WARD'S

Chromosome Simulation Lab Activity Student Study Guide

BACKGROUND

DID YOU KNOW?
All of the genetic material in the sperm and egg cells that produced the Earth's present human population could fit into a space the size of one typical aspirin tablet.

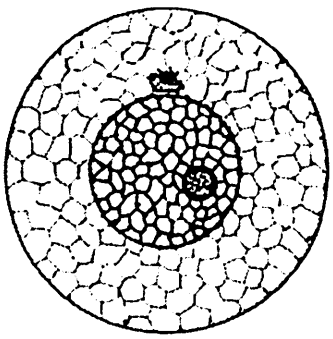
The cell cycle describes the growth and development of actively dividing cells. Although cell division is a continuous process, the process occurs in distinct stages. The two types of cell division are mitosis and meiosis.

Mitosis results in two daughter cells with nuclei that are identical to each other and to the parent cell. Growth and development of an organism, maintenance and repair of the body, and asexual reproduction are all a result of mitotic cell division.

Meiosis differs in that cell division results in the formation of daughter cells with half the chromosome number of the parent cell. Sex cells – gametes and spores – are the result of meiotic cell division.

Preparation for Cell Division

A cell is not always actively dividing. The complex process of cell division involves a great deal of preparation prior to the actual division process. During preparation, a newly formed cell must first grow, synthesize its DNA, and replicate its internal organelles. Collectively this process is referred to as interphase and accounts for approximately 90% of a cell's life.



Interphase - Interphase is generally considered a resting phase and is typically divided into three stages: first growth (G_1), DNA synthesis (S), and second growth (G_2) phases.

First growth (G_1) phase - During the first growth (G_1) phase, the cell grows rapidly and carries out its assigned functions. Some cells remain in the G_1 phase, meaning they never divide and once they die, the body cannot replace them.

DNA synthesis (S) phase - In this phase, a cell's DNA is replicated. By the end of the synthesis phase, each chromosome in the cell consists of two chromatids attached at a centromere.

DID YOU KNOW?
German biologist Theodore Boveri, studying fertilization of egg cells, discovered that one single sperm was required for successful development. He observed fertilizations in which more than one sperm cell successfully entered the egg, resulting in the addition of an extra set of chromosomes and an extra centriole, causing cell disruption. He called this condition "polyspermy".

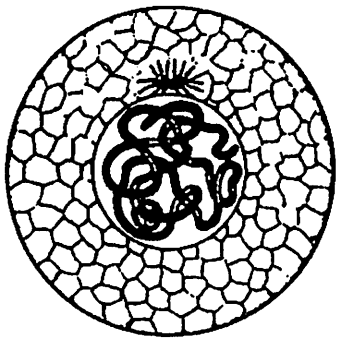
Second growth (G_2) phase - The second growth phase is when preparation for cell division begins. Organelles within the cell begin to replicate, the nucleus prepares for division, and specialized structures and enzymes, used during mitosis, begin to assemble in the cell. After the G_2 phase, the cell is ready to divide.

Mitosis and Cytokinesis

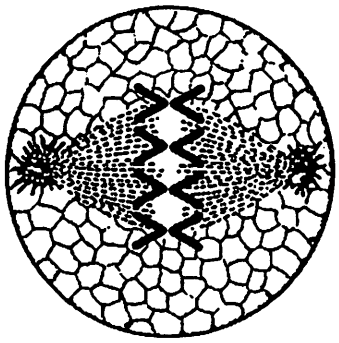
After the final stage of interphase, the cell is ready to begin mitosis. In animal cells, specialized structures called centrioles replicate in the final stages of the G_2 phase and protein fibers, called microtubules, are assembled. During mitosis, these centrioles and microtubules combine to form what are known as spindles, which are structures used to move chromosomes during cell division. Plant cells do not contain centrioles, but form a spindle-like apparatus that is almost identical to that found in an animal cell.

Mitosis occurs in a continuous process but is usually broken into four distinct stages, with discrete events occurring in each stage. The stages of mitosis are referred to as prophase, metaphase, anaphase, and telophase. After telophase, the cell enters a process called cytokinesis, in which the cell's cytoplasm is divided in half and the cell membrane pinches, forming two distinct cells.

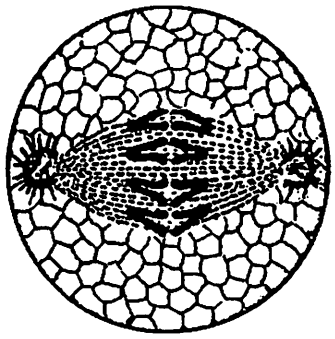
The events occurring during each stage are as follows:



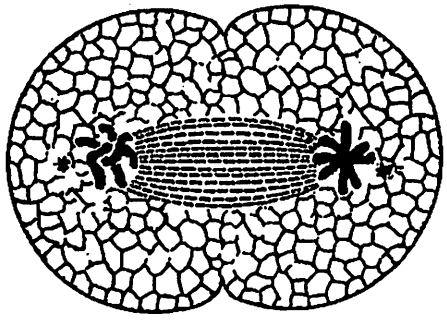
Prophase – the replicated pairs of centrioles migrate to opposite poles of the cell. The chromosomes condense in the cell, becoming shorter and thicker. The spindle fibers form from the centrioles and will eventually attach to each chromosome at the centromere.



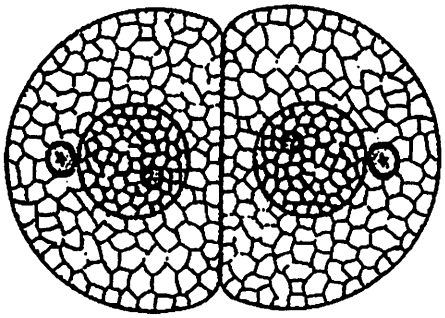
Metaphase – the spindle fibers enter the nuclear region, attaching to a complex system of fibers on the centromere known as the kinetochore. After attachment, the spindle fibers align the centromeres along an equatorial region in the nucleus, known as the metaphase plate, so that the arms of the chromosome point towards the poles of the cell.



Anaphase – the centromere divides and the two chromatids separate from each other forming two identical daughter chromosomes. The spindle fibers pull the newly-divided chromosomes towards the poles and away from the metaphase plate. Though the spindle fibers appear to move, they are in fact continuously forming at one end and disassembling at the other end.



Telophase – after the chromosomes reach the poles of the cell, a nuclear membrane forms around each set of chromosomes, forming daughter nuclei. The chromosomes uncoil and elongate. The spindle fibers break down and disappear and, in animal cells, a cleavage furrow between the two daughter nuclei begins to form.



Cytokinesis – in animal cells, the cleavage furrow continues, pinching together and eventually drawing together completely, separating the cell into two distinct daughter cells. The newly formed cells now enter interphase. In plant cells, there is no formation of a cleavage furrow. Small droplets form along the equatorial region of the cell, and gradually fuse forming a disc that grows outward until it reaches the wall of the dividing cell, completing the separation of the two daughter cells.

Meiosis

Meiosis is a form of cell division that occurs only in reproductive, or germ, cells. Meiosis is termed a reductive division because it results in daughter cells with half the chromosome number of the original parent cell. Like mitosis, meiosis occurs in a series of stages, with some notable differences.

Meiosis actually involves two cell divisions, referred to as meiosis I and meiosis II. The stages in which meiosis occurs are as follows:

Interphase – like mitosis, interphase occurs and results in DNA synthesis and replication of the chromosomes. The cell is also preparing for division, similar to mitosis.

Prophase I – during prophase I, the centrioles migrate to the opposite poles of the cell and the microtubules begin to form. However, the homologous chromosomes in the cell come together as pairs. Sometimes, during this stage of meiosis, the arms of the homologous chromosomes become entwined, crossing each other at sites called chiasmata.

Metaphase I – the homologous chromosome pairs line up along the metaphase plate. Spindle fibers are attached to the centrioles at opposite poles of the cell. The fibers from one pole of the cell attach to the kinetochore of one homologous chromosome and the fibers from the other centrioles attach to the other homologous chromosome.

Anaphase I – as in mitosis, the spindle fibers pull the chromosomes toward opposite poles in the cell. However, during meiosis, the sister chromatids do not separate and the chromosome is pulled intact to one pole while its homologous chromosome is pulled toward the other pole. In cases where the chromosomes have crossed over, the entwined chromosome arms will often break off, swapping segments of the chromosome arms between each other.

DID YOU KNOW?
A shrimp has greater than 100 pairs of chromosomes in each cell. A human has 23 pairs.

Telophase I – the chromosomes continue to move until they each reach their respective poles. Cytokinesis often occurs simultaneously with telophase I in meiosis resulting in two daughter cells, each with half the chromosome number of the parent. It is important to note, however, that the chromosomes in each daughter cell result from each cell receiving half of the homologous chromosomes (each containing both chromatids) instead of each cell receiving one chromatid from the entire chromosome set. In some species, there is a brief interphase stage before the next division, while in others, the telophase cells begin the next division immediately.

Prophase II – the centrioles migrate and the spindle fibers begin to form. Keep in mind that this is occurring in both daughter cells resulting from the first division.

Metaphase II – the chromosomes in each cell line up along a metaphase plate and the spindles attach to the kinetochore on each chromosome. Similarly to mitosis, the chromatid arms are pointing toward opposite poles of the cell.

Anaphase II – the spindle fibers pull the chromosomes to opposite poles of the cell. The chromosomes separate at the centromere and one chromatid from each chromosome is pulled to its respective pole of the cell.

Telophase II – nuclei form, as in mitosis, and the cleavage furrow develops. The chromosomes uncoil and elongate.

Cytokinesis – the cleavage furrow (or disc in plant cells) develops fully, pinching the cytoplasm and separating each of the original daughter cells into two new cells, resulting in a total of four haploid cells.

DID YOU KNOW?
In the time it takes to read this sentence, approximately 50,000 cells in your body will die and be replaced with new cells.

OBJECTIVES

- Understand the cell cycle and process of cell division
- Demonstrate mitosis and meiosis using pop bead models
- Simulate segregation of alleles, independent assortment, and crossing over during cell division

MATERIALS

MATERIALS NEEDED PER GROUP

40 Red pop beads
40 Yellow pop beads
2 Red centrioles
2 Yellow centrioles
4 Plastic tubular centrioles

PROCEDURE

Activity #1: Mitosis

Use Analysis Sheet #1: Mitosis to diagram each stage of mitosis as you simulate it in this exercise.

A. Interphase

What happens:

After cell division takes place, the cell enters the longest stage of the cell cycle. This is called interphase. During this stage, the cell is preparing for the next division. Distinct chromosomes are not visible. DNA exists in an uncoiled state and the chromosome material appears as granular matter, called chromatin, within the nucleus.

To simulate:

1. Construct two strands of seven red pop beads and attach each strand to a red centromere. Repeat with two strands of seven yellow pop beads and a yellow centromere. These will represent a homologous pair of chromosomes.

2. Picture an imaginary boundary in the center of your desk. This boundary will represent the nuclear membrane. Place the chromosomes in the center of the imaginary nucleus.

3. DNA replication occurs, producing a duplicate of each chromosome. Construct two chromosomes identical to the ones you made previously. Each half of the duplicated chromosome is called a chromatid. Join both red chromatids at the centromere to form a pair of sister chromatids. Repeat for the yellow chromosome.

4. Place a pair of plastic centrioles, at ninety degree angles, just outside of your nuclear membrane. The centrioles also replicate during interphase so place another pair next to them in your cell.

It may be helpful to tape your centrioles together during the exercise.

DID YOU KNOW?
Researchers at Cornell University have shown how tiny molecular motors carrying target proteins help guide the mitotic spindle that transfers genetic material from the nucleus of a mother cell to a newly-formed daughter cell. If these molecular motors fail, the spindle cannot properly orient itself with the axis of the cell and genetic material cannot be transferred.

B. Prophase

What happens:

Chromatin condenses within the nucleus and chromosomes become visible. Centrioles migrate to opposite poles (sides) of the cell and spindle fibers begin to form. As the spindle fibers appear, the nuclear membrane disappears. The spindle fibers attach to the centromere region of each chromosome.

To simulate:

1. Move your two pairs of centrioles to opposite poles (sides) of the cell (your desk).

C. Metaphase

What happens:

The chromosomes line up in the middle of the nucleus along the metaphase plate. The centromeres of each sister chromatid are attached, by spindle fibers, to the centrioles at opposite poles of the cell.

To simulate:

1. Center your chromosomes along an imaginary metaphase plate with the centrioles still at opposite poles of the cell.

D. Anaphase

What happens:

The chromatids of each chromosome separate at the centromeres and move to opposite poles of the cell, forming daughter chromosomes.

To simulate:

1. Separate and move the centromeres of each chromosome toward opposite poles of the cell. Notice how the arms of each chromosome trail the centromeres to the poles.

E. Telophase and Cytokinesis

What happens:

The spindle apparatus disappears. Nuclear membranes begin to reappear, forming two separate nuclei; one for each daughter cell. The chromosomes uncoil and become diffuse chromatin. Cytokinesis begins and separates the cytoplasm into two discrete daughter cells.

DID YOU KNOW?
Scientists have discovered several checkpoint mechanisms that ensure each step in the mitotic process is properly executed before the cell moves on to the next phase.

To simulate:

1. Move one red strand and one yellow strand to the centrioles it was heading toward during anaphase. Imagine a cleavage furrow developing between each nuclei and separating the cell into two daughter cells.

2. Note how each cell now contains one red and one yellow chromosome, as well as one pair of centrioles, exactly like the cell with which you began.

Activity #2: Mitosis with Two Pairs of Homologous Chromosomes

Now that you are familiar with the process of mitosis, work with another group of students and repeat the procedure with two pairs of homologous chromosomes. Shorten both arms of one red chromosome to six beads per side and do the same for a yellow chromosome.

Repeat all of the stages of mitosis. After mitosis, you should have two identical daughter cells, each with one long red and yellow chromosome and one short red and yellow chromosome.

Activity #3: Meiosis I & II

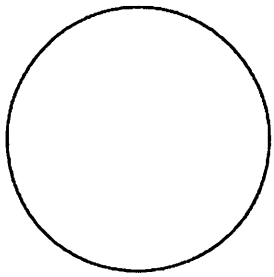
Use Analysis Sheet #2: Meiosis to diagram each stage of meiosis as you simulate it in this exercise.

WARD'S
Chromosome Simulation
Lab Activity

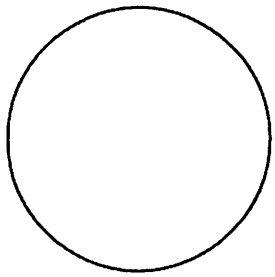
Name: _____
Group: _____
Date: _____

Analysis Sheet #1: Mitosis

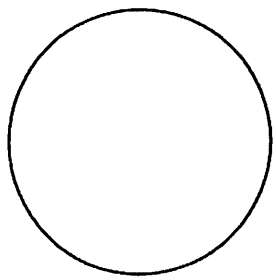
Interphase



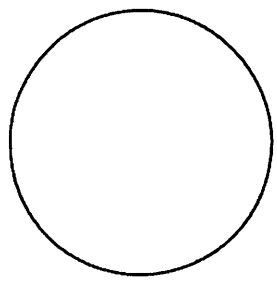
Prophase



Metaphase



Anaphase



Telophase