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.

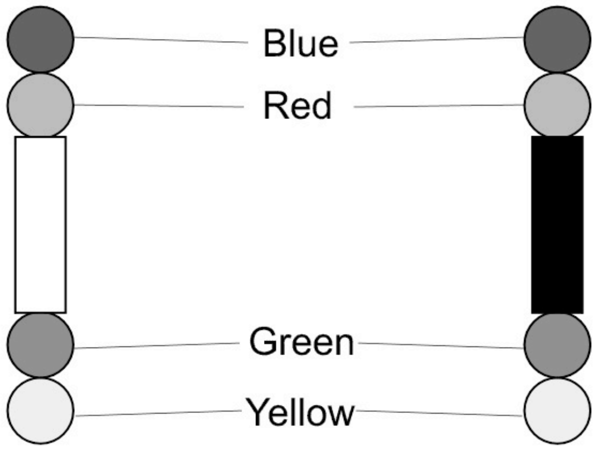
DNA is organized into units called genes. We can define a gene as the DNA that controls one trait. For example, you have a gene that controls your eye color. You have a gene that controls the texture of your hair. You have a gene that controls the shape of your earlobes. You even have a gene that controls 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.

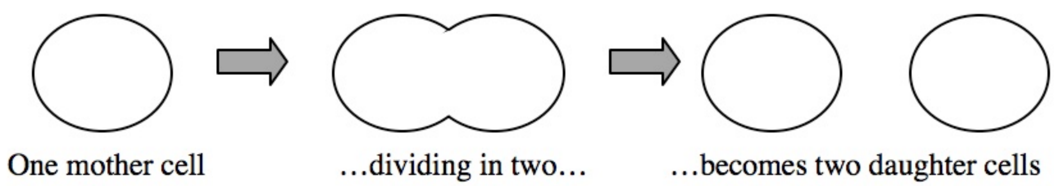
c) Some terms

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).

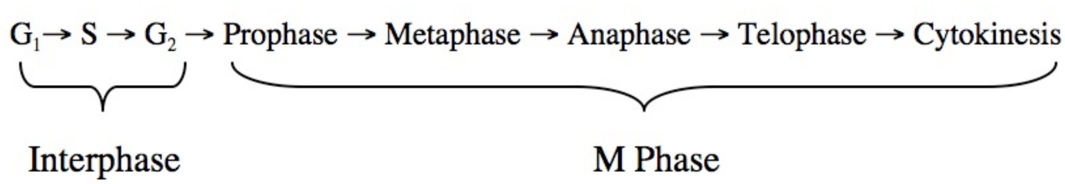
d) Mitosis

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:



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

d) Mitosis performance

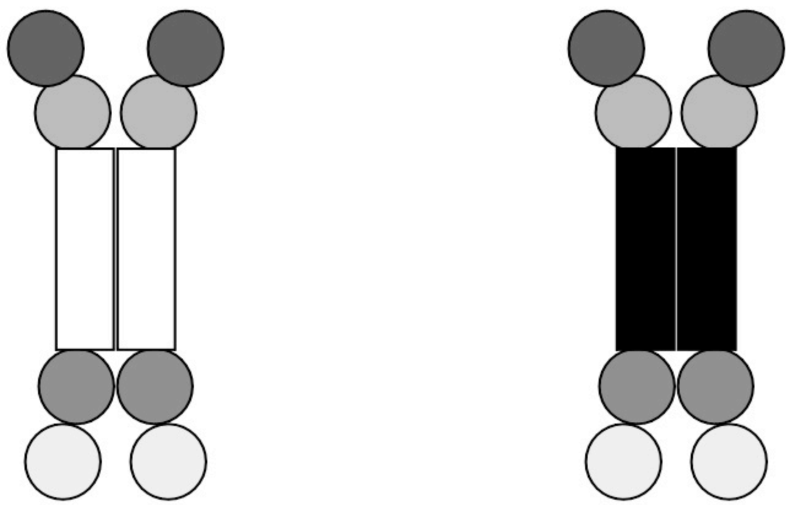
Using the homologous pair of chromosomes you made and the other components of your kit, you will now take a cell through all the steps of mitosis. Place the posterboard flat on your bench top. Put your chromosomes on the posterboard. Take one piece of black yarn out of your kit and slip the free end 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.

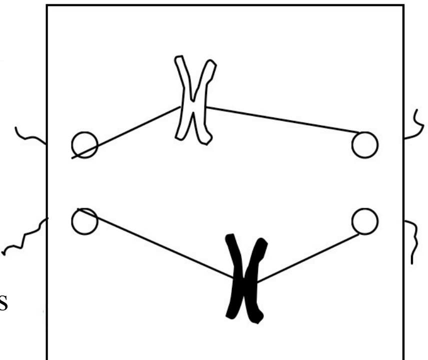


Although it seems counterintuitive, biologists consider each X-shaped duplicated chromosome to be one chromosome, not two. Your cell thus still has only two chromosomes at the end of S phase. But now each chromosome is a duplicated chromosome, not an unduplicated chromosome.

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.

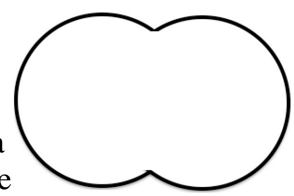


Get the four spindle fibers out of your kit (strings with safety pins). To each centromere hook you should attach one of the safety pins. The strings from one duplicated chromosome should now be threaded through the top left and top right holes, while the strings from the other duplicated chromosome 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.

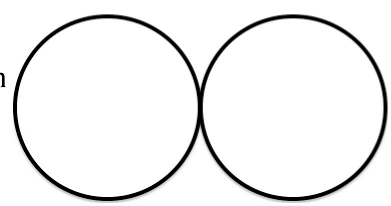
Metaphase: In this step, the spindle fibers maneuver the chromosomes to the equator (the middle) of the cell. Gently tug on the ends of the strings to do this. Don't allow the duplicated chromosomes to come apart.

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

As you have seen, mitosis produces two daughter cells that are exact copies of the mother cell. The daughter cells, just like the mother cell, are diploid, their 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.

There is a second kind of cell division, called meiosis, where the two daughter cells are **not** exact duplicates of the mother cell. Each daughter cell receives only one member of each homologous pair of chromosomes. In other words, for each homologous pair, one daughter cell will get the maternal chromosome and the other daughter cell will get the paternal chromosome. (Recall, cells that have one only member of a homologous pair are called haploid cells). In summary, meiosis produces haploid daughter cells from a diploid mother cell.

In humans and most other members of the animal kingdom, the only haploid cells in the body are the gametes (the sperm and egg sex cells). Gametes must be haploid so that when a sperm fertilizes an egg the offspring receives 23 chromosomes from each parent. This ensures that each generation starts with the correct number of 46 chromosomes.

Meiosis is more complex than mitosis in two ways. First of all, meiosis requires two full cycles of cell division to complete (Recall that mitosis was completed in only one cycle of cell division). Secondly, meiosis has a step called crossing over (or synapse) where the maternal and paternal chromosomes exchange genes. In mitosis, the homologous chromosomes never exchanged genes with each other.

The two cycles of cell division in meiosis are called meiosis I and meiosis II. In the next sections you will perform these two parts of meiosis.

g) Meiosis I performance

Use the kit equipment to assemble and carry out the steps of meiosis I. It may be helpful to look at the mitosis part of figure 11.7 in the textbook as you go through the performance.

G_1: Identical to mitosis.

S: Identical to mitosis.

G_2: Identical to mitosis.

Prophase: This step is when crossing over of the chromosomes occurs.

Crossing over is a process where genes may exchange places between the maternal and paternal members of a homologous pair. A gene crossing over is diagrammed in figure 11.3 of the textbook. Each gene has a 50% chance of crossing over with its partner on the opposite chromosome. In other words, for each gene it is a "coin flip" whether or not that gene will cross over with its partner on the other member of the homologous pair. Because each of your duplicated chromosomes has 8 genes on it, you would need to flip a coin 8 times to decide which genes cross over and which do not.

When done crossing over, place the crossed over the chromosomes back in the cell, but not on the cell equator. Attach the spindle fibers to the chromosomes.

Metaphase: Use the spindle fibers to maneuver the chromosomes to the equator of the cell.

Anaphase: Using the spindle fibers, pull the duplicated maternal chromosome a few inches toward the left pole of the cell. Pull the duplicated paternal chromosome a few inches toward the right pole of the cell. Notice that, unlike mitosis, the duplicated chromosomes do NOT split into two in meiosis I.

Telophase: Maneuver each duplicated chromosome all the way to each pole. Start cytokinesis by pushing the sides of the cell slightly inward at the equator.

Cytokinesis: Push the sides of the yarn further inward until they touch.

Your cell has now completed meiosis I. Notice that each daughter cell is haploid (this is, it now has only the maternal or the paternal chromosome, not both). Also notice that its one chromosome is in a duplicated state. For meiosis to be truly complete, each chromosome must become unduplicated. This will be done in meiosis II, the next division of meiosis.

h) Meiosis II performance

At the end of meiosis I, you ended up with two haploid cells. In meiosis II, the duplicated chromosomes in each daughter cell will split. To perform meiosis II on each cell, it will be necessary to move one of the cells to a new poster board square. Transfer one chromosome and its two spindle fibers to the new square. Get a new piece of yarn and place it around the chromosome. Thread the spindle fibers through the holes in the board as before.

You can begin meiosis II with prophase (yarn as large as possible, chromosome not on the equator). All steps of meiosis II (prophase, metaphase, anaphase, telophase, and cytokinesis) are identical to the steps of mitosis, so you should refer to page 5 of this handout for directions to take the cell through meiosis II. The only difference between meiosis II and mitosis is that cells going through meiosis II are haploid instead of diploid.

After cytokinesis, meiosis is complete. You now have four daughter cells. Notice that all four cells are haploid (that is, they have only a maternal or only a paternal chromosome; not both), and all chromosomes are unduplicated. These cells can now be functional sperm or eggs. Because of crossing over the chromosomes contain a mixture of maternal and paternal genes. This will allow the offspring produced by these sperm or eggs to have chromosomes with allele combinations that did not exist in their parents.

Practice the meiosis performance until each member of your group do their role accurately and smoothly without referring to any written or oral clues. Call your instructor over when your group is ready to perform. During the performance your instructor will flip a coin to determine which gene(s) cross over.

Chromosome exercise review questions

DNA and Chromosomes:

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

2) Define allele as it was defined in lecture:

Mitosis:

It might be helpful to refer to figure 10.6 in the textbook for these mitosis questions.

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. It might be helpful to refer to figure 10.6 in the textbook.

The chromosomes are on the cell equator ____________

Sister chromatids are formed __________

The cell contains 92 separated individual chromatids: ___________

The chromosomes duplicate: __________

The cell begins to bend inward at the sides: __________

The spindle fibers first appear: __________

The organelles in the cell double: __________

The chromosomes become unduplicated __________

The nucleus begins to re-form: ___________

Meiosis:

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.

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

Sister chromatids are formed __________ ____________

The cell contains 23 unduplicated chromosomes: __________ ________

The cell contains 23 duplicated chromosomes: __________ ________

The chromosomes duplicate: __________ __________

Sister chromatids are pulled apart from each other: __________ __________

Duplicated homologous chromosomes move away from each other:
_______ _______

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) In most diploid organisms (like human beings), all the cell division for growth, maintenance, and repair of the body is done by mitosis. Meiosis is only used to make gametes (sperm or eggs). Explain why it is vital that meiosis (and not mitosis) be used to make sperm and eggs?