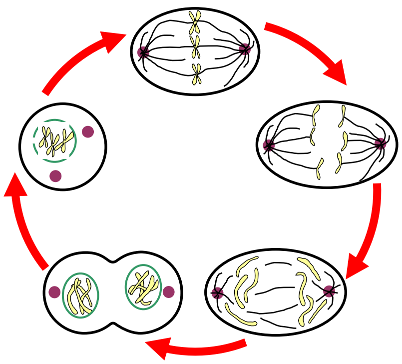
Eukaryotic Cell Cycle

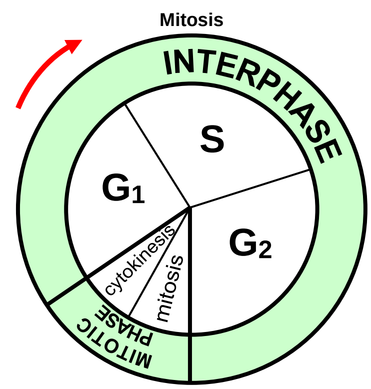


There are two processes that cells in eukaryotes undergo to reproduce: **mitosis** and **meiosis**. Both processes are cycles; they end with cells that are either identical to the parent cells, or with sex cells that are ready to produce a new organism.

Cells don't move continuously through the cell cycle (an example of which is shown to the left). A cell can stop at any of several points in the cell cycle for hours or years before moving on to the next stage. In fact, cells often stop permanently at one stage. Cells go on to the next step in the cycle after receiving signals to re-start, such as growth factor proteins excreted by nearby cells.

While mitosis and meiosis are very different processes, their cell cycles can both be split into two phases; interphase and the cell division (mitotic or meiotic) phase.

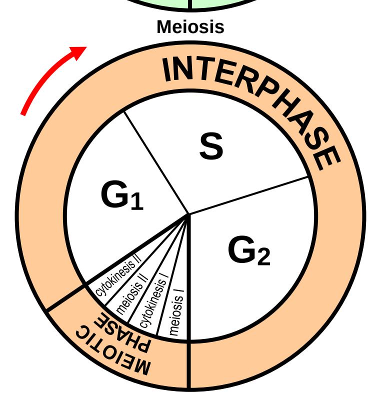
INTERPHASE



Interphase is the time when the cell isn't actively dividing. Most cells spend almost all their time in interphase.

The nucleus of a cell contains loose spools of **chromatin** — a combination of DNA and proteins. During **G_1**, the chromatin coils up and forms densely-packed **chromosomes**. The cell also makes new organelles and proteins in preparation for cell division.

During the **S** phase, DNA replication takes place. Chromosomes are copied and two sister chromatids are made from each chromosome. During **G_2**, more proteins are synthesized and the cell readies for division.



CELL DIVISION

The primary differences between mitosis and meiosis include:

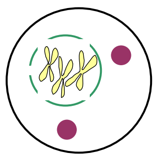
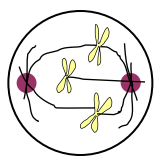
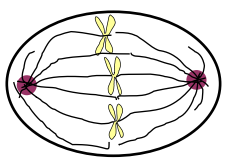
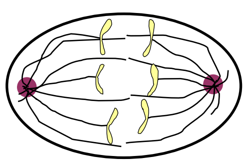
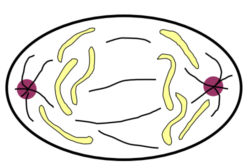
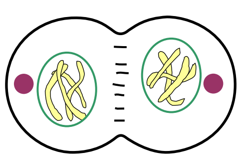
• *Arrangement of chromosomes.* In mitosis, chromosomes remain separate. In meiosis, **homologous** (similar) chromosomes are joined.

• *Exchange of genetic information.* In mitosis, the cells that result are identical to the parent cell. In meiosis, chromosomes exchange information before cell division so that daughter cells contain different information than parent cells, and daughter cells are haploid.

• *Number of cells produced.* Meiosis happens in two rounds, producing four cells rather than two, as in mitosis.

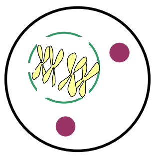
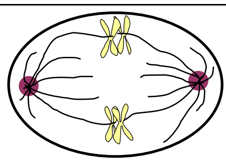
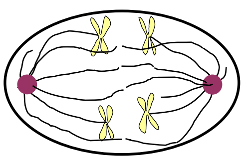
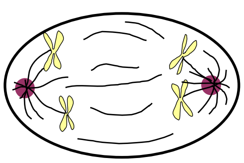
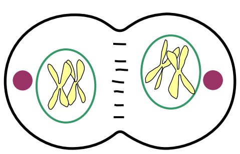
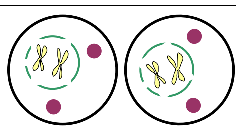
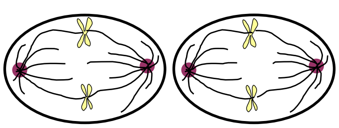
MITOTIC PHASE

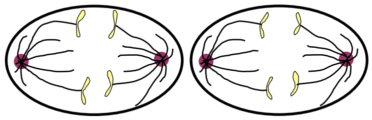
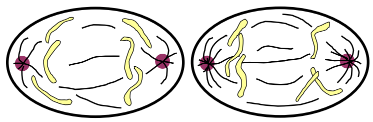
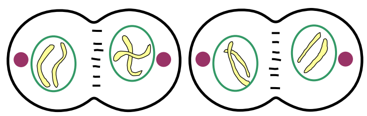
In the mitotic process, the cell's nucleus divides into two nuclei; two exact diploid (2n) copies of the diploid parent cell are created. This is the type of division seen in cell growth, repair, and asexual reproduction (cloning). Mitosis consists of five phases: prophase, prometaphase, metaphase, anaphase, and telophase. These phases are not distinct, but are a continuum, with one phase starting while the previous one is ending.

	In **prophase**, the chromatin condenses into visible chromosomes. The chromosomes are in the form of **sister chromatids** in the shape of a long letter X. The centrioles separate and move towards opposite ends of the cell as the spindle begins to form. The **spindle fibres,** or **microtubules**, extend out toward each other. The nucleolus disappears.
	In **prometaphase** the nuclear membrane breaks down (this can't be seen in the microscope). The microtubules attach to the chromosomes at a point near the centromere of each chromatid called the kinetochore. A spindle from each of the two centrioles is attached to each kinetochore.
	During **metaphase,** the chromosomes align along the centre of the cell at an imaginary surface called the **metaphase plate**. A microtubule from each centriole is attached to the sister chromatids, one on each side. In this phase, everything is in position for the cell to divide. The unattached microtubules from one centriole are in contact with microtubules from the opposite centriole.
	During **anaphase**, the chromatids split as they are pulled towards opposite poles by some of the microtubules, and the cell lengthens. The unattached microtubules push against each other and help to move the two halves of the cell apart. Each separate chromatid is now referred to as a chromosome by itself (so that the number of chromosomes in the cell is momentarily doubled).
	In **telophase**, cell elongation continues. The mitotic spindle disappears and the new chromosomes unfold into chromatin. The nuclear membrane re-forms. (Again, this process is invisible using a microscope.) In other words, the changes the cell went through in prophase and prometaphase are undone.
	During **cytokinesis**, which occurs simultaneously with telophase, the cytoplasm of the cell is divided into two individual cells. In higher plant cells, a plate forms at the centre, between the nuclei and gradually extends to the cell wall. In animal cells, a **cleavage furrow** appears at the cell membrane and tightens to pinch the cell in two.

MEIOTIC PHASE

In **meiosis,** four haploid (n) cells are created from one diploid (2n) cell. This type of cell division is seen in cells involved in sexual reproduction. The meiotic process consists of 2 rounds of cell division, Meiosis I and Meiosis II, each made up of 4 phases: prophase, metaphase, anaphase and telophase. Some biologists add a prometaphase step in between prophase and metaphase; it's arbitrary to define it as a four- or five-phase process. The important thing is to understand what is happening in the cell.

Meiosis I	
	**Prophase I** begins as the chromatin coils into chromosomes. Similar chromosomes come together in pairs (called **tetrads**), bonding with each other at several points. The chromosomes can exchange genetic information at their bonds. This is called **crossing over**. The overall process of forming tetrads and crossing over is called **synapsis**. The tetrads move towards the equator of the cell. The nuclear membrane breaks down at the end of prophase.
	During **metaphase I**, the paired chromosomes line up at the metaphase plate, creating a double line of centromeres. The spindle attaches to the kinetochores at the centromeres, with one chromosome from each tetrad attached to each of the poles.
	During **anaphase I**, the paired chromosomes separate and a whole chromosome is pulled to each pole.
	In **telophase I**, the cell continues to lengthen and the spindle disappears. The nuclear membrane re-forms.
	During **cytokinesis I**, the cell splits into two separate cells. In higher plant cells, a cell plate forms between the nuclei and gradually extends to the cell wall. In animal cells, a cleavage furrow appears at the cell membrane and slowly tightens to pinch the cell in two. As in mitosis, cytokinesis occurs at the same time as telophase.
Meiosis II	
Meiosis II occurs after meiosis I, resulting in four cells at the end of the cycle.	
	In **prophase II**, the nuclear membrane breaks down and the spindle forms.
	The chromosomes line up along the equatorial line during **metaphase II**. Unlike metaphase I, the centromeres now line up *individually* along the equator (there are no chromosome pairs). A spindle from each pole is attached to each centromere at the kinetochore.

	The chromosomes split during **anaphase II**. Each chromatid is pulled towards an opposite pole, and the cell lengthens along that pole.
	In **telophase II,** the cell continues to lengthen, the spindle disappears and the nuclear membrane re-forms.
	**Cytokinesis II** begins as the cell membrane pinches off, forming two separate cells, as in meiosis I.

EXERCISES

A. Review and synthesis questions:

1) What is the difference between a haploid and a diploid cell?

2) Where would haploid and diploid cells be found in your body?

3) Why is the chromosome reduction of meiosis necessary?

4) What might be the evolutionary advantage of ‘crossing over’ of chromosome information in meiosis, especially in the case of asexual reproduction?

5) What are the evolutionary advantages of sexual reproduction?

SOLUTIONS

1) A haploid cell has half the number of chromosomes as a diploid cell. In humans, diploid cells have 46 chromosomes, and haploid cells have 23.

2) Haploid cells are usually found in reproductive cells, like sperm and egg cells in humans. Diploid cells are found in most non-reproductive cells of animals and many plants.

3) Without chromosome reduction, the offspring from sexual reproduction would have double the number of chromosomes of either parent, and that child would go on to have offspring with twice the number of its parents’ chromosomes, and so on. At a certain point, chromatin storage would dominate the cell, and other functions would be compromised. By reducing the chromosomes to a diploid number, the number of chromosomes in an organism is the same through successive generations.

4) Crossing over creates new sequences of DNA, which creates offspring that are genetically different from the parent without sexual reproduction.

5) Sexual reproduction creates offspring that are genetically different from either parent, which ensures that a variety of genotypes are in the population. Sexual reproduction also ensures that the organisms that have the opportunity to mate are those that have been most successful, and hence the best-adapted genes are passed on in the greatest numbers. Perhaps the most important advantage, however, is that the risk of errors such as mutations and genetic disorders being expressed in offspring is minimized by having two copies of each chromosome.