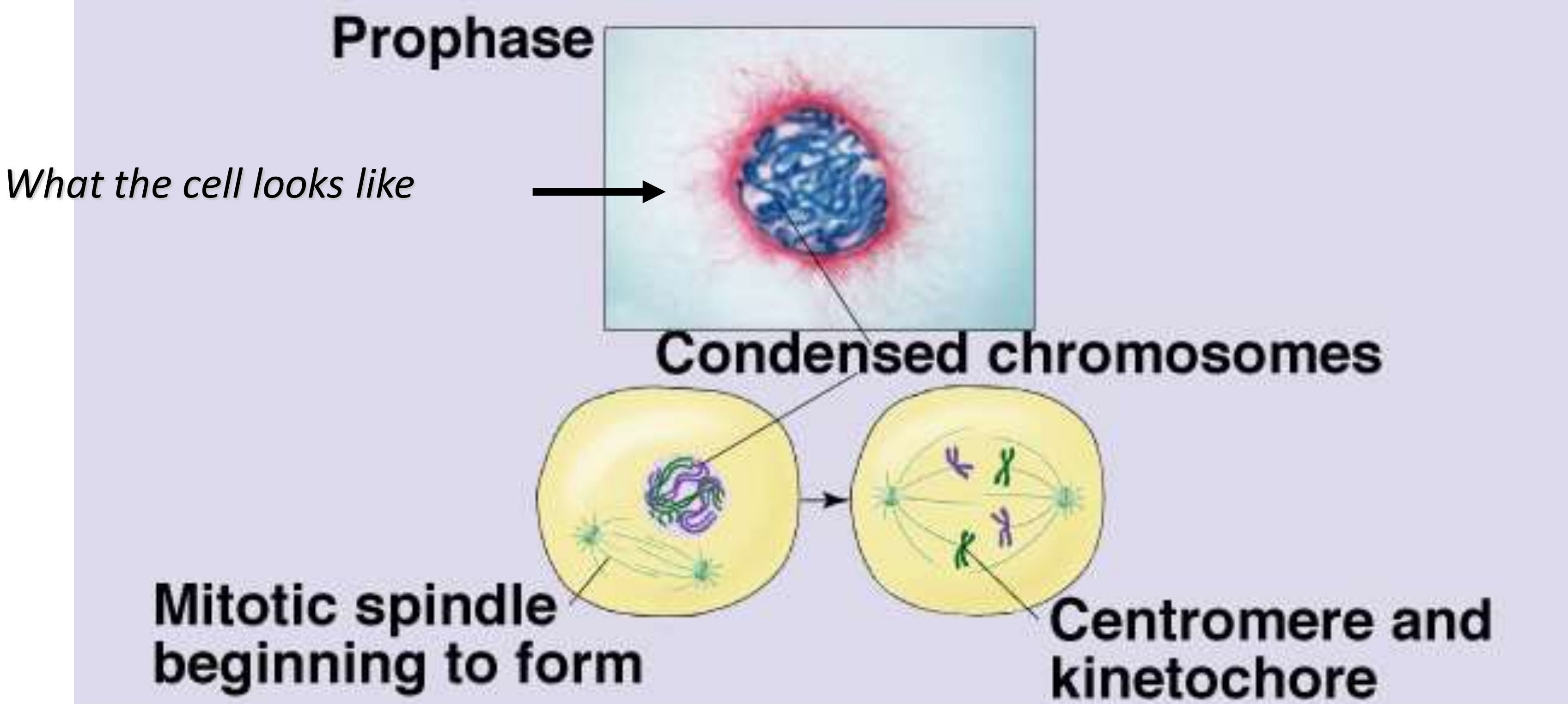


Important changes also take place outside of the nucleus during prophase:

- In particular, two structures called **centrosomes**

move to opposite sides of the cell during this phase and begin building the **mitotic spindle**. The mitotic spindle plays acritical role during the later phases of mitosis as **it orchestrates the movement of sister chromatids to opposite poles of the cell** (Figure 2).

Review of Prophase

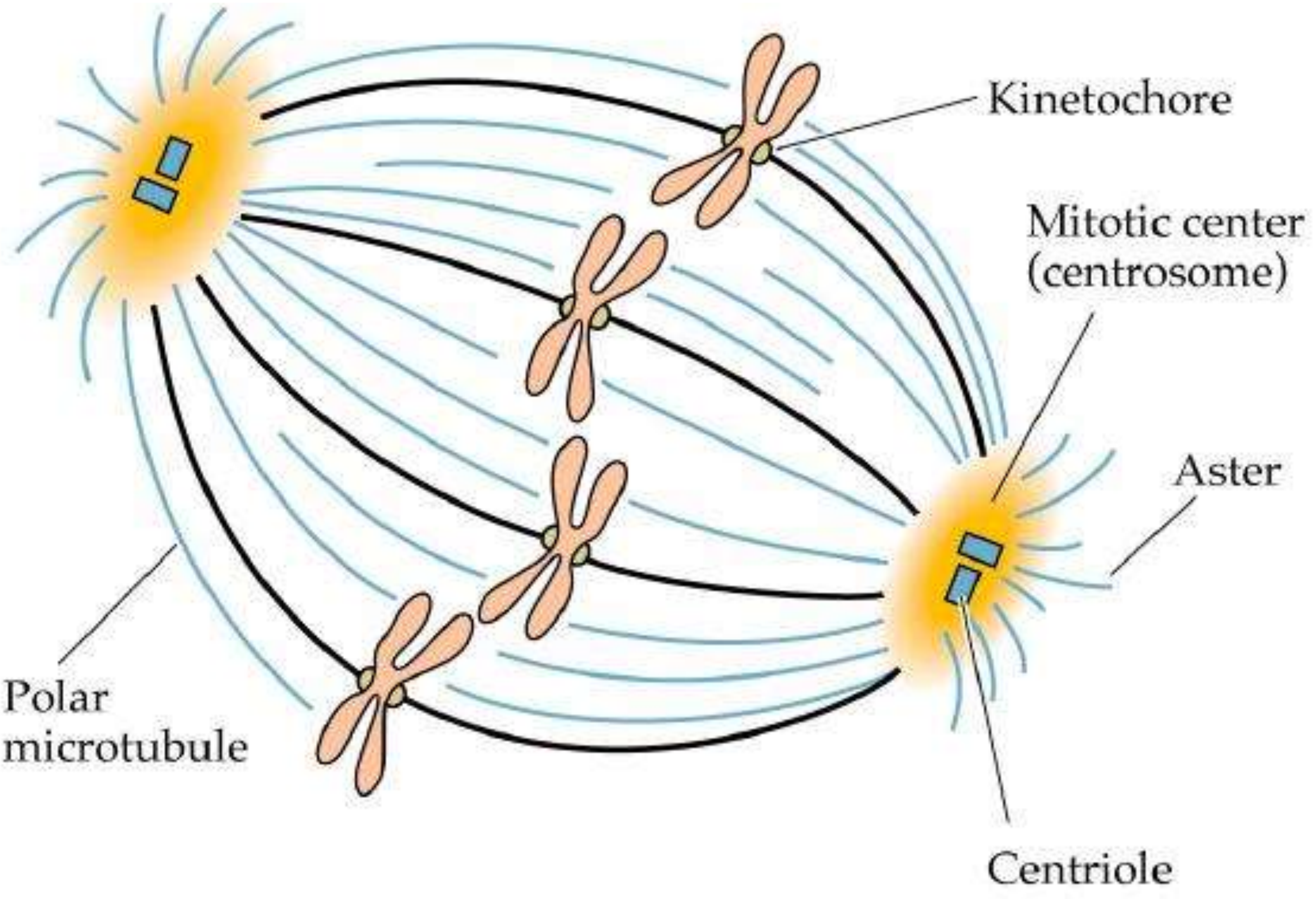


- Nuclear membrane disintegrates, and nucleolus disappears
- Chromosomes condense
- Mitotic spindle begins to form and is complete at the end of prophase
- Kinetochores begin to mature and attach to spindle

Spindle Fibers

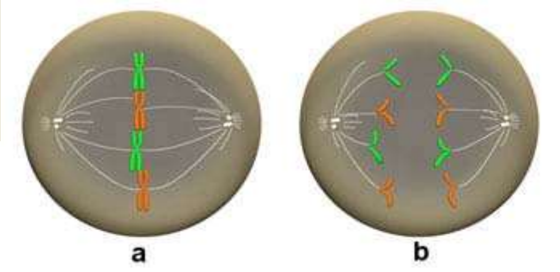
- ✓The mitotic spindle form from the microtubules in plants and centrioles in animal cells
- ✓Polar fibers extend from one pole of the cell to the opposite pole
- ✓Kinetochore fibers extend from the pole to the centromere of the chromosome to which they attach
- Asters are short fibers radiating from centrioles ✓

Sketch The Spindle



Prometaphase

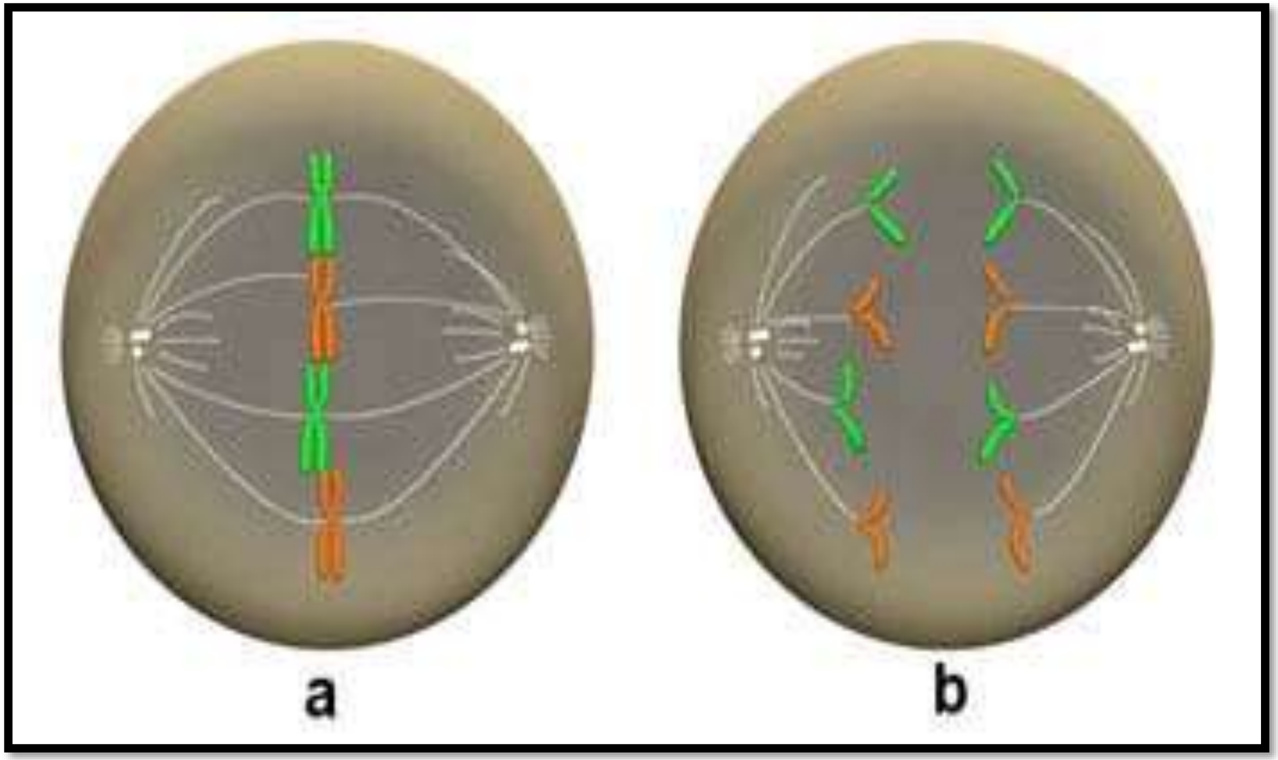
- After prophase is complete, the cell enters **prometaphase**.
- During prometaphase, the nuclear membrane disintegrates and the mitotic spindle gains access to the chromosomes.
- During this phase, a protein structure called the kinetochore is associated with the centromere on each sister **chromatid. Stringlike structures called microtubules grow out from the spindle and connect to the sister chromatids at their kinetochores;** one microtubule from one side of the spindle attaches to one sister chromatid in each chromosome, and one microtubule from the other side of the spindle attaches to the other sister chromatid (Figure 3a).
-



Metaphase

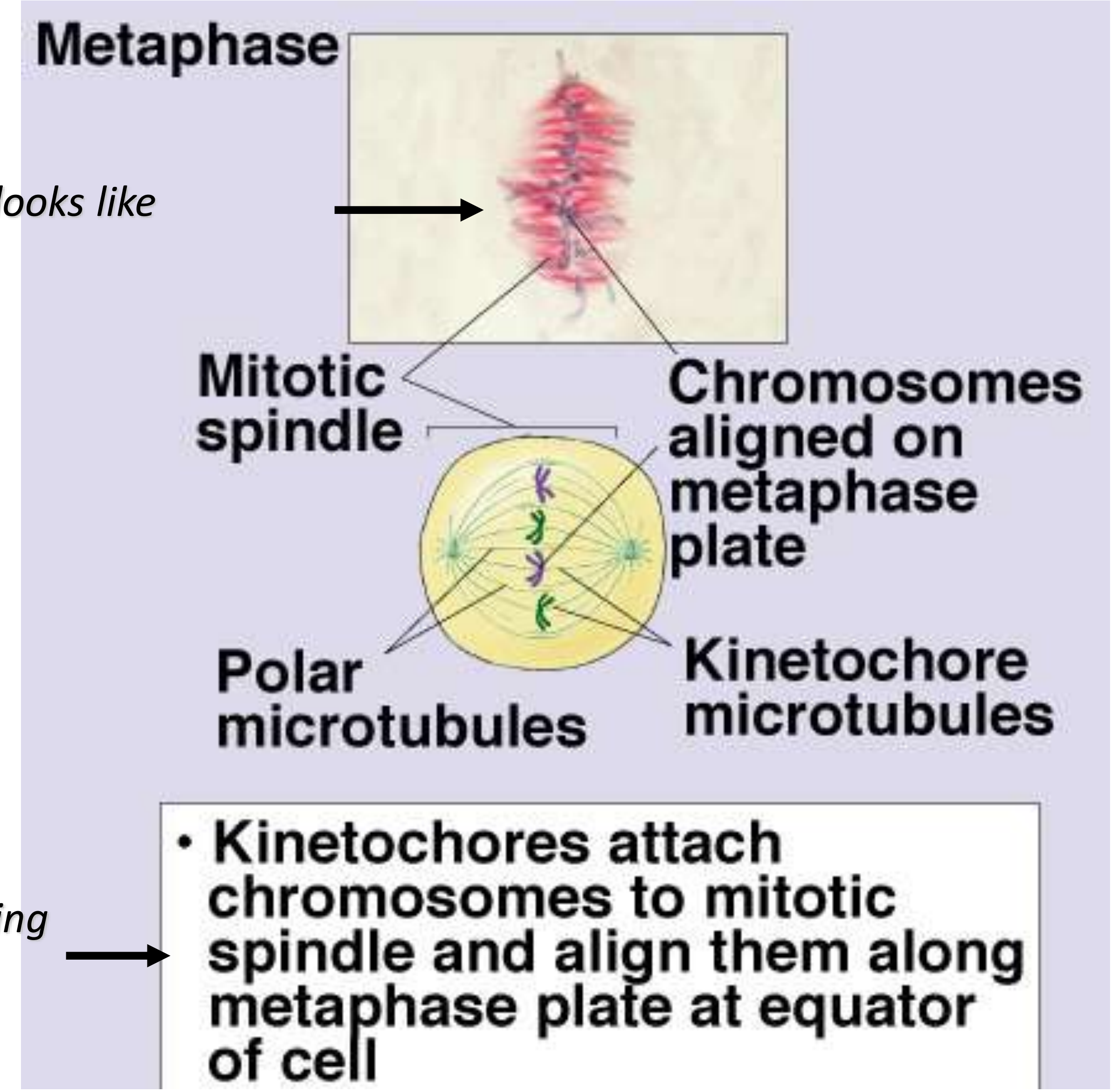
- Following prometaphase, **metaphase** begins. At the start of metaphase, the microtubules arrange the chromosomes **in a line along the equator of the cell, known as the metaphase plate (Figure 3b).**
- The centrosomes, on opposite poles of the cell, then prepare to separate the sister chromatid

Figure 3: In metaphase (a), the microtubules of the spindle (white) have attached and the chromosomes have lined up on the metaphase plate. During anaphase (b), the sister chromatids are pulled apart and move toward opposite poles of the cell.



Review of Metaphase

What the cell looks like



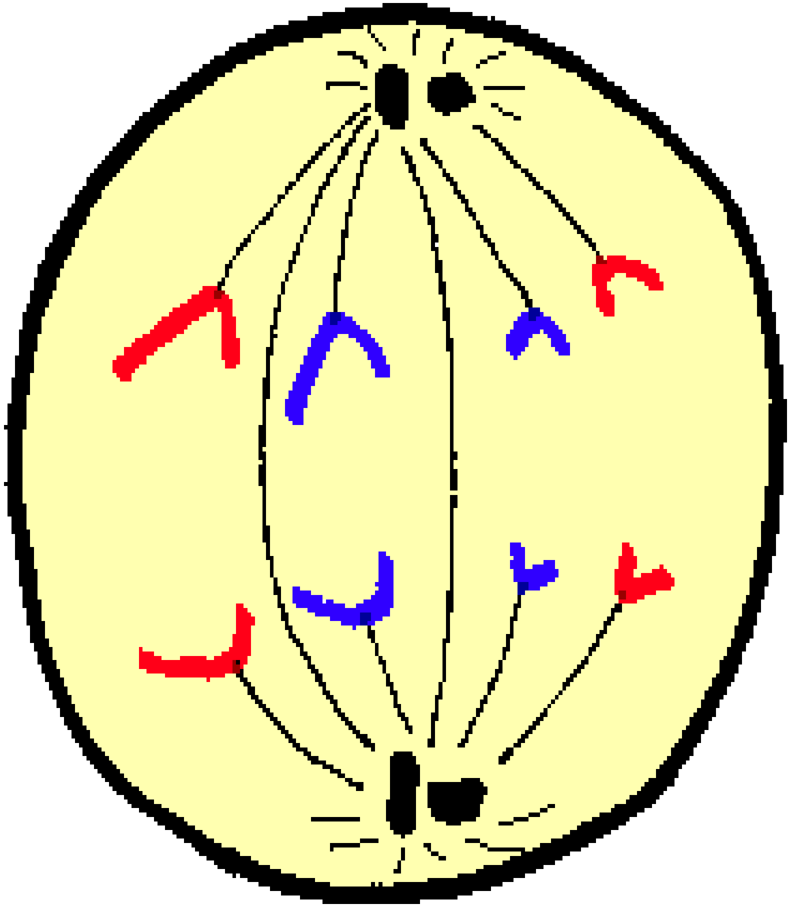
What's occurring

Anaphase

After metaphase is complete, the cell enters anaphase. During anaphase, the microtubules attached to the kinetochores contract, which pulls the sister chromatids apart and toward opposite poles of the cell (Figure 3c). At this point, each chromatid is considered a separate chromosome. .

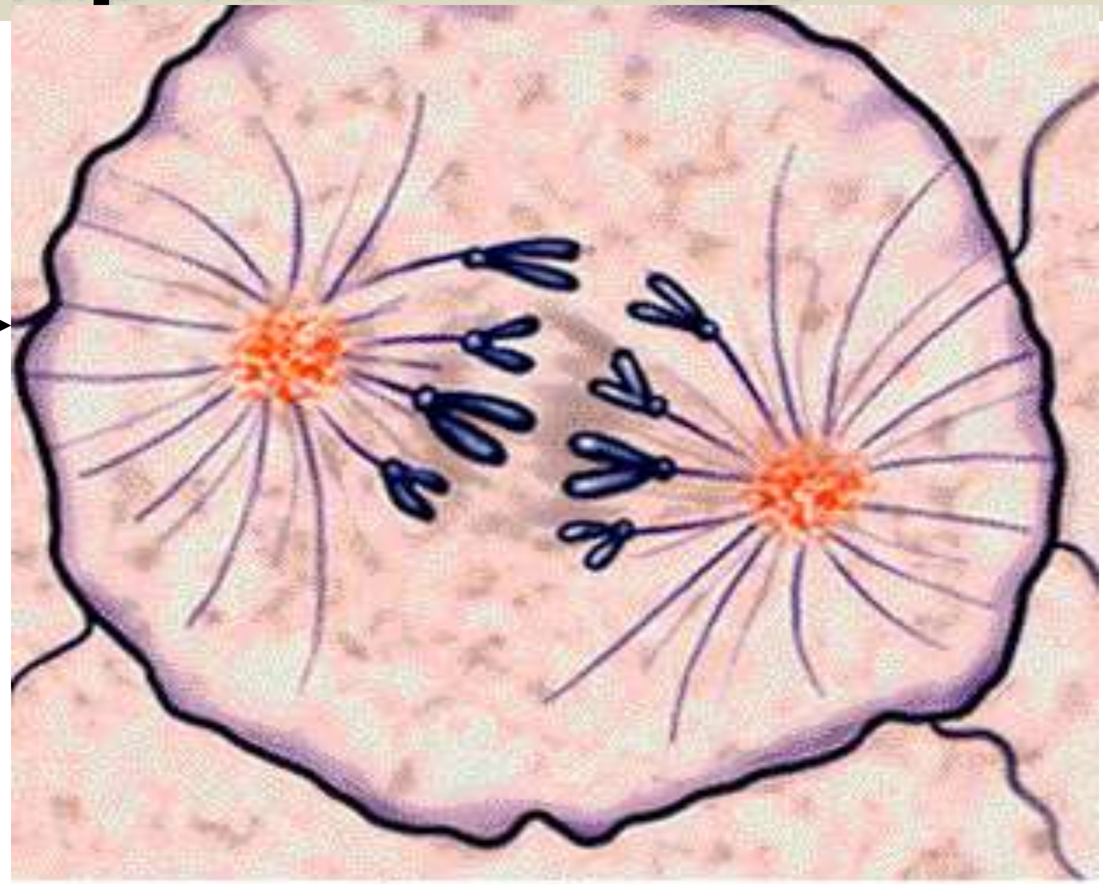
Anaphase

- ✓Occurs rapidly
- ✓Sister chromatids are pulled apart to opposite poles of the cell by kinetochore fibers



Anaphase Review

What the cell looks like



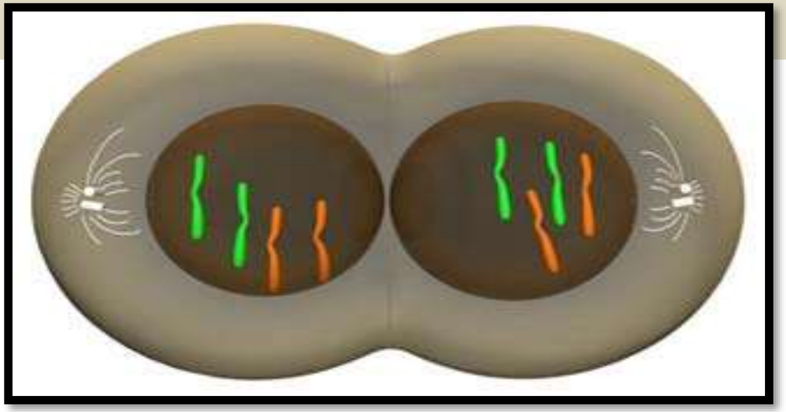
What's occurring

Anaphase

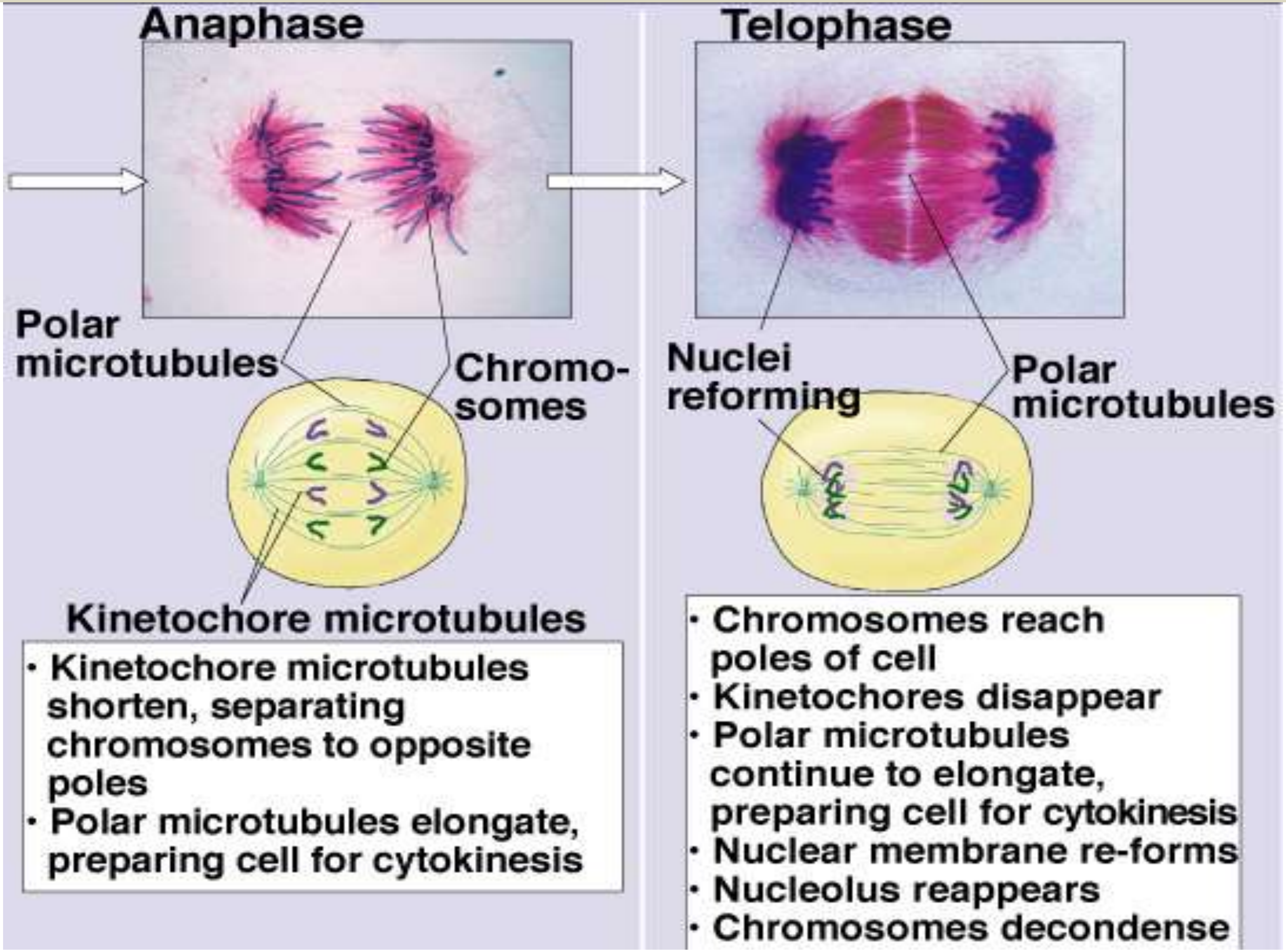
Centromeres divide in two.
Spindle fibers pull sister chromatids to opposite poles of cell.
Each pole (future daughter cell) now has an identical set of genes.

Telophase

- Finally, once anaphase is complete, the cell enters the last stage of the division process — **telophase**. During telophase, the newly separated chromosomes reach the mitotic spindle and a nuclear membrane forms around each set of chromosomes, thus creating two separate nuclei inside the same cell. As Figure 4 illustrates, the cytoplasm then divides to produce two identical cells.
-



Comparison of Anaphase & Telophase



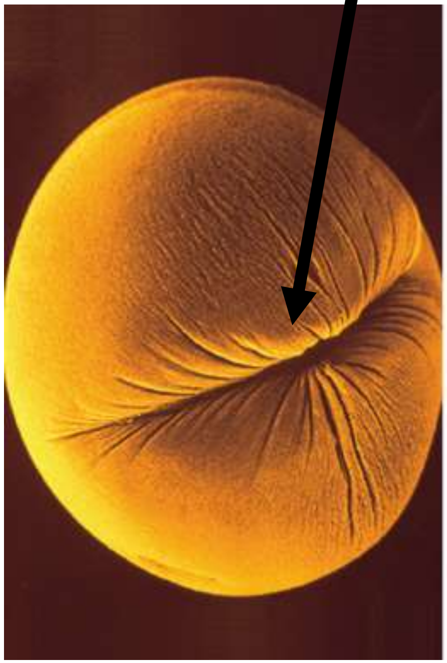
Cytokinesis

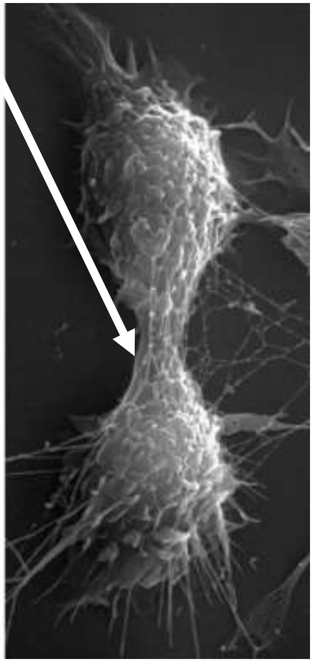
- ✓Means division of the cytoplasm
- ✓Division of cell into two, identical halves called daughter cells
- ✓In plant cells, cell plate forms at the equator to divide cell
- ✓In animal cells, cleavage furrow forms to split cell

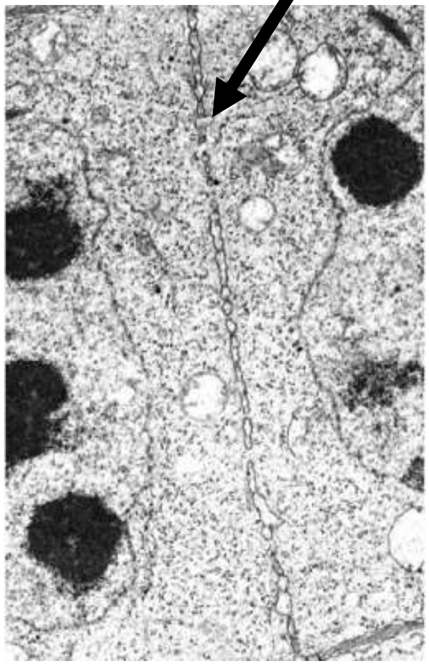
Cytokinesis

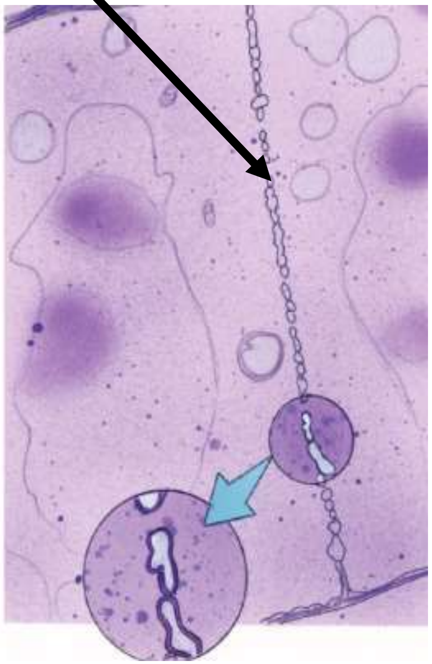
Cleavage furrow in animal cell

Cell plate in plant cell

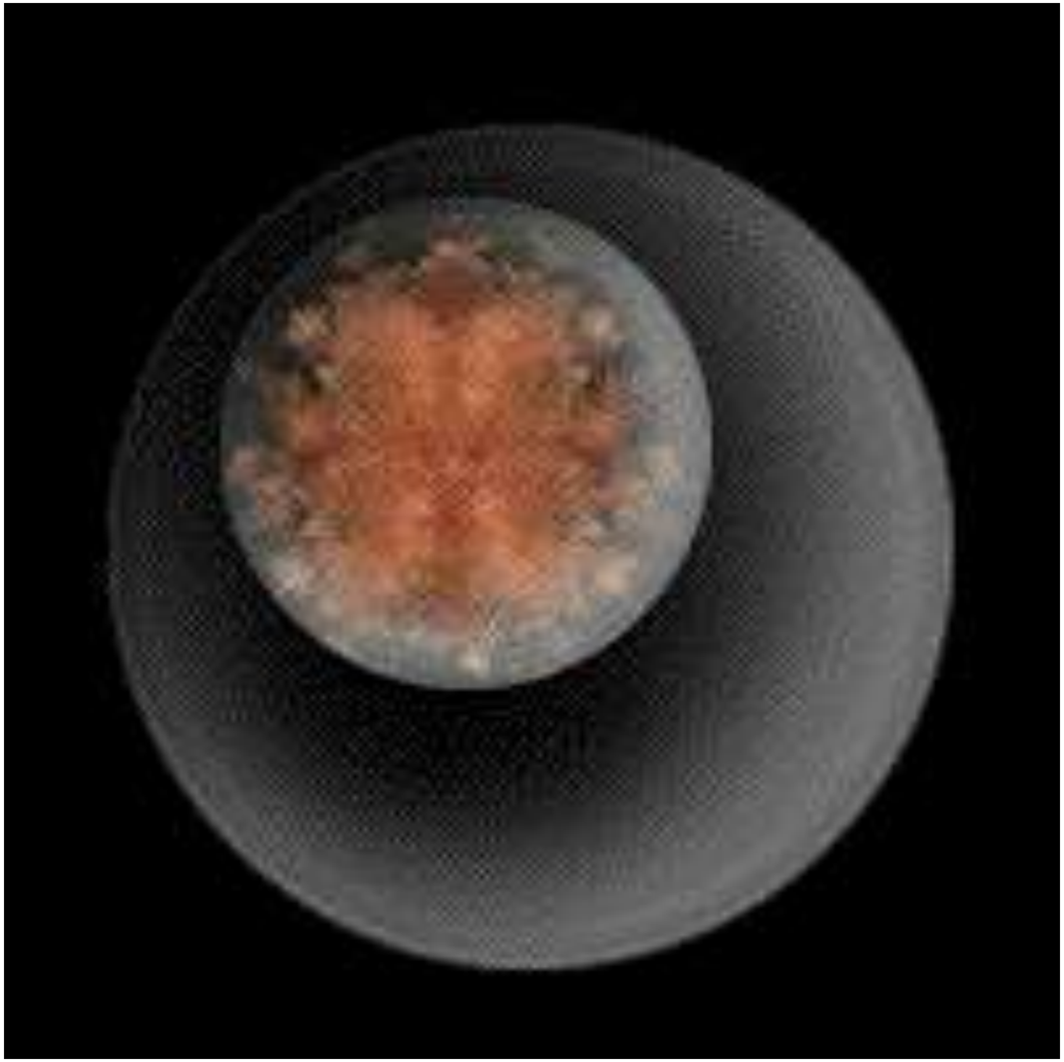








Review of Mitosis



Why is mitosis important?

- As previously mentioned, most eukaryotic cells that are not involved in the production of gametes undergo mitosis.
- These cells, known as somatic cells, are **important to the survival of eukaryotic organisms, and it is essential that somatic parent and daughter cells do not vary from one another.**

- Mitosis **ensures that each successive cellular generation has the same genetic composition as the previous generation, as well as an identical chromosome set.**

Meiosis

Formation of Gametes

(Eggs & Sperm)

Facts About Meiosis

- Preceded by interphase which includes chromosome replication
- Two meiotic divisions --- Meiosis I and Meiosis II
- Called Reduction- division
- Original cell is diploid (2n)
- Four daughter cells produced that are monoploid (1n)

Facts About Meiosis

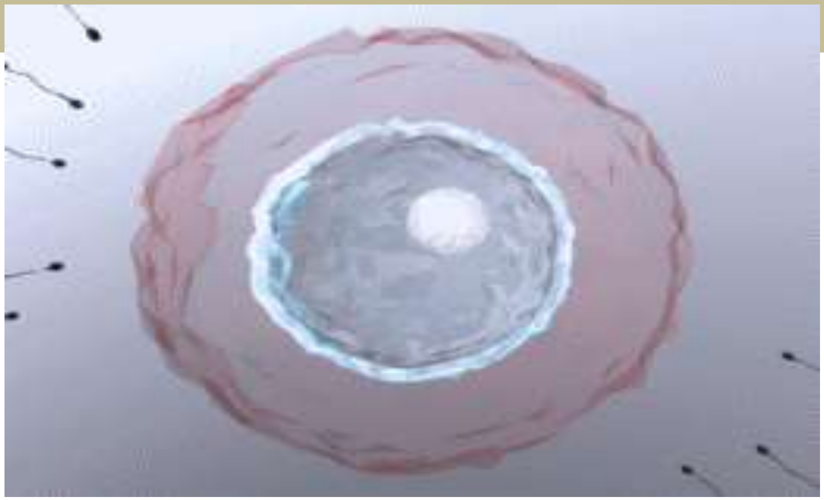
- ✓ Daughter cells contain half the number of chromosomes as the original cell
- ✓ Produces gametes (eggs & sperm)
- ✓ Occurs in the testes in males (Spermatogenesis)
- ✓ Occurs in the ovaries in females (Oogenesis)

More Meiosis Facts

- Start with 46 double stranded chromosomes (2n)
- After 1 division - 23 double stranded chromosomes (n)
- After 2nd division - 23 single stranded chromosomes (n)
- Occurs in our germ cells that produce gametes

Why Do we Need Meiosis?

- ✓ It is the fundamental basis of sexual reproduction
- ✓ Two haploid (1n) gametes are brought together through fertilization to form a diploid (2n) zygote



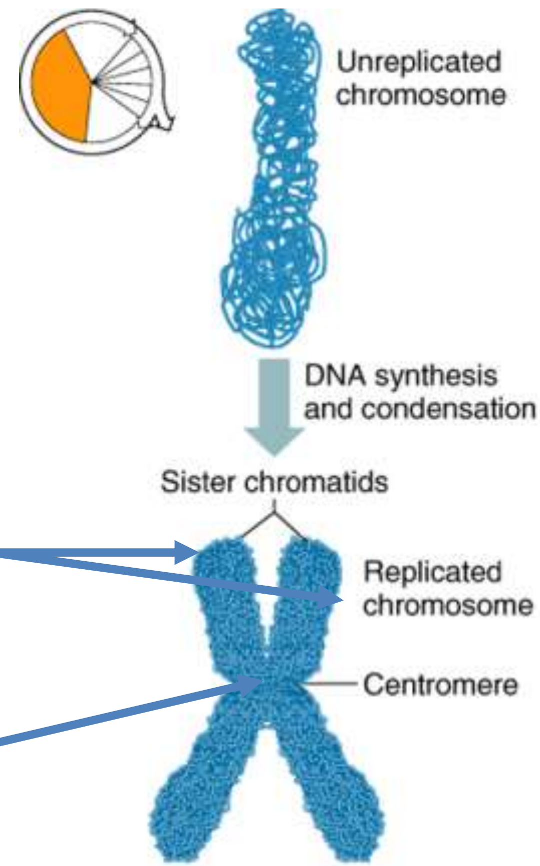
What happens during meiosis I?

- As previously mentioned, the first round of nuclear division that occurs during the formation of gametes is called **meiosis I**. It is also known as the **reduction division** because it results in cells that have half the number of chromosomes as the parent cell.
- **Meiosis** I consists of four phases: **prophase I, metaphase I, anaphase I, and telophase I.**

Replication of Chromosomes

- ✓ Replication is the process of duplicating a chromosome
- ✓ Occurs prior to division
- ✓ Replicated copies are called sister chromatids
- ✓ Held together at centromere

Occurs in Interphase



Prophase I

- During **prophase I**, the chromosomes condense and become visible inside the nucleus. *Because each chromosome was duplicated during the S phase that occurred just before prophase I*, each now consists of two sister chromatids joined at the centromere. This arrangement means that each chromosome has the shape of an X.

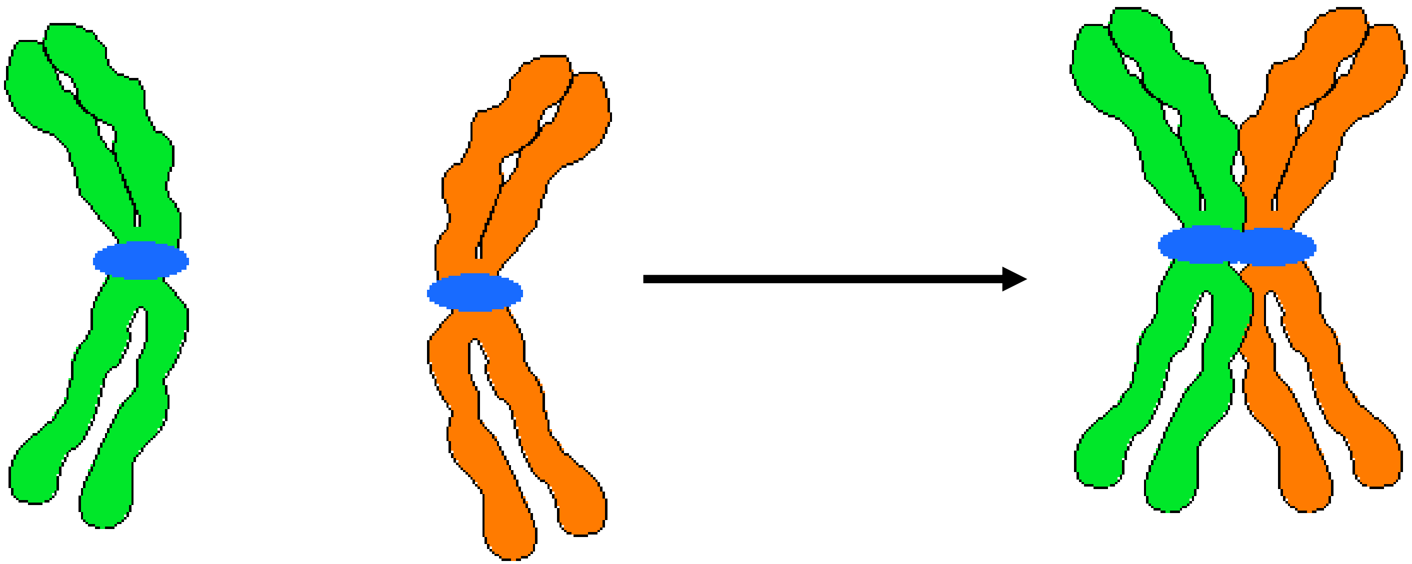
- Once this chromosomal condensation has occurred, the members of each chromosome pair *(called **homologous chromosomes**, because they are similar in size and contain similar genes)*, align next to each other.
- At this point, the two chromosomes in each pair **become tightly associated** with each other along their lengths in a process called **synapsis.**

- Then, while the **homologous chromosomes** are tightly paired, the members of each pair **trade** adjacent bits of DNA in a process called **crossing over,** also known **as recombination.** This trading of genetic material creates **unique chromosomes that contain new combinations of alleles.**

Tetrads Form in Prophase I

Homologous chromosomes
(each with sister chromatids)

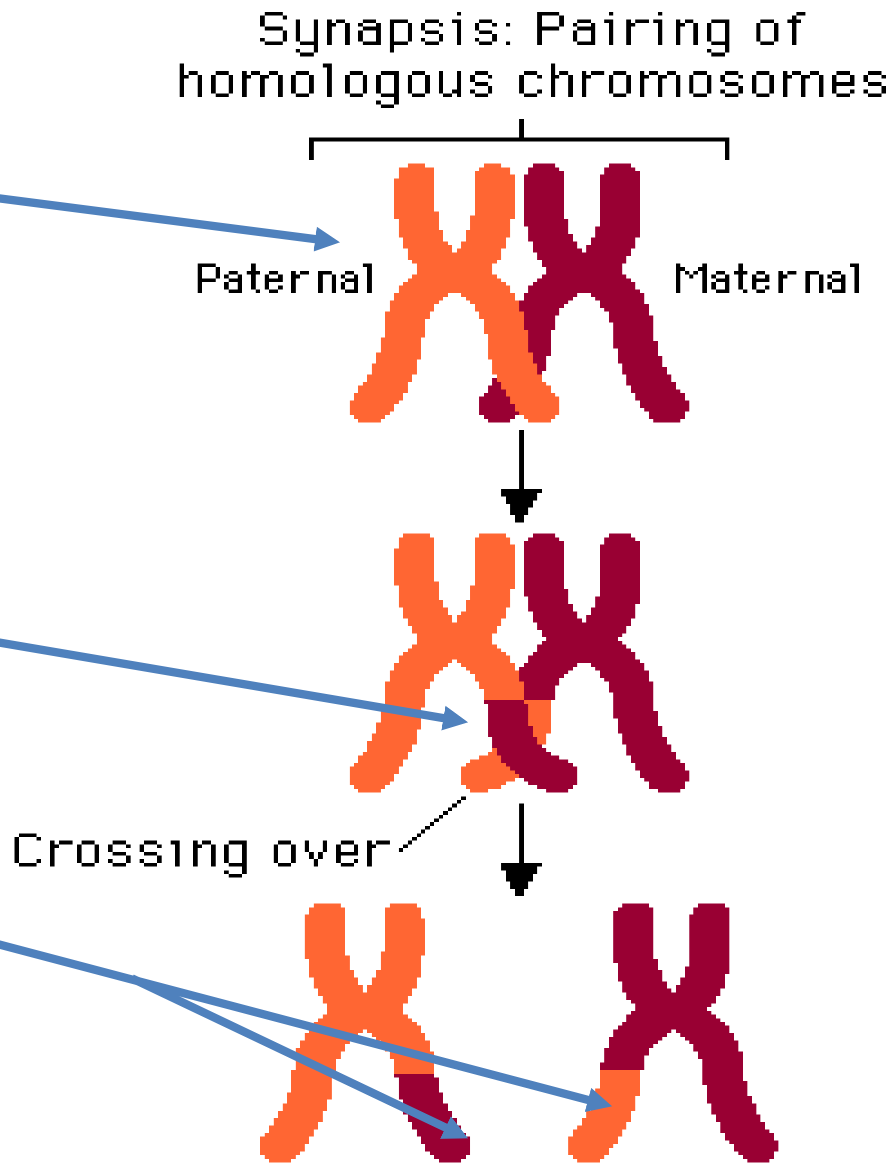
Join to form a TETRAD



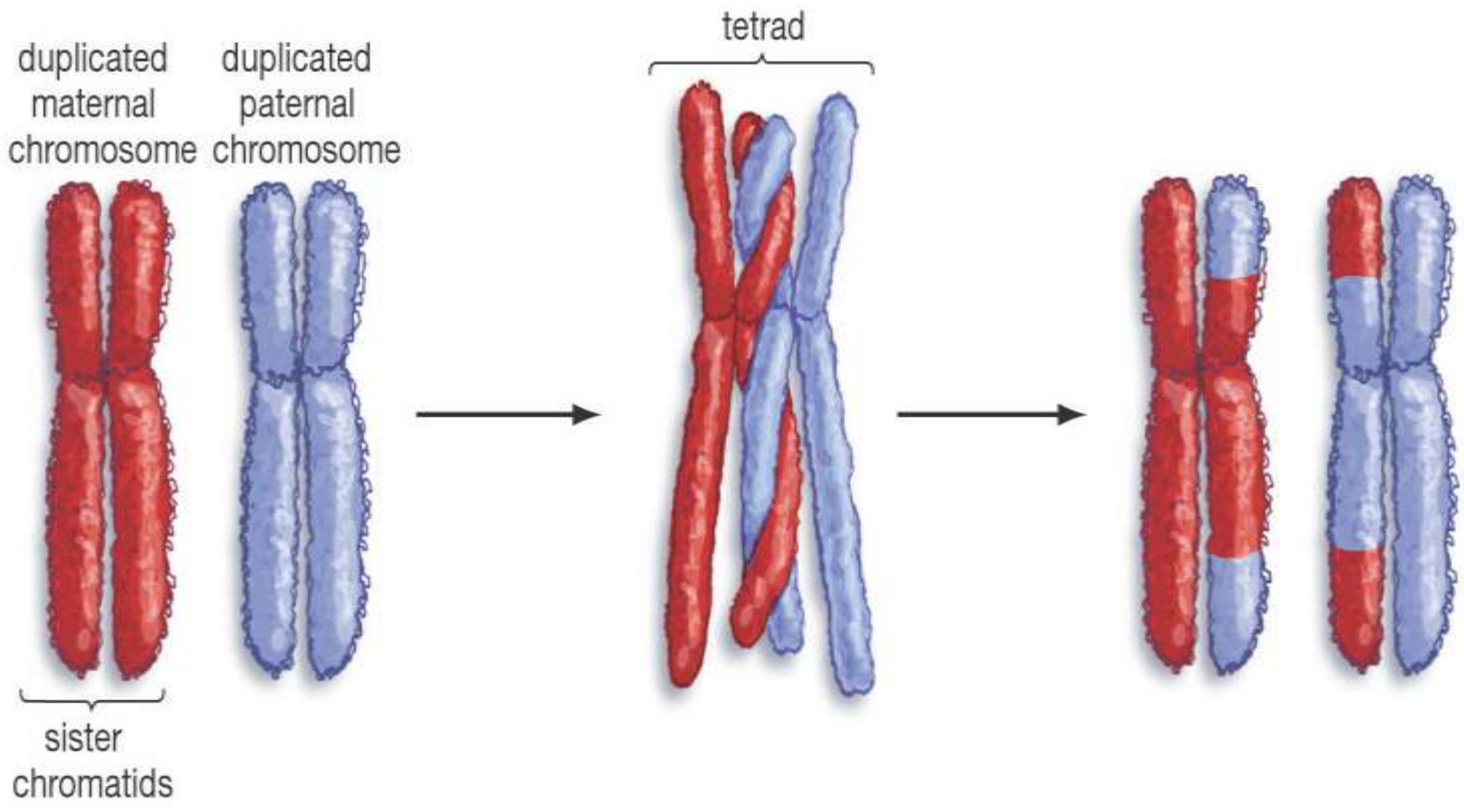
Called Synapsis

Crossing-Over

- Homologous chromosomes in a tetrad cross over each other
- Pieces of chromosomes or genes are exchanged
- Produces Genetic recombination in the offspring



Crossing-Over



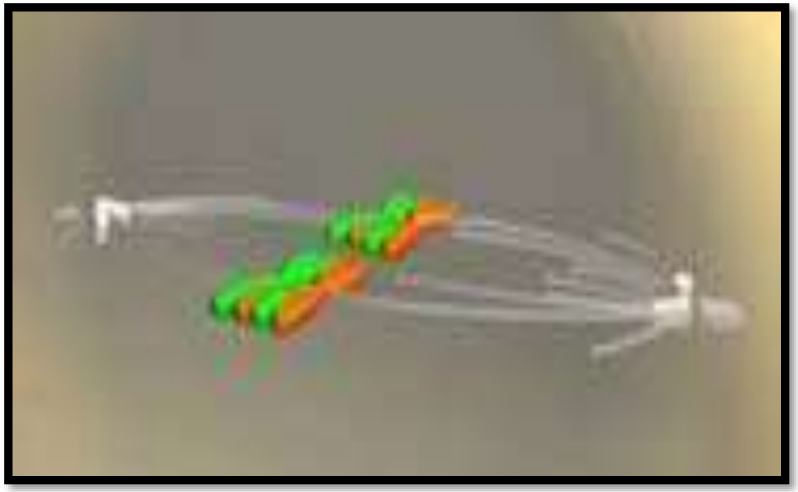
Crossing-over multiplies the already huge number of different gamete types produced by independent assortment

- At the end of prophase I, the nuclear membrane finally begins to break down. Outside the nucleus, the spindle grows out from centrosomes on each side of the cell.
- As in mitosis, the microtubules of the spindle are responsible for moving and arranging the chromosomes during division.

Metaphase I

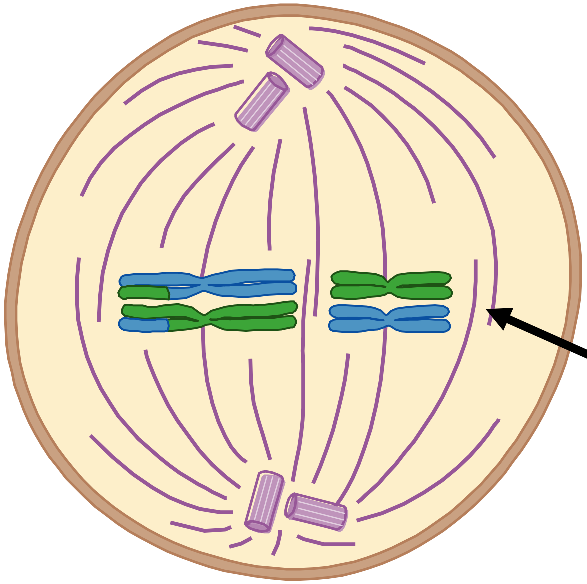
- At the start of **metaphase I**, **microtubules emerge from the spindle and attach to the kinetochore near the centromere of each chromosome.**

- In particular, microtubules from one side of the spindle attach to one of the chromosomes in each homologous pair, while microtubules from the other side of the spindle attach to the other member of each pair.
- With the aid of these microtubules, the chromosome pairs *then line up along the equator of the cell, termed the metaphase plate (Figure 2).*



- Figure 2: Near the end of metaphase I, the homologous chromosomes align on the metaphase plate

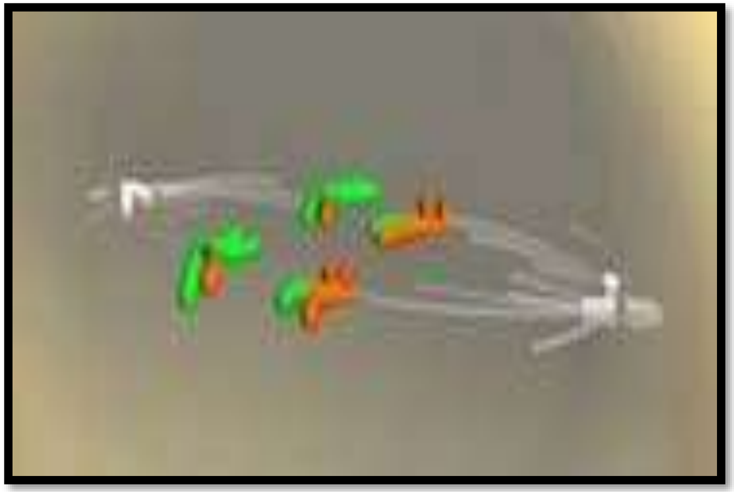
Metaphase I



Homologous pairs of chromosomes align along the equator of the cell

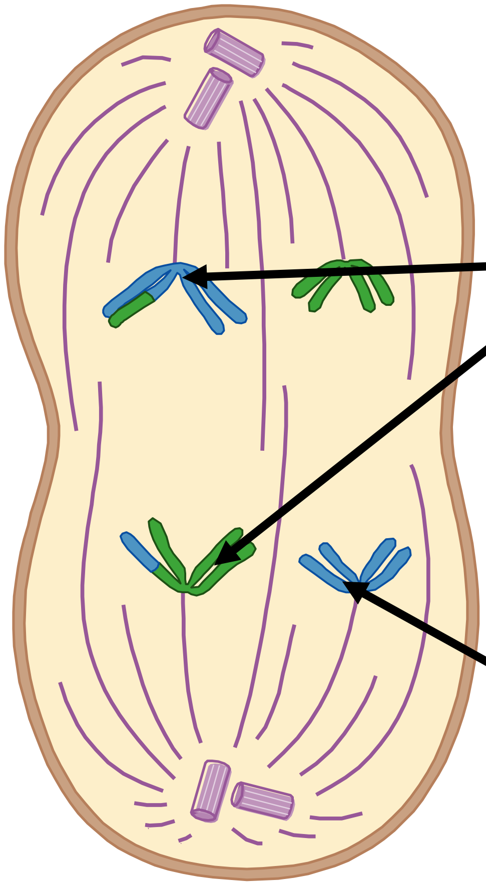
Anaphase I

- During anaphase I, the microtubules disassemble and contract; this, in turn, separates the homologous chromosomes such that the two chromosomes in each pair are pulled toward opposite ends of the cell .
- This separation means **that each of the daughter cells that results from meiosis I will have half the number of chromosomes of the original parent cell after interphase.**
- Also, **the sister chromatids in each chromosome still remain connected. As a result, each chromosome maintains its X-shaped structure.**
-



- Figure 3: During anaphase I, the homologous chromosomes are pulled toward opposite poles of the cell.

Anaphase I

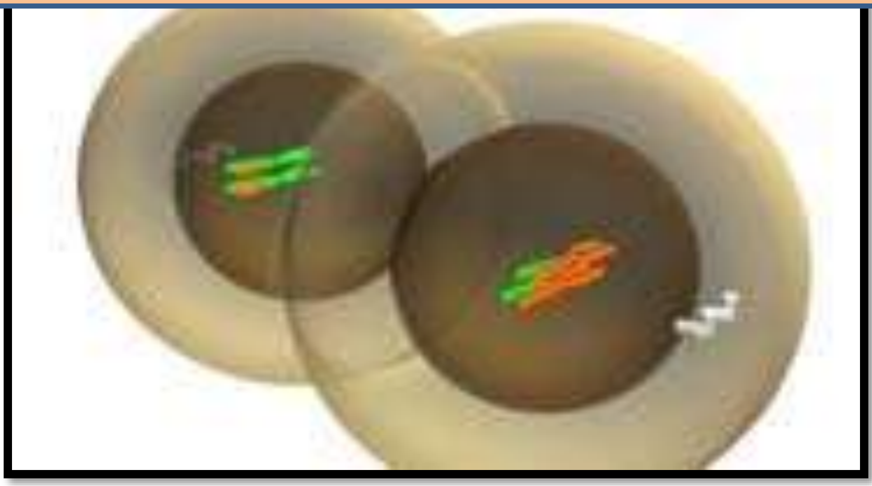


Homologs separate and move to opposite poles.

Sister chromatids remain attached at their centromeres.

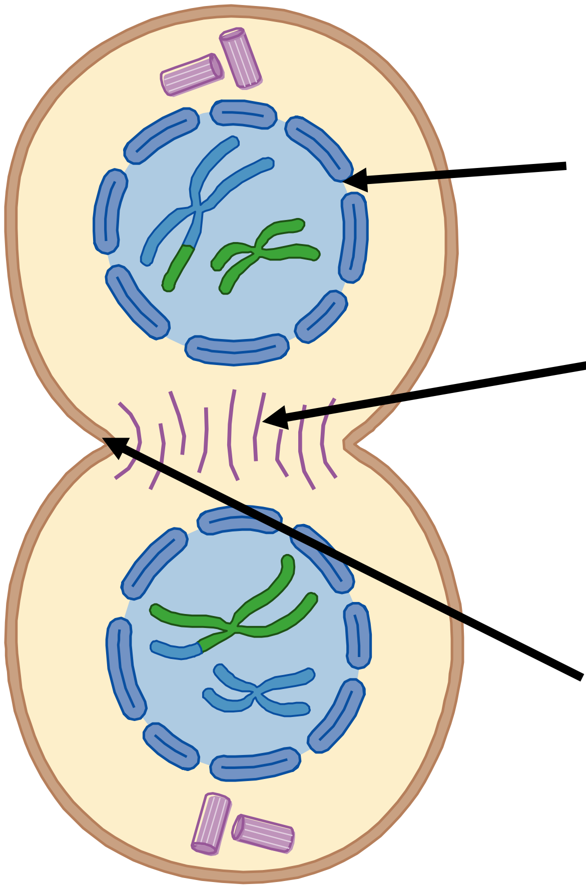
Telophase I

- As the new chromosomes reach the spindle during **telophase I,** the cytoplasm organizes itself and divides in two.
- There are now two cells, and each cell contains half the number of chromosomes as the parent cell.
- In addition, the two daughter cells are not genetically identical to each other because of the recombination that occurred during prophase I .



- Figure 4: Telophase I results in the production of two nonidentical daughter cells, each of which has half the number of chromosomes of the original parent cell.

Telophase I

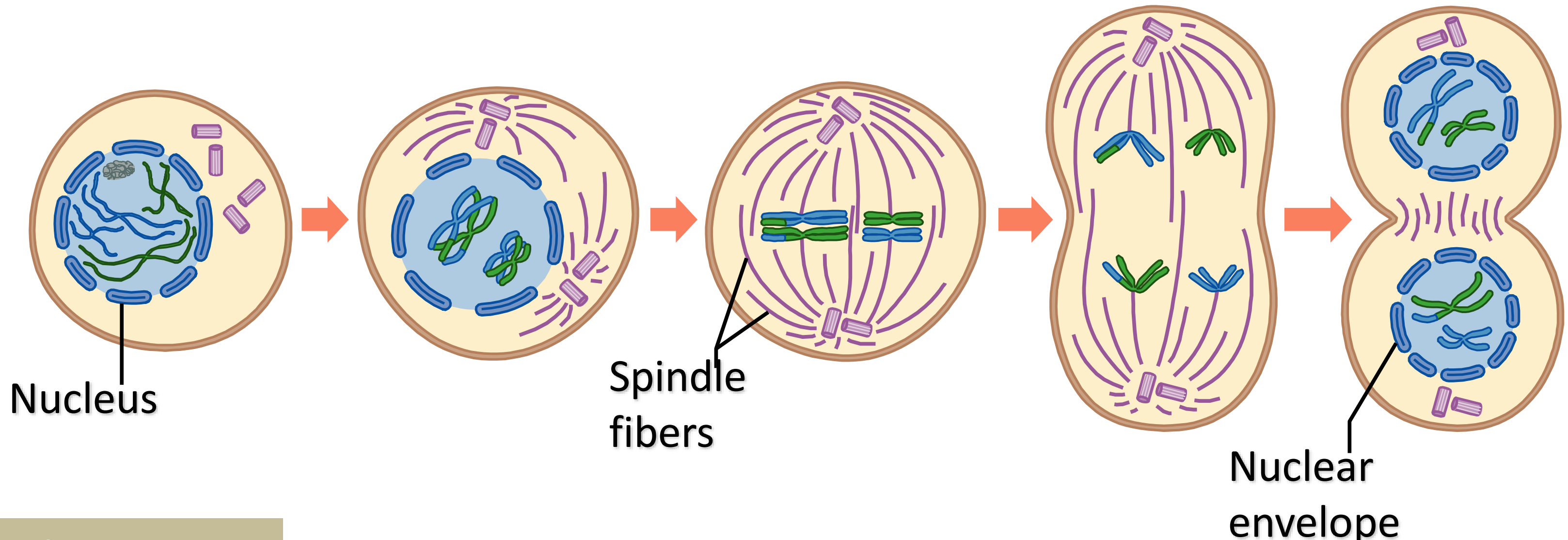


Nuclear envelopes reassemble.

Spindle disappears.

Cytokinesis divides cell into two.

Meiosis I: Reduction Division



Early Prophase I (Chromosome number doubled)

Late Prophase I

Metaphase I

Anaphase I

Telophase I (diploid)

Interkinesis

- At this point, the first division of meiosis is complete. The cell now rests for a bit before beginning the second meiotic division. During this period, called **interkinesis**, *the nuclear membrane in each of the two cells reforms around the chromosomes. In some cells, the spindle also disintegrates and the chromosomes relax (although most often, the spindle remains intact).*
- It is important to note, however, that no chromosomal duplication occurs during this stage.
-

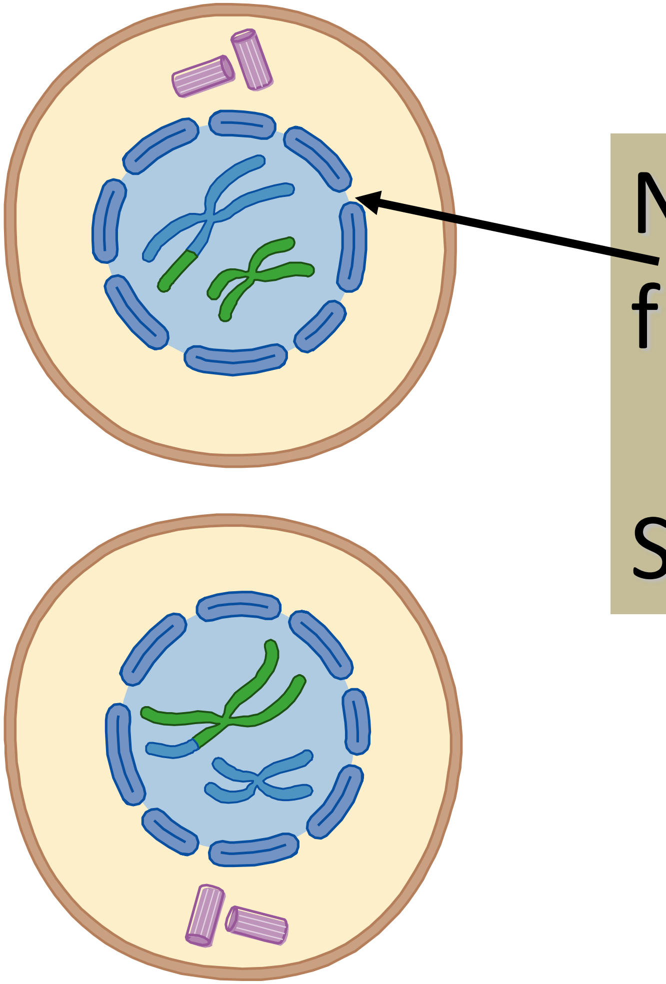
What happens during meiosis II?

- ***During meiosis II, the two cells once again cycle through four phases of division.***
- Meiosis II is sometimes referred to as an equational division because it does not reduce chromosome number in the daughter cells — rather, the daughter cells that result from meiosis II have the same number of chromosomes as the "parent" cells that enter meiosis II.

Prophase II

- As **prophase II** begins, the chromosomes once again condense into tight structures, and the nuclear membrane disintegrates. In addition, if the spindle was disassembled during interkinesis, it reforms at this point in time.

Prophase II

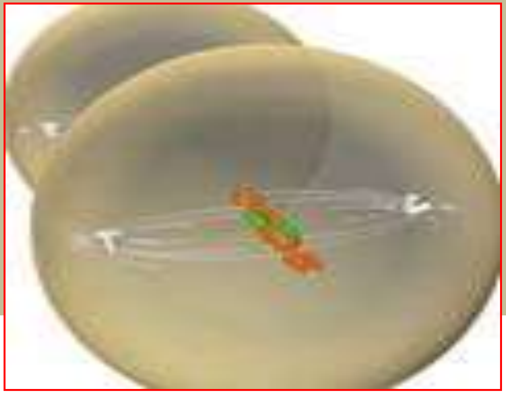


Nuclear envelope fragments.

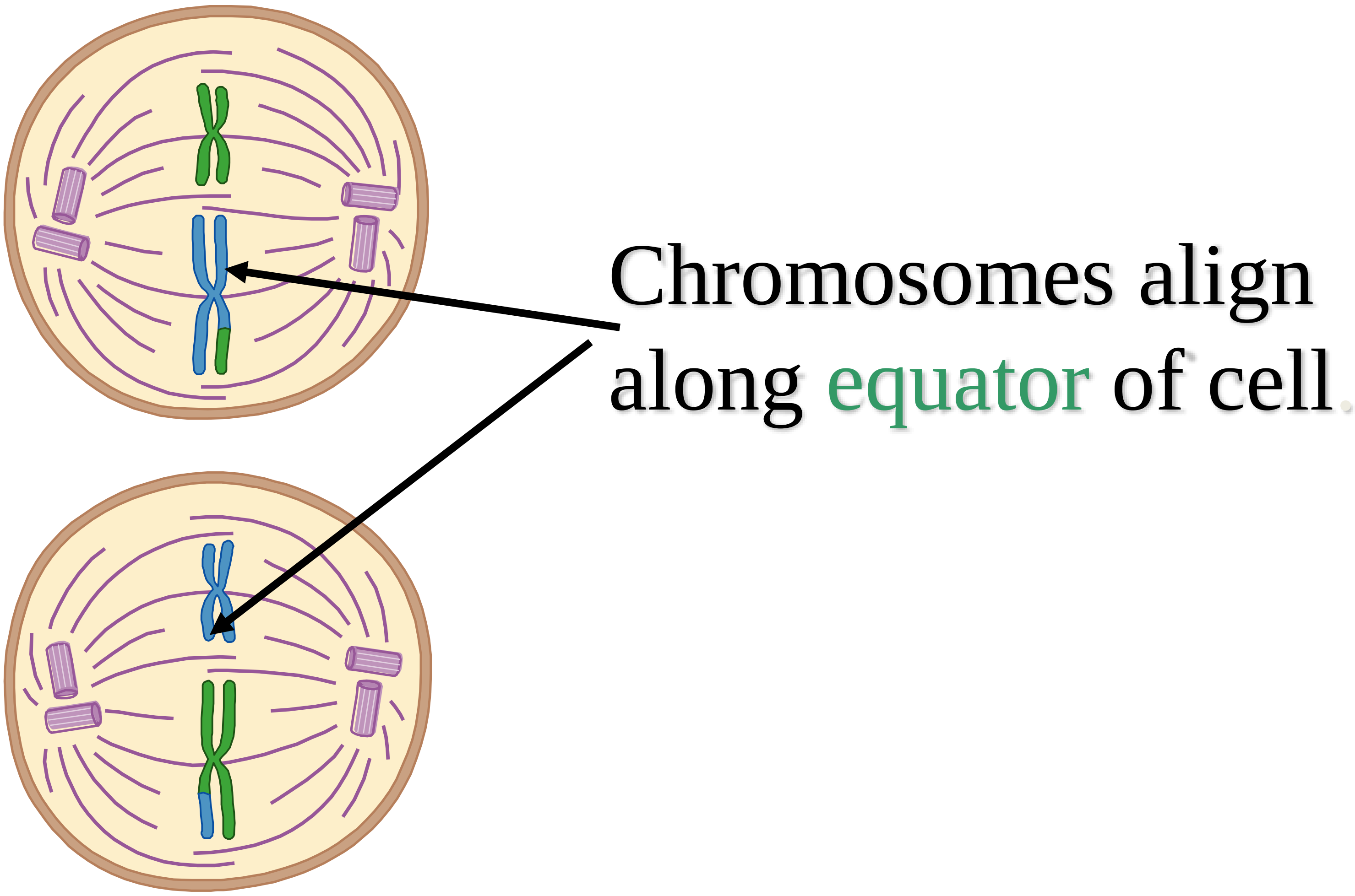
Spindle forms.

Metaphase II

- The events of **metaphase II** are similar to those of mitotic metaphase — in both processes, the chromosomes line up along the cell's equatorial plate, also called the metaphase plate, in preparation for their eventual separation (Figure 5).

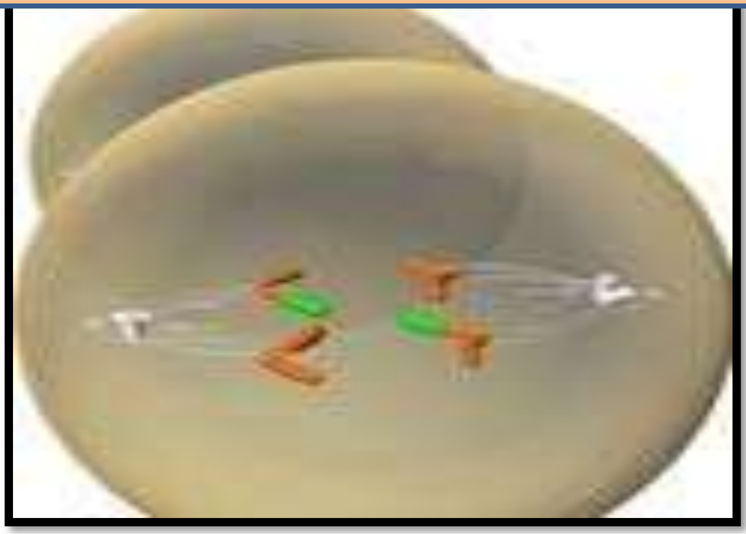


Metaphase II



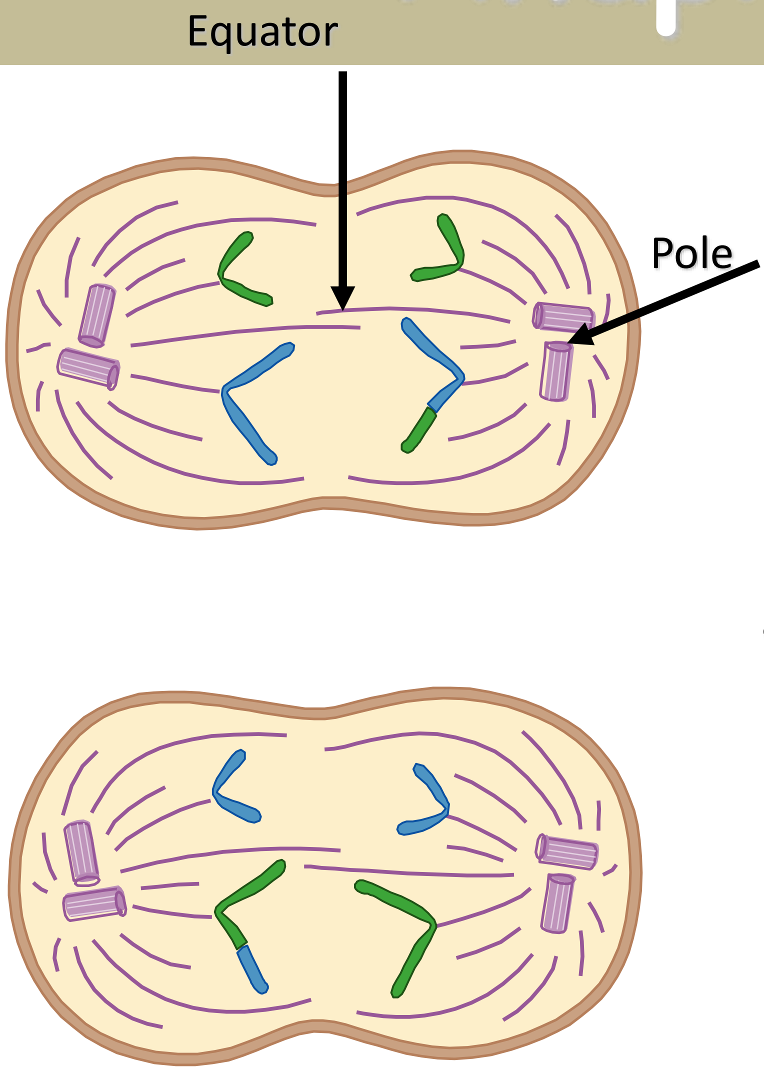
Anaphase II

- During **anaphase II**, microtubules from each spindle attach to each sister chromatid at the kinetochore. The sister chromatids then separate, and the microtubules pull them to opposite poles of the cell. As in mitosis, each chromatid is now considered a separate chromosome (Figure 6).
- This means that the cells that result from meiosis II will have the same number of chromosomes as the "parent" cells that entered meiosis II.



- Figure 6: Anaphase II involves separation of the sister chromatids

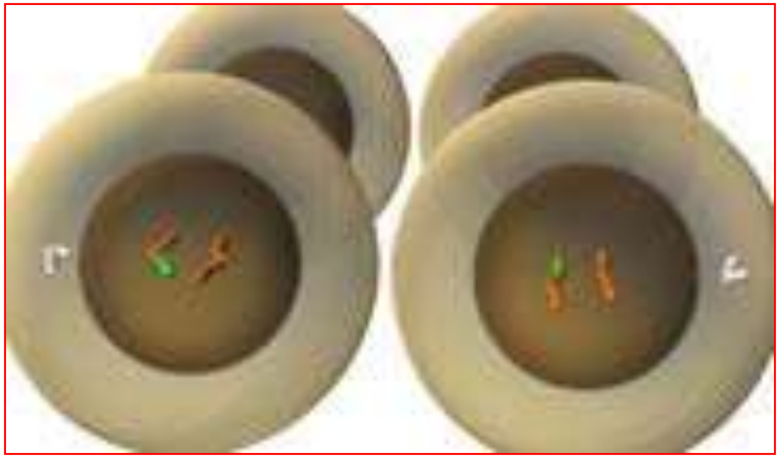
Anaphase II



Sister chromatids separate and move to opposite poles.

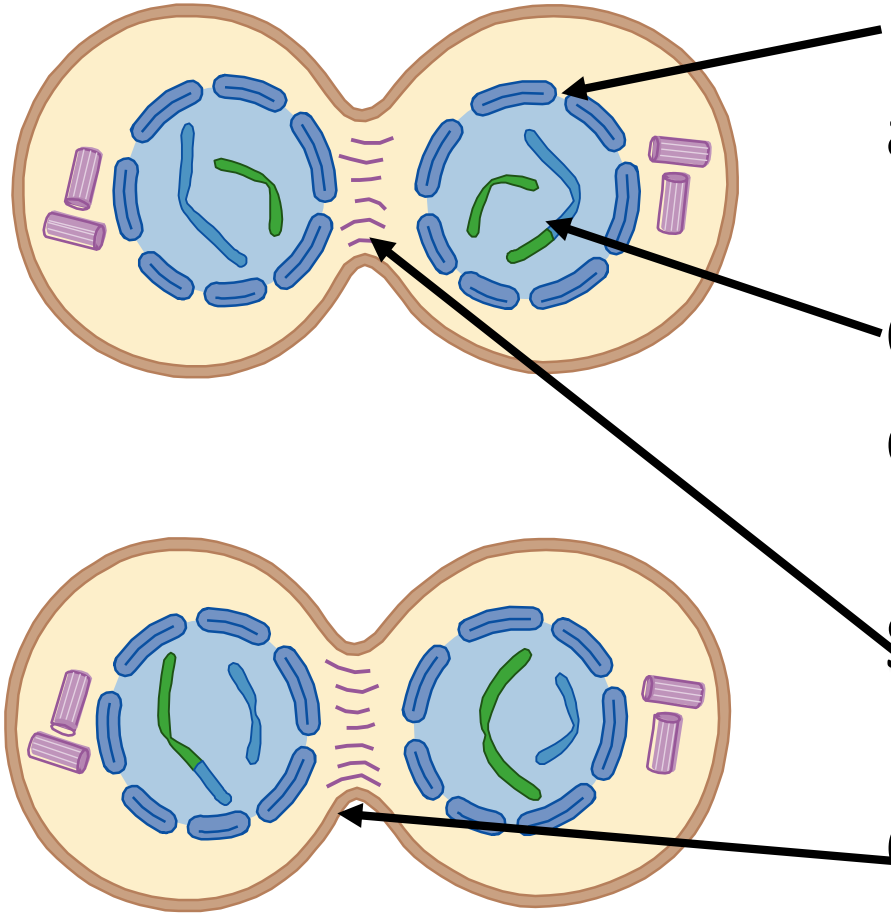
Telophase II

- Finally, in **telophase II**, nuclear membranes reform around the newly separated chromosomes, which relax and fade from view. As soon as the cytoplasm divides, meiosis is complete. There are now four daughter cells — two from each of the two cells that entered meiosis II — and each daughter cell has half the normal number of chromosomes (Figure 7). Each also contains new mixtures of genes within its chromosomes, thanks to recombination during meiosis I.



- Figure 7: Telophase II results in the production of four daughter cells

Telophase II



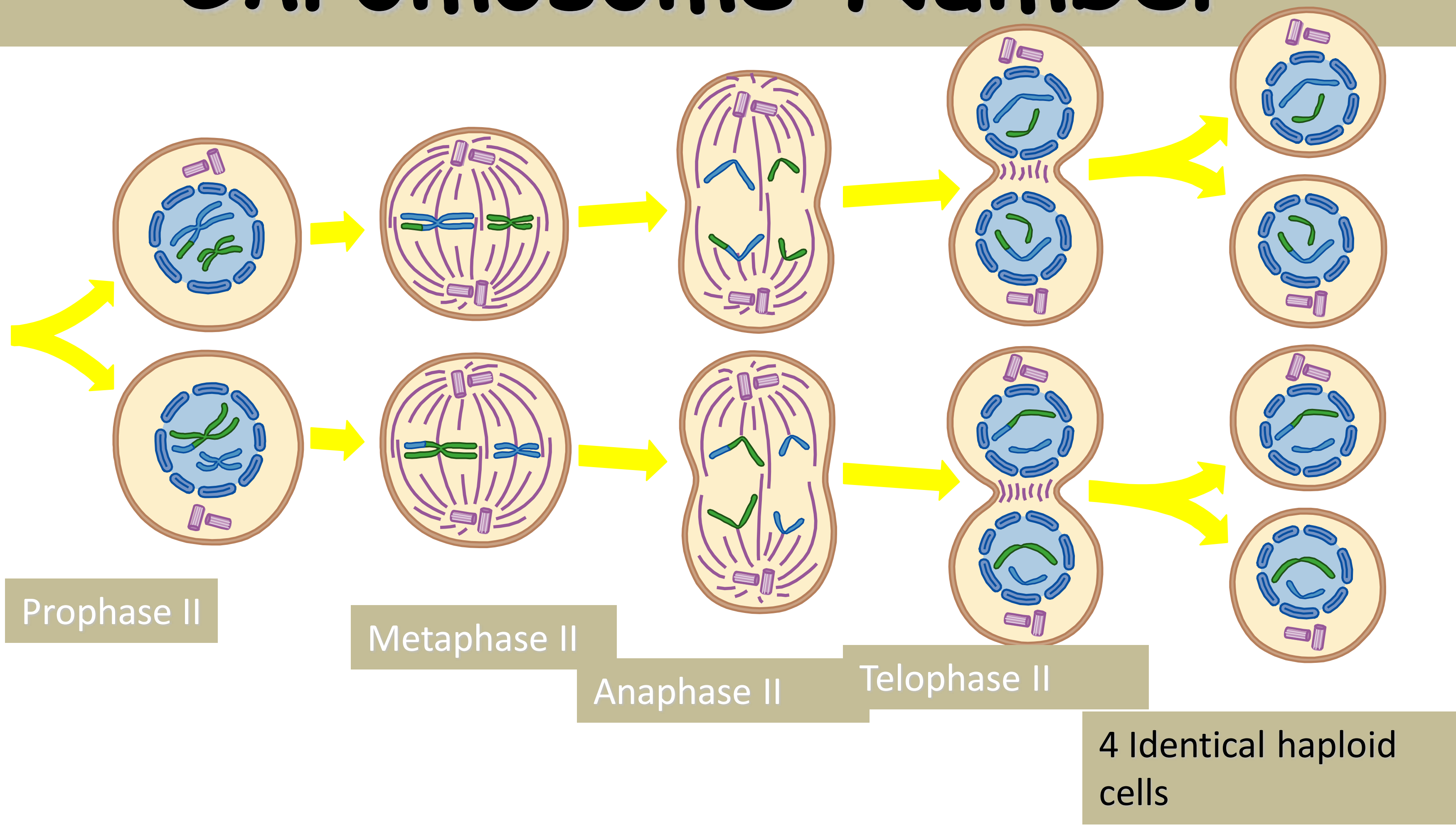
Nuclear envelope assembles.

Chromosomes decondense.

Spindle disappears.

Cytokinesis divides cell into two.

Meiosis II: Reducing Chromosome Number



Why is meiosis important?

- Meiosis is important because it ensures that all **organisms produced via sexual reproduction contain the correct number of chromosomes. Meiosis also produces genetic variation by way of the process of recombination.** Later, this variation is increased even further when two gametes unite during fertilization, thereby creating offspring with unique combinations of DNA. This constant mixing of parental DNA in sexual reproduction helps fuel the incredible diversity of life on Earth.

- Like mitosis, **meiosis** is a form of eukaryotic cell division. However, these two processes distribute genetic material among the resulting daughter cells in very different ways.
- **Mitosis** creates two identical daughter cells that each contain the same number of chromosomes as their parent cell.

- In contrast, **meiosis** gives rise to four unique daughter cells, each of which has half the number of chromosomes as the parent cell.
- Because **meiosis** creates cells that are destined to become **gametes** (or reproductive cells), this reduction in chromosome number is critical — without it, the union of two gametes during fertilization would result in offspring with twice the normal number of chromosomes!

- Apart from this reduction in chromosome number, **meiosis differs from mitosis** in yet another way.
- Specifically, meiosis creates new combinations of genetic material in each of the four daughter cells. These new combinations result from the exchange of DNA between paired chromosomes. Such exchange means that the gametes produced through meiosis exhibit an amazing range of genetic variation.

- Finally, unlike mitosis, meiosis involves two rounds of nuclear division, not just one. Despite this fact, many of the other events of meiosis are similar to those that occur in mitosis. For example, prior to undergoing meiosis, a cell goes through an interphase period in which it grows, replicates its chromosomes, and checks all of its systems to ensure that it is ready to divide.

- Like **mitosis**, meiosis also has distinct stages called prophase, metaphase, anaphase, and telophase. A key difference, however, is that during meiosis, each of these phases occurs twice — once during the first round of division, called meiosis I, and again during the second round of division, called meiosis II

Comparison of Divisions

	Mitosis	Meiosis
Number of divisions	1	2
Number of daughter cells	2	4
Genetically identical?	Yes	No
Chromosome #	Same as parent	Half of parent
Where	Somatic cells	Germ cells
When	Throughout life	At sexual maturity
Role	Growth and repair	Sexual reproduction

Questions