Chromosomes, Mitosis, and Meiosis

In this laboratory exercise you will learn about cell division. Your group will use models of chromosomes and cells to perform a live demonstration of cell division for your instructor. Since everyone in your group will have a role in the performance, everyone must understand the core concepts of DNA, chromosomes, mitosis, and meiosis that are described in this handout. Please allow all members of your group enough time to read and grasp these concepts, and help each other understand the material.

A) DNA

All living things have DNA in their cells. DNA is sometimes called the "genetic molecule" or the "blueprints of life" because it gives living things their physical traits. A human being has different physical traits than a lion, for example, because humans and lions have different DNA molecules.

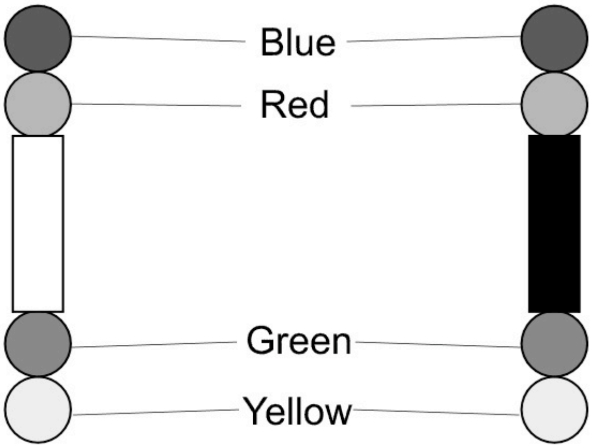
DNA is organized into units called genes. We can define a gene as the DNA that controls one trait. For example, you have a gene that controls your eye color. You have a gene that controls the texture of your hair. You have a gene that controls the shape of your earlobes. You even have a gene that controls whether you can curl your tongue or not. Human beings have about 25,000 genes. Bacteria (being simpler organisms) typically have around 3,000 genes.

B) Chromosomes

Our genes are part of larger structures called chromosomes. You can think of a chromosome as a chain of genes linked together. In addition to genes, each chromosome contains a centromere. The centromere is the chromosome's central region and acts as a "handle" for moving the chromosome.

Real chromosomes hold hundreds or thousands of genes, but to keep today's exercise simple we will imagine a very short chromosome that holds only four genes. In your kit you will find round pop beads the represent genes and white tubes that represent centromeres (the central region of the chromosome). There are four different colors of beads to represent four different genes on the chromosomes in today's exercise.

Open your kit and construct the two chromosomes shown below. Put a piece of black tape on one of the centromere tubes to make the chromosome on the right.



Notice that both the chromosomes you made have the same genes in the same order. A pair of chromosomes such as the two you just made that have the same genes are called homologous chromosomes. In other words, you have made one homologous pair of chromosomes.

All of our chromosomes come in homologous pairs like this. To be exact, human beings have 23 homologous pairs chromosomes, making a total of 46 chromosomes.

Why do all our chromosomes come in homologous pairs? Because we have two parents. Each of your two parents gave you one set of 23 chromosomes, so you end up with 23 pairs of chromosomes. In other words, in each of the 23 pairs that you have, one chromosome came from your father and one came from your mother. The white centromere will represent the maternal member and the black centromere will represent the paternal member of one homologous pair.

Although a homologous pair of chromosomes always have the same genes in the same order as each other, the homologous pair does **not** have to have the same alleles of the genes as one another. For example, if the blue bead on your homologous pair represents the gene that controls eye color, then your maternal chromosome and your paternal chromosome of the homologous pair may have different alleles of that gene. For example, the maternal chromosome may have the allele for blue eyes and the paternal chromosome may have the allele for brown eyes.

In today's exercise, you will make a cell that contains the homologous pair of chromosomes you just assembled. As you go through the exercise, keep in mind that if this were a human cell there would be 22 other homologous pairs, all going through the same changes as the one homologous pair you will be working with.

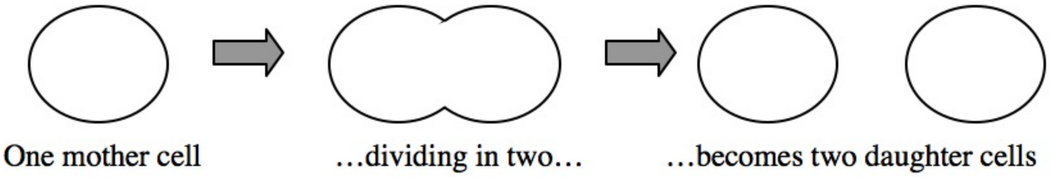
c) Some terms

An organism that has two different alleles for a gene is said to be heterozygous for that gene. An organism that has two of the same allele for a gene is said to be homozygous for that gene.

Cells like human cells, where all chromosomes are found in homologous pairs, are called diploid cells (written as 2n). Some cells have only one set of chromosomes. That type of cell is called haploid (written as n).

d) Mitosis

Cells sometimes need to reproduce themselves. If you scrape your skin, for example, the surrounding cells will reproduce to replace the missing cells and heal the wound. When a cell reproduces, the "mother cell" simply divides down the middle to produce two "daughter cells":



The most common method of cellular division is called mitosis. Mitosis is the type of cell division that is used for all growth, maintenance, and repair in our bodies. The defining feature of mitosis is that the daughter cells are exact duplicates of the mother cell. For example, if the mother cell is diploid (all chromosomes in homologous pairs), then both daughter cells will be diploid too.

Mitosis is a multi-step process. The two main steps are called Interphase and M phase, but both of these steps are subdivided into smaller phases, as is shown below:

$$\underbrace{G_1 \rightarrow S \rightarrow G_2}_{\text{Interphase}} \rightarrow \underbrace{\text{Prophase} \rightarrow \text{Metaphase} \rightarrow \text{Anaphase} \rightarrow \text{Telophase} \rightarrow \text{Cytokinesis}}_{\text{M Phase}}$$

The changes that take place in each of these phases will be explained in the following section.

d) Mitosis performance

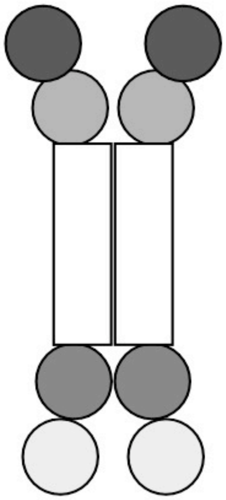
Using the homologous pair of chromosomes you made and the other components of your kit, you will now take a cell through all the steps of mitosis. Place the posterboard flat on your bench top. Put your chromosomes on the posterboard. Take one piece of black yarn out of your kit and slip the free end through the looped end. Lay the yarn on the board and arrange it in a circle, about 15 cm in diameter, around the chromosomes. You can slide the yarn through its loop to adjust the circle size. The yarn represents the cell membrane.

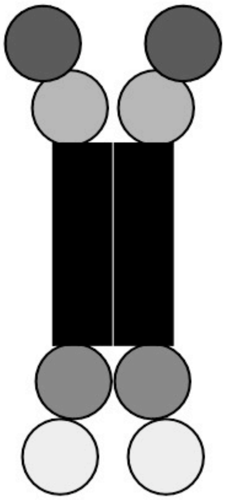
You are now ready to take your cell through mitosis.

Interphase: During the three steps of interphase (G_1, S, and G_2) the cell is preparing to divide by growing and duplicating its chromosomes.

G_1: The cell grows during this phase. Make the cell grow by adding yarn to the loop until the circle is about 25 cm in diameter.

S: In this step each of the chromosomes duplicate. Make an exact duplicate of each chromosome (same genes in the same order) and attach the duplicates together magnetically.





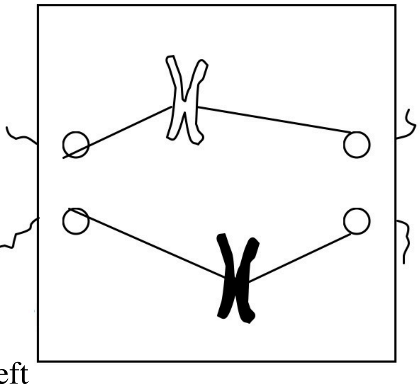
Although it seems counterintuitive, biologists consider each X-shaped duplicated chromosome to be one chromosome, not two. Your cell thus still has only two chromosomes at the end of S phase. But now each chromosome is a duplicated chromosome, not an unduplicated chromosome.

G_2: This is another period of cellular growth. Add all the remaining yarn to the loop to make your cell as big as possible. The cell should now be big enough to include the holes in the posterboard. Don't worry if some if the membrane is hanging off of the board.

G_2 is the end of interphase. The cell is now prepared to divide. The five steps of M phase that follow (prophase, metaphase, anaphase, telophase, and cytokinesis) will transform the mother cell into two daughter cells. See figure 10.6 and the mitosis part of figure 11.7 in the textbook.

Prophase: In prophase, the spindle fibers appear. Spindle fibers are thread-like structures made out of microtubules (a protein material) that the cell uses to move the chromosomes.

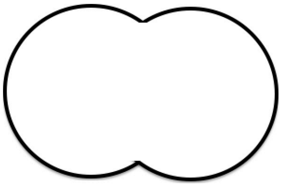
Get the four spindle fibers out of your kit (strings with safety pins). To each centromere hook you should attach one of the safety pins. The strings from one duplicated chromosome should now be threaded through the top left and top right holes, while the strings from the other duplicated chromosome should be threaded through the bottom left and right holes. The chromosomes should be randomly distributed in the cell (not in the exact middle) during prophase.



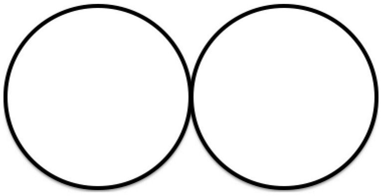
Metaphase: In this step, the spindle fibers maneuver the chromosomes to the equator (the middle) of the cell. Gently tug on the ends of the strings to do this. Don't allow the duplicated chromosomes to come apart.

Anaphase: Anaphase is when the spindle fibers split each duplicated chromosome. Pull the ends of the strings to separate the chromosomes by a few inches. Don't pull them all the way to the poles.

Telophase: Two things happen in telophase. The chromosomes separate even further and cytokinesis (the splitting of the cell in two) begins. Pull on the strings until the chromosomes are just a few inches from the poles. As the chromosomes are moving toward the poles, push the yarn inward at the equator to show cytokinesis beginning.



Cytokinesis: Cytokinesis (cell splitting) finishes in this step. Push the sides of the yarn further inward until they touch. This now represents two daughter cells.



Mitosis is now complete. Notice that the two daughter cells are exactly the same as the mother cell that produced them: They are diploid, the chromosomes are unduplicated, and each chromosome has the same genes and alleles it had before. Nothing has changed except that one cell has become two.

Now it is time for your group to perform mitosis live for your instructor. There are four roles in the performance, one for each group member:

Cell membrane: This performer is in charge of adjusting the yarn on each step. This includes keeping the cell shape nice and round.

Maternal chromosome: This performer handles everything related to the maternal chromosome, including duplicating it and maneuvering it using the spindle fibers.

Paternal chromosome: The same as above, except for the paternal chromosome.

The director: This person announces what stage of mitosis the cell will do next. For example, at the start the director should say "Interphase G_1." This is the cue for the other performers to arrange the cell into G_1. When they have successfully put the cell into G_1, the director announces "Interphase S," which the performers then do. The director continues through all steps of mitosis.

Practice the performance until your group can do it accurately and smoothly without referring to written or oral clues of any sort. Call your instructor over when your group is ready for your big opening night performance. Break a leg.

e) Viewing mitosis under a microscope

For the moment, put aside your chromosome kit and take out your microscopes. The group should view a Whitefish Blastula slide at 400X. The cells in this specimen show all phases of mitosis. Your group should find an example of each mitosis phase (prophase, metaphase, anaphase, and telophase) on their slide. If you have trouble finding one of the mitosis phases or if you want to confirm that you have identified a phase correctly, then please call your instructor over.

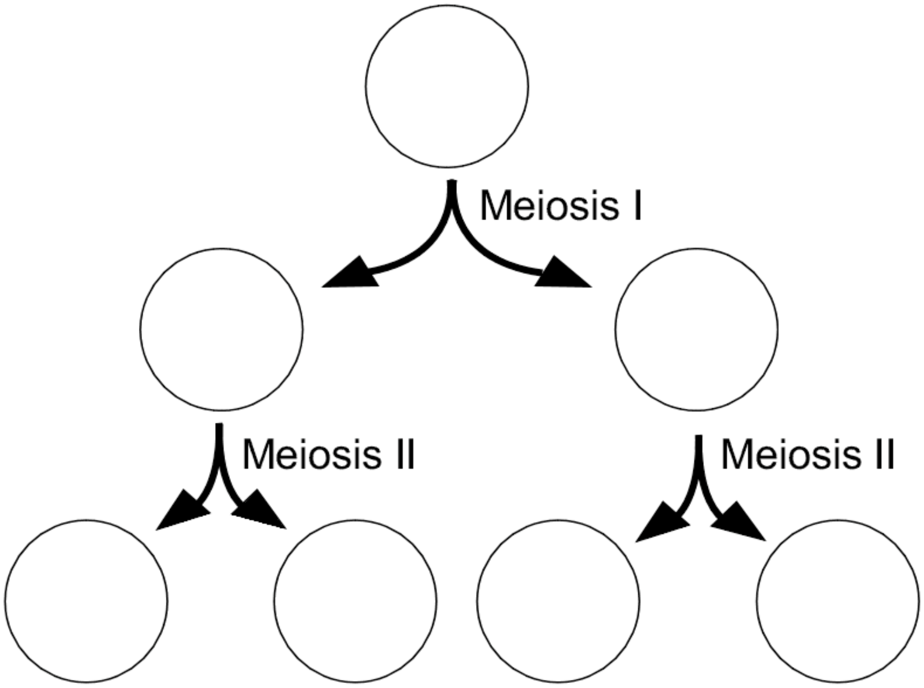
f) Meiosis

There is no hands-on laboratory activity for meiosis. Instead, your lab group should watch the video listed below and then read through the description of meiosis that begins on the next page of the handout.

https://www.youtube.com/watch?v=kQu6Yfrr6j0

In the previous sections of this handout you learned about mitosis. There is a second kind of cell division, called meiosis, that you will learn about by reading this section of the handout. Meiosis produces haploid daughter cells from a diploid mother cell. In humans and most other members of the animal kingdom, the haploid cells from meiosis are the gametes (also called sex cells, the sperm cells and the egg cells) that are used to make offspring.

Meiosis requires two full cycles of cell division (In contrast, mitosis was completed in only one cycle of cell division). The two cell divisions of meiosis are called meiosis I and meiosis II. The diagram below shows a cell going through meiosis I and II.

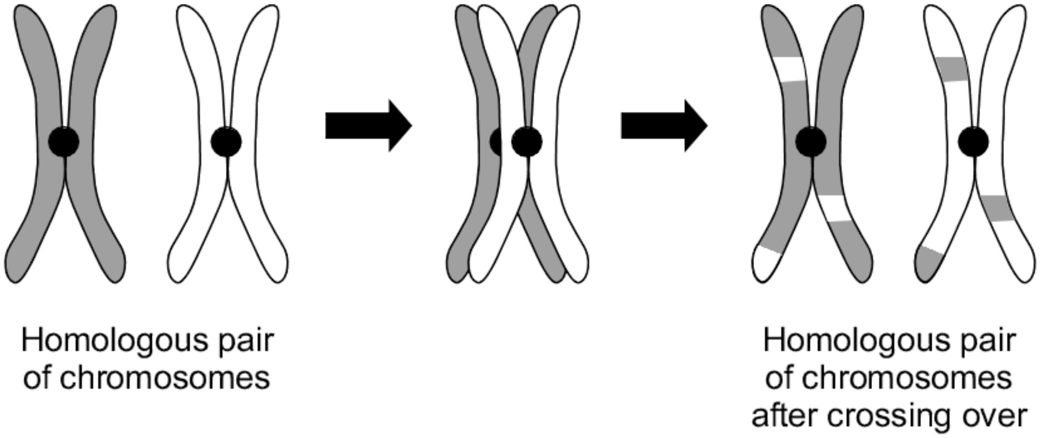


Meiosis produces four haploid cells from the original diploid mother cell. In the diagram above all of the cells are haploid except the mother cell at the top of the diagram, which is diploid.

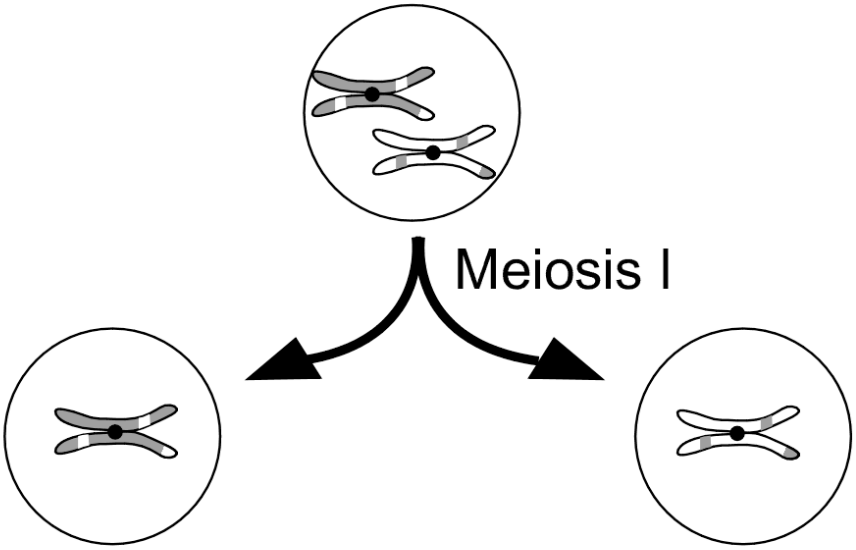
Meiosis I has four phases, called prophase I, metaphase I, anaphase I, and telophase I. Likewise, meiosis II has four phases, called prophase II, metaphase II, anaphase II, and telophase II. Although these meiosis phases are generally the same as the matching phases in mitosis, nevertheless there are a few differences between these phases in meiosis versus the same phases in mitosis.

One difference in the phases is that a process called crossing over of chromosomes happens in prophase I of meiosis. Crossing over does not occur in any phase of mitosis.

In crossing over, each chromosome exchanges some of its DNA with the other homologous chromosome of its homologous pair. As an example of crossing over, look at the figure below. The two chromosomes on the left side of the figure represent a homologous pair of chromosomes. The dark chromosome is the paternal chromosome and the light chromosome is the maternal chromosome of the homologous pair. In crossing over, the homologous pair of chromosomes line up on top of one another (center part of illustration) and they exchange some DNA with each other (right side of the illustration). Each gene has a 50% chance of crossing over to the other chromosome.

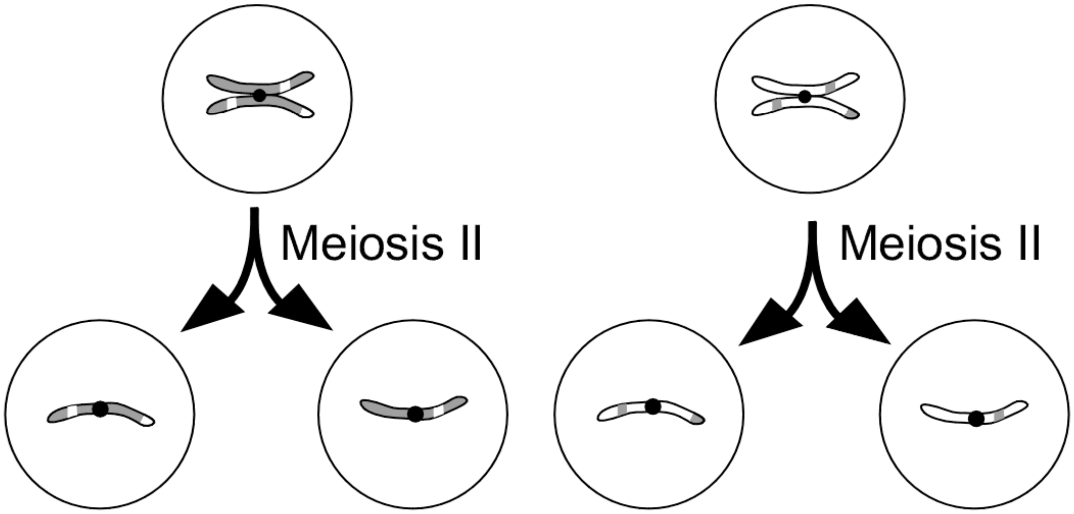


There is a second difference between meiosis I and mitosis: During meiosis I, the duplicated chromosomes do NOT split apart. In contrast, in mitosis each duplicated chromosome does split into two unduplicated chromosomes. The non-splitting of the duplicated chromosomes happens in anaphase I, when the duplicated chromosomes move apart from each other and end up in separate daughter cells.



The two daughter at the end of meiosis I (the cells at the bottom of the figure) are halpoid cells with duplicated chromosomes. Each of those two daughter cells will now go through meiosis II.

In meiosis II, the duplicated chromosomes DO split apart into unduplicated chromosomes. This is exactly the same as what happens in mitosis. The splitting apart of the duplicated chromosomes in meiosis II is illustrated below.



All four cells that are produced at the end of meiosis II are haploid with unduplicated chromosomes.

g) Review questions

1) Define homologous chromosomes as it was defined in lecture:

2) Define allele as it was defined in lecture:

It might be helpful to refer to mitosis figure 10.6 in the textbook for questions 3 - 5.

3) If a cell could not make spindle fibers, the chromosomes would end up _________.
(there are 2 correct answers).

- a) At the cell equator
- b) Randomly scattered in the cell
- c) At the cell poles
- d) In a duplicated state
- e) In an unduplicated state

4) In animal cells, the spindle fibers that move the chromosomes originate _________.
(there are 2 correct answers).

- a) From the centromeres
- b) From the centrioles
- c) From the poles of the cell
- d) From the equator of the cell
- e) From the cleavage furrow

5) After each statement about human cells, write which of the 7 steps of mitosis it describes. (You may use one-letter abbreviations: for the seven steps: G_1, S, G_2, P, M, A, T, or C). If the statement describes more than one stage, name the stage it **FIRST** occurs in.

a) The chromosomes are on the cell equator ____________

b) Sister chromatids are formed __________

c) The cell contains 92 separated individual chromatids: ___________

d) The chromosomes duplicate: __________

e) The cell begins to bend inward at the sides: __________

f) The spindle fibers first appear: __________

g) The cell grows and the number of organelles increases: __________

h) The chromosomes become unduplicated __________

i) The nucleus begins to re-form: ___________

6) In the first blank after each statement about human cells, write whether it describes a step in meiosis I or meiosis II. In the second blank after each statement, write which of the 7 steps of meiosis I or meiosis II it describes. (You may use one-letter abbreviations: for the seven steps: G_1, S, G_2, P, M, A, T, or C). It might be helpful to refer to figures 11.6 and 11.7 in the textbook for these meiosis questions.

a) The first step in which the cell becomes haploid: _______ _______

b) Sister chromatids are formed __________ ____________

c) The cell contains 23 unduplicated chromosomes: __________ ________

d) The cell contains 23 duplicated chromosomes: __________ ________

e) The chromosomes duplicate: __________ __________

f) Sister chromatids are split apart from each other: __________ __________

g) Duplicated homologous chromosomes move away from each other:
_______ _______

h) Crossing over occurs: __________ __________

7) When crossing over occurs, what is the chance a gene on a paternal chromosome will exchange with the gene on a maternal chromosome? __________

8) Dogs have 78 chromsomes in all of their cells (except their gamete cells).

a) How many chromosomes are in each dog sperm cell? ______

b) How many chromosomes are in each dog egg cell?

c) Are the chromosomes duplicated or unduplicated in dog sperm and egg cells?

g) Review question answers

1) Two chromosomes of the same size, same centromere location, and containing genes that affect the same traits (although not necessarily the same alleles of those genes).

2) Alleles are different versions of the same gene.

3) B and D

4) B and C

5) a) M

b) S

c) A

d) S

e) T

f) P

g) G_1 and G_2

h) A

i) T

6) a) Meiosis I C

b) Meiosis I S

c) Meiosis II C

d) Meiosis I C

e) Meiosis I S

f) Meiosis II A

g) Meiosis I A

h) Meiosis I P

7) 50%

8) a) 39
   b) 39
   c) Unduplicated