Connecting Meiosis and Genetics

Objectives

After completing this exercise, you should be able to:

- name and describe the stages of meiosis
- correctly use and understand the terminology associated with cell division and genetics
- demonstrate an understanding of the changes in chromosome number that occur during meiosis and fertilization
- compare meiosis I with meiosis II in terms of the position of the chromosomes in each stage, changes in chromosome number, and number of daughter cells produced
- explain the process and importance of crossing-over between homologous chromosomes
- draw and complete Punnett squares and use them to determine genetic probabilities in monohybrid crosses

CONTENT FOCUS

Your body cells contain **46 chromosomes** within the nucleus. As you probably know, **half** of this genetic information (23 chromosomes) is inherited from your mother and **half** (the other 23 chromosomes) from your father.

The genetic information carried by the **gametes** (the sperm and egg), when incorporated into a fertilized egg, will determine all the physical and physiological traits of the offspring.

There is a special type of cell division that changes the chromosome number from the normal **diploid** number (46) to the **haploid** number (23) found in sperm and eggs. This special type of cell division is called **meiosis.**

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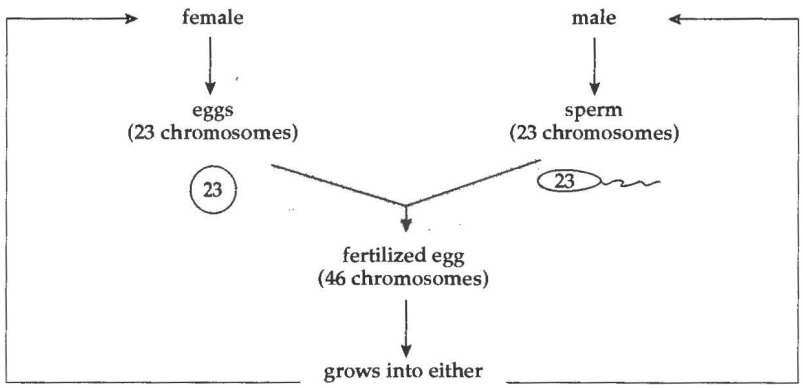


The stages of meiosis, in most respects, are similar to those of mitosis. The important differences include the following:

- the chromosome number is reduced from diploid to haploid to form gametes
- an exchange of genetic material takes place in a process known as **crossing-over;** gametes produced by meiosis are **not** genetically alike
- meiosis involves two cell divisions (meiosis I and meiosis II); one occurs immediately after the other

The genes on a chromosome may exist in **more than one form,** called **alleles.** Individuals inherit **two alleles for each trait,** one received from the mother in the egg and the other from the father in the sperm.

If the two inherited alleles represent **different** forms of the gene (**different** alleles), an individual is called **heterozygous for that trait (Bb).** The allele that is **expressed in heterozygous individuals** is referred to as **dominant** and is represented by a capital letter **(B).**

The allele **not expressed** in heterozygous individuals is called **recessive.** Recessive alleles are represented with lowercase letters **(b).**

If individuals inherit two identical alleles for a trait **(BB or bb),** they are said to be **homozygous for that trait.**

The **combination of alleles** for a trait represents an individual's **genotype** (such as BB or Bb).

The **physical description** of a specific trait is called the **phenotype** (such as brown eyes, blood type, or freckles).

In this exercise, you'll work through the process of meiosis to **form** male and female **gametes, decode** the genetic information carried by these gametes, and use that information to **build** your baby's face.

ACTIVITY 1 GETTING STARTED: BUILD A PAIR OF CHROMOSOMES

1. Work in groups. Get the following supplies: a **bag labeled "diploid human genome, male"** or **"diploid human genome, female."**

   In the supply area, you'll find containers of **beads** of several colors and shapes (representing **alleles**) and magnetic **connectors** (representing **centromeres**).

   Although humans have 23 pairs of chromosomes, we'll simplify the process by using only **one chromosome pair.**

2. Fill your bag with **four beads from each jar.** Note that there are two jars of beads of each color. In one jar, the beads are striped. In the other jar they're solid.

   Solid-colored beads represent **dominant alleles** and **striped beads** represent **recessive alleles for the same trait.**

   Get **two red centromeres and two yellow centromeres.**

3. **Remove Table 1 from one group member's book and lay it flat on the laboratory table. As you draw each bead (representing the alleles of your maternal and paternal chromosomes), place it into the appropriate box in Table 1.**

   Bead selection is random! Don't look in the bag while you're drawing the beads.

   a. The first bead you draw will become part of the chromosome you inherited from your **mother** (**maternal** chromosome).

   b. The next bead of the **same color** you draw will become part of the chromosome you inherited from your **father** (**paternal** chromosome).

   c. Additional beads of the **same color** you draw will be **THROWN BACK INTO THE BAG.**

   d. Draw beads until you've drawn **one of each color or shape for the maternal chromosome and one of each color or shape for the paternal chromosome.**

4. When you've drawn all the beads you need for both chromosomes, you're ready to hook your alleles together.

   Take a **yellow centromere** and hook it into position **between the green and red beads** of your **maternal chromosome.**

   Keeping the beads in the **correct order,** attach the remaining beads to the chromosome.

TABLE 1

TRAITS ON YOUR CHROMOSOMES

Bead Color or Shape	Maternal Alleles	Paternal Alleles	Trait	Alleles (Genotype)
Purple			Face shape	FF or Ff — round ff — triangular
Orange			Hair texture	HH — curly Hh — wavy hh — straight
Yellow			Eye size	EE — large Ee — medium ee — small
Blue			Eye distance	DD — close together Dd — medium spacing dd — far apart
Green			Eyebrow shape	BB or Bb — thick bb — thin
Red			Eyelash length	LL or Ll — long ll — short
White			Nose size	NN — big Nn — medium nn — small
Pink			Lips	GG or Gg — thick gg — thin
Black			Ear lobes	RR or Rr — free rr — attached
White oval			Cleft in chin	TT or Tt — present tt — absent
White twisted			Freckles	QQ or Qq — freckles qq — no freckles

5. **Repeat step 4** to connect the alleles of the **paternal chromosome** using the **red centromere.**

   Together these **two chromosomes (maternal and paternal)** are referred to as **homologous chromosomes.** Homologous chromosomes carry alleles for the **same traits** (face shape, eye size, etc.), although the genetic information is **not identical.**

6. Fill in **Table 2 with the genotypes and phenotypes of the traits on the chromosomes** you've just constructed.

   Solid beads = dominant alleles. Striped beads = recessive alleles.

TABLE 2
WHAT ARE YOUR TRAITS?

TRAIT	YOUR GENOTYPE	YOUR PHENOTYPE
Face shape		
Hair texture		
Eye size		
Eye distance		
Eyebrow shape		
Eyelash length		
Nose size		
Lips		
Ear lobes		
Cleft in chin		
Freckles		

Note:

When selecting your genotypes and phenotypes from Table 1, you probably noticed something unusual. Some of the traits have two possible phenotypes (round face or triangular face) and others have three options (curly hair, wavy hair, or straight hair).

The traits with three possible phenotypes represent a different mode of inheritance called incomplete dominance. Incomplete dominance is a special type of inheritance that occurs when an allele exerts only partial dominance over another allele. This results in a third, intermediate phenotype in heterozygous individuals.

ACTIVITY 2 HOMOLOGOUS CHROMOSOMES SEPARATE IN MEIOSIS TO FORM GAMETES

1. Draw a series of circles that are the same as those shown in **Figure 2.**

   Make the circles big enough for your chromosomes to fit comfortably.

2. Place your pair of chromosomes in the **first** circle. Your cell is now in **interphase.**

   The diploid number of chromosomes in our simulated cell is 2.

   How many chromosomes came from your mother? _____

   How many from your father? _____

   How many **traits** are represented on your chromosomes? _____

   How many **alleles** are represented on your chromosomes? _____

3. An important event that occurs during **interphase** involves the replication of chromosomes. Use the spare beads in your genome bag to **replicate** your two chromosomes.

   Two identical (replicated) DNA strands are called **sister chromatids.**

   Attach the new **sister chromatids** for your **maternal chromosome** together at the centromeres. Do the same for your replicated **paternal chromosome.**

4. Move your duplicated chromosomes to the next circle, marked **prophase** through **telophase of meiosis I.**

   You'll complete **prophase through telophase of meiosis I** in the **same circle.**

5. As shown in **Figure 1,** during **prophase I,** the **two homologous chromosomes** find each other and pair up in a process called **synapsis.**

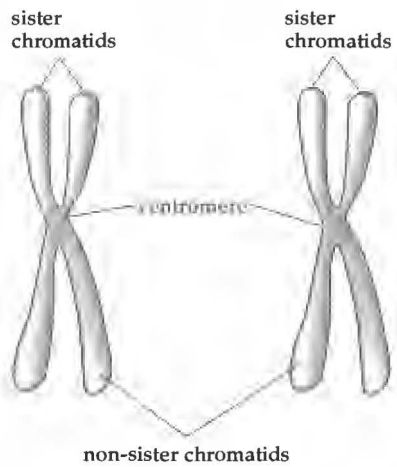


FIGURE 1. Pattern for Meiosis Simulation

6. During synapsis, the **non-sister chromatids** exchange genetic information. This process is called **crossing-over.**

   Simulate crossing-over between **two non-sister chromatids** in your homologous pair (exchange of alleles between **one maternal and one paternal** chromosome).

   Exchange alleles for the **last five traits** (nose size through freckles).

Note:

Exchange alleles ONLY for two NON-SISTER chromatids!

7. Simulate **metaphase I** by placing the chromosomes **in the correct position** relative to the **equator.**

   To simulate **anaphase I,** separate the two homologous chromosomes by moving them to the opposite poles of the cell.

   To simulate the division of the cytoplasm in **telophase I,** draw a dotted line that represents the separated **daughter cells.**

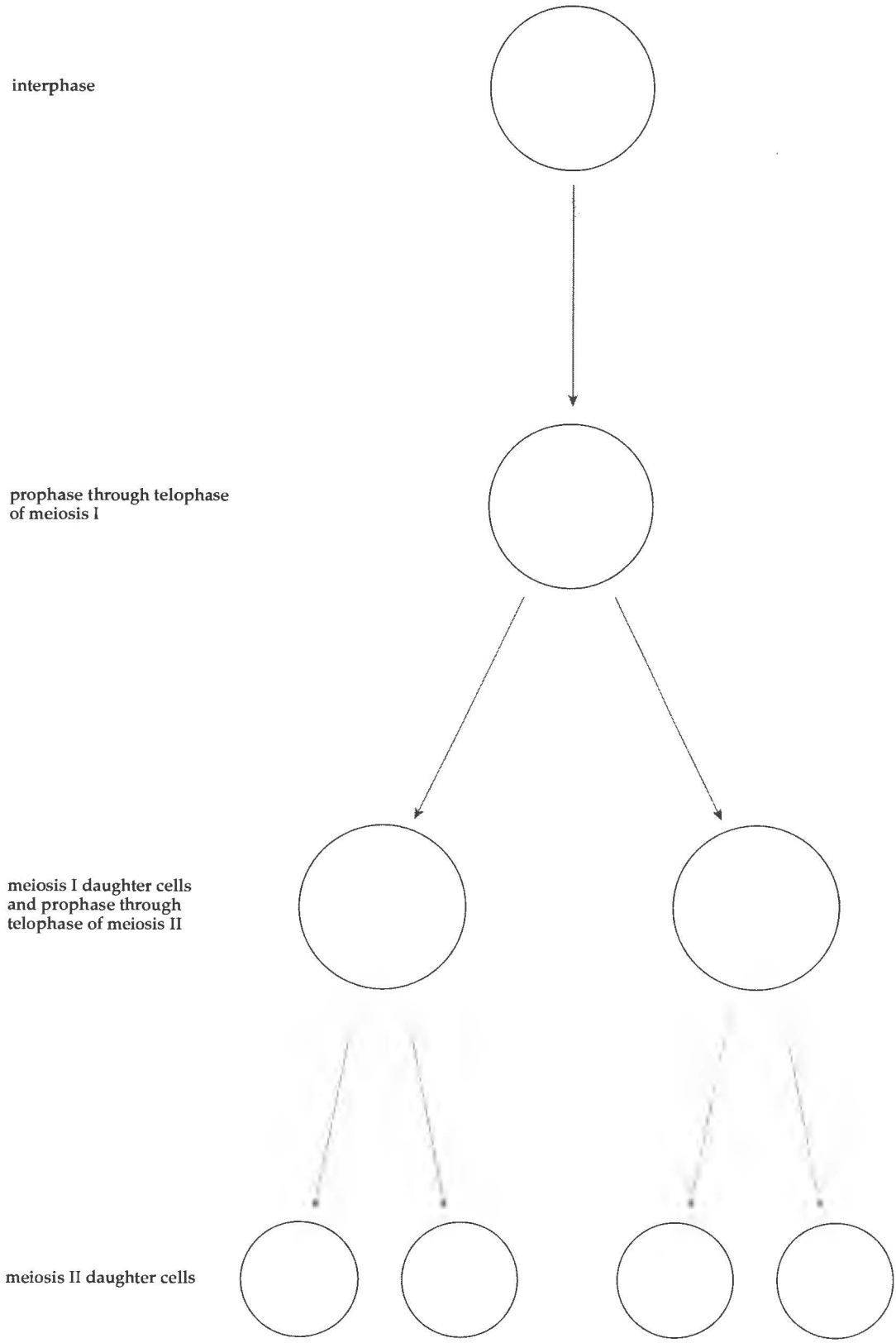


FIGURE 2. Duplicated Homologous Pair (Tetrad)

8. Move your chromosomes to the next two circles that are labeled **meiosis I daughter cells.**

Comprehension Check

1. What is the number of chromosomes in each daughter cell? _____

2. Does this number represent the **diploid** or the **haploid** chromosome number? _____

3. What happened to the **maternal and paternal** chromosomes from the original parent cell?

   Are the two daughter cells genetically identical? _____ **Explain** your answer.

9. Meiosis continues with a second cellular division.

   Simulate meiosis II **without moving your chromosomes** to another set of circles. Note that the circles you're now using have two labels. In **addition** to meiosis I daughter cells, the circles are also labeled **prophase through telophase of meiosis II.**

   Nothing unusual occurs to the chromosomes in prophase II.

   To simulate **metaphase II,** place the chromosomes **in the correct position** relative to the **equator.**

   To simulate **anaphase II,** separate the two **sister chromatids** by moving them to the opposite poles of the cell.

   Move your chromosomes to the four circles that are labeled **meiosis II daughter cells.** Each of these daughter cells has the potential to develop into a sperm or egg.

Check the movement of your chromosomes through meiosis I and II with your instructor before you continue.

Comprehension Check

1. The original parent cell in your meiosis simulation had two alleles for each trait.

   How many alleles for each trait are **now** in each daughter cell? _____

2. Are your daughter cells diploid or haploid? _____

3. Are the four daughter cells **genetically identical?** _____ **Explain** your answer.

4. Where in the body does meiosis occur in **males?** _____

   Where does it occur in **females?** _____

Check your answers with your instructor before you continue.

ACTIVITY 3 FERTILIZATION: NATURE'S EQUIVALENT TO ROLLING THE DICE

1. As you know, **only one sperm and one egg** can participate in fertilization.

   Any of the four sperm can potentially fertilize an egg, but the development of female gametes is slightly different. **Only one** of the four daughter cells will develop into an egg cell. The other three aren't functional and are referred to as **polar bodies.**

   You'll simulate fertilization of your gametes with a roll of the dice. Get a **single six-sided die.**

   Are **your** gametes potential sperm or eggs? _____

2. Choose the gamete that will participate in fertilization as follows:

   a. **Number your daughter cells** 1 through 4.

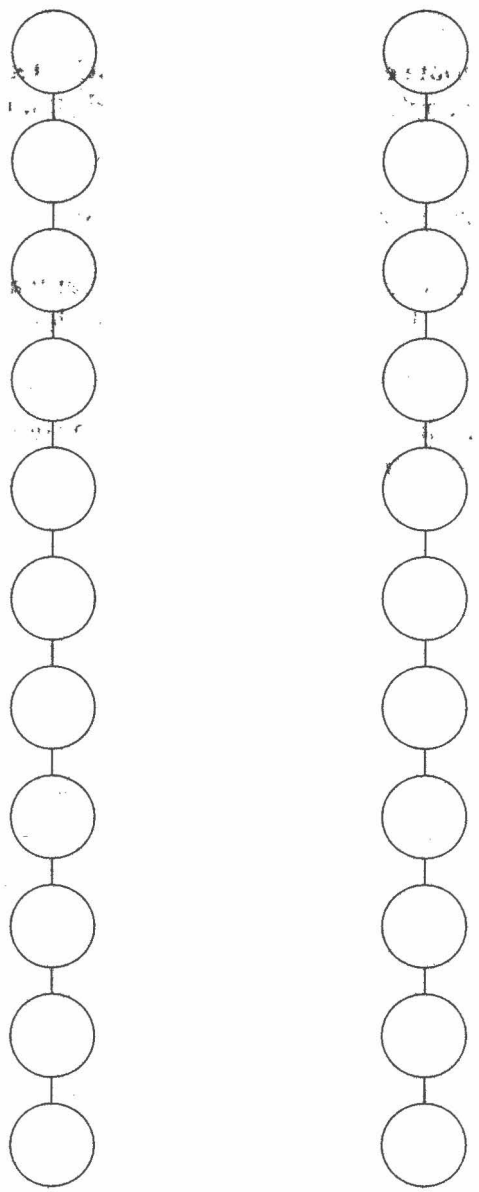
   b. **Roll the die.** If you get a number between 1 and 4, that's your lucky gamete. If you get 5 or 6, roll again.

3. Link up with a group that has produced a gamete of the opposite sex. Take the chromosomes from both gametes and **place them in a circle** labeled **"Fertilized Egg."**

ACTIVITY 4 WHAT'S YOUR BABY'S GENOTYPE?

1. On the two chromosomes in **Figure 3,** list your baby's **alleles in their correct order.**

   Solid beads = dominant alleles. Striped beads = recessive alleles.



Maternal Chromosome Paternal Chromosome

FIGURE 3. Maternal and Paternal Chromosomes of the Fertilized Egg

ACTIVITY 5 GENOTYPE DETERMINES PHENOTYPE

1. Now that you know your baby's **genotype** for each trait, turn back to **Table 1.** In **Table 1, highlight or circle** your baby's **genotype and phenotype** for each trait.

   Now that you know your baby's **phenotype** for each trait, you're ready to see what your baby will look like!

2. Choose the appropriate **face shape outline** to begin your baby (**Figures 4** and **5**).

   Cut out the appropriate **eyes, ears, and other facial features** and use **tape** to attach them to your baby's face **(Figures 6 through 13).** If your baby has freckles, **draw them** in.

   Add the appropriate **eyelashes** to your baby's face.

   Are you pleased with your results? If not, remember that each time a sperm fertilizes an egg you get a different combination of alleles. You may have better luck next time.

3. **Roll the die again** to determine if your baby is a boy or a girl. If you roll **1 through 3,** it's a **girl.** If you roll **4 through 6,** it's a **boy.**

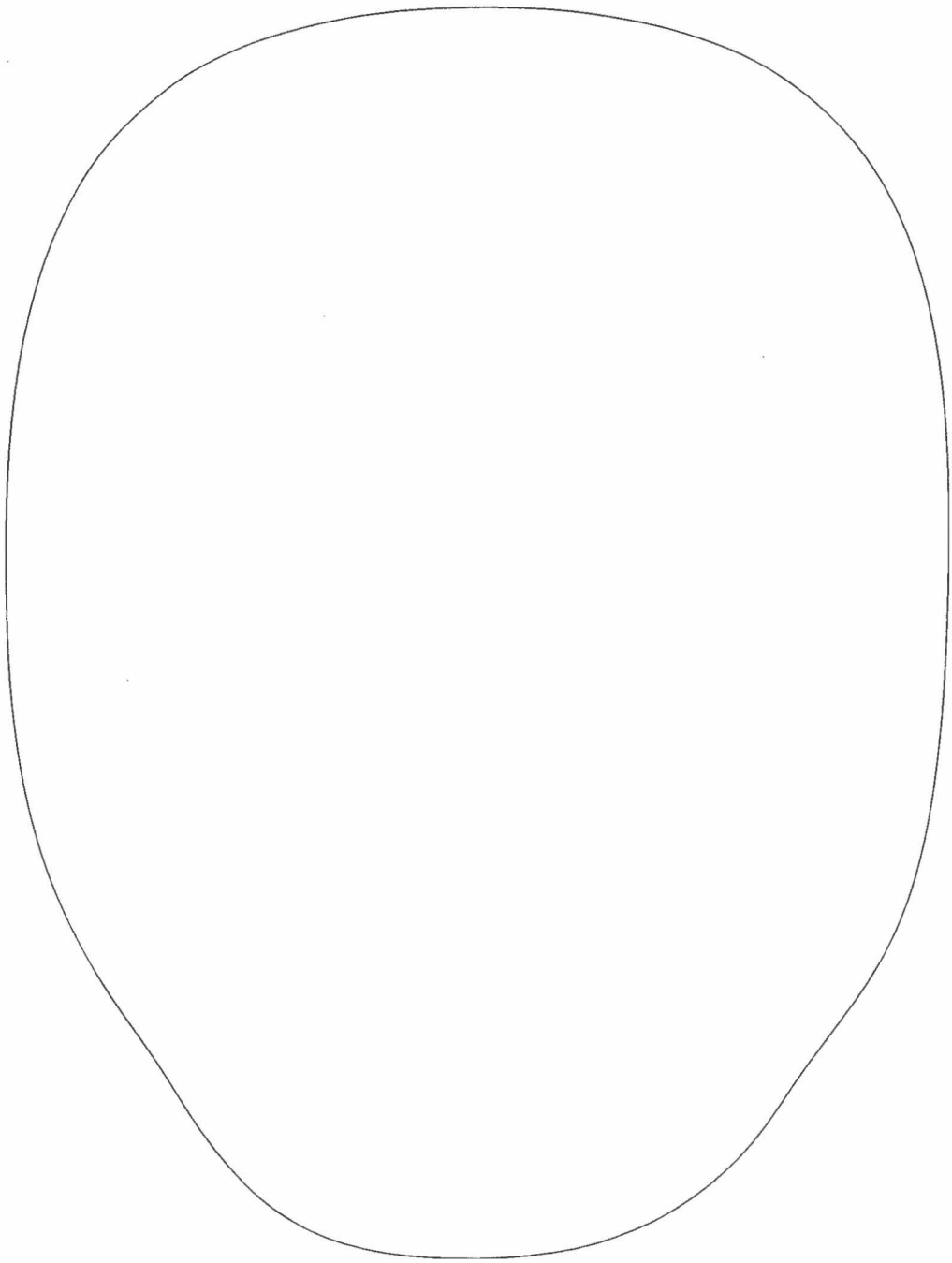


FIGURE 4. Round Face

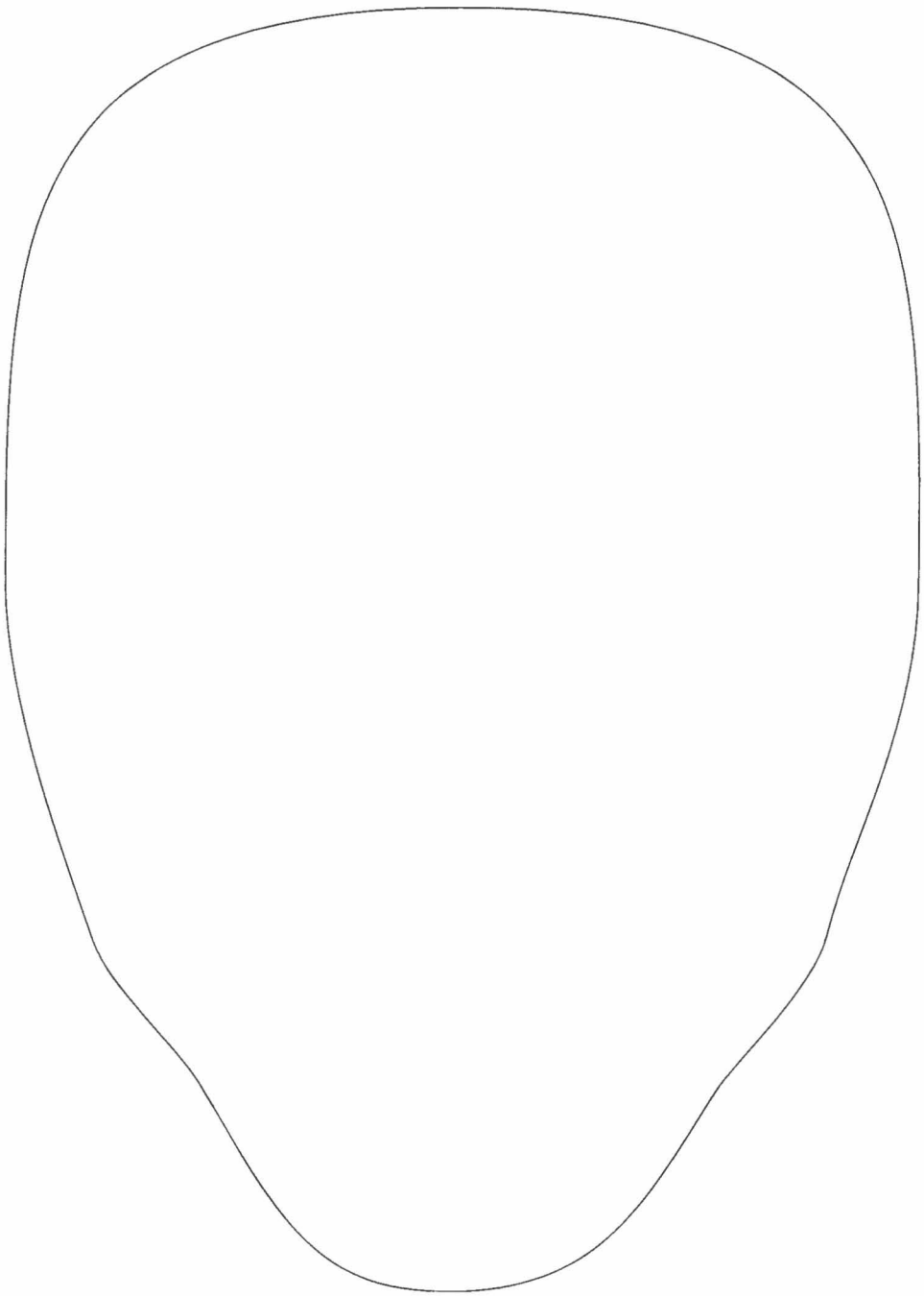


FIGURE 5. Triangular Face

FIGURE 6. Curly Hair

FIGURE 7. Wavy Hair

FIGURE 8. Straight Hair

Large Eyes

Medium Eyes

Small Eyes

FIGURE 9. Eye Types

Thick Eyebrows

Thin Eyebrows

FIGURE 10. Eyebrow Shapes

Thick Lips

Thin Lips

FIGURE 11. Lip Types

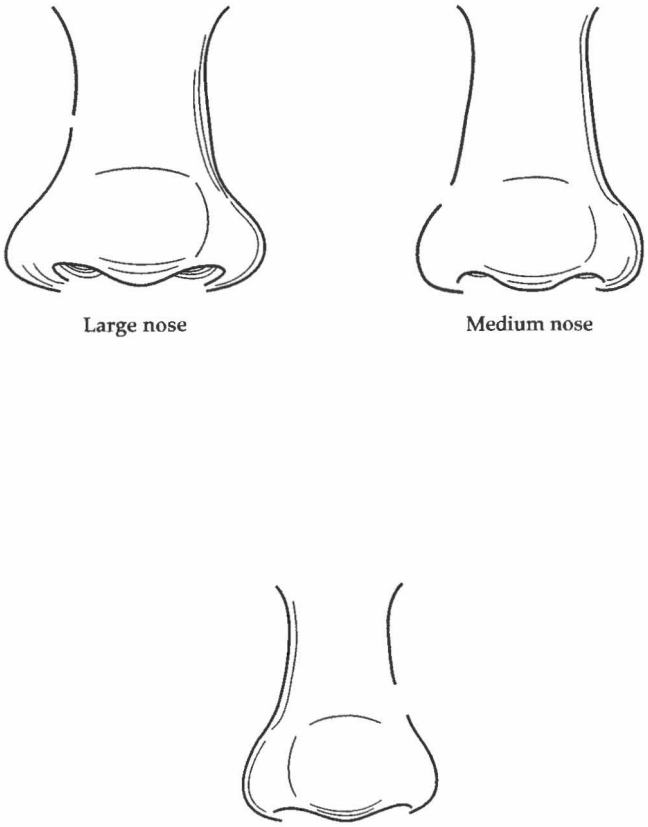


FIGURE 12. Nose Size

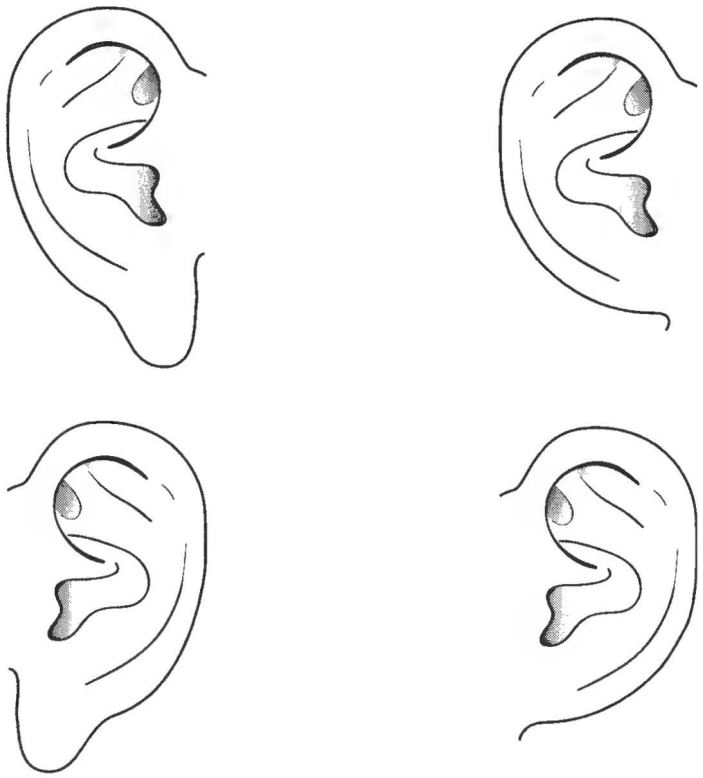


FIGURE 13. Ear Lobes

ACTIVITY 6 PASSING ON TRAITS

Twenty-four years have passed. Your baby is now an adult and has married someone who's **heterozygous for freckles.** What is the probability that they'll have a child with freckles?

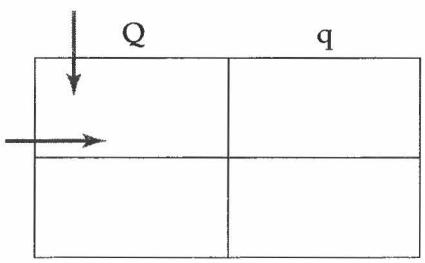
The first step in calculating the probability of freckles is to **determine the alleles carried by the sperm and eggs** of this couple.

As you know, alleles separate in meiosis, so each sperm and each egg has only **one allele from each homologous pair.**

Your child's genotype for the freckle trait _____ _____

1. A **Punnett Square** is a convenient way to visualize the different combinations of alleles that might occur during fertilization.

2. The spouse's alleles have been entered on the top row of the Punnett Square. Enter the alleles for **your child** along the left side of the square.



3. Using the Punnett Square as a guide, fill in the boxes by carrying the alleles down from the top and across (from left to right).

   Each box in the Punnett Square represents a **25% probability** of having a baby with that specific genotype.

   What's the probability that this couple will have a child with freckles? _____

ACTIVITY 7 PRACTICING GENETICS PROBLEMS

1. Nicole Johnson is an **albino,** a condition inherited by a **recessive allele (a).** She's marrying a man with normal skin color, whose father was an albino. Nicole makes an appointment for genetic counseling because she wants to evaluate the risk of passing her condition on to her children. What is the probability that a child from this marriage will be an albino? **Show your work.**

2. In humans, assume that **brown eyes (B) are dominant over blue eyes (b).** A blue-eyed man whose father was brown eyed and whose mother was blue eyed marries a brown-eyed woman whose father had brown eyes and whose mother had blue eyes. What are the genotypes of all the individuals? **Show your work.**

   blue-eyed man _____ brown-eyed woman _____

   his father _____ her father _____

   his mother _____ her mother _____

   What is the probability that this couple will have a blue-eyed child? _____

   What is the probability of a brown-eyed child? _____

3. **Polydactyly** (extra fingers or toes) is inherited by a **dominant allele (F).** A father is polydactyl, the mother has the normal number of fingers, and they have had one normal child. What are the genotypes of all the individuals involved? What is the probability that a second child will have a normal number of fingers? **Show your work.**

   the father _____ the mother _____

   the first child _____

   probability of a child with five fingers _____

4. Assume that the baby you made in **Activity 5** has **wavy hair,** inherited through **incomplete dominance (Hh)** and grows up to marry a person who also has **wavy hair.**

   What is the probability you'll have grandchildren with **straight** hair? _____

   Curly hair? _____

   Wavy hair? _____

   Show your work.

Self-Test

1. Mark each statement below as **true (T) or false (F).**

_____ Sperm cells have the same number of chromosomes as the man that produced them.

_____ A zygote is a fertilized egg.

_____ Crossing-over occurs in both mitosis and meiosis.

_____ Gametes are genetically identical to each other.

_____ The letters AA are used to indicate a heterozygous phenotype.

_____ Sister chromatids are identical before crossing-over occurs.

_____ Sister chromatids are held together by a structure called synapsis.

_____ Daughter cells produced by meiosis are haploid.

_____ When the chromosomes line up during metaphase I of meiosis, the equator separates the maternal and paternal members of each pair.

_____ The daughter cells produced by meiosis have both a maternal and a paternal chromosome from each homologous pair.

2. Can a sperm cell contain maternal chromosomes? **Explain** your answer.

3. Why are chromosomes sometimes drawn as a straight line and other times in an "X" configuration?

4. **Albinism** is a **recessive** condition **(aa)** in which body cells can't manufacture the pigment **melanin,** which colors eyes, hair, and skin. **Normal pigment production is dominant (AA or Aa).** A normally pigmented woman marries a normally pigmented man. To their surprise, they have an albino child. Give the genotypes of the parents and the child:

   the father _____ the mother _____ the child_____

   What is the probability that this couple will have another albino child? _____

   What is the probability that they'll have a normally pigmented child? _____

   Show your work.

5. **Tay-Sachs disease** in humans is controlled by a **recessive allele (t).** This disease is characterized by the inabili ty to produce an enzyme needed to metabolize lipids in brain cells. Without this enzyme, lipids accumulate in the brain cells and gradually destroy the ability of the cells to function. Children affected with this disease usually die by age five.

   What genotypes **must** be found in **both parents** in order to have a child with Tay-Sachs? _____ _____

   Explain your answer and **include a Punnett Square** that shows the possible genotypes among the children of this marriage.

6. Imagine you're a zookeeper in the Big Cat house of the National Zoo in Washington, D.C. Among the tigers, two yellow-coated parents (Ghandi and Sabrina) give birth to a cub named Snowflake that has a rare color variation — a white coat with black stripes.

   Assuming that the **white coat is inherited as a recessive allele (c),** what are the genotypes of the three tigers?

   Ghandi _____ Sabrina _____ Snowflake _____

   If these parents have another cub, what is the probability that the cub will be **heterozygous** for the coat-color trait? **Show your work.**

7. Another zoo wants to start its own tiger exhibit. So far, they have one tiger in their collection, a white one. If the National Zoo sends Ghandi on breeding loan to this zoo, what is the probability that the zoo will get another white tiger for their new exhibit? **Show your work.**

Self-Test Answers

1. False
2. True
3. False
4. False
5. False
6. True
7. False
8. True
9. True
10. False
11. Yes — During meiosis, as chromosomes separate, a mixture of maternal or paternal chromosomes will be present in each of the gametes. Reminder: Maternal chromosomes are those that you (as a man) inherited from your mother and will pass on to your children through your sperm. Those maternal chromosomes present in the sperm will become the paternal chromosomes for your children, because they inherit them from you, their father.
12. When the cell isn't dividing, there's only one copy of each chromosome (drawn as a single line). When a cell prepared for mitosis or meiosis, however, a duplicate forms of each chromosome, giving it the appearance of an X.
13. The father Aa

    The mother Aa

    The child aa

    Probability of an albino child 25%

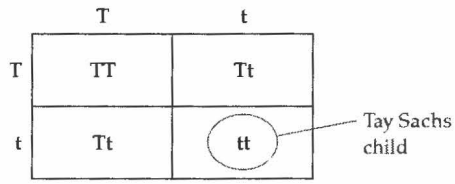
    Probability of normally pigmented child 75%

    Explanation: A child inherits **one** allele from each parent; therefore, each parent must have one little "a."

14. Mother Tt

    Father Tt

    First child tt



Explanation: A child inherits **one** allele from each parent; therefore, each parent must have one little "t." The parents could not, however, be homozygous recessive, since people with Tay-Sachs disease die in early childhood.

15. Ghandi Cc

    Sabrina Cc

    Snowflake cc

    Probability of heterozygous cub 50%

16. Ghandi Cc

    White tiger at zoo cc

    Probability of another white cub 50%