Unit Overview

Unit 4 presents genetics and its role in determining traits of organisms. Chapter 10 introduces genetics through a historical presentation of Gregor Mendel’s work. Meiosis is then introduced. Chapter 11 presents the structure of DNA and replication is explained. Transcription and translation are explained. Various mutations are described. Chapter 12 examines non-Mendelian heredity and the principles of human genetics. Chapter 13 discusses selective breeding, DNA technology, and the Human Genome Project.

Introducing the Unit

Have students look at the picture of the tiger cubs and describe the traits they see. The white tiger is not an albino, or a separate species. It is a tiger with recessive color genes. Unit 4 will discuss how genes determine an organism’s physical traits, as well as how those traits are inherited.

Why It’s Important

Physical traits, such as the stripes of these tigers, are encoded in small segments of a chromosome called genes, which are passed from one generation to the next. By studying the inheritance pattern of a trait through several generations, the probability that future offspring will express that trait can be predicted.

California Standards

The following standards are covered in Unit 4:
- Investigation and Experimentation: 1a, 1d, 1i, 1j, 1k, 1m
- Biology/Life Sciences: 2a, 2b, 2c, 2d, 2e, 3a, 3b, 3c, 3d, 4a, 4b, 4c, 5a, 5b, 5c, 5d, 5e, 7b, 7c

Understanding the Photo

White tigers differ from orange tigers by having ice-blue eyes, a pink nose, and creamy white fur with brown or black stripes. They are not albinos. The only time a white tiger is born is when its parents each carry the white-coloring gene. White tigers are very rare, and today, they are only seen in zoos.

Discussion

As students read Unit 4, have them refer to the above time line. Ask students to infer how Mendel’s discovery of the rules of inheritance (1865) led to the conclusion that DNA is the genetic material (1952) and how both events led to the Human Genome Project (1990s). Have student groups research and discuss future uses of the human genome map.
The following materials may need to be ordered a few weeks in advance of the planned activity.

**Chapter 10**
- **MiniLab** (p. 254) microscope slide and coverslip, microscope
- **Project** (p. 257) *Brassica rapa* seeds
- **MiniLab** (p. 268) clay
- **BioLab** (p. 274) small flowerpots or seedling flats

**Chapter 11**
- **Additional Lab** (p. 282) 3-ply yarn
- **Quick Demo** (p. 285) zipper
- **Quick Demo** (p. 298) coiled telephone cord

**Chapter 12**
- **Additional Lab** (p. 316) heterozygous tobacco seeds
- **Project** (p. 321) mustard seeds
- **Additional Lab** (p. 324) prepared slides of male and female cheek cells
- **BioLab** (p. 330) *Brassica rapa* seeds—normal and variegated

**Chapter 13**
- **MiniLab** (p. 350) Random page from a novel
- **Additional Lab** (p. 350) prepared slide of cheek cells, human hair (blond and dark)
- **Quick Demo** (p. 351) human chromosome map

**Using the Library**

**Intrapersonal** Research one disease in which gene therapy is an experimental therapeutic approach such as cancer, hemophilia, Alzheimer’s disease, and sickle cell anemia.

**Interview**

**Linguistic** Interview someone with a family pedigree that demonstrates an inherited disease such as Huntington’s disease, hemophilia, and Tay-Sachs disease.

**Final Report**

Have student groups present their findings about genetics in reports that could be presented to students at your local middle school.
### Section Objectives

#### Section 10.1
2 sessions, 2 blocks

1. **Relate** Mendel’s two laws to the results he obtained in his experiments with garden peas.
2. **Predict** the possible offspring of a genetic cross by using a Punnett square.

#### Section 10.2
3 sessions, 2 blocks

3. **Analyze** how meiosis maintains a constant number of chromosomes within a species.
4. **Infer** how meiosis leads to variation in a species.
5. **Relate** Mendel’s laws of heredity to the events of meiosis.

### National Science Standards

<table>
<thead>
<tr>
<th>UCP.1–3</th>
<th>UCP.5</th>
<th>A.1, A.2</th>
<th>G.1–3</th>
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### State/Local Standards

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<th>Biology/Life Sciences</th>
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### Advanced Lab and Demo Planning

#### Student Labs:
- **MiniLab 10.1,** p. 254: flower, water, glass slide, coverslip, pencil with eraser, microscope
- **Problem-Solving Lab 10.1,** p. 262

#### Teacher Demonstration:
- **Quick Demo,** p. 259: 300 black beans, 100 white beans, small cup or bag

#### Additional Lab, p. 266:
- long length of yarn, paper clips, long length of string, toothpicks, tape or glue, scissors
- **MiniLab 10.2,** p. 268: clay
- **Internet BioLab,** p. 274: See materials below.

#### Teacher Demonstration:
- **Quick Demo,** p. 266

#### Student Lab:
- **Internet BioLab,** p. 274: potting soil, small flowerpots or seedling flats, two groups of tobacco seeds, hand lens, light source, thermometer, plant-watering bottle

### Key to Teaching Strategies

- **L1** Level 1 activities should be appropriate for students with learning difficulties.
- **L2** Level 2 activities should be within the ability range of all students.
- **L3** Level 3 activities are designed for above-average students.
- **ELL** ELL activities should be within the ability range of English Language Learners.

**COOP LEARN** Cooperative Learning activities are designed for small group work.
### Reproducible Masters and Transparencies

**Unit 4 FAST FILE Resources**
- MiniLab Worksheet, p. 3
- BioLab Worksheet, pp. 5–6
- Real World BioApplications, pp. 7–8
- Reinforcement and Study Guide in English, pp. 9–10
- Reinforcement and Study Guide in Spanish, pp. 13–14
- Critical Thinking/Problem Solving, p. 18
- Transparency Worksheets, pp. 19, 21–22, 25–26

**Reading Essentials for Biology, Section 10.1**
- Section Focus Transparency 24
- Basic Concepts Transparency 14
- Reteaching Skills Transparency 16

### Technology

**Interactive Chalkboard CD-ROM: Section 10.1 Presentation**
- **TeacherWorks™ CD-ROM**

**Guided Reading Audio Summaries MP3**
- Virtual Labs CD-ROM
  - Virtual Lab: Punnett Squares

**Interactive Chalkboard CD-ROM: Section 10.2 Presentation**
- **TeacherWorks™ CD-ROM**

**Guided Reading Audio Summaries MP3**

**Interactive Chalkboard:** Chapter 10 Assessment
- MindJogger Videoquizzes DVD/VHS
- ExamView® Pro Test Bank CD-ROM
- **TeacherWorks™ CD-ROM**
- Succeeding on National Standards CD-ROM

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**Legend**
- Transparency
- CD-ROM
- MP3
- Videocassette
- DVD

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**Indicates materials created specifically for California.**
Short on Time?

The BioDigest at the end of this unit can be used as a(n):
• preview to introduce important unit concepts.
• overview if time does not permit teaching the entire chapter.
• review of key unit concepts.

Understanding the Photo
A zebra’s stripes are thought to be an adaptation that helps them avoid predators. Zebras recognize each other by their stripes. Their stripes are like fingerprints—they are passed on genetically, and every zebra’s stripe pattern is different.

What You’ll Learn
- You will identify the basic concepts of genetics.
- You will examine the process of meiosis.

Why It’s Important
Genetics explains why you have inherited certain traits from your parents. If you understand how meiosis occurs, you can see how these traits were passed on to you.

Understanding the Photo
Zebras usually travel in large groups, and each zebra’s stripes blend in with the stripes of the zebras around it. This confuses predators. Rather than seeing individual zebras, predators see a large, striped mass. Zebra stripe patterns are like human fingerprints—they are genetically determined, and every zebra’s stripe pattern is unique.

Demo
Show students wrinkled and smooth pea seeds. Have them compare and contrast the physical traits of the pea seeds. Encourage them to speculate about less obvious traits such as biochemical or physiological characteristics. The wrinkled nature of the seeds is due to a lack of well-formed starch grains and lower water retention.
Mendel’s Laws of Heredity

Mendel’s Laws of Heredity

Why Mendel Succeeded

People have noticed for thousands of years that family resemblances are inherited from generation to generation. However, it was not until the mid-nineteenth century that Gregor Mendel, an Austrian monk, carried out important studies of heredity—the passing on of characteristics from parents to offspring. Characteristics that are inherited are called traits.

Mendel chose his subject carefully

Mendel chose to use the garden pea in his experiments for several reasons. Garden pea plants reproduce sexually, which means that they produce male and female sex cells, called gametes. The male gamete forms in the pollen grain, which is produced in the male reproductive organ. The female gamete forms in the female reproductive organ. In a process called fertilization, the male gamete unites with the female gamete. The resulting fertilized cell, called a zygote (ZI goht), then develops into a seed.

10.1 MENDEL’S LAWS OF HEREDITY 253
In his experiments, Mendel often had to transfer pollen from one plant to another plant with different traits. This is called making a cross. Describe How did Mendel make a cross?

The transfer of pollen grains from a male reproductive organ to a female reproductive organ in a plant is called pollination. In peas, both organs are located in the same flower and are tightly enclosed by petals. This prevents pollen from other flowers from entering the pea flower. As a result, peas normally reproduce by self-pollination; that is, the male and female gametes come from the same plant. In many of Mendel’s experiments, this is exactly what he wanted. When he wanted to breed, or cross, one plant with another, Mendel opened the petals of a flower and removed the male organs, as shown in Figure 10.1A. He then dusted the female organ with pollen from the plant he wished to cross it with, as shown in Figure 10.1B. This process is called cross-pollination. By using this technique, Mendel could be sure of the parents in his cross.

Mendel was a careful researcher

Mendel carefully controlled his experiments and the peas he used. He studied only one trait at a time to control variables, and he analyzed his data mathematically. The tall pea plants he worked with were from populations of plants that had been tall for many generations and had always produced tall offspring. Such plants are said to be true breeding for tallness. Likewise, the short plants he worked with were true breeding for shortness.
Mendel’s Monohybrid Crosses

What did Mendel do with the tall and short pea plants he selected? He crossed them to produce new plants. Mendel referred to the offspring of this cross as hybrids. A hybrid is the offspring of parents that have different forms of a trait, such as tall and short height. Mendel’s first experiments are called monohybrid crosses because mono means “one” and the two parent plants differed from each other by a single trait—height.

The first generation

Mendel selected a six-foot-tall pea plant that came from a population of pea plants, all of which were over six feet tall. He cross-pollinated this tall pea plant with pollen from a short pea plant that was less than two feet tall and which came from a population of pea plants that were all short. When he planted the seeds from this cross, he found that all of the offspring grew to be as tall as the taller parent. In this first generation, it was as if the shorter parent had never existed.

The second generation

Next, Mendel allowed the tall plants in this first generation to self-pollinate. After the seeds formed, he planted them and counted more than 1000 plants in this second generation. Mendel found that three-fourths of the offspring were tall and one-fourth were short. He also found that one-fourth of the offspring were as short as the short plants in the parent generation. In other words, in the second generation, tall and short plants occurred in a ratio of about three tall plants to one short plant, as shown in Figure 10.2. The short trait had reappeared as if from nowhere.

The original parents, the true-breeding plants, are known as the P₁ generation. The P stands for “parent.” The offspring of the parent plants are known as the F₁ generation. The F stands for “filial”—son or daughter. When you cross two F₁ plants with each other, their offspring are the F₂ generation—the second filial generation. You might find it easier to understand these terms if you:

Figure 10.2

When Mendel crossed true-breeding tall pea plants with true-breeding short pea plants, all the offspring were tall. When he allowed first-generation tall plants to self-pollinate, three-fourths of the offspring were tall and one-fourth were short.

Enrichment

Linguistic Some researchers have doubted Mendel’s honesty, despite the accuracy of his conclusions. One claim is that Mendel deliberately excluded data from traits that do not independently assort because he had only one chance in 6000 of randomly selecting one gene on each of seven chromosomes. Another claim is that Mendel fabricated some of his data in order to make them fit expected ratios.

Countering these claims are other analyses of Mendel’s data that concluded he actually had a one in three chance of choosing only traits that independently assort, and a suggestion that Mendel intended to present something like a demonstration rather than an exact experiment. Have interested students research this topic and draw their own conclusions in a report for their portfolios.

Inclusion Strategies

Visually Impaired: Kinesthetic Obtain a large flower model. Allow those students who are visually impaired to handle the model. Direct their attention to the stamen and pistil. Then, have students examine an actual flower after having studied the model.

Mendel For those students needing an additional challenge, have them draw a concept map of Mendel’s monohybrid cross through the second generation. They should include which traits were dominant and which were recessive. Post well organized concept maps around the classroom.

California Content Standards

Pages 254–255: Biology/Life Sciences 2c
look at your own family. Your parents are the P1 generation. You are the F1 generation, and any children you might have in the future would be the F2 generation.

Mendel did similar monohybrid crosses with a total of seven pairs of traits, studying one pair of traits at a time. These pairs of traits are shown in Figure 10.3. In every case, he found that one trait of a pair seemed to disappear in the F1 generation, only to reappear unchanged in one-fourth of the F2 plants.

The rule of unit factors
Mendel concluded that each organism has two factors that control each of its traits. We now know that these factors are genes and that they are located on chromosomes. Genes exist in alternative forms. We call these different gene forms alleles (uh LEELZ). For example, each of Mendel’s pea plants had two alleles of the gene that determined its height. A plant could have two alleles for tallness, two alleles for shortness, or one allele for tallness and one for shortness. An organism’s two alleles are located on different copies of a chromosome—one inherited from the female parent and one from the male parent.

The rule of dominance
Remember what happened when Mendel crossed a tall P1 plant with a short P1 plant? The F1 offspring were all tall. In other words, only one trait was observed. In such crosses, Mendel called the observed trait dominant and the trait that disappeared recessive. Mendel concluded that the allele for tall plants is dominant to the allele for short plants. Thus, plants that had one allele for tallness and one for shortness were tall.

Almost all students think that the dominant trait must be most common or desirable. However, the dominant trait is merely one that masks an alternate allele that may be present in the heterozygous condition.

Uncover the Misconception
Ask students to give examples of dominant traits. When a student names a recessive trait that is really dominant, point out the error.

Demonstrate the Concept
Explain that Huntington’s disease, polydactyly, and hypercholesterolemia (having dangerously high levels of blood cholesterol) are three dominant traits inherited in humans, although all three traits are very rare.

Assess New Knowledge
Have students state the definition of dominance. Ask them to state how it is possible for a dominant trait to rarely appear. The number of recessive alleles in the gene pool for a particular trait may be far greater than the number of dominant alleles in the pool.

Rules of Heredity
For students needing an additional challenge, have them work in groups and imagine that they are Gregor Mendel and that they have just formulated the principles of dominance and segregation. Have them work together to write an illustrated article describing their findings for a local newspaper. They should remember that the year is 1863. See BioChallenges and Enrichment for additional projects and activities.
Expressed another way, the allele for short plants is recessive to the allele for tall plants. Pea plants with two alleles for tallness were tall, and those with two alleles for shortness were short. You can see in Figure 10.4 how the rule of dominance explained the resulting F₁ generation.

When recording the results of crosses, it is customary to use the same letter for different alleles of the same gene. An uppercase letter is used for the dominant allele and a lowercase letter for the recessive allele. The dominant allele is always written first. Thus, the allele for tallness is written as \( T \) and the allele for shortness as \( t \), as it is in Figure 10.4.

**The law of segregation**

Now recall the results of Mendel’s cross between F₁ tall plants, when the trait of shortness reappeared. To explain this result, Mendel formulated the first of his two laws of heredity. He concluded that each tall plant in the F₁ generation carried one dominant allele for tallness and one unexpressed recessive allele for shortness. Each plant received the allele for tallness from its tall parent and the allele for shortness from its short parent in the P₁ generation. Because each F₁ plant has two different alleles, it can produce two types of gametes—“tall” gametes and “short” gametes. This conclusion, illustrated in Figure 10.5 on the next page, is called the **law of segregation**. The law of segregation states that every individual has two alleles of each gene and when gametes are produced, each gamete receives one of these alleles. During fertilization, these gametes randomly pair to produce four combinations of alleles.

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**Experimental Crosses** Rapid-cycling *Brassica rapa* plants complete their life cycle in 30 to 40 days. They are ideal for use in the classroom because within this short time, the plants flower and form seeds for the next generation. Genetic studies can be carried out using different traits, such as petal-less flowers or hairy stems. Students will find it easy to carry out the pollinating between plants. These plants are an ideal experimental organism for genetic studies.

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**Visual Learning**

Figure 10.4 Have students write out the three important written conventions that are described with this diagram. Use the same letter for different alleles of the same gene; use uppercase letters for dominant alleles and lowercase letters for recessive alleles; and always write the dominant allele first.

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**Reading Check** The rule of unit factors says that there are two different factors that control each trait. The rule of dominance explains that one of the two factors (dominant allele) governs a trait and the alternate form of the trait (recessive) is only present if the dominant factor is not present.

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**California Content Standards**

Pages 256–257: Biology/Life Sciences 2c, 2g, 3a, 3b
Inv. & Exp. 1k
Phenotypes and Genotypes

Mendel showed that tall plants are not all the same. Some tall plants, when crossed with each other, yielded only tall offspring. These were Mendel’s original P1 true-breeding tall plants. Other tall plants, when crossed with each other, yielded both tall and short offspring. These were the F1 tall plants in Figure 10.5 that came from a cross between a tall plant and a short plant.

Two organisms, therefore, can look alike but have different underlying allele combinations. The way an organism looks and behaves is called its phenotype. The phenotype of a tall plant is tall, whether it is TT or Tt. The allele combination an organism contains is known as its genotype. The genotype of a tall plant that has two alleles for tallness is TT. The genotype of a tall plant that has one allele for tallness and one allele for shortness is Tt. You can see that an organism’s genotype can’t always be known by its phenotype.

An organism is homozygous (hoh moh ZI gus) for a trait if its two alleles for the trait are the same. The true-breeding tall plant that had two alleles for tallness (TT) would be homozygous for the trait of height. Because tallness is dominant, a TT individual is homozygous dominant for that trait. A short plant would always have two alleles for shortness (tt). It would, therefore, always be homozygous recessive for the trait of height.

Using Science Terms

It is sometimes easier for students to remember the meaning of the term genotype by reversing the word so it becomes “type of gene.” When stated this way, students can associate the term genotype with its definition. Pheno means “to show.” Thus, the phenotype shows the type of trait or how it appears.

Concept Development

- Ask students to supply the correct term—genotype or phenotype—to the following examples: (a) LL, (b) blond hair, (c) dimpled chin, (d) blue eyes, (e) Dd, (f) ss, (g) white and green leaves. a, e, and f are genotypes; b, c, d, and g are phenotypes.
- Have students provide the following information for this example: G = green pea pod, g = yellow pea pod. (a) Give the phenotypes of plants with these genotypes: Gg, GG, and gg. (b) Use the terms homozygous or heterozygous to describe each of the three examples above. (a) green, green, yellow; (b) heterozygous, homozygous, homozygous.

Word Origin

Phenotype from the Greek words phainein, meaning “to show,” and typos, meaning “model.” The visible characteristics of an organism make up its phenotype.

Genotype from the Greek words gen or geno, meaning “race,” and typos, meaning “model.” The allele combination of an organism makes up its genotype.

Have the students research to find and define other words with “homo” as part of the root, such as homogenous and homologous.

Phenotypes and Genotypes

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Selective Breeding: Kinesthetic

Selective breeding of plants is crucial to agriculture. Students can try this for themselves by using fast-growing plants and selecting for a desired trait. During this activity, students will have to plant and care for their plants as well as perform the cross-pollinations.
Mendel’s Dihybrid Crosses

Mendel performed another set of crosses in which he used peas that differed from each other in two traits rather than only one. Such a cross involving two different traits is called a dihybrid cross because di means “two.” In a dihybrid cross, will the two traits stay together in the next generation or will they be inherited independently of each other?

The first generation

Mendel took true-breeding pea plants that had round yellow seeds (RRYY) and crossed them with true-breeding pea plants that had wrinkled green seeds (rryy). He already knew that when he crossed plants that produced round seeds with plants that produced wrinkled seeds, all the plants in the F1 generation produced seeds that were round. In other words, just as tall plants were dominant to short plants, the round-seeded trait was dominant to the wrinkled-seeded trait. Similarly, when he crossed plants that produced yellow seeds with plants that produced green seeds, all the plants in the F1 generation produced yellow seeds—yellow was dominant. Therefore, Mendel was not surprised when he found that the F1 plants of his dihybrid cross all had the two dominant traits of round and yellow seeds, as Figure 10.6 shows.

The second generation

Mendel then let the F1 plants pollinate themselves. As you might expect, he found some plants that produced round yellow seeds and others that produced wrinkled green seeds. But that’s not all. He also found some plants with round green seeds and others with wrinkled yellow seeds. When Mendel sorted and counted the plants of the F2 generation, he found they appeared in a definite ratio of phenotypes—9 round yellow: 3 round green: 3 wrinkled yellow: 1 wrinkled green. To explain the results of this dihybrid cross, Mendel formulated his second law.

Word Origin

heterozygous from the Greek words heteros, meaning “other,” and zygotos, meaning “joined together”; A trait is heterozygous when an individual has two different alleles for that trait.

DIHYBRID CROSS ROUND YELLOW X WRINKLED GREEN

P1 Round yellow × wrinkled green

F1 All round yellow

F2 9 Round yellow 3 Round green 3 Wrinkled yellow 1 Wrinkled green

Figure 10.6

When Mendel crossed true-breeding plants that produced round yellow seeds with true-breeding plants that produced wrinkled green seeds, the seeds of all the offspring were round and yellow. When the F1 plants were allowed to self-pollinate, they produced four different kinds of plants in the F2 generation.
Concept Development

Logical-Mathematical

Have students construct Punnett squares and solve these problems, giving the genotypic and phenotypic ratios expected. (a) Homozygous tall plant bred to a homozygous short plant. All offspring will be tall and heterozygous. (b) Homozygous tall plant bred to a heterozygous tall plant. All offspring will be tall, half being TT and half being Tt. (c) Heterozygous tall plant bred to a homozygous short plant. Half will be tall and half will be short; all tall offspring will be Tt and all short offspring will be tt.

Virtual Lab

CD-ROM Students will predict the traits of offspring in Punnett Square.

Biology Journal

Punnett Square

Have students construct a Punnett square to illustrate the probable bean parents from the Quick Demo on the previous page. Ask students to write a prediction of what the outcome would be if two white beans were crossed.

Caption Question Answer

Figure 10.7 Two

The law of independent assortment

Mendel’s second law states that genes for different traits—for example, seed shape and seed color—are inherited independently of each other. This conclusion is known as the law of independent assortment. When a pea plant with the genotype RrYy produces gametes, the alleles R and r will separate from each other (the law of segregation) as well as from the alleles Y and y (the law of independent assortment), and vice versa. These alleles can then recombine in four different ways. If the alleles for seed shape and color were inherited together, only two kinds of pea seeds would have been produced: round yellow and wrinkled green.

Punnett Squares

In 1905, Reginald Punnett, an English biologist, devised a shorthand way of finding the expected proportions of possible genotypes in the offspring of a cross. This method is called a Punnett square. It takes account of the fact that fertilization occurs at random, as Mendel’s law of segregation states. If you know the genotypes of the parents, you can use a Punnett square to predict the possible genotypes of their offspring.

Monohybrid crosses

Consider the cross between two F₁ tall pea plants, each of which has the genotype Tt. Half the gametes of each parent would contain the T allele, and the other half would contain the t allele. A Punnett square for this cross is two boxes tall and two boxes wide because each parent can produce two kinds of gametes for this trait. The two kinds of gametes from one parent are listed on top of the square, and the two kinds of gametes from the other parent are listed on the left side, as Figure 10.7A shows. It doesn’t matter which set of gametes is on top and which is on the side, that is, which parent contributes the T allele and which contributes the t allele. Refer to the Punnett square in Figure 10.7B to determine the possible genotypes of the offspring. Each box is filled in with the gametes above and to the left side of that box. You can see that each box then contains two alleles—one possible genotype.

Using Models

Candy Genes

Provide students with two large and two small round pieces of candy plus two large and two small buttons. Advise them that the buttons and candy represent two different genes and the large-sized objects represent dominant alleles. Ask them to prepare two sets of objects (alleles) for two traits in two parents, making both parents heterozygous for both traits. Then have students arrange their parental gene sets into independently assorted gametes of two alleles each. Advise them that they cannot have two candies or two buttons in their final groups. Have them explain how this illustrates the law of independent assortment.

California Content Standards

Pages 260–261:
Biology/Life Sciences 2c, 2g, 3a, 3b
After the genotypes have been determined, you can determine the phenotypes. Looking again at the Punnett square in Figure 10.7B, you can see that three-fourths of the offspring are expected to be tall because they have at least one dominant allele. One-fourth are expected to be short because they lack a dominant allele. Of the tall offspring, one-third will be homozygous dominant (TT) and two-thirds will be heterozygous (Tt). Note that whereas the genotype ratio is 1TT:2Tt:1tt, the phenotype ratio is 3 tall:1 short. You can practice doing calculations such as Mendel did in the Connection to Math at the end of this chapter.

**Dihybrid crosses**

What happens in a Punnett square when two traits are considered? Think again about Mendel’s cross between pea plants producing round yellow seeds and plants producing wrinkled green seeds. All the F1 plants produced seeds that were round and yellow and were heterozygous for each trait (RrYy). What kind of gametes will these F1 plants form?

Mendel explained that the traits for seed shape and seed color would be inherited independently of each other. This means that each F1 plant will produce gametes containing the following combinations of genes with equal frequency: round yellow (RY), round green (Ry), wrinkled yellow (rY), and wrinkled green (ry). A Punnett square for a dihybrid cross will then need to be four boxes on each side for a total of 16 boxes, as Figure 10.8 shows.

**Probability**

Punnett squares are good for showing all the possible combinations of gametes and the likelihood that each will occur. In reality, however, you don’t get the exact ratio of results shown in the square. That’s because, in some ways, genetics is like flipping a coin—it follows the rules of chance.

When you toss a coin, it lands either heads up or tails up. The probability or chance that an event will occur can be determined by dividing the number of desired outcomes by the total number of possible outcomes. Therefore, the probability of getting heads when you toss a coin would be one in two chances, written as 1⁄2 or 1/2. A Punnett square can be used to determine the probability of getting a pea plant that produces round seeds when two plants that are heterozygous (Rr) are crossed.

**Visual Learning**

Figure 10.8 Ask students how many different genotypes and phenotypes resulted from this cross. 9 genotypes and 4 phenotypes

**3 Assess**

**Check for Understanding**

Have students describe the relationship between or among the following terms. 

- a. pollination—fertilization
- b. allele—dominant—recessive
- c. genotype—phenotype
- d. homozygous—heterozygous
- e. monohybrid—dihybrid

**Reteach**

Have students provide an example of each relationship provided in Check for Understanding.

**Resources**

For more practice, use Reading Essentials for Biology, Section 10.1.

**Extension**

Have students list the genotypes and phenotypes resulting from (a) an RrYy plant cross-pollinated by an RRyy plant; (b) an rrYY plant cross-pollinated by a RrYy plant. 

(a) genotypes: RrYy, RRyy, RRyy, Rryy; phenotypes: 1/2 round yellow, 1/2 round green; (b) genotypes: RrYY, RrYy, Rryy, rrYY, rrYy, rryy; phenotypes: 3 round yellow; 3 wrinkled yellow; 1 round green; 1 wrinkled green

**Knowledge**

Have students explain what each of the following represents in a Punnett square: (a) the letters written at the top and side of the square; (b) the letters written within each box; (c) the boxes. (a) gametes; (b) genotype of an offspring; (c) possible offspring
**Problem-Solving Lab 10.1**

**Purpose**
Students will convert and express two sets of related numbers as a ratio.

**Background**
The round seeds contain an abundance of well-formed starch grains and have higher water retention than the wrinkled seeds. A lack of well-formed starch grains and lower water retention account for the wrinkled appearance.

**Process Skills**
Use and interpret data, calculate ratios.

**Teaching Strategies**
- Have students work in groups. Place students with poor math skills with students working at grade level.
- Provide students with an example if they are having difficulty in determining a ratio.

**Thinking Critically**
1. The observed ratio is slightly lower than expected.
2. The observed and expected ratios may differ slightly due to chance.

**Assessment**
- **Skill** Provide students with other examples of traits and data. Have them calculate ratios. Use the Performance Task Assessment List for Using Math in Science in PASC, p. 101.

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**Analyze Information**

**Data Analysis** In addition to crossing tall and short pea plants, Mendel crossed plants that formed round seeds with plants that formed wrinkled seeds. He found a 3:1 ratio of round-seeded plants to wrinkled-seeded plants in the F2 generation.

**Solve the Problem**
Mendel's F2 results are shown to the right.

<table>
<thead>
<tr>
<th>Kind of Plant</th>
<th>Number of Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round-seeded</td>
<td>5474</td>
</tr>
<tr>
<td>Wrinkled-seeded</td>
<td>1850</td>
</tr>
</tbody>
</table>

1. Calculate the actual ratio of round-seeded plants to wrinkled-seeded plants by dividing the number of round-seeded plants by the number of wrinkled-seeded plants. Your answer tells you how many more times round-seeded plants resulted than wrinkled-seeded plants.
2. To express your answer as a ratio, write the number from step 1 followed by a colon and the numeral 1.

**Thinking Critically**
1. Compare How does Mendel's observed ratio compare with the expected 3:1 ratio?
2. Analyze Why did the actual and expected ratios differ?

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**Understanding Main Ideas**
1. What structural features of pea plant flowers made them suitable for Mendel's genetic studies?
2. What are the genotypes of a homozygous and a heterozygous tall pea plant?
3. One parent is homozygous tall and the other is heterozygous. Make a Punnett square to show how many offspring will be heterozygous.
4. How many different gametes can an RRYy parent form? What are they?
5. In garden peas, the allele for yellow peas is dominant to the allele for green peas. Suppose you have a plant that produces yellow peas, but you don't know whether it is homozygous dominant or heterozygous. What experiment could you do to find out? Draw Punnett squares to help you.

**6. Observe and Infer**
The offspring of a cross between a plant with purple flowers and a plant with white flowers are 23 plants with purple flowers and 26 plants with white flowers. Use the letter P for purple and p for white. What are the genotypes of the parent plants? Explain your reasoning. For more help, refer to Observe and Infer in the Skill Handbook.
Meiosis

Solving the Puzzle

Using an Analogy

Mendel's study of inheritance was based on careful observations of pea plants, but pieces of the hereditary puzzle were still missing. Modern technologies such as high-power microscopes allow us a glimpse of things that Mendel could only imagine. Chromosomes, such as those shown here, were the missing pieces of the puzzle because they carry the traits that Mendel described. The key to solving the puzzle was discovering the process by which these traits are transmitted to the next generation.

Genes, Chromosomes, and Numbers

Organisms have tens of thousands of genes that determine individual traits. Genes do not exist free in the nucleus of a cell; they are lined up on chromosomes. Typically, a chromosome can contain a thousand or more genes along its length.

Diploid and haploid cells

If you examined the nucleus in a cell of one of Mendel's pea plants, you would find it had 14 chromosomes—seven pairs. In the body cells of animals and most plants, chromosomes occur in pairs. One chromosome in each pair came from the male parent, and the other came from the female parent. A cell with two of each kind of chromosome is called a diploid cell and is said to contain a diploid, or \(2n\), number of chromosomes. This pairing supports Mendel's conclusion that organisms have two factors—alleles—for each trait. One allele is located on each of the paired chromosomes.

Organisms produce gametes that contain one of each kind of chromosome. A cell containing one of each kind of chromosome is called a haploid cell and is said to contain a haploid, or \(n\), number of chromosomes.
This fact supports Mendel’s conclusion that parent organisms give one factor, or allele, for each trait to each of their offspring.

Each species of organism contains a characteristic number of chromosomes. Table 10.1 shows the diploid and haploid numbers of chromosomes of some species. Note the large range of chromosome numbers. Note also that the chromosome number of a species is not related to the complexity of the organism.

**Homologous chromosomes**

The two chromosomes of each pair in a diploid cell are called **homologous** (hoh MAH luh gus) chromosomes. Each of a pair of homologous chromosomes has genes for the same traits, such as plant height. On homologous chromosomes, these genes are arranged in the same order, but because there are different possible alleles for the same gene, the two chromosomes in a homologous pair are not always identical to each other. Identify the homologous chromosomes in the Problem-Solving Lab.

Let’s look at the seven pairs of homologous chromosomes in the cells of Mendel’s peas. These chromosome pairs are numbered 1 through 7. Each pair contains certain genes located at specific places on the chromosome. Chromosome 4 contains the genes for three of the traits that Mendel studied. Many other genes can be found on this chromosome as well.

Every pea plant has two copies of chromosome 4. It received one from each of its parents and will give one at random to each of its offspring. Remember, however, that the two copies of chromosome 4 in a pea plant may not necessarily have identical alleles. Each chromosome can have one of the different alleles possible for each gene. The homologous chromosomes diagrammed in Figure 10.10 show both alleles for each of three traits. Thus, the plant represented by these chromosomes is heterozygous for each of the traits.

**Problem-Solving Lab 10.2**

**Purpose**

Students will compare alleles on homologous chromosomes.

**Process Skills**

Interpret scientific diagrams, apply concepts, compare and contrast, think critically

**Teaching Strategies**

Review the meaning of alleles and homologous chromosomes.

**Thinking Critically**

1. 2 is homologous with 1. Alleles may or may not be identical, as long as they are positioned at the same location on matching chromosomes.
2. 3 is not homologous with 1. Genes must be identical. Gene K is not the same as gene J.
3. 4 is not homologous with 1. Chromosomes must match in physical size and location of genes in order to be homologous. (Sex chromosomes are an exception to the rule of matching physical size.)
4. 5 is homologous with 1 for the same reasons as in question 1.

**Assessment**

Performance Ask students to make a diagram of a chromosome with three marked gene locations. Have them diagram all the homologous chromosomes that are possible for this chromosome. Use the Performance Task Assessment List for Scientific Drawing in PASC, p. 127.

**Cultural Diversity**

Everett Anderson Introduce students to the contribution of African American cell biologist Everett Anderson to the modern understanding of the meiotic process. Anderson (1928), who received his Ph.D. in 1955, has been one of the leading researchers in developing electron microscopic techniques to study meiosis. Obtain a copy of Anderson’s 1972 publication, The Meiotic Process: Pairing, Recombination, and Chromosome Movements, and discuss with students the methodologies used in studying the process of meiosis.
Why meiosis?

When cells divide by mitosis, the new cells have exactly the same number and kind of chromosomes as the original cells. Imagine if mitosis were the only means of cell division. Each pea plant parent, which has 14 chromosomes, would produce gametes that contained a complete set of 14 chromosomes. That means that each offspring formed by fertilization of gametes would have twice the number of chromosomes as each of its parents. The F1 pea plants would have cell nuclei with 28 chromosomes, and the F2 plants would have cell nuclei with 56 chromosomes.

Clearly, there must be another form of cell division that allows offspring to have the same number of chromosomes as their parents. This kind of cell division, which produces gametes containing half the number of chromosomes as a parent’s body cell, is called meiosis (mi oh sus). Meiosis occurs in the specialized body cells of each parent that produce gametes.

Meiosis consists of two separate divisions, known as meiosis I and meiosis II. Meiosis I begins with one diploid (2n) cell. By the end of meiosis II, there are four haploid (n) cells. These haploid cells are called sex cells—gametes. Male gametes are called sperm. Female gametes are called eggs. When a sperm fertilizes an egg, the resulting zygote once again has the diploid number of chromosomes.

Visual Learning

Table 10.1 Ask students whether there is any evidence to support the idea that plants have fewer chromosomes than animals. Tell students to use examples from the table to support their answers. No; apples have 34 chromosomes, which is more than fruit flies or frogs have. Ask for the chromosome numbers in skin cells of a leopard frog and a dog, 26 and 78 and in root cells of tomatoes and garden peas. 24 and 14

Inquiry

Discussion Show students an egg and explain that it is a gamete. Based on previous information, students should be able to tell how many alleles are present for each trait. One Ask why an organism cannot produce gametes by mitosis. Mitosis produces a cell with two alleles for each trait.

Learning Disabled: Kinesthetic Have students use pipe cleaners or jelly beans to show why meiosis is necessary to prevent the number of chromosomes from doubling in each generation. Students should start with a cell containing two pipe cleaners or jelly beans, 2n. After meiosis, gametes should each contain one, n. After fertilization, the zygote has two. Students can repeat the process for several generations, assuming gametes are formed by mitosis. Students will see that the number of chromosomes doubles in each generation.
The zygote then develops by mitosis into a multicellular organism. This pattern of reproduction, involving the production and subsequent fusion of haploid sex cells, is called sexual reproduction. It is illustrated in Figure 10.11.

**The Phases of Meiosis**

During meiosis, a spindle forms and the cytoplasm divides in the same ways they do during mitosis. However, what happens to the chromosomes in meiosis is very different. Figure 10.12 illustrates interphase and the phases of meiosis. Examine the diagram and photo of each phase as you read about it.

**Interphase**

Recall from Chapter 8 that, during interphase, the cell replicates its chromosomes. The chromosomes are replicated during interphase that precedes meiosis I, also. After replication, each chromosome consists of two identical sister chromatids, held together by a centromere.

**Prophase I**

A cell entering prophase I behaves in a similar way to one entering prophase of mitosis. The DNA of the chromosomes coils up and a spindle forms. As the DNA coils, homologous chromosomes line up with each other, gene by gene along their length, to form a four-part structure called a tetrad. A tetrad consists of two homologous chromosomes, each made up of two sister chromatids. The chromatids in a tetrad pair tightly. In fact, they pair so tightly that non-sister chromatids from homologous chromosomes can actually break and exchange genetic material in a process known as **crossing over**. Crossing over can occur at any location on a chromosome, and it can occur at several locations at the same time.

**Meiosis**

Meiosis is necessary to provide variation and maintain the diploid number of chromosomes after reproduction.

**Figure 10.11**

In sexual reproduction, the doubling of the chromosome number that results from fertilization is balanced by the halving of the chromosome number that results from meiosis.

**Visual Learning**

Figure 10.12 Ask students how the processes of mitosis and meiosis are different. Events that occur in meiosis but not in mitosis include (1) in prophase I, pairs of homologous chromosomes form tetrads and crossing over can occur; (2) in metaphase I, homologous chromosomes line up in pairs rather than independently; (3) in anaphase I, homologous chromosomes, not chromatids, separate; (4) in telophase I, each cell has only one chromosome from each pair; and (5) at the end of meiosis II, each new cell has the haploid number of chromosomes.

**Word Origin**

*meiosis* from the Greek word *meioi*, meaning “to diminish”. Meiosis is cell division that results in a gamete containing half the number of chromosomes of its parent.

**Additional Lab**

**Modeling Meiosis**

**Purpose**
Students will observe the changes that occur during meiosis.

**Safety Precautions**

**Preparation**
- cut 9 sheets of unlined paper or poster board into 30-cm squares
- long length of yarn, paper clips, long length of string, toothpicks, tape or glue, scissors

**Materials**
- long length of yarn, paper clips, long length of string, toothpicks, tape or glue, scissors

**Procedure**
Given students the following directions.

1. Work in groups of nine students. Each student is to model one phase of interphase and meiosis. Each model is to have a phase name, labels, and an explanation of the events taking place.
2. Represent cell structures as follows: yarn strands = chromosomes, paper clips = centromeres, string = nuclear membranes, toothpicks = spindle fibers.
3. Place models on large sheets of paper or poster board.
**Using an Analogy**

To reinforce the concept of homologous chromosomes, sister chromatids, tetrad formation, crossing over, and anaphase I, try the following analogy: A magic pair of shoes (left and right) is found on a shelf (homologous chromosomes in a cell). These shoes, being magic, can and do replicate (interphase replication). Each copy is tied to its original with its shoelaces (centromere; both lefts are tied together and both rights are tied together). Both rights are now called right sister shoes (sister chromatids). Both lefts are now called left sister shoes (sister chromatids). All four shoes line up next to one another (tetrad formation).

While next to one another, part of one nonsister shoe (a left shoe) exchanges its innersole with another nonsister shoe (a right shoe) (crossing over). Right shoes move away from left shoes to different shelves (anaphase I, with homologous chromosomes separating and going to two different cells. Both rights are still tied together and both lefts are still tied together).

To improve the analogy, locate two identical pairs of shoes to demonstrate the events as they are described.

**Caption Question Answer**

*Figure 10.12* There are two divisions in meiosis and only one in mitosis. Meiosis produces haploid cells and mitosis produces diploid cells.

**Analysis**

1. What happens to the chromosome number during meiosis? Reduced by 1/2
2. How many cells are formed during meiosis? 4
3. What is the fate of the cells formed during meiosis? They form either egg or sperm cells.

**Assessment Knowledge** Ask students to write a paragraph explaining the value of making models such as the ones in this lab. Use the Performance Task Assessment List for Writing in Science in PASC, p. 159. L2

4. Only one pair of chromosomes is to be followed through all models. Glue or tape all parts in place.

5. Model interphase, prophase I, metaphase I, anaphase I, and telophase I, prophase II, metaphase II, anaphase II, and telophase II.

**Expected Results**

Students will gain an understanding of meiosis when visualizing each phase.
Purpose
Students will model the process of crossing over.

Process Skills
apply concepts, compare and contrast, formulate models, recognize cause and effect, think critically, define operationally

Teaching Strategies
- Plasticene or clay is available from biological supply houses or craft stores.
- String or twine may be used as a substitute for twist ties.
- Review the concept that gametes contain only one chromosome from each pair.
- Make sure students wash their hands after the lab.

Expected Results
All gametes will show the same combination of genes if no crossing over occurs and different combinations of genes if crossing over does occur.

Analysis
1. Only two chromosomes should be drawn. The sequence of genes would be C B A on one chromosome and C B a on the other.
2. Yes, crossing over is the exchange of genetic material between nonsister chromatids during prophase I of meiosis.
3. Student answers will vary. There is a mixing of the gene traits from their original order as would occur in shuffling cards.
4. There would be no mixing of gene traits when compared with the original chromosomes because sister chromatids are identical.
5. Student answers will vary. For the purposes of explaining crossing over, the model is simplistic but accurate.

Modified Assessment
Performance Ask students to model the appearance of gamete cells if crossing over occurred between sister chromatids. This should confirm their answer to question 5. Use the Performance Task Assessment Assessment List for Task Assessment List for Model in PASC, p. 123.

It is estimated that during prophase I of meiosis in humans, there is an average of two to three crossovers for each pair of homologous chromosomes. This exchange of genetic material is diagrammed in Figure 10.13B. Crossing over results in new combinations of alleles on a chromosome, as you can see in Figure 10.13C. You can practice modeling crossing over in the MiniLab at the left.

Metaphase I
During metaphase I, the centromere of each chromosome becomes attached to a spindle fiber. The spindle fibers pull the tetrads into the middle, or equator, of the spindle. This is an important step unique to meiosis. Note that homologous chromosomes are lined up side by side as tetrads. In mitosis, on the other hand, they line up on the spindle's equator independently of each other.

Anaphase I
Anaphase I begins as homologous chromosomes, each with its two chromatids, separate and move to opposite ends of the cell. This separation occurs because the centromeres holding the sister chromatids together do not split as they do during anaphase in mitosis. This critical step ensures that each new cell will receive only one chromosome from each homologous pair.

Telophase I
Events occur in the reverse order from the events of prophase I. The spindle is broken down, the chromosomes uncoil, and the cytoplasm divides to yield two new cells. Each cell has half the genetic information of the original cell because it has only one chromosome from each homologous pair. However, another cell division is needed because each chromosome is still doubled.
The phases of meiosis II

The newly formed cells in some organisms undergo a short resting stage. In other organisms, however, the cells go from late anaphase of meiosis I directly to metaphase of meiosis II.

The second division in meiosis is simply a mitotic division of the products of meiosis I. Meiosis II consists of prophase II, metaphase II, anaphase II, and telophase II. During prophase II, a spindle forms in each of the two new cells and the spindle fibers attach to the chromosomes. The chromosomes, still made up of sister chromatids, are pulled to the center of the cell and line up randomly at the equator during metaphase II. Anaphase II begins as the centromere of each chromosome splits, allowing the sister chromatids to separate and move to opposite poles. Finally, nuclei re-form, the spindles break down, and the cytoplasm divides during telophase II. The events of meiosis II are identical to those you studied for mitosis except that the chromosomes do not replicate before they divide at the centromeres.

At the end of meiosis II, four haploid cells have been formed from one diploid cell. Each haploid cell contains one chromosome from each homologous pair. These haploid cells will become gametes, transmitting the genes they contain to offspring.

Meiosis Provides for Genetic Variation

Cells that are formed by mitosis are identical to each other and to the parent cell. Crossing over during meiosis, however, provides a way to rearrange allele combinations. Rather than the alleles from each parent staying together, new combinations of alleles can form. Thus, variability is increased.

Genetic recombination

How many different kinds of sperm can a pea plant produce? Each cell undergoing meiosis has seven pairs of chromosomes. Because each of the seven pairs of chromosomes can align up at the cell’s equator in two different ways, 128 different kinds of sperm are possible ($2^n = 2^7 = 128$).

Concept Development

The chances of two humans being born exactly alike is almost an impossibility (except for identical twins). Explain why children in the same family can nevertheless resemble one another rather closely.

Using an Analogy

Continue the shoe analogy or demonstration of meiosis to illustrate telophase I, metaphase II, and telophase II events.

Start with two right shoes tied together. Both sets are separate from each other on different closet shelves (two new cells formed after telophase I). The shoes untie (centromere splits after metaphase II). They move to different shelves in the closet (two new cells formed in telophase II).

Ask students: (a) How many shoes are now on separate shelves (separate cells)? 4 (b) How many shoes were present at the start of this analogy? 2 (c) Is the chromosome number in a cell diploid or haploid before a cell undergoes meiosis? diploid (d) How many shoes are present on each shelf at the end of the process? 1 (e) How many shoes were on the original shelf? 2 (f) Is the chromosome number in each of the four new cells formed in meiosis reduced by half? yes

Using Models

Meiosis Use models of plant or animal cell meiosis (available from biological supply houses) to help students visualize the process.
In the same way, any pea plant can form 128 different eggs. Because any egg can be fertilized by any sperm, the number of different possible offspring is 16,384 (128 × 128). A simple example of how genetic recombination occurs is shown in Figure 10.14A. You can see that the gene combinations in the gametes vary depending on how each pair of homologous chromosomes lines up during metaphase I, a random process.

These numbers increase greatly as the number of chromosomes in the species increases. In humans, \( n = 23 \), so the number of different kinds of eggs or sperm a person can produce is more than 8 million \( (2^{23}) \). When fertilization occurs, \( 2^{23} \times 2^{23} \), or 70 trillion, different zygotes are possible! It’s no wonder that each individual is unique.

In addition, crossing over can occur almost anywhere at random on a chromosome. This means that an almost endless number of different possible chromosomes can be produced by crossing over, providing additional variation to the variation already produced by the random assortment of chromosomes. This reassortment of chromosomes and the genetic information they carry, either by crossing over or by independent segregation of homologous chromosomes, is called genetic recombination. It is a major source of variation among organisms. Variation is important to a species because it is the raw material that forms the basis for evolution.

**Meiosis explains Mendel’s results**

The behavior of the chromosomes in meiosis provides the physical basis for explaining Mendel’s results. The segregation of chromosomes in anaphase I of meiosis explains Mendel’s observation that each parent gives one allele for each trait at random to each offspring, regardless of whether the allele is expressed. The segregation of chromosomes at random during anaphase I also explains how factors, or genes, for different traits are inherited independently of each other. Today, Mendel’s laws and the events of meiosis together form the foundation of the chromosome theory of heredity.

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**Portfolio**

Comparing Mitosis and Meiosis

Provide students with two sets of simple line drawings, one showing interphase and the phases of mitosis and the other showing interphase and meiosis. Place comparable phases next to each other when possible (prophase of mitosis next to prophase I of meiosis, and so on). Ask students to describe in their portfolios the similarities and differences between processes. Also have them indicate the type of cell formed at the end of the process—body or gamete—and whether its chromosome number would be diploid or haploid.

**Figure 10.14**

If a cell has two pairs of chromosomes—\( A \) and \( a \), \( B \) and \( b \) \( (n = 2) \)—four kinds of gametes \( (2^2) \) are possible, depending on how the homologous chromosomes line up at the equator during meiosis I \( (A) \). This event is a matter of chance. When zygotes are formed by the union of these gametes, \( 2^2 \times 2^2 \) or 16 possible combinations may occur \( (B) \).

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**Using Models**

**Modeling the Membrane**

Have student groups invent a mechanism for demonstrating how the plasma membrane of an animal cell pinches together during telophase I and II of meiosis. Students can use a variety of common objects as models, such as balloons, string, and wire.
**Nondisjunction**

Although the events of meiosis usually proceed accurately, sometimes chromosomes fail to separate correctly. The failure of homologous chromosomes to separate properly during meiosis is called **nondisjunction**. Recall that during meiosis I, one chromosome from each homologous pair moves to each pole of the cell. In nondisjunction, both chromosomes of a homologous pair move to the same pole of the cell.

In one form of nondisjunction, two kinds of gametes result. One has an extra chromosome, and the other is missing a chromosome. The effects of nondisjunction are often seen after gametes fuse. For example, when a gamete with an extra chromosome is fertilized by a normal gamete, the zygote will have an extra chromosome. This condition is called trisomy (TRI soh mee). In humans, if a gamete with monosomy do not survive. If a zygote with monosomy does survive, the resulting organism usually does not. An example of monosomy that is not lethal is Turner syndrome, in which human females have only a single X chromosome instead of two.

Another form of nondisjunction involves a total lack of separation of homologous chromosomes. When this happens, a gamete inherits a complete diploid set of chromosomes, like those shown in **Figure 10.15**. When a gamete with an extra set of chromosomes is fertilized by a normal haploid gamete, the offspring has three sets of chromosomes and is triploid. The fusion of two gametes, each with an extra set of chromosomes, produces offspring with four sets of chromosomes—a tetraploid.

**Figure 10.15**

Follow the steps to see how a tetraploid plant, such as this chrysanthemum, is produced.

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**Display**

Make a bulletin board display of disorders caused by abnormal numbers of chromosomes, which result from nondisjunction. Include a diagram, similar to Figure 10.15, showing the steps of nondisjunction. You may want to include photos, descriptions, and symptoms of each disorder.

Some examples of nondisjunction are:

- Trisomy 21—Down syndrome
- Trisomy 13—Patau's syndrome
- XO—Turner's syndrome
- XXX—Trisomy X (metafemales)
- XXY—Klinefelter's syndrome
- XXXY—Jacob's syndrome
- OY—males (lethal)

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**Tech Prep**

Polyploidy in Plants: *Linguistic*

Have students research and report on how plant breeders create polyploidy flowers. Students should draw some of the plants and indicate how many sets of chromosomes each has.
Chromosome Mapping

Crossing over, the exchange of genetic material by nonsister chromatids, provides information that can be used to make chromosome maps. Crossing over occurs more frequently between genes that are far apart on a chromosome than between genes that are closer together. Critical Thinking Why is the frequency of crossing over related to the distance between genes on a chromosome?

Mapping

Crossing over produces new allele combinations. Geneticists use the frequency of crossing over to map the relative positions of genes on a chromosome. Genes that are farther apart on a chromosome are more likely to have crossing over occur between them than are genes that are closer together.

Frequencies and distance

Suppose there are four genes—A, B, C, and D—on a chromosome. Geneticists determine that the frequencies of recombination among them are as follows: between A and B—50%; between A and D—10%; between B and C—5%; between C and D—35%. The recombination frequencies can be converted to map units: A–B = 50; A–D = 10; B–C = 5; C–D = 35. These map units are not actual distances on the chromosome, but they give relative distances between genes. Geneticists line up the genes as shown above.

Making the map

The genes can be arranged in the sequence that reflects the recombination data. This sequence is a chromosome map.

Chromosome Mapping

Have interested students map the four genes on a chromosome given that the frequencies of recombination between the genes are as follows: A and D—60%, A and B—15%, C and D—10%, and B and C—35%. Have them predict where on the chromosome crossing over is most likely to occur.

Purpose

Students study the process of crossing over and its importance in genetic recombination.

Teaching Strategies

Ask students to describe the process of crossing over.

Visual Learning

- Have students examine the photograph and count the chiasmata—regions where chromosomes appear to be physically linked.
- Visual-Spatial Have students draw chromosomes before and after crossing over. The use of colored pencils will help students visualize how this process leads to genetic recombination.

Critical Thinking

The farther apart two alleles are from each other on a chromosome, the greater the chance that the chromosome will be tangled, broken, and rearranged between them.

Caption Question Answer

Figure 10.17 There are no seeds in the fruits.
Polyploidy

Organisms with more than the usual number of chromosome sets are called polyploids. Polyploidy is rare in animals and almost always causes death of the zygote. However, polyploidy frequently occurs in plants. Often, the flowers and fruits of these plants are larger than normal, and the plants are healthier. Many polyploid plants, such as the sterile banana plant shown in Figure 10.17, are of great commercial value.

Meiosis is a complex process, and the results of an error occurring are sometimes unfortunate. However, the resulting changes can be beneficial, such as those that have occurred in agriculture. Hexaploid (6n) wheat, triploid (3n) apples, and polyploid chrysanthemums all are available commercially. You can see that a thorough understanding of meiosis and genetics would be very helpful to plant breeders. In fact, plant breeders have learned to produce polyploid plants artificially by using chemicals that cause nondisjunction.

Gene Linkage and Maps

Genes sometimes appear to be inherited together instead of independently. If genes are close together on the same chromosome, they usually are inherited together. These genes are said to be linked. In fact, all the genes on a chromosome usually are linked and inherited together. It is the chromosomes, rather than the individual genes, that follow Mendel’s law of independent assortment.

Linked genes may become separated on different homologous chromosomes as a result of crossing over. When crossing over produces new gene combinations, geneticists can use the frequencies of these new gene combinations to make a chromosome map showing the relative locations of the genes. Figure 10.16 illustrates this process.

Understanding Main Ideas

1. How are the cells at the end of meiosis different from the cells at the beginning of meiosis? Use the terms chromosome number, haploid, and diploid in your answer.
2. What is the significance of meiosis to sexual reproduction?
3. Why are there so many varied phenotypes within a species such as humans?
4. If the diploid number of a plant is 10, how many chromosomes would you expect to find in its triploid offspring?

Thinking Critically

5. How do the events that take place during meiosis explain Mendel’s law of independent assortment?

Extension

Oogenesis and spermatogenesis are terms used to describe egg and sperm cell formation in humans through meiosis. Have students research how these processes differ and how they are alike.

Check for Understanding

Ask students to explain how the words in the following combinations are related.

- diploid—haploid
- homologous chromosomes—allele
- sperm—egg—zygote
- meiosis—gamete
- crossing over—genetic recombination

Reteach

Ask students to prepare a list of important characteristics of each step in meiosis. Then have them prepare a second list of the reasons meiosis is important to organisms that reproduce sexually.

Resources

For more practice, use Reading Essentials for Biology, Section 10.2.

Skill

Provide students with simple line diagrams of various phases of meiosis. The diagrams should not be in sequence. Have students place the diagrams in proper sequence, name each phase, and describe what is occurring.

Assessment

1. The chromosome number in a cell at the end is half the chromosome number in a parent cell. The original cell has a diploid number of chromosomes and each of the new cells has a haploid number.
2. Meiosis reduces the chromosome number in gametes. When sexual reproduction occurs, the zygote recombines the chromosomes and maintains the 2n condition.
3. Crossing over as well as the reassortment of the 46 chromosomes both contribute to the large number of phenotypes that are possible.
4. 15
5. After meiosis, only one member of each homologous chromosome pair can be found in a gamete. Thus, no gamete will end up with two homologues. Alleles on different chromosomes will sort independently from one another.
6. Tetrad formation does not occur during mitosis. This prevents crossing over from taking place.
How can phenotypes and genotypes of plants be determined?

**Problem**
Can the phenotypes and genotypes of the parent plants that produced two groups of seeds be determined from the phenotypes of the plants grown from the seeds?

**Hypotheses**
Have your group agree on a hypothesis to be tested that will answer the problem question. Record your hypothesis.

**Objectives**
In this BioLab, you will:
- Analyze the results of growing two groups of seeds.
- Draw conclusions about phenotypes and genotypes based on those results.
- Use the Internet to collect and compare data from other students.

**Possible Materials**
- potting soil
- light source
- small flowerpots or seedling flats
- thermometer or temperature probe
- two groups of tobacco seeds
- plant-watering bottle
- hand lens

**Safety Precautions**
CAUTION: Always wash your hands after handling plant materials. Always wear goggles in the lab.

**Possible Hypotheses**
- If the parent plants were true breeding for green color, then all offspring will be green.
- If the parent plants were heterozygous for green color, then offspring will show an approximate ratio of 3 green to 1 white.

**Troubleshooting**
- Students should keep growing conditions for the two seed groups as constant as possible. Soil should be kept moist at all times. Natural window light should be sufficient. Temperature should be kept above 20°C.
- Seeds should be planted about 1 cm below the soil. Planting is easier if the soil is moist.
- Be sure students mark the seed type planted in the flat or pot. Craft sticks can serve as markers.
3. Design an experiment that will allow you to collect quantitative data. For example, how many plants do you think you will need to examine?
4. Prepare a numbered list of directions. Include a list of materials and the quantities you will need.
5. Make a data table for recording your observations.

Check the Plan
1. Carefully determine what data you are going to collect. How many seeds will you need? How long will you carry out the experiment?
2. What variables, if any, will have to be controlled? (Hint: Think about the growing conditions for the plants.)
3. Make sure your teacher has approved your experimental plan before you proceed further.
4. Carry out your experiment. Make any needed observations, such as the numbers of green and albino plants in each group, and complete your data table.
5. Visit ca.bdol.glencoe.com/internet_lab to post your data.
6. 

**ANALYZE AND CONCLUDE**

1. **Think Critically** Why was it necessary to grow plants from the seeds in order to determine the phenotypes of the plants that formed the seeds?
2. **Draw Conclusions** Using the information in the introduction, describe how the gene for green color (C) is inherited.
3. **Make Inferences** For the group of seeds that yielded all green plants, are you able to determine exactly the genotypes of the parents that formed these seeds? Can you determine the genotype of each plant observed? Explain.
4. **Make Inferences** For the group of seeds that yielded some green and some albino plants, are you able to determine exactly the genotypes of the parents that formed these seeds? Can you determine the genotype of each plant observed? Explain.
5. **ERROR ANALYSIS** Use the data posted on ca.bdol.glencoe.com/internet_lab to compare your experimental design with that of other students. Were your results similar? What might account for the differences?

**Assessment**
**Portfolio** Ask students to make diagrams that show the parental and offspring genotypes and phenotypes for both groups of seeds used in this experiment. Use the Performance Task Assessment List for Scientific Drawing in PASC, p. 127.

**Share Your Data**
Find this BioLab using the link below and post your results in the table provided. Briefly describe your experimental design.

**Data and Observations**
Seeds that came from true breeding plants will produce plants that are all green. Seeds from heterozygous parents will produce both green and albino seedlings in the ratio of about 3 green to 1 albino. Have students review Problem-Solving Lab 10.1 for help in calculating the ratio of green to albino plants.
A Solution from Ratios

In 1866, Gregor Mendel, an Austrian monk, published the results of eight years of experiments with garden peas. His work was ignored until 1900, when it was rediscovered.

Mendel had three qualities that led to his discovery of the laws of heredity. First, he was curious, impelled to find out why things happened. Second, he was a keen observer. Third, he was a skilled mathematician. Mendel was the first biologist who relied heavily on statistics for solutions to how traits are inherited.

Darwin missed his chance About the same time that Mendel was carrying out his experiments with pea plants, Charles Darwin was gathering data on snapdragon flowers. When Darwin crossed plants that had normal-shaped flowers with plants that had odd-shaped flowers, all the offspring had normal-shaped flowers. He thought the two traits had blended. When he allowed the F1 plants to self-pollinate, his results were 88 plants with normal-shaped flowers and 37 plants with odd-shaped flowers. Darwin was puzzled by the results and did not continue his studies with these plants. Lacking Mendel’s statistical skills, Darwin failed to see the significance of the ratio of normal-shaped flowers to odd-shaped flowers in the F2 generation. What was this ratio? Was it similar to Mendel’s ratio of dominant to recessive traits in pea plants?

Finding the ratios for four other traits Figure 10.3 on page 256 shows seven traits that Mendel studied in pea plants. You have already looked at Mendel’s data for plant height and seed shape. Now use the data for seed color, flower position, pod color, and pod shape to find the ratios of dominant to recessive for these traits in the F2 generation.

Table A  Mendel’s Results

<table>
<thead>
<tr>
<th>Seed Color</th>
<th>Flower Position</th>
<th>Pod Color</th>
<th>Pod Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>Axial</td>
<td>Green</td>
<td>Inflated</td>
</tr>
<tr>
<td>6022</td>
<td>651</td>
<td>428</td>
<td>882</td>
</tr>
<tr>
<td>Green</td>
<td>Terminal</td>
<td>Yellow</td>
<td>Constricted</td>
</tr>
<tr>
<td>2001</td>
<td>207</td>
<td>152</td>
<td>299</td>
</tr>
</tbody>
</table>

Table B  Calculating Ratios for Mendel’s Results

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Seed Color</th>
<th>Flower Position</th>
<th>Pod Color</th>
<th>Pod Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>6022/2001</td>
<td>3.00</td>
<td>3.14</td>
<td>2.82</td>
<td>2.95</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ratio</th>
<th>yellow: green</th>
</tr>
</thead>
<tbody>
<tr>
<td>3:1</td>
<td></td>
</tr>
</tbody>
</table>

Draw Table B in your notebook or journal. Calculate the ratios for the data in Table A and complete Table B by following these steps:

- Step 1  Divide the larger number by the smaller number.
- Step 2  Round to the nearest hundredth.
- Step 3  To express your answer as a ratio, write the number from step 2 followed by a colon and the number 1.

Math in Biology

Try It! Why are ratios so important in understanding how dominant and recessive traits are inherited?

To find out more about Mendel’s work, visit ca.b dol.glencoe.com/math
Chapter 10 Assessment

Section 10.1

Mendel’s Laws of Heredity

Key Concepts
- Genes are located on chromosomes and exist in alternative forms called alleles. A dominant allele can mask the expression of a recessive allele.
- When Mendel crossed pea plants differing in one trait, one form of the trait disappeared until the second generation of offspring. To explain his results, Mendel formulated the law of segregation.
- Mendel formulated the law of independent assortment to explain that two traits are inherited independently.
- Events in genetics are governed by the laws of probability.

Vocabulary
- allele (p. 256)
- dominant (p. 256)
- fertilization (p. 253)
- gamete (p. 253)
- genetics (p. 253)
- genotype (p. 258)
- heredity (p. 253)
- heterozygous (p. 259)
- homozygous (p. 258)
- hybrid (p. 255)
- law of independent assortment (p. 260)
- law of segregation (p. 257)
- phenotype (p. 258)
- pollination (p. 254)
- recessive (p. 256)
- trait (p. 253)
- zygote (p. 253)

Section 10.2

Meiosis

Key Concepts
- In meiosis, one diploid (2n) cell produces four haploid (n) cells, providing a way for offspring to have the same number of chromosomes as their parents.
- In prophase I of meiosis, homologous chromosomes come together and pair tightly. Exchange of genetic material, called crossing over, takes place.
- Mendel’s results can be explained by the distribution of chromosomes during meiosis.
- Random assortment and crossing over during meiosis provide for genetic variation among the members of a species.
- The outcome of meiosis may vary due to nondisjunction, the failure of chromosomes to separate properly during cell division.
- All the genes on a chromosome are linked and are inherited together. It is the chromosomes rather than the individual genes that are assorted independently.

Vocabulary
- crossing over (p. 266)
- diploid (p. 263)
- egg (p. 265)
- genetic recombination (p. 270)
- haploid (p. 263)
- homologous chromosome (p. 264)
- meiosis (p. 265)
- nondisjunction (p. 271)
- sexual reproduction (p. 266)
- sperm (p. 265)

Vocabulary PuzzleMaker
For additional help with vocabulary, have students access the Vocabulary PuzzleMaker online at ca.b dol.glencoe.com/vocabulary_puzzlemaker

Foldables™
Have students use their Foldables to review the content of Section 10.1. On the back of the paper, use Mendel’s laws of heredity to determine the offspring from the following cross: AaBbCc × AaBbCc.

Use the ExamView® Pro Test Bank CD-ROM to:
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- Change English tests to Spanish with one mouse click and vice versa
Chapter 10 Assessment

Vocabulary Review

1. A zygote results from the union of egg and sperm.
2. Homozygous contains two identical alleles.
3. Alleles are the factors that produce genotypes and phenotypes.
4. Nondisjunction is a failure of crossing over and its resulting genetic recombination.
5. Gametes are haploid.

Understanding Key Concepts

6. At the end of meiosis, how many haploid cells have been formed from the original cell? A. one C. three
   B. two D. four
7. When Mendel transferred pollen from one pea plant to another, he was _______ the plants.
   A. self-pollinating C. self-fertilizing
   B. cross-pollinating D. cross-fertilizing
8. Which of these does NOT show a recessive trait in garden peas?
   A. B. C. D.
9. During what phase of meiosis do sister chromatids separate? A. prophase I C. anaphase II
   B. telophase I D. telophase II
10. During what phase of meiosis do nonsister chromatids cross over? A. prophase I C. telophase I
    B. anaphase I D. telophase II
11. A dihybrid cross between two heterozygotes produces a phenotypic ratio of ________.
    A. 3:1 C. 9:3:3:1
    B. 1:2:1 D. 1:6:9

Constructed Response

12. The probability of a family with six girls is (1/2)^6, but the probability of an entire school of girls would be (1/2)^500.
13. If the dominant allele completely masks the recessive allele, you cannot tell if an organism with the dominant trait is homozygous or heterozygous for the dominant trait.
14. Genetic recombination involves crossing over and its result is the production of genetically different gametes.
15. Sexual reproduction provides for variations, some of which will be able to survive and reproduce during changing conditions.
16. Observe and Infer Why is it possible to have a family of six girls and no boys, but extremely unlikely that there will be a public school with 500 girls and no boys?
17. Recognize Cause and Effect Why is it sometimes impossible to determine the genotype of an organism that has a dominant phenotype?
18. Cross-pollinating While examining a cell in prophase I of meiosis, you observe a pair of homologous chromosomes pairing tightly. What is the significance of the places at which the chromosomes are joined?
19. Real World BioChallenge Several human genetic disorders result from nondisjunction in meiosis, including Down syndrome, Klinefelter’s syndrome, and Turner syndrome. Visit ca.bdol.glencoe.com to investigate these disorders. What characteristic is common to each? Choose one of these disorders, or another human disorder caused by nondisjunction, and prepare a visual display that explains the disorder. Explain the disorder to your class.

Thinking Critically

16. The probability of a family with six girls is (1/2)^6, but the probability of an entire school of girls would be (1/2)^500.
17. If the dominant allele completely masks the recessive allele, you cannot tell if an organism with the dominant trait is homozygous or heterozygous for the dominant trait.
18. These are places where crossing over takes place and genetic material is exchanged.
19. All three disorders result from nondisjunction. Students may make displays that show karyotypes or examples of people with the disorders.
Part 1 Multiple Choice
Use the diagram to answer questions 20–23.

20. Which of the following is true?
   3a  A. Individual 1 is heterozygous.
       B. Individuals 2 and 3 are homozygous.
       C. Individual 4 is recessive.
       D. All individuals will be male.

21. Which of the following has the Tt genotype?
   3a  A. 1  C. 3
       B. 2  D. 2 and 3

22. If T is the allele for purple flowers and t is the allele for white flowers, the results would be ________.
    3a  A. 3 out of 4 are purple
        B. 3 out of 4 are white
        C. equal numbers of white and purple
        D. all of the same color

23. Which of Mendel’s observations would describe the results of the experimental cross in question 22?
    3b  A. rule of dominance
        B. law of segregation
        C. law of independent assortment
        D. rule of unit factors

24. Recessive traits appear only when an organism is ________.
    A. mature
    B. different from its parents
    C. heterozygous
    D. homozygous

25. The stage of meiosis shown here is ________.
    2a  A. anaphase I
        B. metaphase II
        C. telophase I
        D. telophase II

Study the diagram and answer questions 26–28.

26. What name is given to the process shown above?
    A. fertilization
    B. zygote
    C. meiosis
    D. gametes

27. What name is given to the cells shown in the diagram above?
    A. fertilization
    B. zygote
    C. meiosis
    D. gametes

28. If each of the cells shown in the diagram has 16 chromosomes, how many chromosomes would you expect to find in a skin cell of the resulting organism?
    A. 16
    B. 64
    C. 32
    D. 8

Part 2 Constructed Response/Grid In
Record your answers on your answer document.

29. Open Ended Explain the difference between trisomy and triploidy. Describe a way that each condition could occur. Use diagrams to clarify your answer.

30. Open Ended Compare metaphase of mitosis with metaphase I of meiosis. Explain the significance of the differences between the two stages in terms of sexual reproduction and genetic variation.

California Standards Practice


29. Trisomy—three chromosomes of the same type. Triploidy—three sets of chromosomes in a cell.

30. In mitosis, metaphase is the stage where duplicated chromosomes line up on the equator. Each sister chromatid is attached to a spindle fiber, which extends to opposite poles. The sister chromatids will separate into two new cells. There is no genetic variation in these new cells. In meiosis, metaphase I is the point where alleles on homologous chromosomes pair up on the equator, and spindle fibers are attached to each chromosome on opposing poles. The new cells formed are haploid. If the alleles are different, then half of the daughter cells will carry a genetic variation different from the other.

Rubric
For more help evaluating open-ended assessment questions, see the rubric on p. 9T.