Chromosomes and Cell Division

Before you begin the activities in this lab topic, you should be able to

1. Explain the role of DNA in genetics.
2. Explain how the eukaryotic genome is organized.
3. Define the terms chromosome and gamete.
4. Distinguish the general purpose of mitosis from the purpose of meiosis.

Introduction

The genetic information of all organisms is found in deoxyribonucleic acid (DNA), which consists of varying sequences of the four nucleotides adenine, thymine, guanine, and cytosine. Discrete sections of DNA are called genes, and they are the "blueprints" that make organisms. In the cells of eukaryotes such as wheat and humans, DNA is packaged with proteins. Most of the time this DNA-protein complex is found in a threadlike form called chromatin. Recall Lab Topic 4 when you looked at your cheek cells under the microscope. The most prominent feature of the cells was the nucleus, but you needed to use the high-power objective to see it clearly. If the DNA molecules in one of those microscopic nuclei were unwound, attached together, and pulled out like a string, it would be two meters long! It fits inside the nuclei because it is extremely thin. In this lab topic, you will extract DNA from wheat cells to see this famous molecule for yourself.

During cell division, the chromatin is elaborately wound up into the coiled structures called chromosomes. When cells give rise to new cells, there must be a way for each new cell to receive an exact copy of all of the chromosomes. In this lab topic you will examine how the process of **mitosis** accomplishes this.

Genetic information must also be passed from parents to offspring, and in this lab topic you will see how the process of **meiosis** distributes chromosomes into gametes for the purpose of sexual reproduction.

Outline

Exercise 8.1: The Genetic Material
- Activity A: Extracting DNA from Cells
- Activity B: Karyotypes

EXERCISE 8.1

The Genetic Material

Objectives

After completing this exercise, you should be able to

1. Describe how DNA can be extracted from cells.
2. Explain what a karyotype shows.
3. Define the following terms: homologous chromosomes, centromere, diploid, and haploid.

Activity A: Extracting DNA from Cells

DNA is found in almost every cell of every organism. You've heard about it, you've seen diagrams of its structure, but have you ever actually seen DNA molecules? In this activity you will extract DNA from the embryonic cells of wheat seeds, also known as wheat germ. After softening the cell walls of the wheat germ in warm water, detergent is used to break up the membranes. The DNA is then separated from the rest of the cell contents.

Procedure

1. Weigh out 1 g of wheat germ.
2. Put the wheat germ in a large (50-mL) test tube.
3. Dip warm water from the water bath and measure 20 mL in a graduated cylinder. Pour the water into the test tube with the wheat germ.
4. Using a wooden stick, stir the wheat germ *gently* for 3 minutes.
5. Get a pasteur pipetful of detergent and release it into the test tube with the wheat germ.
6. Stir the wheat germ mixture gently for 5 minutes, being careful not to create any foam.

Stir slowly to avoid making bubbles!

7. Measure 15 mL of *cold* alcohol in a graduated cylinder.

8. Tilt the test tube containing wheat germ at a 45-degree angle and *very slowly* pour the alcohol from the graduated cylinder down the side of the wheat germ tube. The alcohol should just trickle down the side and come to rest on the top of the water so that it forms a separate layer.

Pour very slowly, taking care not to let the layers mix.

9. Once you have poured in all the alcohol, place the test tube in its rack and do not move it for at least 15 minutes. The DNA will begin precipitating out immediately between the two layers of liquid.
10. After 15 minutes, the DNA should be floating on the top of the test tube. Use the wooden stick to spool it like cotton candy.

Describe what the DNA looks like.

The precipitated DNA in the alcohol layer is only part of the total DNA from the wheat cells. Much of the DNA is still in the water below. You can bring this DNA into the alcohol, where it will precipitate. Tilt the test tube slightly and insert the wooden stick into the yellowish water fraction, then pull the stick up into the alcohol. You should see more DNA come up with it. Be careful not to stir the layers together, though! When it reaches the alcohol, the DNA will precipitate in its stringy form and you can spool it, too.

Most protocols for DNA extraction use an enzyme to digest proteins. That step was omitted in this procedure to get faster results. How would your results be different if you used a protein-digesting enzyme?

Activity B: Karyotypes

Although most of the DNA in a prokaryotic organism such as bacteria is carried on a single chromosome, in eukaryotes (animals, plants, fungi, and protists) the DNA is divided among numerous chromosomes. Each eukaryotic species has a characteristic number of chromosomes, but that number does not indicate the complexity of the organism. For example, redwood trees have 66 chromosomes, gypsy moths have 62, yeast have 32, and catfish have 58. We humans have 46 chromosomes in each body cell. Guppies also have 46 chromosomes, but there are many differences in the genetic “blueprints” that make a guppy and the genetic “blueprints” that make a human.

We can study an organism’s chromosomes by making a karyotype of them. To make a karyotype, the nucleus of the cell is ruptured to isolate the chromosomes and then a microscopic digital image is made. A technician uses

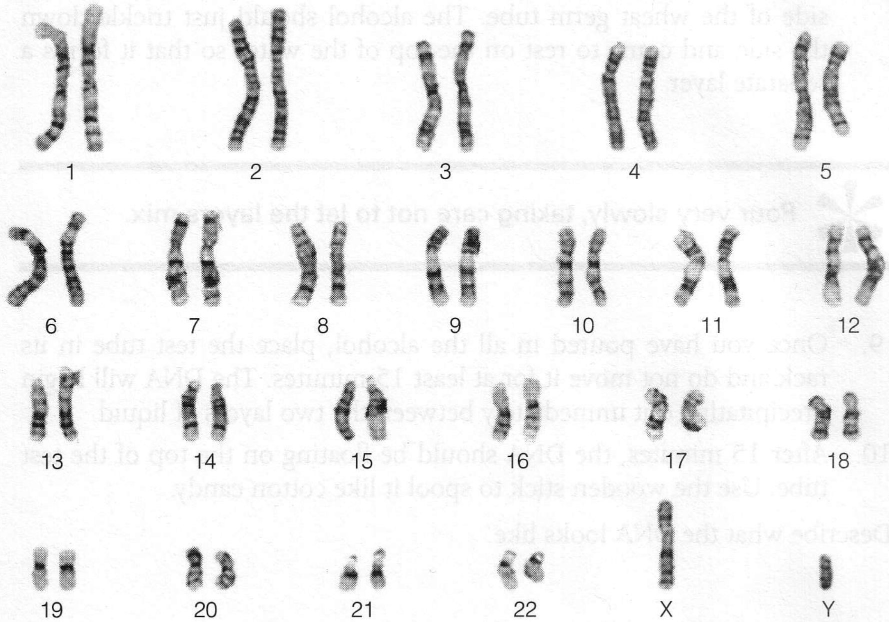


Figure 8.1.
Karyotype of human male.

a computer program to arrange the images of the chromosomes in **homologous pairs** (Figure 8.1). The pairs are matched by comparing physical characteristics such as length and staining pattern. Homologous chromosomes have these physical similarities because they are genetically similar: they carry the same genes in the same order.

Figure 8.1 shows a finished karyotype of a human male. In humans there are 22 homologous pairs of autosomes (chromosomes that are not concerned with sex determination) plus a pair of sex chromosomes. Females have a homologous pair of X chromosomes, but the male's X and Y, shown here, don't match.

The karyotype, as well as other pictures of chromosomes that you have seen in books, shows chromosomes from cells that are undergoing mitosis. Thus the chromosomes are distinct, thickly coiled structures rather than the thready chromatin form. You may also be able to see that the chromosomes in Figure 8.1 are doubled, which makes each one look like a slender "X." Before a new nucleus can be made, the DNA in each chromosome must replicate (make an exact copy) so that each new cell will have exactly the same genetic material as the original cell. After replication, the chromosomes remain attached at a place called the **centromere.** The point of attachment is not always in the center of the chromosomes. The position of the centromere is another characteristic that technicians use to match homologous pairs.

How many *homologous pairs* of chromosomes do the following organisms have?

redwood tree—

gypsy moth—

catfish—

guppy—

A cell that contains the correct number of homologous pairs for its species is said to be **diploid.** A cell with only one member of each homologous pair is said to be **haploid.**

Almost all of the cells in our bodies are diploid. What cells are haploid, and why?

Suppose the karyotype shown in Figure 8.1 was taken from a cheek cell. What cell division process would produce a new cheek cell?

Describe what the karyotype of a new cheek cell from this same individual would look like. That is, how many chromosomes would it have? Would it be haploid or diploid?

Suppose we made a karyotype of a gamete from this individual. What would it look like? How many chromosomes would it have? Would it be haploid or diploid?

EXERCISE 8.2

The Process of Mitosis

Objectives

After completing this exercise, you should be able to

1. Explain the purpose and location of mitosis in organisms.
2. Describe and recognize the phases of mitosis.

The union of a haploid egg with a haploid sperm produces a diploid zygote. The zygote has a nucleus that holds the chromosomes, which in turn contain the entire blueprint to make the organism. From that single cell, the process of **mitosis** produces the many (sometimes trillions of) diploid cells that make up the body of a multicellular organism. Therefore each of the organism's cells contains an exact copy of the same genetic material.

Because cells must constantly be replaced, mitosis also produces new diploid cells throughout the life of an organism. For example, your entire epidermis is replaced every 15 to 30 days, and your body makes approximately 200 billion new red blood cells every day. That's a lot of mitosis!

In the following activities you will examine the steps in mitosis by using models of chromosomes. You will then identify these steps in onion cells.

Activity A: Pop Bead Simulation of Mitosis

You will use pop beads to represent chromosomes and follow them through the processes of cell division. Your instructor will give you a set of "chromosomes" to work with.

Before you begin, take stock of your chromosomes. How many chromosomes are there?

How many homologous pairs of chromosomes?

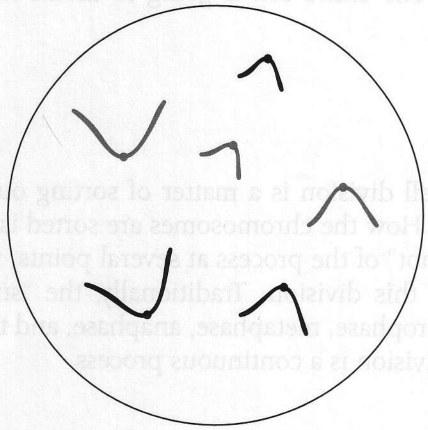
How can you tell which chromosomes are homologous?

How can you distinguish the members of the homologous pair *from each other*?

What differences between the chromosomes are represented by the different colors? That is, what is different about the maternal and paternal chromosomes?

Procedure

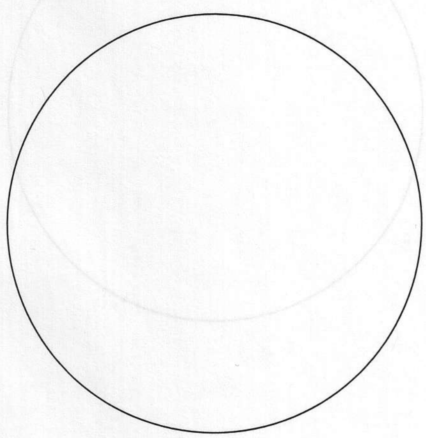
In the space below, sketch your chromosomes. You shouldn't take the time to draw each pop bead, but do be sure that homologous pairs can be identified in your drawing. An example is shown below.



Interphase

Before cell division begins, each chromosome must replicate. This event happens while the chromosomes are still in their long, stringy, uncoiled state, so when interphase is viewed under the microscope, the chromosomes are not even identifiable.

Using more pop beads, make an exact copy of each of your chromosomes. At this point the chromosome is doubled, with an attachment point called the centromere. Each strand of the doubled chromosome is called a chromatid. Because they are identical, chromatids that are attached to each other are called sister chromatids. Sketch the chromosomes below.



How many chromosomes are there now? (As long as the chromatids are attached, the structure is considered one chromosome.)

How many homologous pairs of chromosomes?

How many chromatids?

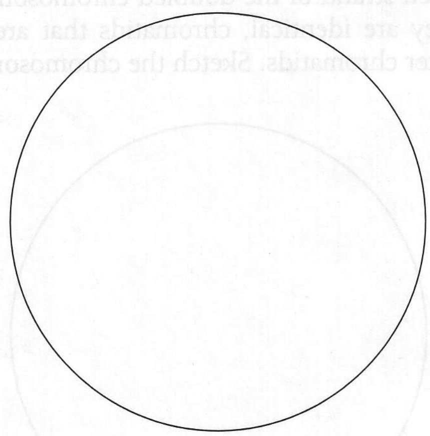
Besides replication of the chromosomes, what else should happen during interphase? (Hint: The entire cell is going to divide in half, not just the nucleus.)

After interphase, cell division is a matter of sorting out the cell contents into two new cells. How the chromosomes are sorted is of special interest. By taking a "snapshot" of the process at several points, we can understand the mechanism of this division. Traditionally, the "snapshot" phases of mitosis are called prophase, metaphase, anaphase, and telophase, but keep in mind that cell division is a continuous process.

Prophase

It is during prophase that the chromosomes coil more tightly and become visible as distinct structures. Since we already modeled short, thick chromosomes during interphase, there are no changes to our pop bead model.

By the end of prophase, the nuclear envelope disintegrates, enabling the chromosomes to be snared by protein fibers that have grown out of two centrosomes that formed in the cytoplasm. Together these protein fibers form the spindle, an apparatus that will eventually allow the sister chromatids to separate from each other.



Metaphase

By metaphase the two centrosomes have moved to opposite ends of the cell with their protein fibers attached, and many of these protein fibers are also attached to the centromere region of a chromosome. One sister chromatid of each chromosome is connected to each pole by this spindle apparatus.

The distinctive characteristic of metaphase is the alignment of the chromosomes in a plane through the center of the cell. (Only the centromeres are aligned.) Place your chromosome models in this position and sketch metaphase in the circle below.

Based on what you know about the outcome of mitosis, can you guess what's going to happen next?

Anaphase

During anaphase the centromeres joining the sister chromatids separate and the chromatids—now called chromosomes—move along the spindle fibers to opposite poles. The number of chromosomes in the cell is briefly double as the cell is prepared for the final phase of division.

Place your chromosome models in the anaphase positions and sketch them in the circle below.

Telophase and Cytokinesis

Now that the chromatids have separated, the division of chromosomes is complete. All that remains is to reconstruct the nuclear envelopes and divide the cytoplasm between the two new cells. These processes will be finished by the end of telophase, and the chromosomes will resume their typical long, stringy form.

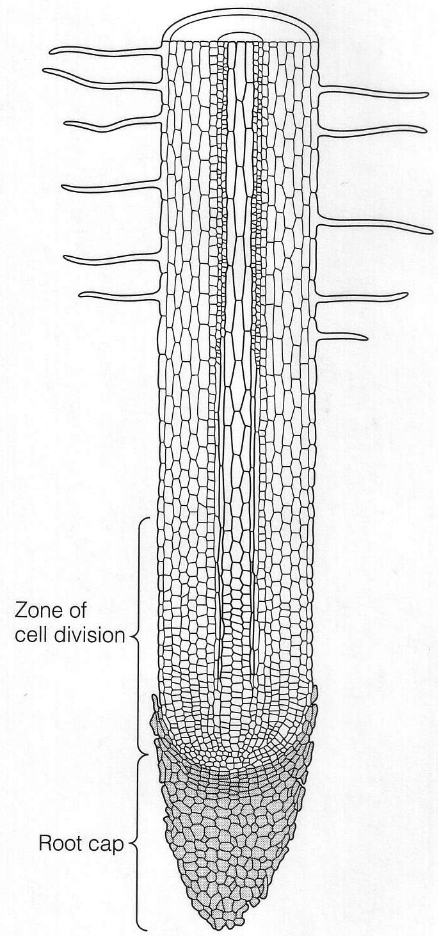
How many chromosomes are there in each new cell?

How many homologous pairs of chromosomes in each new cell?

What is the overall result of mitosis?

After seeing the phases of mitosis, you may be wondering why cell division is such an elaborate process. Once interphase is complete, why not cut to the chase—telophase? Mitosis has to be carefully choreographed so that each daughter cell has the same number and type of chromosomes—that is, so the division of chromosomes is absolutely equal. Did you ever share a bag of M&Ms with a sibling or friend by carefully counting out and dividing one color at a time? The purpose was to be sure that the distribution was exactly equal, and mitosis has the same purpose regarding chromosomes. On the other hand, you were probably willing to divide a Snickers bar down the middle, without bothering to count every last peanut. You made the assumption that both halves were more or less equal. That's how the cytoplasm and included organelles are divided.

Figure 8.2.
Onion root tip.



Activity B: Viewing Mitosis in Onion Root Tip Cells

Plants have regions of cell division where growth occurs. One such region is the root tip, whose growth enables the roots to elongate and reach through the soil. Since these tips are fine, threadlike tissues, it is easy to press them flat on a slide to view them under a microscope. Mitosis is concentrated in one particular region of the root tip (see Figure 8.2). After the new cells are produced, they will enlarge and mature into different cell types in the root. To produce these root tips, small white onions were placed in water. After several days of root growth, the root tips were cut off and preserved. They were then placed in a staining solution that makes their chromosomes visible.

Procedure

1. Use forceps to pick a root tip out of the vial and place it on a microscope slide.
2. Add a small drop of water to the slide.
3. Place a coverslip over the root tip.
4. Use the eraser end of a pencil to press gently on the coverslip. This should spread the tissues apart. Go easy at first—you don't want to crack the coverslip, and you can always press again if necessary.
5. Place the root tip slide on the stage of your microscope and find the pointed end of the root using scanning power.

6. Turn to low power to locate the region of cell division. If the cells do not look clear, you have not squashed the root tip enough. When it is properly squashed you will be able to see a single layer of cells.
7. Once you have located the area of cell division and are able to see cells clearly, position one cell in the center of the lens and turn to high power. You should now be able to see the chromosomes. Identify which (if any) stage of mitosis the cell is in and draw it in the appropriate box below.
8. Move the slide around to find cells in different phases of mitosis. You may need to switch back and forth between high and low power to do this.

Keep in mind that mitosis is a continuous process. Some cells will be between the "snapshot" phases.

Interphase	Prophase
Metaphase	Anaphase
Telophase	Cytokinesis

EXERCISE 8.3

The Process of Meiosis

Objectives

After completing this exercise, you should be able to

1. Explain the purpose and location of meiosis in organisms.
2. Describe and recognize the phases of meiosis.
3. Explain how the process of meiosis results in genetic variation of offspring.

Mitosis produces an exact copy of a cell and is an essential process for growth and repair in multicellular organisms. But multicellular organisms also need a special type of cell division to produce gametes (eggs and sperm), and that process is called meiosis. Unlike mitosis, which occurs throughout the body, meiosis occurs only in specialized reproductive tissues.

One outcome of meiosis is reduction of chromosome number. Look again at Figure 8.1, the human karyotype, which shows the homologous pairs of a diploid cell. Gametes made from this cell will be *haploid* with 23 chromosomes. How should 23 chromosomes be selected to go into each gamete?

Enormous genetic variation of gametes is another outcome of meiosis. On the karyotype in Figure 8.1, randomly label each chromosome as maternal (M) or paternal (P). Then randomly choose one member of each pair to put in a gamete (or flip a coin to choose) and write your selections (M or P) below for each chromosome.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	sex
__	__	__	__	__	__	__	__	__	__	__	__	__	__	__	__	__	__	__	__	__	__	__

Again, each chromosome is a DNA molecule that encodes information and each segment of information is called a gene. So distributed on the 46 chromosomes in the karyotype in Figure 8.1 are the 30,000 to 40,000 genes that make up the human genome, the set of instructions that produces a human being. In the next lab topic you will consider the distribution of genes during meiosis, but for now we are going to examine how the chromosomes themselves are sorted into gametes.

Activity A: Pop Bead Simulation of Meiosis

To see how the process of meiosis results in haploid gametes that differ from each other genetically, you will take a cell through the steps of meiosis as you did for mitosis. The mechanisms of mitosis, such as the centrosomes and spindle fibers, are also used in meiosis, and the same names—prophase, metaphase, anaphase, telophase—are given to the "snapshot" phases. But meiosis will result in four cells rather than two, so two divisions take place. The two divisions are designated meiosis I and meiosis II. Also, while many different types of cells can undergo mitosis, only specific cells can undergo meiosis. In animals, meiosis is carried out in the cells that produce gametes. In plants, meiosis produces spores (Lab Topic 12).

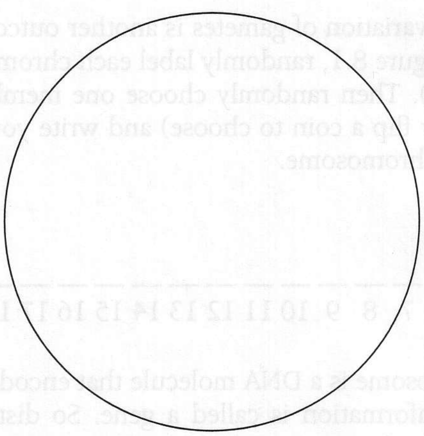
Where in the human body does meiosis occur?

Procedure

Begin with the same three homologous pairs of chromosomes that you used for mitosis.

Interphase

Before meiosis begins, the chromosomes must replicate. Make an exact copy of each of your chromosomes, then draw the interphase nucleus in the cell below.



Prophase I

As in mitosis, the chromosomes become visible and the nuclear envelope disintegrates during this phase. But something very different happens, too. Homologous pairs associate closely with each other, even to the point of entwining their "arms." Each pair of pairs is called a **tetrad**. Group your chromosomes into tetrads.

While they are in close contact, the chromatids of homologous chromosomes can exchange pieces of DNA. The size of these exchanged segments varies. You can simulate this process, called crossing over, by popping a few beads off of one chromatid and exchanging them for the same number of beads on a chromatid from its homologue.

What is the result of crossing over in a homologous pair?

Sketch prophase I below.

Metaphase I

Recall that metaphase of mitosis is when the chromosomes are attached to the spindle apparatus and aligned along the center of the cell. Metaphase I in meiosis is similar, but each tetrad stays together. Line up your tetrads and sketch them below.

Anaphase I

In anaphase I, homologous pairs are separated from each other and move to opposite poles, but sister chromatids remain attached. How does this differ from anaphase of mitosis?

Move your chromosomes to simulate anaphase I and sketch it below.

Telophase I and Cytokinesis

Once the homologous pairs of chromosomes are at opposite poles, the cytoplasm divides to form two daughter cells. Move your chromosomes into the two new daughter cells that will be formed when cytokinesis is completed. Make a sketch below.

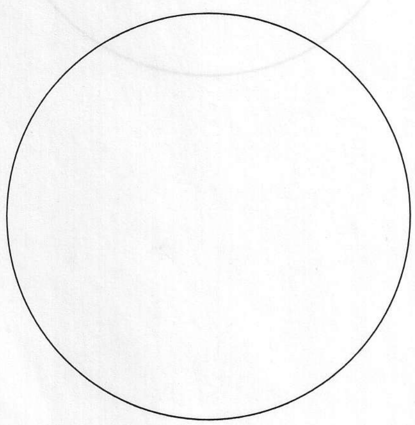
List by color the chromosomes that are in each daughter cell you made. For example, if your chromosomes are red and yellow, your daughter cells might be red, red, yellow and yellow, yellow, red. (For chromosomes that underwent crossing over, list the predominant color.)

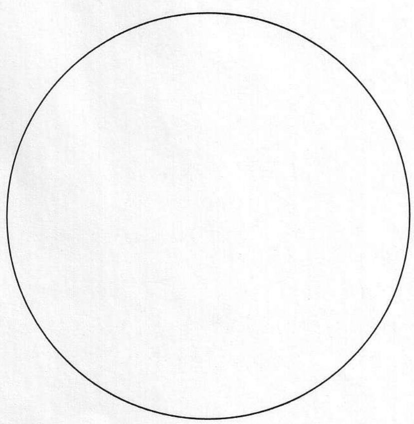
Check with other students to see whether their daughter cells are the same as yours. If there are different combinations, can you explain why? (Hint: Review the metaphase I sketch of someone whose daughter cells turned out differently than yours.)

Crossing over during prophase I is one source of genetic variation that results from meiosis. The random alignment of tetrads at metaphase I is another source. With only three pairs of chromosomes, there are eight different combinations of chromosomes in the gametes (two for each possible alignment). Imagine how many possibilities exist with 23 pairs of chromosomes!

Each cell that results from meiosis I has one member of each homologous pair, which is the desired outcome for gametes. Why isn't this the end of meiosis?

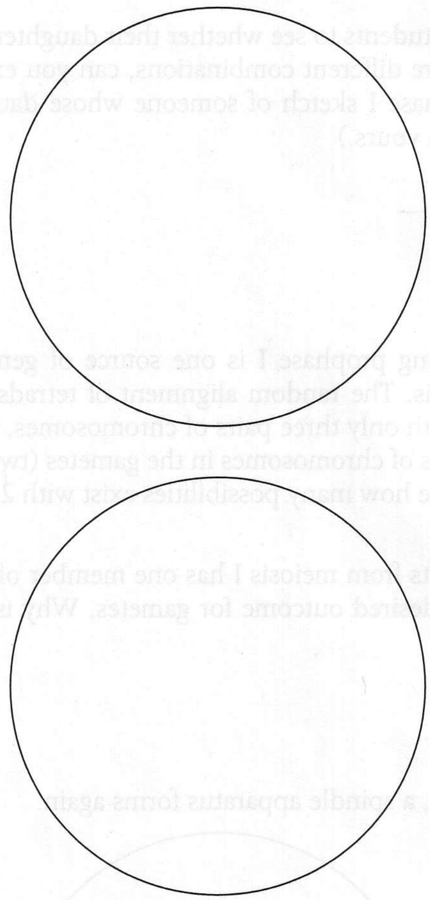
Prophase II
During prophase II, a spindle apparatus forms again.





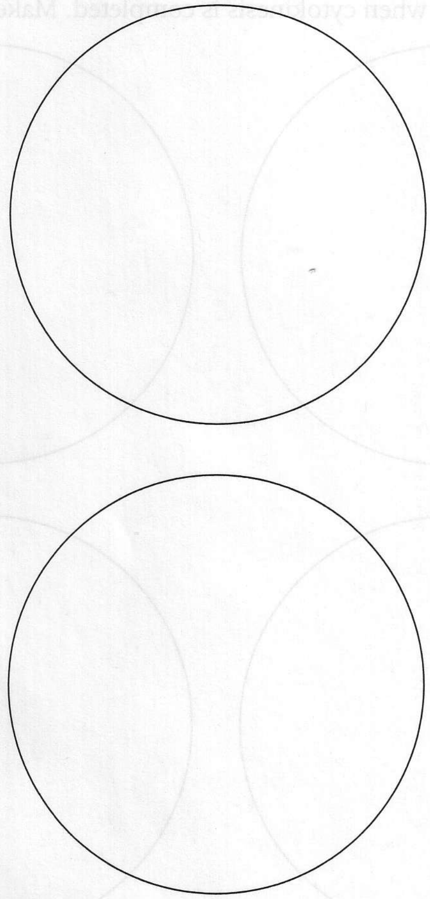
Metaphase II

With each chromatid attached to spindle fibers, the chromosomes line up in the center of the cell.



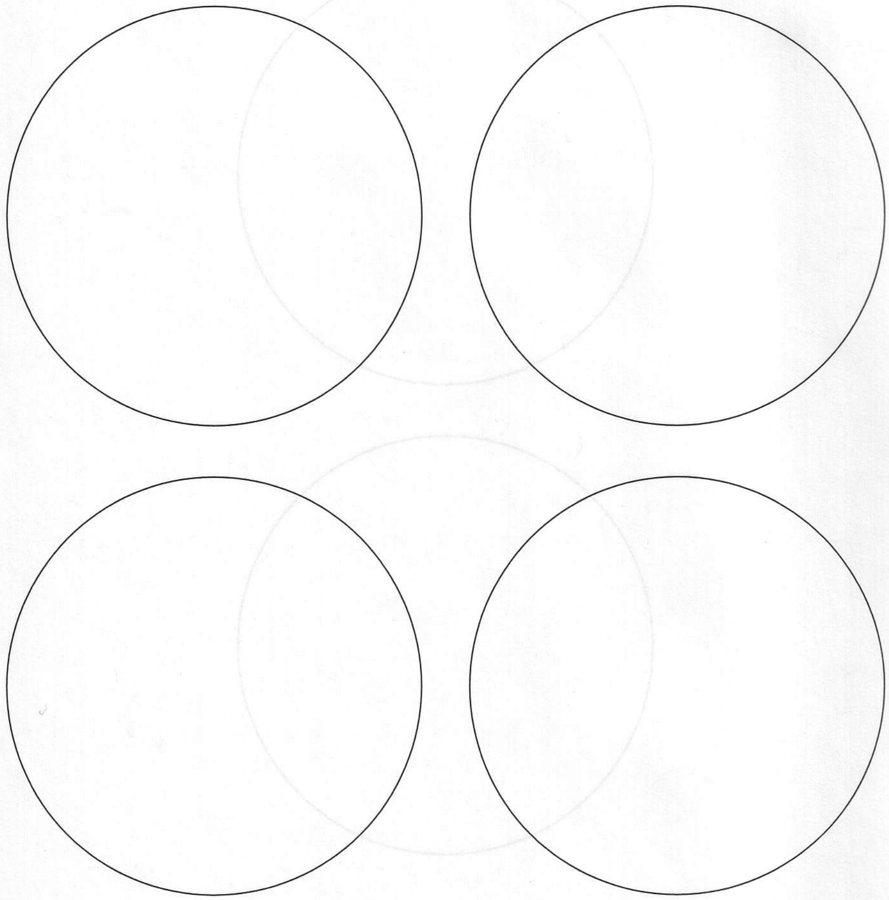
Anaphase II

During this anaphase, the sister chromatids move to opposite poles.



Telophase II and Cytokinesis

The division of chromatids is completed, and the cytoplasm divides to form new daughter cells. Move your chromosomes into the new daughter cells that will be formed when cytokinesis is completed. Make a sketch below.



How many chromosomes does each cell have?

How many homologous pairs does each cell have?

Are these cells haploid or diploid?

List by color the chromosomes that are in each daughter cell you made.

Check with other students to see whether their gametes turned out the same as yours. Make a complete list of all possible chromosome combinations in the gametes.

Activity B: Viewing Meiosis in Organisms

You will view professionally prepared slides to see what actual cells look like during the phases of meiosis. If you were to use animal tissue for this exercise, what parts of the animal would be used to show meiosis?

If you were to use plant material, which parts would you look at to see meiosis? (Hint: Where does sexual reproduction take place?)

Procedure

1. Your instructor will supply you with prepared microscope slides to examine. Begin by using scanning power to locate the specimen. Switch to low power to identify an area that includes cells undergoing meiosis.
2. Using high power, sketch the positions of the chromosomes during different stages of meiosis in the spaces below. Label your drawing with the name of the stage, as best you can identify it.

Why isn't it as easy to identify the stages of meiosis in cells as it was to identify the stages of mitosis?

Questions for Review

1. What purpose does mitosis serve in development and growth? (Hint: A zygote is the first cell formed after conception, but by adulthood a human body has many trillions of cells.)

2. After an adult has all his trillions of cells, does he still need the process of mitosis? Explain.

3. Which phase(s) of mitosis could the karyotype in Figure 8.1 have been made from? Explain your reasoning.

4. Besides the root tips, where else in plants would you expect mitosis to take place?

5. Meiosis is from a Greek root meaning "to diminish or lessen." Why is this an appropriate term?

6. Summarize the sources of genetic variation in meiosis.

7. Which phase of meiosis is responsible for the genetic variation of gametes demonstrated in the introduction to Exercise 8.2?

8. Most people who have Down syndrome have an extra copy of chromosome 21 (trisomy 21), which is a result of an egg or sperm that carried an extra copy of chromosome 21. How could a gamete with an extra chromosome come about?

9. You have homologous pairs of chromosomes because you got one member of each pair from each parent. Your parents got their chromosomes from your grandparents, and so on. But are the chromosomes that are passed along through the generations exactly the same? From example, is your maternal chromosome #1 exactly the same one that your mother received from one of her parents? Explain.