Labs 7 and 8: Mitosis, Meiosis, Gametes and Genetics

In Biology 107, our discussion of the cell has focused on the structure and function of subcellular organelles. The next topics, genetics and molecular biology, deal with the replication, maintenance, inheritance, and expression of biological information. Cell division links the behavior of chromosomes during nuclear division with the behavior of genes during reproduction.

Objectives

When you have successfully completed this lab, you should be able to:

1. Understand how chromosomes behave during mitosis and meiosis.
2. Distinguish between haploid and diploid cells and understand homologous chromosomes.
3. Draw or identify each stage of nuclear division, mitotic or meiotic.
4. Understand how the rules of probability influence gamete formation and fertilization

Introduction

All cells arise from the division of existing cells. Most cell division is mitotic, a process that involves the duplication of the cell’s DNA and the apportionment of one copy to each of two identical daughter cells. Cells that are destined to become gametes (sperm and egg cells) divide by a process called meiosis. In meiosis, the DNA is duplicated once, but cell division occurs twice, leaving the four resulting cells each with one half the DNA originally present in the parent cell. The fact that the cells resulting from meiosis are not identical is the basis for the shuffling of genes that occurs in sexual reproduction.

It is essential that you have a detailed understanding of meiosis. Without a good grasp of the process of gamete formation, it is impossible to understand how genes are inherited. Before coming to lab, students should review the lecture material on mitosis and meiosis. Your text has excellent diagrams on pages 218-219 and 240-243. These will be very helpful during lab, so remember to bring your textbook with you. In addition, you should bring the completed homework assignment on Mendelian genetics (Section B).

Procedures

Section A - Meiosis

Your lab instructor will demonstrate the use of pop-beads as a model for how chromosomes behave during mitosis and meiosis. After the demonstration, open your bag of beads and practice with your group until you feel that you understand how chromosomes behave during mitosis and meiosis. Be prepared to explain which cells are haploid and which are diploid.

You should understand the difference between ploidy (haploid or diploid) and duplication state. In both haploid and diploid cells, the DNA can be either duplicated or unduplicated. Haploid cells contain one version of each chromosome. There can be two copies of the one version, but the cell is still haploid. Diploid cells contain two versions of each chromosome. Use the pink and yellow pop-beads to help understand these important concepts.

After you have practiced, demonstrate to your lab instructor or student assistant that you understand meiosis, including which cells are haploid or diploid, when DNA has been duplicated, which cells are gam-
Section B - Gametes and Genetics

After you have reviewed lecture and text material on mitosis and meiosis, but before coming to lab, work through the following section. After completing this section, you should have a better understanding of gamete formation and fertilization. Write your answers in the space provided so that your work can be collected and graded in class. Whenever you write the genotype of a gamete, circle it, to reinforce the fact that gamete cells are haploid. You will need a red and a blue pencil (or pen) to complete this exercise.

Mendel’s rules of inheritance were originally formulated to explain the inheritance of several traits in garden peas. These rules were so significant that they continue to form the basis of our understanding of how biological information is inherited. A modern summary of these rules is a useful way to introduce the vocabulary of genetics.

1. Biological information, about **characters** like flower color or plant height, for example, is carried on discrete units called **genes**. Genes are passed unchanged (mostly) from parents to offspring.

2. **Alleles** are versions of a gene that specify different **traits** (red or white flower color, for example.) The alleles present in the organism are its **genotype**. **Phenotype** refers to the observable trait.

3. When one **dominant** and one **recessive** allele are present in an organism, only the trait specified by the dominant allele will be expressed. In this exercise, we will only be concerned with two alleles, one dominant and one recessive, for each gene. Keep in mind, though, that we have discussed a number of other possibilities in class.

4. Gametes are **haploid**. Each **diploid** parent contributes only one of its two alleles to each gamete. This is where an understanding of the process of meiosis is extremely helpful.

5. When gametes unite at **fertilization**, the two alleles in the new diploid organism (**zygote**) are contributed by the gametes involved in the fertilization. Diploid organisms are **homozygous** for a gene when both alleles are the same and **heterozygous** when the two alleles differ.

To understand how these rules apply to inheritance, let’s create an example of a cross between two individuals of a certain plant species. The plants are diploid, and reproduction occurs when male and female gametes (haploid) fuse to form a zygote (diploid). In our example, the flower color character has two traits: red and white. Flower color is monogenic, meaning that it is determined by a single gene. That gene has two alleles: R, conferring Red flower color, and r, conferring white flowers.

The individuals in our original cross (Figure 1) are both homozygous for the gene determining flower color. One parent has white flowers and an rr (homozygous recessive) genotype, while the other has red flowers (genotype RR, homozygous dominant). When these parents are crossed, all offspring have red flowers.

![Figure 1](image)

This cross, already familiar from lecture and text reading, illustrates the thinking involved in solving genetics problems. Since we know the genotypes of the parent plants, we know which alleles they have, and our knowledge of meiosis allows us to determine the types of gametes each parent can produce. In this example, the red parent produces R gametes and the white parent produces r gametes.

These gametes are produced from a diploid cell in the process of meiosis - the same process you will
simulate with the pop-beads. Figure 2 begins with the cells destined to produce gametes. Where in the plant would these cells be located? Write your answer here. ________________.

In preparation for sexual reproduction, the homologous chromosomes (two versions, red and blue) are duplicated and the cell divides. Are the cells resulting from meiosis I haploid or diploid? Write your answer here. ________________.

After a second meiotic division, four gametes are produced. In Figure 2, use colored pencils or pens to illustrate the chromosomes and alleles in the other parent.

What is the probability that any given gamete from the white-flowered parent carries a recessive allele? Write your answer here. ________________.

Remember that probabilities are numbers from zero to one.

What is the genotype of the individuals from the F1 generation in Figure 1? Write your answer here. ________________.

Now, two F1 individuals are crossed. Just like the first cross, plant cells undergo meiosis to produce haploid gametes, and gametes from two parents fuse to generate a diploid zygote. Cells from the two parents in this cross are shown in Figure 3. Use colored pencils or pens to illustrate the chromosomes and alleles during meiosis in these plants.

If you have done this correctly, each parent produces two types of gametes: (R) and (r). The probability of any given gamete from either parent being R is 1/2.

Since each plant can produce two kinds of gametes, there are four possible ways these gametes can combine during fertilization. To illustrate this, we can use a Punnett Square. This device is designed to help you see how probability determines the genotypes of individuals resulting from a cross. It represents all of the possible combinations of gametes and alleles in a fertilization. Each offspring will have one of these combinations. In Figure 4, on the next page, the columns represent gametes from the female parent and the rows represent gametes from the male parent. Go to this figure, write in the genotypes of the offspring, one in each of the four empty boxes. Write alleles contributed by the male parent in blue and alleles contributed by the female parent in red. Review your text or lecture notes if you need to.

In the Punnett Square, the probability of any given offspring having a certain genotype can be determined easily. You could count all of the Rr offspring, and divide by the total. 2/4 = a probability of 1/2.
What ratio of red to white flowers would you predict in the F2 generation? Write your answer here. ____________________.

Figure 5 shows the results of a cross of two F1 individuals. What is the actual ratio of red to white flowers in this cross? Is this the same or different from your predicted ratio? Why is it the same or different? Write your answers to these questions in the space below.
The answer to the last question, regarding whether the ratio of red- to white-flowered plants was as predicted, bears further explanation. As an illustration, take out two coins. If you flip both of them at once, there are three possible outcomes head-head (HH), head-tail (HT) and tail-tail (TT). We would expect one quarter HH, one half HT and one quarter TT. Notice that this is analogous to the Punnett Square on page four. Flip your coins twenty times and record the results in the table below. We will discuss the results and pool class averages in lab.

Table 1. Coin Toss Results

<table>
<thead>
<tr>
<th></th>
<th>HH</th>
<th>HT</th>
<th>TT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected</td>
<td>5</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Observed</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Class Totals</td>
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</tbody>
</table>

In our model species, inheritance of plant height follows the same pattern of inheritance as flower color. It is a Mendelian monogenic character with two traits states (tall and dwarf). Only one dominant allele (D) and one recessive allele (d) exist. The parents in Figure 1 are true-breeding (homozygous) for the gene that determines plant height. Based on this information, answer the following questions, referring only to the genotypes and phenotypes related to plant height.

1. What are the genotypes of the parents in Figure 1?

2. What types of gametes can each of these plants produce?

3. Which allele is dominant?

4. Can you tell which trait is dominant from Figure 1? Explain.

5. What is the genotype of the F1 offspring

6. What types of gametes can the F1 plants produce? Indicate in the diagram below, using colored pencils as above, how these gametes are produced.

7. Draw a Punnett Square illustrating the possible combinations of alleles in the F2 generation. What ratio of phenotypes would you predict? What ratio do you observe in the F2 generation in Figure 5?
Finally, if we assume that the genes for flower color and plant height are carried on different chromosomes, then these characters will be inherited independently. When you simulate this with pop-beads, you will use long and short strings of beads to indicate the two chromosomes. The plants in Figure 1, since they are true-breeding, must have the genotypes RRdd and rrDD. Now, keeping track of both genes, complete the diagram below, using color to distinguish between the members of a pair of homologous chromosomes and size to distinguish between the chromosomes carrying the height and color genes. Then, answer the questions below.

Figure 6.

1. What kinds of gametes can each plant produce?

2. What are the genotype and phenotype of the F1 plants?

Now, think about The F2 generation. As always, we will begin by asking “what types of gametes are produced?” Since the genes for flower color and plant height are on different chromosomes, they assort independently. This means that there are two possible ways that the chromosomes could move in the first meiotic division. Half of the cells undergoing meiosis will take each of the two possible routes. Complete the diagram and answer the questions.
Lab Assignment
This assignment is to be handed in next week at the beginning of lab (before your quiz). Each student must complete this assignment individually.

1. Using the pop beads provided for each pair of students, demonstrate that you understand mitosis and meiosis. Your Instructor or lab assistant must sign this sheet before you leave lab.

   Instructor’s Signature ____________________________

2. On a separate sheet, using the same color and size cues you learned for this exercise, draw the stages of meiosis for an organism with three pairs of chromosomes.

3. The techniques you learned in this lab exercise are useful in solving genetics problems. Answer each of the following questions, with an explanation, typed, on a separate sheet. Use the same letters and numbers as used below. These problems are intended to supplement, not to replace the homework problems assigned from the text. Keep in mind that on the exam, you would have about three minutes to answer each question.

   A. Sarah and Dave each have a sibling with cystic fibrosis. Neither Sarah, Dave, nor any of their parents have the disease. What is the probability that if Sarah and Dave have a child, the child will have cystic fibrosis?

   B. A brown mouse was crossed with an white mouse to produce nine brown offspring. When the white mouse was crossed with a second brown one, seven white and five brown offspring were produced. What is the best explanation for this pattern of inheritance. Write genotypes for all parents and offspring described.

   C. Tay-Sachs disease is caused by a recessive allele. If a woman and her husband are both heterozygous for this allele, what is the probability of each of the following?
      1. All three of their children will have normal phenotype.
      2. One or more of their three children will have the disease.
      3. All three children will have the disease.
      4. At least one child will be phenotypically normal.

   D. The pedigree below was obtained for a rare brain disease. Deduce the mode of inheritance, and explain your reasoning. What is the probability that individual 1 from the fourth generation will have the disease?

   ![Pedigree Diagram](image-url)
Genetics questions, continued.

E. A sex-linked recessive allele \( c \) produces red-green color blindness in humans. A normal woman whose father was color blind marries Fred, a color blind man.

1. What genotypes are possible for Fred’s mother?
2. What is the probability that the first child from this marriage will be color blind boy?
3. Of all the children produced by these parents, what fraction will have normal vision?

F. In cats, white patches are caused by the dominant allele \( P \), whereas \( pp \) individuals are solid-colored. Short hair is caused by a dominant allele \( S \), whereas \( ss \) cats have long hair. A long-haired cat with patches whose mother was solid-colored and short-haired mates with a short-haired solid-colored cat whose mother was long-haired and solid-colored. What kinds of kittens can arise from this mating, and in what proportions?

G. In a maternity ward, four babies become mixed up. The ABO blood types of the four babies are known to be A, B, O, and AB. The ABO blood types of the four sets of parents are determined. Indicate which baby belongs to each of the following sets of parents:

1. A x AB
2. AB x O
3. A x O
4. O x O

H. A cross between two plants differing in four independently assorting gene pairs \( AABBCCDD \) x \( aabbcddd \) produces an F1 which is then self-fertilized. Assuming complete dominance:

1. How many different genotypes are possible in the F2 generation?
2. How many of the F2 genotypes will be phenotypically dominant for all four factors?
3. Would your answers to 1. and 2. be different if the initial cross were \( AAbbCCdd \) x \( aaBbCcDD \)? Explain