Introduction

For organisms to grow and reproduce, cells must divide. Mitosis and meiosis are both processes of cell division, but their outcomes are very different.

Key Concepts I: Mitosis

There are two kinds of cell division in eukaryotes. Mitosis is division involved in development of an adult organism from a single fertilized egg, in growth and repair of tissues, in regeneration of body parts, and in asexual reproduction. In mitosis, the parent cell produces two "daughter cells" that are genetically identical. (The term "daughter cell" is conventional, but does not indicate the sex of the offspring cell.) Mitosis can occur in both diploid (2n) and haploid (n) cells; a diploid cell is shown below.

In meiosis, diploid parent cells divide and produce the gametes or spores that give rise to new individuals. The parent cell produces four haploid daughter cells.

Prior to both mitosis and meiosis, the chromosomes in the nucleus are replicated. The nucleus then divides. Nuclear division is usually followed by division of the cytoplasm. In mitosis, there is one such division. Meiosis consists of two divisions; since the chromosomes have replicated only once, the four daughter cells have half as many chromosomes as the parent cell.

Let's look more closely at each process, beginning with the cell cycle.
The Cell Cycle

Though we frequently use the term mitosis to refer to the overall process of cell division, mitosis is actually only one phase of the cell cycle. The cell cycle is the orderly sequence of events that occurs from the time a cell divides to form two daughter cells to the time those daughter cells divide again. The phases of the cell cycle occur in meiosis as well as mitosis; you will see later how they differ.

The length of time of the cell cycle varies among organisms and among cell types. Later in this laboratory you will calculate the length of time a cell spends in several phases of the cell cycle.

Select each phase for a closer look.

Interphase

Most of the cell cycle is spent in interphase. During interphase the cell is growing and metabolic activity is very high. Toward the end of interphase, new DNA is synthesized and the chromosomes are replicated. Each chromosome of the homologous pair is then composed of two sister chromatids.

Nuclear Division (Karyokinesis)

During the process known as karyokinesis, the nucleus divides. Nuclear division includes several subphases, which we will study in detail later. Karyokinesis is usually followed by cytokinesis.
Cytoplasmic Division (Cytokinesis)

In the process called cytokinesis, the cytoplasm divides and two identical daughter cells are formed.

Homologous Chromosomes

In diploid (2n) organisms, the genome is composed of homologous chromosomes. One chromosome of each homologous pair comes from the mother (called a maternal chromosome) and one comes from the father (paternal chromosome).

Homologous chromosomes are similar but not identical. Each carries the same genes in the same order, but the alleles for each trait may not be the same. In garden peas, for example, the gene for pod color on the maternal chromosome might be the yellow allele; the gene on the homologous paternal chromosome might be the green allele.

Design of the Experiment I

Observing Mitosis Using Prepared Slides

In your laboratory, you will study and sketch the events of cell division in either plant or animal cells, using a microscope slide of cells arrested at various stages in the process of division.

To help you identify which phase of the cycle a cell is in, let's go over the features to look for in each phase.
Next let's see how the phases of division look in real cells.

**Identifying the Phases of Mitosis**

Select each dividing cell in the micrograph of the whitefish blastula below to see an enlarged drawing of that stage.
**Interphase**

The nucleolus and the nuclear envelope are distinct and the chromosomes are in the form of thread-like chromatin.

**Prophase**

The chromosomes appear condensed, and the nuclear envelope is not apparent.

**Metaphase (THIS LINK IS BROKEN)**

Thick, coiled chromosomes are lined up in the center of the cell on the metaphase plate. Spindle fibers are attached to the chromosomes.

**Anaphase**

The chromosomes have separated and are moving toward the poles.

**Telophase**

The chromosomes are at the poles, and are becoming more diffuse. The nuclear envelope is reforming. The cytoplasm may be dividing.
Observing Mitosis in a Living Cell

The cell cycle is something like a dance routine or football play — it is a process that runs continuously, but it is possible to stop the action at any point for analysis. From a "dead" collection of cells on a lab slide, it may be hard for you to grasp the dynamics of mitosis. Here is a movie clip of mitosis in a plant cell. As you view the clip, try to identify each stage of cell division. Then proceed to Analysis of Results I to calculate the length of time for each stage.

Analysis of Results I

Timing the Stages of Cell Division
You've now seen that cell division is a dynamic event. Once you know the approximate duration of a particular cell cycle, it's possible to calculate the amount of time the cell spends in each phase. You can do this even though you are looking at a slide of cells that have been arrested in the process of division. Follow these steps:

1. Determine the approximate duration of the entire cycle for the cells you are studying (1440 minutes for an onion cell).
2. Looking at the slide, count and record the number of cells in the field of view that are in each phase.
3. Determine the total number of cells counted.
4. Determine the percent of cells that are in each phase.
5. To calculate the time (in minutes) for each phase, multiply the percent of cells in that phase by the number of minutes for the whole cycle.

We will practice with the slide of onion root cells below. Looking at the cells marked with an X, count the number of cells in each phase.

The average time for onion root tip cells to complete the cell cycle is 24 hours = 1440 minutes. To calculate the time for each stage:

\[ \text{% of cells in the stage} \times 1440 \text{ minutes} = \text{number of minutes in the stage} \]
Calculate the time for each stage and fill in the table below; then check your answer.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Number of cells</th>
<th>Time (in minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interphase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prophase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metaphase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anaphase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telophase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total number of cells</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[check answer]
Lab Quiz I

1. Select the phase of the cell cycle depicted in the image below.
   
   ![Image of cell cycle phase](image)
   
   a. prophase  
   b. metaphase  
   c. anaphase  
   d. telophase  
   e. interphase

2. Select the phase of the cell cycle depicted in the image below.
   
   ![Image of cell cycle phase](image)
   
   a. prophase  
   b. metaphase  
   c. anaphase  
   d. telophase  
   e. interphase

3. Select the phase of the cell cycle depicted in the image below.
   
   ![Image of cell cycle phase](image)
   
   a. prophase  
   b. metaphase  
   c. anaphase  
   d. telophase  
   e. interphase
4. Select the phase of the cell cycle depicted in the image below.

   a. prophase   b. metaphase   c. anaphase   d. telophase   e. interphase
Key Concepts II: Meiosis

Meiosis follows phases similar to those in mitosis, but the outcome of the process is very different. The DNA of the parent cells is replicated in interphase preceding both mitosis and meiosis. However, in meiosis, replication is followed by two divisions.

Meiosis reduces the chromosome number of the parent cell so that four daughter cells are produced, each with one-half the chromosome number of the parent cell. Each daughter cell contains only one chromosome from each homologous pair.
Crossing Over

Each parent cell has pairs of homologous chromosomes, one homologue from the father and one from the mother. In meiosis, the maternal and paternal chromosomes can be shuffled into the daughter cells in many different combinations (in humans there are $2^{23}$ possible combinations!). This ensures genetic variation in sexually reproducing organisms. Further genetic variation comes from crossing over, which may occur during prophase I of meiosis.

In prophase I of meiosis, the replicated homologous pair of chromosomes comes together in the process called synthesis, and sections of the chromosomes are exchanged. You can see that after crossing over, the resultant chromosomes are neither entirely maternal nor entirely paternal, but contain genes from both parents. Synapsis and crossing over occur only in meiosis.

Design of the Experiment II

In this exercise you observe the results of crossing over in a fungus, Sordaria. In the figure below, a cross between two haploid strains of Sordaria produces spores of different colors.

Where the growing filaments of the two strains meet, fertilization occurs and zygotes form. Meiosis occurs within fruiting bodies to form haploid ascospores, spores contained in asci (special sacs). Then one mitotic division doubles the number of ascospores to eight.

To study the process of spore formation, select the magnifying glass above.
Spore Formation in Sordaria

Four black ascospores in a row next to four tan ascospores in a row indicates that crossing over has NOT occurred. Any other arrangement of ascospores indicates that crossing over has taken place. Continue to the next page to see all the possible arrangements of spores.

Possible Arrangements of Ascospores

On the next page you will evaluate crossing over in a slide of Sordaria.

A. No crossing over  B. Crossing over during meiosis
Analysis of Results II

Study this small section of a slide of Sordaria to determine if crossing over has occurred in the asci designated by an X.

If the ascospores are arranged 4 dark/4 light, count the ascus as "No crossing over." If the arrangement of ascospores is in any other combination, count it as "Crossing over." (Keep track of your counts with paper and pencil.)

In this exercise, we are interested only in asci that form when mating occurs between the black-spore strain and the tan-spore strain, so ignore any asci that have all black spores or all tan spores. Occasionally the asci rupture and spores escape. You can see them here as individual spores not in one of the possible arrangements, so don't include them in your count.

1. In the photo, how many asci marked with an X show no evidence of crossing over?
   
   
   [Check Your Answers]

2. In the photo, how many asci marked with an X show evidence of crossing over?
   
   
   [Check Your Answers]
3. In the photo, what is the total number of asci marked with an X?

Check Your Answers

4. What is the percent of crossovers? (number of asci with crossovers divided by total number of asci multiplied by 100)

%  
Check Your Answers

By studying the frequency of crossing over, you can gather information that lets you draw a map of the relative location of genes on a chromosome. A map unit is a relative measure of the distance between two linked genes, or between a gene and the **centromere**. **The greater the number of crossovers, the greater the map distance.**

From the crossing over data you gather for Sordaria, you will be able to calculate the map distance between the gene for spore color and the centromere. To find the number of map units, you divide the percent of crossovers by 2. (In an actual lab, you should count at least 50 asci before calculating map units.)

Why divide by two? Each crossover produces two spores like the parents and two spores that are a result of the crossover. Thus, to determine the number of crossovers, you must divide the number of asci counted by two since only half the spores in each ascus result from crossing over.

A **map unit** is an arbitrary unit of measure used to describe relative distances between linked genes. **The number of map units between two genes or between a gene and the centromere is equal to the percentage of recombinants.** Customary units cannot be used because we cannot directly visualize genes with the light microscope. However, due to the relationship between distance and crossover frequency, we may use the map unit.

5. For the sample shown here, what is the map distance between the gene for spore color and the centromere? (percent of crossovers divided by 2)

%  
Check Your Answers

The frequency of crossing over appears to be governed largely by the distance between genes.

The probability of a crossover occurring between two particular genes on the same chromosome (linked genes) increases as the distance between those genes becomes larger.

The frequency of crossover, therefore, appears to be directly proportional to the distance between genes.
Comparison of Mitosis and Meiosis

Now that you've studied both mitosis and meiosis, answer the following questions to reinforce your understanding of the differences between the two processes.

1. In what cellular processes is mitosis involved? In what cellular processes is meiosis involved?

2. In what type of cells does mitosis occur? In what type of cells does meiosis occur?

3. How many times does DNA replicate in mitosis? How many times does DNA replicate in meiosis?

4. How many cellular divisions occur in mitosis? How many cellular divisions occur in meiosis?

5. How many daughter cells are formed by mitosis? How many daughter cells are formed by meiosis?
6. What is the chromosome number in daughter cells formed by mitosis from diploid parent cells? What is the chromosome number in daughter cells formed by meiosis from diploid parent cells?

7. In mitosis, are daughter cells identical to or different from parent cells? In meiosis, are daughter cells identical or different from parent cells?

8. In mitosis, when do synapsis and crossing over occur? In meiosis, when do synapsis and crossing over occur?
Lab Quiz II

1. Which of the following statements is correct?
   a. crossing over occurs in prophase I of meiosis and metaphase of mitosis
   b. DNA replication occurs once prior to mitosis and twice prior to meiosis
   c. both mitosis and meiosis result in daughter cells identical to the parent cells
   d. Karyokinesis occurs once in mitosis and twice in meiosis
   e. synapsis occurs in prophase of mitosis

2. The cell cycle in a certain cell type has a duration of 16 hours. The nuclei of 660 cells showed 13 cells in anaphase. What is the approximate duration of anaphase in these cells?
   a. 2 minutes   b. 13 minutes   c. 19 minutes   d. 32 minutes   e. 647 minutes

3. Use the figure below to answer the question. For an organism with a diploid number of 6, how are the chromosomes arranged during metaphase I of meiosis?
4. Which sketch shows the arrangement of chromosomes that you would expect to see in metaphase of mitosis for a cell with a diploid chromosome number of 6?

- a. A
- b. B
- c. C
- d. D

5. A group of asci formed from crossing light-spored Sordaria with dark-spored produced the following results:

<table>
<thead>
<tr>
<th>Number of Asci Counted</th>
<th>Spore Arrangement</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>4 light/4 dark spores</td>
</tr>
<tr>
<td>8</td>
<td>4 dark/4 light spores</td>
</tr>
<tr>
<td>3</td>
<td>2 light/2 dark/2 light/2 dark spores</td>
</tr>
<tr>
<td>4</td>
<td>2 dark/2 light/2 dark/2 light spores</td>
</tr>
<tr>
<td>1</td>
<td>2 dark/4 light/2 dark spores</td>
</tr>
<tr>
<td>2</td>
<td>2 light/4 dark/2 light spores</td>
</tr>
</tbody>
</table>

How many of these asci contain a spore arrangement that resulted from crossing over?

- a. 3
- b. 7
- c. 8
- d. 10
- e. 15

6. A group of asci formed from crossing light-spored Sordaria with dark-spored produced the following results:

<table>
<thead>
<tr>
<th>Number of Asci Counted</th>
<th>Spore Arrangement</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>4 light/4 dark spores</td>
</tr>
<tr>
<td>8</td>
<td>4 dark/4 light spores</td>
</tr>
<tr>
<td>3</td>
<td>2 light/2 dark/2 light/2 dark spores</td>
</tr>
<tr>
<td>4</td>
<td>2 dark/2 light/2 dark/2 light spores</td>
</tr>
<tr>
<td>1</td>
<td>2 dark/4 light/2 dark spores</td>
</tr>
<tr>
<td>2</td>
<td>2 light/4 dark/2 light spores</td>
</tr>
</tbody>
</table>
7. From this small sample, calculate the map distance between the gene and centromere.

   a. 10 map units   b. 20 map units   c. 30 map units   d. 40 map units

**POST LAB ANALYSIS QUESTIONS**

1. List at least 2 ways that mitosis differs in the cells of animals and higher plants.

2. List at least 2 ways that prokaryotic cell division is similar to eukaryotic cell division.

3. On the basis of your observations during this lab activity and the information on the events of mitosis from your textbook, explain why some phases of mitosis are longer than others. Refer specifically to each phase.

4. List at least 3 ways in which meiosis differs from mitosis.

5. What is the relationship of meiosis to variation in populations (including humans)?
6. The FARTHER APART two gene loci are on a chromosome, the MORE LIKELY it is that a crossover event will occur between them. By counting the frequency of crossover events between two gene loci, geneticists can determine the relative distance between them. In this way, LINKAGE MAPS have been produced for many organisms – including humans. REVIEW THE INFORMATION ON CALCULATING MAP UNITS ON PAGE 14 OF THE LAB. Describe below how map units are calculated:

________________________________________________________________________________________________________
________________________________________________________________________________________________________
________________________________________________________________________________________________________
________________________________________________________________________________________________________

7. Complete the data table below for calculation of map units given the following information:

<table>
<thead>
<tr>
<th>Sample Data</th>
<th># of MI Asci (4:4)</th>
<th># of MII Asci (2:4:2 or 2:2:2:2)</th>
<th>Total Asci (MI + MII)</th>
<th>% MII Asci (# of MII/Total)</th>
<th>Gent-to-Centromere Distance (%MII/2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>172</td>
<td>177</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8. Does crossing-over increase or decrease genetic variation? Support your answer.

________________________________________________________________________________________________________
________________________________________________________________________________________________________

9. A city creates a new lake for its water supply system. The lake is colonized by two water plants, species A and species B. Species A reproduces exclusively by means of buds that grow from rhizomes (runners). Species B reproduces by budding but also reproduces by seeds, which involves sexual reproduction. Given that for both species n = 7, would you expect to find more genetic variation in the population of species A or species B? Explain your answer.

________________________________________________________________________________________________________
________________________________________________________________________________________________________

10. Suppose that the data collected in the table above (question # 7) showed 397 MI asci and 0 MII asci. What would you conclude from this?

________________________________________________________________________________________________________
________________________________________________________________________________________________________

L. Carnes 20