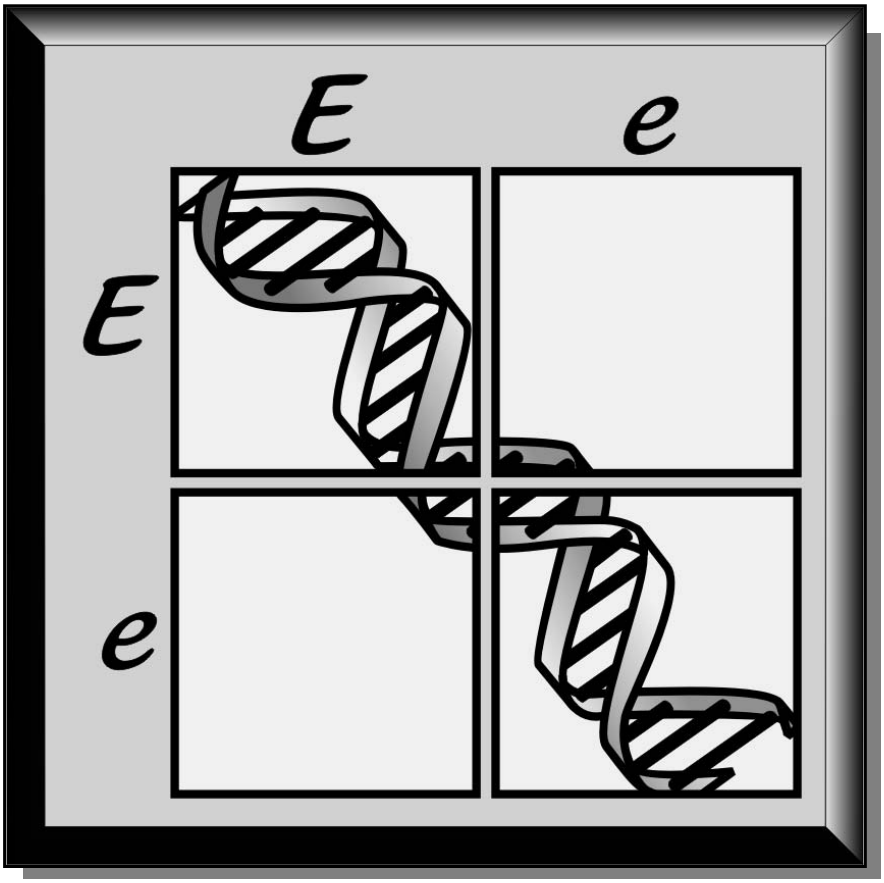
The Principles, Theories & Precepts of Biology

This chapter requires a companion activity book in which students respond to questions on text content. Answers are found in the *Teacher's Resource Kit*.



Chapter 3

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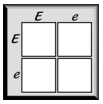
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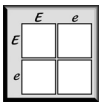
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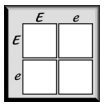
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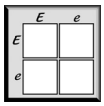
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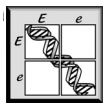
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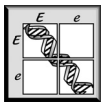


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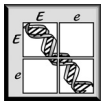


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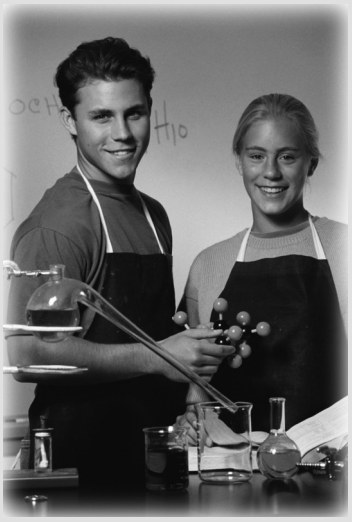
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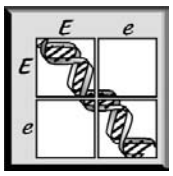
"Biology is man's attempt to understand who he is, where he came from, why he is here, and where he is going."

—Ronald E. Johnson, C.Ph.D.



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Mendelian Genetics

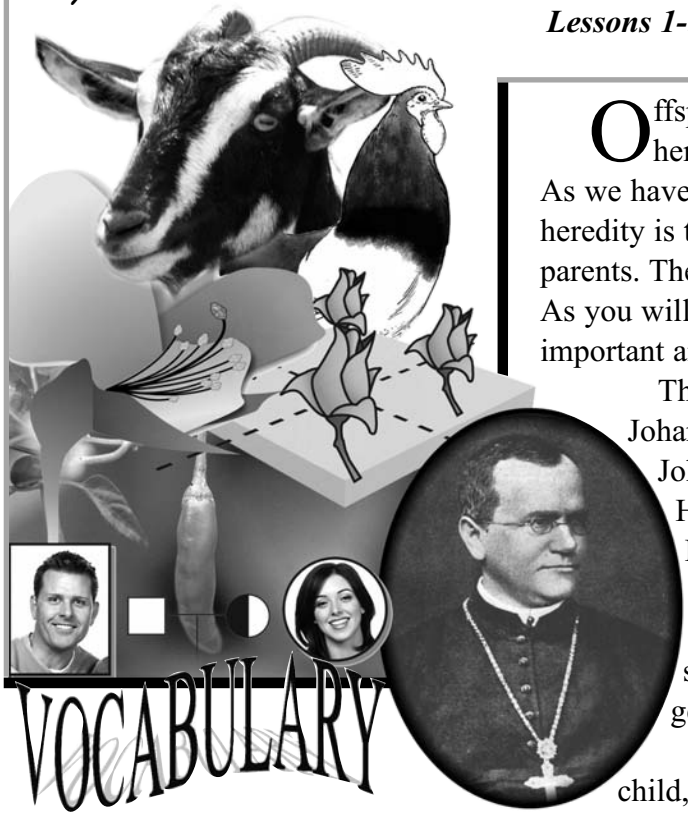
Lesson 1

Chapter 3

GREGOR MENDEL AND HIS WORK: THE HISTORY

Section 1

Lessons 1-5



Offspring resemble their parents because of heredity or their biological inheritance factors. As we have seen in the previous chapter, an organism's heredity is the set of characteristics received from its parents. The study of heredity is known as ***genetics***. As you will discover, genetics is one of the most important and fascinating branches of biology.

The study of genetics is based on the work of Johann (pronounced Yo-hän) Gregor Mendel. Johann Mendel was born in 1822 in Heinzendorf, Austria (now in The Czech Republic). Johann's father was a peasant farmer who taught his son the techniques of animal breeding and plant ***grafting***; those skills helped prepare Johann for his work in genetics.

Because he showed great promise as a child, he was encouraged by his teachers to pursue higher education. Unfortunately, such education was too expensive for his parents to provide. Mendel struggled to pay for his own schooling, and his younger sister even sacrificed part of her ***dowry*** to help Mendel with his educational expenses.

In 1843, Johann Mendel entered the Augustinian monastery in Brünn, Austria (now *Brno* in the Czech Republic), although he did not feel called to be a priest. Here he was required to assume a new name, and would henceforth be known as "Gregor Mendel". This monastery was known for great scholarship in philosophy, mathematics, ***mineralogy*** and ***botany***, and was a perfect setting for Gregor's brilliant mind to grow and develop. Botanical gardens and ***herbarium*** provided ideal laboratories for Mendel's lifelong research.

Austrian Emperor Franz I had ordered the monastery ***abbot*** to prepare his monks for the teaching of mathematics and science at various high schools. In preparation for a teaching assignment, Mendel was sent to study higher math

VOCABULARY

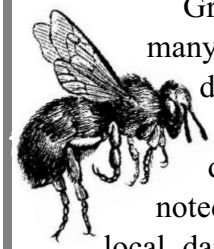
Genetics: the study of heredity
Grafting: inserting a bud or shoot of one plant into a slit in another closely related plant so that the bud or shoot becomes a permanent part of the host plant
Dowry: a gift of money, goods or property given by a person to his or her spouse in marriage
Mineralogy: the scientific study of minerals, involved geology, chemistry and physics
Botany: the scientific study of plants
Herbarium: a collection of dried plant specimens systematically arranged for studying

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and science (zoology, botany, chemistry and physics) at the University of Vienna in 1851. While at the university, Mendel studied under Johann Christian Doppler, a physicist who became famous for discovering an ***acoustical effect*** now known as the ***Doppler effect***. Modern weather reports often refer to "Doppler Radar", which is based on the work of Johann Doppler. Under Doppler's ***tutelage***, Mendel learned a great deal about the mathematic/scientific method of discovery. Such training gave Mendel a perfect foundation for his future genetic work.

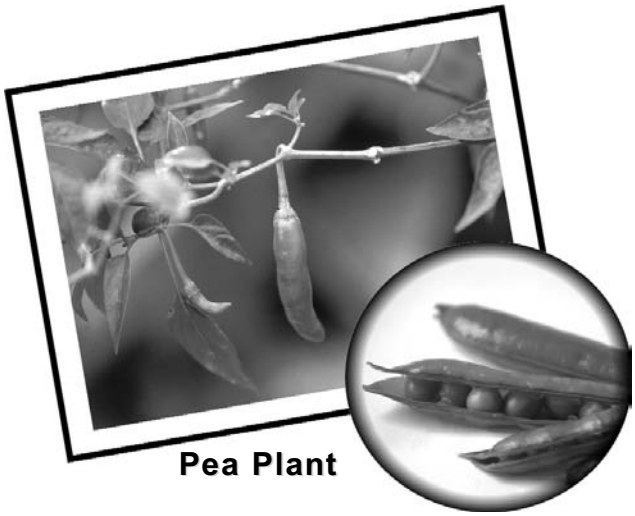


Gregor Mendel



Gregor Mendel was a man of many interests. In addition to his duties at the monastery, he raised and bred bees and designed bee hives. He was a noted meteorologist who logged local, daily weather patterns, including a detailed analysis of a tornado that struck his town in 1870. He also tracked and recorded sunspot activity.

The work for which Mendel is most often remembered began in 1856. For eight years, he conducted experiments on plant reproduction. He raised over 20,000 pea plants and carefully documented the results of breeding and cross-breeding them. At the end of those eight years, Mendel published a brilliant formal document in which he presented a series of four conclusions based on his controlled experiments and statistical data. These conclusions are the basis for what biologists call *Mendelian Genetics* or Mendel's Laws. However, at the time, Mendel's work was ignored by the scientific community of which he had been a part.



Pea Plant

The idea of controlled experiments and mathematical statistics were accepted in physical sciences, but until then had not been applied to life sciences. Part of the reason for the rejection of Mendel's work was a lack of understanding of the significance of his discoveries. Also, the "hot topic" of the 1860's scientific world was Darwin's theory of evolution which a great number of scientists had rushed to embrace, ***sans*** supporting evidence. Mendel urged the scientific community to evaluate *observation* over *speculation*. He said:

> Species do not transform one into the other. They show stability from generation

VOCABULARY

Abbot: the "superior" in charge of a monastery
Acoustical Effect: an effect of sound
Doppler Effect: a change in wavelength, observable when the source of radiation (sound, light, etc.) is in motion
Tutelage: teaching or tutoring
Sans: without

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> to generation, and my experiments demonstrate that fact. Isn't anyone listening?

Mendel had meticulously demonstrated that species were resistant to change and that traits were inherited without alteration, generation after generation.

Darwin's theory, on the other hand, required that variations be inherited and that characteristics be able to evolve in order to be acted upon by natural selection. Clearly, Mendel's less-popular statistics presented a challenge to Darwin's more-popular theory: if traits remained unchanged over generations, how could new variations (let alone different species) evolve?

Mendel gave up his scientific endeavors shortly after his peers discounted his work as unimportant. Instead, he became involved in a political controversy regarding the taxation of monasteries. As a deeply committed Christian, Mendel believed that government taxation of monasteries was an attack on religious freedom. He spent the rest of his life fighting for religious freedom from government control. When Mendel died in 1884, no one knew the significance of his experiments concerning genetics. Then, in 1900, three researchers working independently reached the same conclusions on genetics that Mendel had reached 40 years previously. By 1935, Mendel's work was finally recognized as critical to the scientific method of discovery, and his work became well known throughout the scientific community.

Today, he is known as the Father of Genetics. Gregor Mendel's life can be inspiring from several perspectives. His experiences teach what can happen when a person has a desire to learn. Mendel was willing to make great sacrifices for an education. Because he did, he was able to unlock one of the most marvelous and deep mysteries of life. Mendel's story also teaches that failure is not final, and that sooner or later the truth of a matter will be revealed. Mendel's persistent experiments presented the scientific community with the fundamentals of genetics.

In the next section, we will examine Mendel's experiments with pea plants.

LIFE PRINCIPLE

"Loneliness and Truth frequently travel hand in hand."



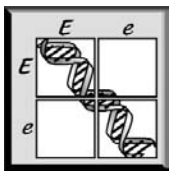
—Barry C. Forbes (1880-1954)
Journalist and philosopher

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Lesson 2

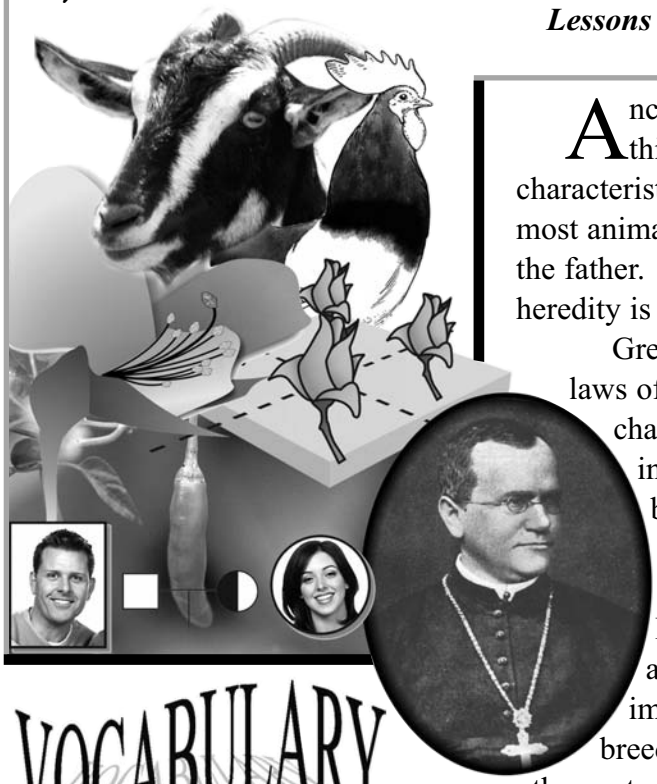
Mendelian Genetics

Chapter 3

GREGOR MENDEL AND HIS WORK: THE EXPERIMENTS

Section 1

Lessons 1-5



Ancient people thought the heredity of a living thing was merely a blend of parental characteristics. That perception seemed logical because most animals look a little like the mother and a little like the father. Scientists have discovered in recent years that heredity is not such a simple process.

Gregor Mendel was successful in unraveling the laws of inheritance by demonstrating that inherited characteristics were a result of discrete, individual units called ***genes***. Before beginning his experiments, Mendel spent several years choosing which species of organism and which characteristics to study. He finally chose garden peas. Peas were available in many different varieties and, most importantly, in ***true-breeding*** stocks. A true-breeding stock always passes its characteristics to the next generation. For example, one *true-breeding* stock of pea plants might always produce tall plants with green pods, while another stock might always produce short plants with yellow pods. By crossing two different varieties of peas, Mendel could trace the inheritance of particular traits that were different in the two original varieties.

The flower structure of peas was another characteristic that made peas ideal for Mendel's

VOCABULARY

Gene: segment of DNA that codes for a specific trait; the unit by which hereditary traits are transmitted

True-breeding: a stock of plants that always passes its traits to the next generation

Stamen: male part of the plant that produces pollen

Carpel: female part of a flower

Hybrid: offspring of parents with different characteristics

F1 generation: the first hybrid generation in Mendel's experiment; the letter *F* stands for *filius* which means "son" in Latin.

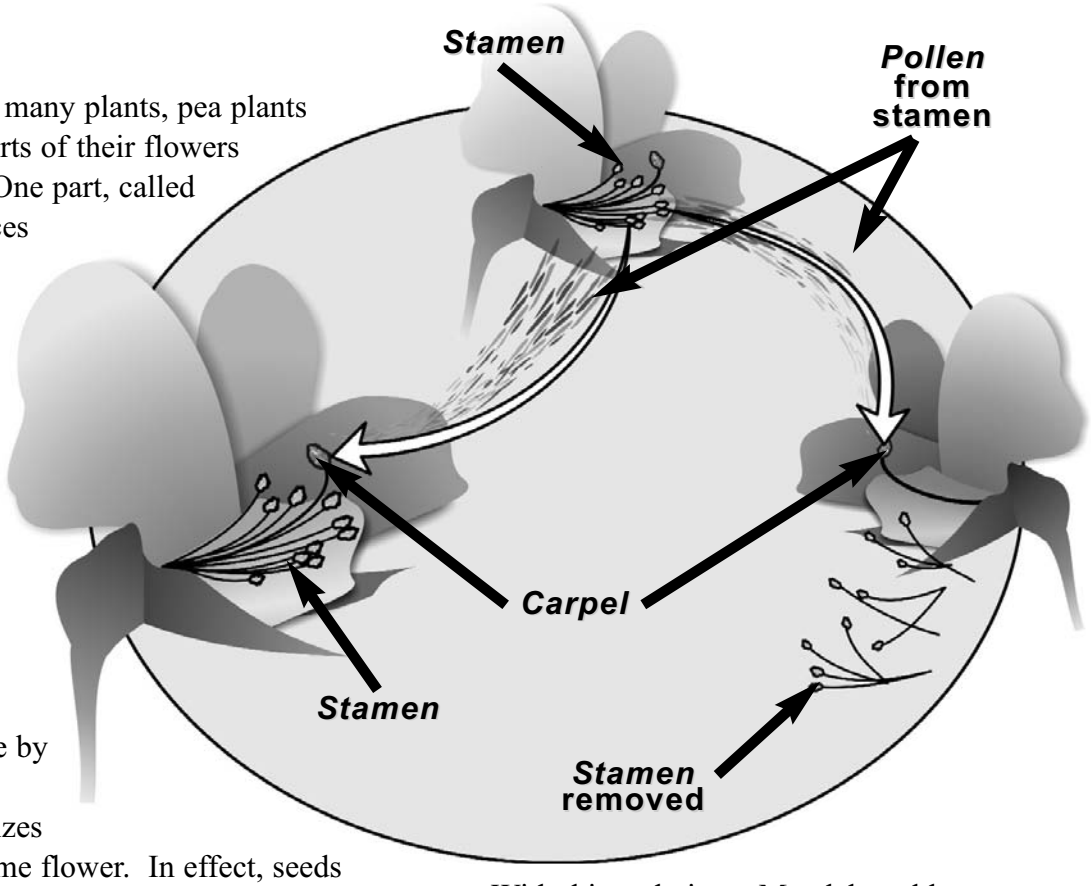
Contrasting characteristics of Pea Plants

Characteristics	Contrasting Characteristics
Seed shape	Round  Wrinkled 
Seed color	Green  Yellow 
Flower color	White  Purple 
Pod color	 Green Yellow

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experiments. Like many plants, pea plants have designated parts of their flowers for reproduction. One part, called the ***stamen***, produces pollen—the male sex cells—and another part, called the ***carpel***, produces egg cells—the female sex cells. When pollen fertilizes an egg cell, a seed for a new plant is produced.



Pea plants normally reproduce by *self-pollination*, in which pollen fertilizes egg cells on the same flower. In effect, seeds that are produced from self-pollination have only one plant as a parent. However, pea-plants can *cross-pollinate*. In cross-pollination, pollen from the flower on one plant fertilizes the egg cells of a flower on another plant. The seeds produced from cross-pollination have two plants as parents.

In order to control cross-pollination and prevent self-pollination, Mendel cut away the male parts of the flower. Then, he dusted that flower with pollen from a second flower.

With this technique, Mendel could choose any two pea plants to cross-pollinate, or cross. To simplify his investigation, Mendel chose to study only seven traits in pea plants. A *trait* is a characteristic that distinguishes one individual from another. In retrospect, we realize that one of Mendel's most important decisions was to study just a small number of traits. Also, each of these traits has two contrasting forms. For example, seed shape is either round or wrinkled and pod color is either green or yellow.

VOCABULARY

P generation: the parental or original parents in Mendel's experiments
F2 generation: the second generation in Mendel's experiments

F1 Generation

Using true-breeding stocks for each of the seven traits, Mendel crossed pea plants of each of the opposite traits. For example, he crossed red flowered pea plants with white flowered pea-plants, and plants with round seeds with plants with wrinkled seeds. The offspring of these crosses are called ***hybrids***.

Mendel called the hybrids of this crossing the ***F1 generation***. The letter *F*

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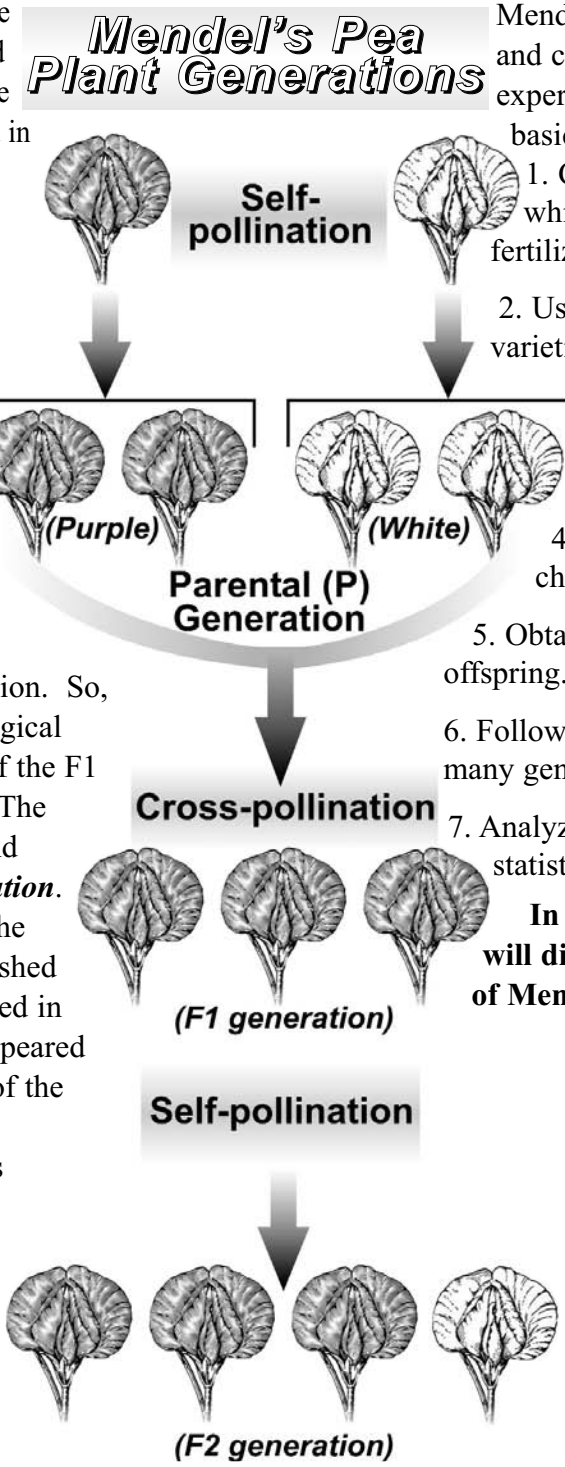
stands for *filius* which means "son" in Latin. The parent generation, or the true-breeding plants, Mendel called the ***P generation***. The letter *P* stands for the Latin word *parentis*, meaning "of the parents."

To Mendel's surprise, the traits of the parents did not blend in the F1 generation. Instead, the traits of just one parent appeared in the offspring. The traits of the other parent seemed to have disappeared.

F2 Generation

Had Mendel stopped with the F1 generation, his work might not be remembered today. However, he was curious about what had happened to the traits that seemed to have disappeared in the F1 generation. So, he decided to take the next logical step. He crossed the plants of the F1 generation with themselves. The plants produced by this second cross he called the ***F2 generation***. For each of the seven traits, the form that had seemingly vanished in the F1 generation reappeared in the F2 generation. They reappeared in approximately one fourth of the plants in the F2 generation.

Mendel knew that this pattern could not be a simple coincidence. Instead, he realized that he had stumbled across something very important about the nature of heredity.



Successful Science

Mendel was successful with his experiments for several reasons. His detailed research and scientific discovery was preceded by careful thought and planning. Mendel patiently planned and carried out his experiments based on seven basic rules:

1. Choose pea-plants which normally self-fertilize (simple to use).
2. Use pure-breeding varieties.
3. Choose traits with distinctly contrasting forms.
4. Follow one characteristic at a time.
5. Obtain a large number of offspring.
6. Follow characteristics for many generations.
7. Analyze results using statistical methods.

In the next lesson, we will discuss the conclusions of Mendel's experiments.

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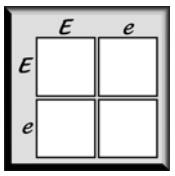
LIFE PRINCIPLE

"Species do not transform one into the other. They show stability from generation to generation. . . ."

—Gregor Mendel (1822-1884)
Father of Genetics

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Lesson 3

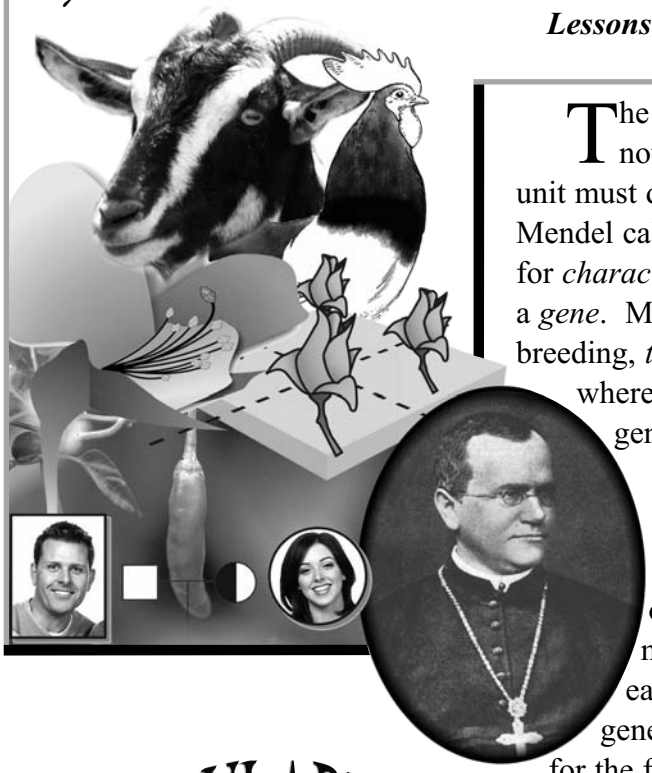
Mendelian Genetics

Chapter 3

GREGOR MENDEL AND HIS WORK: THE CONCLUSIONS

Section 1

Lessons 1-5



The observable traits in Mendel's experiments did not blend. He reasoned that some indivisible unit must determine each of the traits he investigated. Mendel called this unit a "merkmal" which is German for *character*. Today, this trait-determining unit is called a *gene*. Mendel could therefore conclude that true-breeding, *tall* pea plants contain genes for tallness, whereas true-breeding *short* pea plants contain genes for shortness.

ALLELES

Mendel further concluded that for each of the seven traits he investigated, a pea plant must contain at least two genes—one from each parent. Today, the different forms of a gene are called ***alleles***. For example, two alleles for the flower-color occur: the red flower allele and the white flower allele. In humans, two alleles for earlobe construction occur. One allele is for earlobes that are attached, while the other allele is for earlobes that hang free. The type of earlobe a person has is determined by the alleles inherited from the parents.

In certain cases, more than two alleles exist for a particular characteristic. Even though an individual has only two alleles (one from each parent), additional alleles may be present in the population. This condition is called ***multiple alleles.***

As illustrated, all the plants in Mendel's P generation contain two copies of an allele. Each tall plant contains two copies of the allele for tallness, and each short plant contains two copies of the allele for shortness.

When pea plants reproduce, each parent produces sex cells or ***gametes***—either pollen or egg cells. Unlike other cells, the sex cells contain only *one* copy of each gene. (Recall your study of gametes in the lesson on meiosis.) Therefore, when a sex cell from a true-breeding tall plant

VOCABULARY

Allele: (al la lee) the different forms of a gene; portions of DNA that carry the information for contrasting forms of the same genetic trait (e.g. red and white flowers)

Multiple alleles: a gene that is determined by more than two alleles for a single trait

Gamete: a sexual reproductive cell that must fuse with another such cell before development begins; an egg or a male sex cell that contains a haploid number of genes

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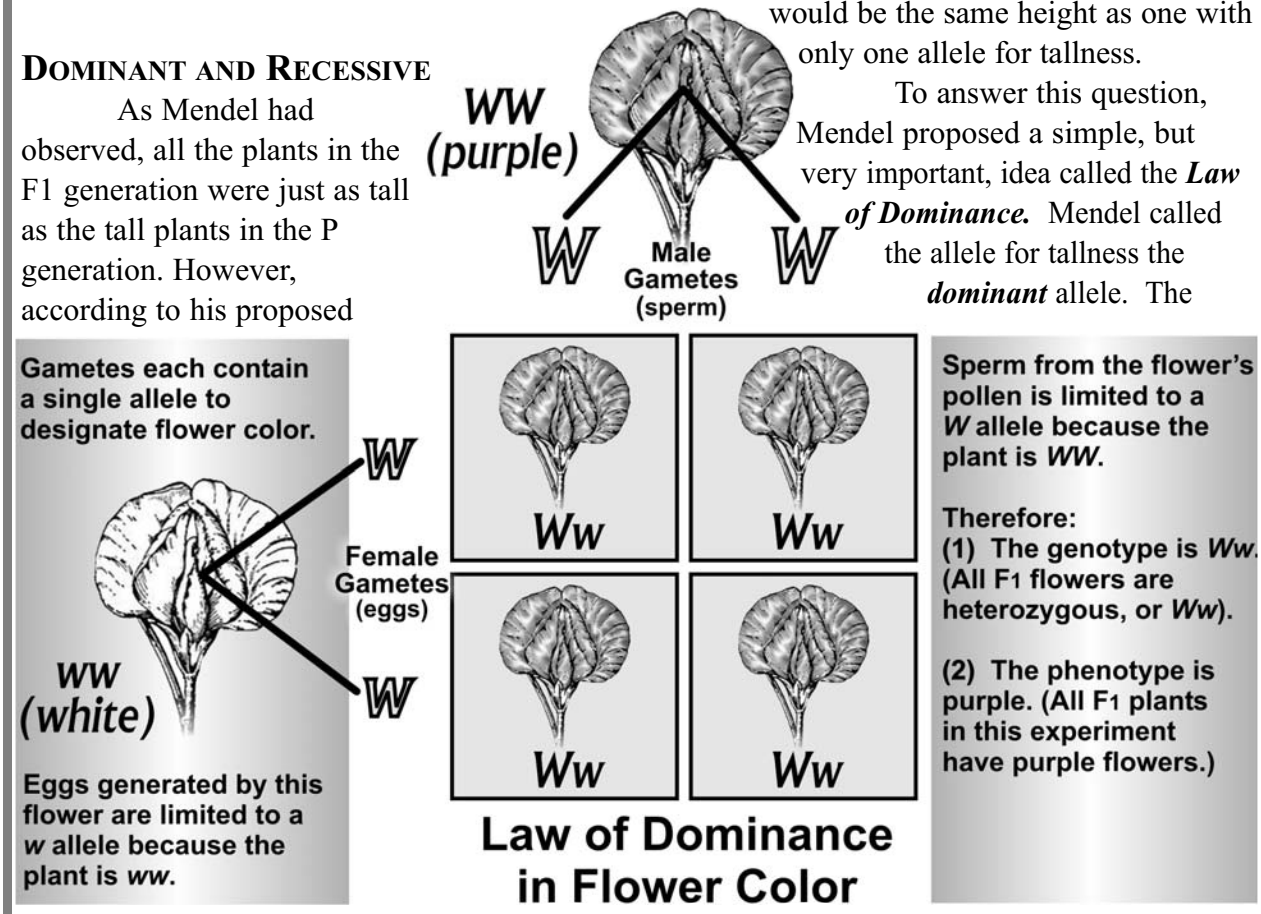
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unites with one from a true-breeding short plant, the seed produced will contain one allele for tallness and one allele for shortness.

Dominant and Recessive

As Mendel had observed, all the plants in the F1 generation were just as tall as the tall plants in the P generation. However, according to his proposed model, the plants in the two generations contained different alleles. Mendel wondered how a plant with two alleles for tallness would be the same height as one with only one allele for tallness.

To answer this question, Mendel proposed a simple, but very important, idea called the ***Law of Dominance.*** Mendel called the allele for tallness the ***dominant*** allele. The allele for shortness he called the ***recessive*** allele. In other words, in pea plants that have both alleles, only the dominant allele—the allele for tallness—is expressed. The same principle applies to flower color and all other traits in plants and animals. Biologists represent a dominant allele with a capital letter and a recessive allele with a lowercase letter. Thus, for pea plants, a capital letter "T" represents the allele for tallness and a lowercase letter "t" represents the allele for shortness.



VOCABULARY

Law of Dominance: a Mendelian principle which concludes that in a heterozygous condition, one allele of a gene may express itself and mask the presence of the other allele
Dominant: form of gene that is expressed when present, excludes the recessive form; represented by an uppercase letter
Recessive: form of gene that is not expressed in the presence of the dominant form; represented by a lowercase letter
Phenotype: outward manifestation of a genetic trait displayed by an organism

Phenotype and Genotype

An organism's ***phenotype*** is its physical appearance. Pea plants, for example, express either the phenotype for

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These two goats have different phenotypes because their collection of genes, or genotypes, varies.

tallness or the phenotype for shortness. Mendel proposed that identical phenotypes could be produced by more than one ***genotype***, which is an organism's genetic composition.

Organisms that have an identical pair of alleles for a trait—such as TT or tt—are said to be ***homozygous*** for the trait. The prefix *homo* means "same" and the suffix *zygous* means "joined together." An organism that has a mixed pair of alleles, such as Tt (one allele for tallness and one for shortness), is said to be ***heterozygous*** for that trait. The prefix *hetero* means "different."

As you will recall from the previous lesson, in his F1 cross, Mendel crossed plants that were homozygous for tallness (TT) with plants that were homozygous for shortness (tt). All the offspring were heterozygous for height (Tt), yet were just as tall as the homozygous plants. Because the T allele is dominant, the tallness phenotype expresses itself when the genotype is heterozygous.

VOCABULARY

Genotype: genetic composition and description of an organism
Homozygous: description of an organism that has an identical pair of alleles for a trait
Heterozygous: description of an organism that has a mixed pair of alleles for a trait
Law of Segregation: a Mendelian principle which concludes that paired genes must separate from each other during gamete formation (meiosis)
Punnett square: a convenient diagram used to predict the genotypes of offspring
Independent assortment: a Mendelian law or principle which concludes that different genes do not influence each other's segregation during gamete formation
Dihybrid cross: involves two pairs of contrasting traits, either homozygous or heterozygous; is illustrated by a 16-box Punnett square

SEGREGATION

In our study of meiosis, we saw that the members of each pair of homologous chromosomes separate into different nuclei during gamete formation. The process and steps of meiosis were unknown to Mendel, but he did recognize that paired genes must separate from each other during gamete formation and this reasoning is now known as Mendel's ***Law of Segregation***.

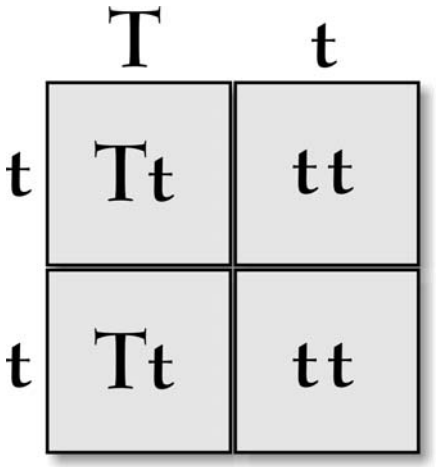
Remember that all the plants in the F1 generation have the heterozygous genotype for height (Tt). Therefore, when a plant with the genotype Tt produces pollen or egg cells (gametes), half the sex cells will carry the allele for tallness (T) and the other half will carry the allele for shortness (t).

In the F2 generation, half the pollen cells and half the egg cells carry the recessive allele (t), so one fourth of the offspring should have two copies of the recessive allele (tt). Therefore, one fourth of the offspring should be short plants and the remaining three-fourths should be tall (TT or Tt genotypes). Indeed, the ratios are almost exactly what Mendel's F2 generation produced.

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Punnett Squares

When the genotypes of parents used in a cross are known, a convenient way of predicting the genotypes of their offspring is to draw a ***Punnett square*** (named after the geneticist, Reginald Crundall Punnett). To construct a Punnett square, the genes present in the gametes of one parent are written along the top, and those from the other parent are listed down the left side. The boxes in the square show the possible genotypes of offspring.

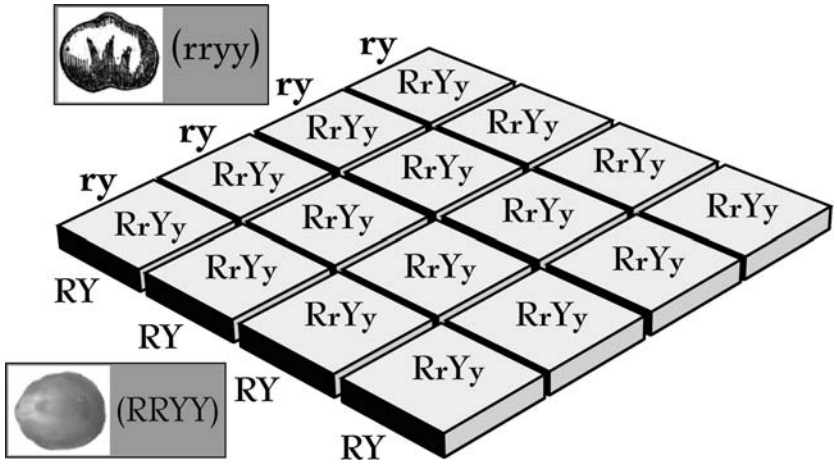


Punnett Square

Independent Assortment of Genes

Mendel had one more important question to answer. He wanted to know if the inheritance of one gene affected the inheritance of another. In order to test this, Mendel performed an experiment in which he could follow two different genes as they passed from one generation to the next.

From his earlier experiments, Mendel knew that the gene for seed shape had two forms—round (R) and wrinkled (r) and that the allele for roundness was dominant. He also knew that the gene for seed color had two forms—yellow (Y) and green (y)—and that the allele for yellow color was dominant.



A Homozygous Dihybrid Cross

To follow both genes, Mendel first performed an F1 cross between plants that were true-breeding for round yellow seeds (RRYY) and plants that were true-breeding for green wrinkled seeds (rryy). This is known as a ***dihybrid cross***. As he expected, every plant in the F1 generation had round yellow seeds. Mendel reasoned that each of these plants received the dominant alleles (RY) from one parent, providing them with the heterozygous genotype for both traits (RrYy).

Mendel then crossed the F1 plants. This second cross produced plants with expected and distinct ratios of different combinations of seed shape and color. This included both round green seeds and wrinkled yellow seeds. He concluded that the alleles for seed shape segregated independently of those for seed color. This principle is known today as ***independent assortment***. In other words, genes that segregate independently—such as these for seed shape and color—do not influence each other's inheritance.

Unfortunately for Mendel, his work did not bring him fame and fortune, nor did it lead to an immediate revolution in biology. In fact, Mendel's work went almost unnoticed for more than 30 years. During the early 1900s, a number of scientists rediscovered Mendel's work and saw that his principles could be applied to animal life as well as plant life.

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Today, Mendel is recognized as the Father of Genetics and is noted for several important genetic principles, four of which are called *Mendel's Laws* and constitute the foundation of modern genetics:

1. **The Law of Genes**
   Individual units, called genes, determine biological characteristics.

2. **The Law of Segregation**
   For each gene, an organism receives one allele from each parent. The alleles separate from each other—a process called segregation—when reproductive cells (gametes) are formed.

3. **The Law of Dominance**
   If an organism inherits different alleles for the same trait, one allele may dominate over the other.

4. **The Law of Assortment**
   Some genes segregate independently.

In the next lesson, we will examine a few more basic genetic principles which have developed as a result of Mendel's work.

LIFE PRINCIPLE

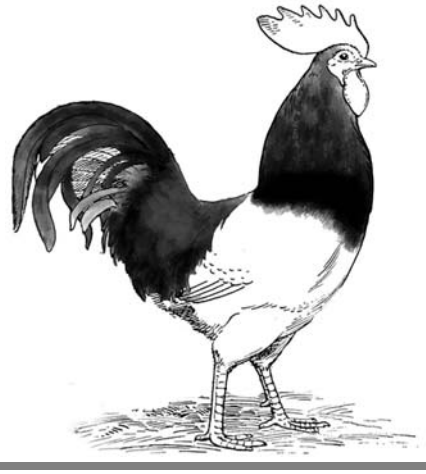


"Science without religion is lame, religion without science is blind."

–Albert Einstein (1879-1955)
German-American
physicist and mathematician

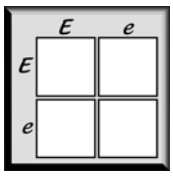
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Lesson 4

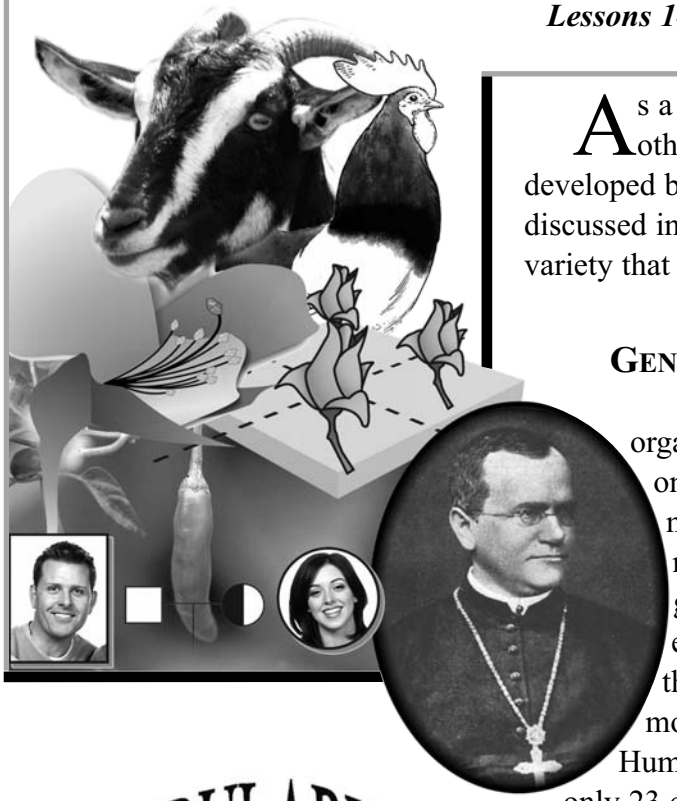
Mendelian Genetics

Chapter 3

Section 1

Lessons 1-5

PRINCIPLES OF HEREDITY



As a result of Gregor Mendel's work, several other principles of heredity have been developed by geneticists over the years. Those discussed in this lesson help to explain the incredible variety that we see in the world among all living things.

Gene Linkage and Crossing Over

According to Mendel's principles, an organism has two copies of each gene, but only one copy is passed on to an offspring. As you may recall from the study of meiosis, this means that when an organism forms gametes, each gamete must end up with exactly half the number of chromosomes as the other cells in the organism. For example, most human cells contain 46 chromosomes. Human gametes—sperm and egg cells—contain only 23 chromosomes each. The fusion of the sperm and the egg brings together chromosomes from both parents, just as Mendel's principles state. Large numbers of genes are commonly inherited together if they are located on the same chromosome. This is called ***gene linkage***.

In the first division of meiosis, homologous chromosomes go through a process called ***crossing-over*** in which alleles switch from one chromosome to another. This event produces a great variety of genetic differentiation in an organism. Because of gene linkage, however, some genes will remain together even after crossing-over. Genes that are close to one another tend to remain together during crossing-over episodes.

Incomplete Dominance and Co-dominance

Many genes have alleles that are neither dominant nor recessive. Instead, the two characteristics blend. In such an instance, both alleles have the opportunity to express

VOCABULARY

Gene Linkage: the condition in which genes are inherited together due to their close proximity on the same chromosome

Crossing-over: exchange of genetic material between homologous chromosomes during meiosis

Incomplete Dominance: genetic condition in which neither allele is completely dominant or recessive; results in a blending of the phenotypes but not the genes

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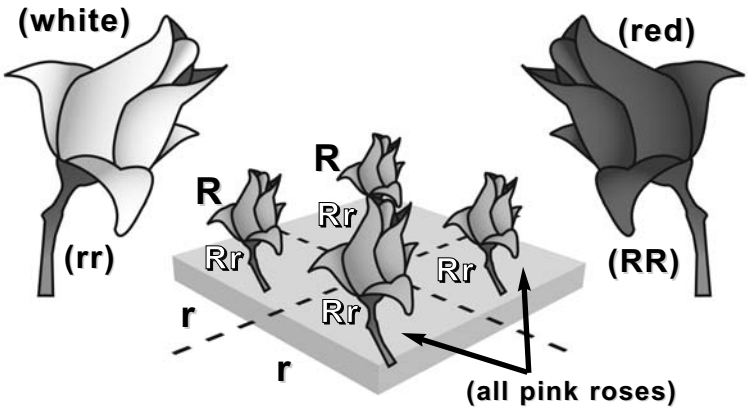
themselves. Snapdragon flowers, for example, have two alleles for flower color—red (R) and white (r) . Snapdragons that are homozygous for red (RR) produce red flowers and those that are homozygous for white (rr) produce white flowers. However, the heterozygous plants (Rr) are neither red nor white; they are pink.

The red allele is said to display ***incomplete dominance*** over the white allele. In this case, the heterozygous phenotype displayed is between the two heterozygous phenotypes.

If two pink flowers such as snapdragons (or roses) are crossed, the phenotype ratio of the offspring would be one red, two pink and one white. These results show that genes themselves remain independent; only the expressions of the genes blend.

Another case in which both alleles affect phenotype is known as ***co-dominance***. In co-dominance, both alleles of a gene are expressed. For example, in an ***erminette*** chicken, two co-dominant alleles for feather color exist—one for black feathers and one for white feathers. The chickens with the heterozygous genotype will have both black and white feathers.

Incomplete Dominance

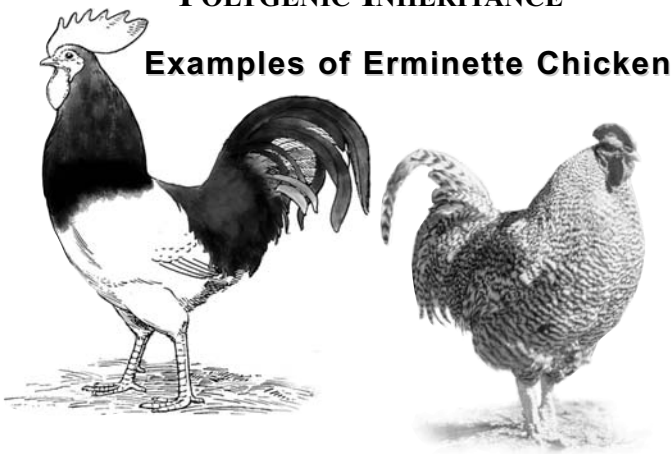


Multiple Alleles

In certain cases, more than two alleles for a particular characteristic may be present. Even though an individual has only two alleles for a characteristic, additional alleles may exist in the population. As you recall from lesson 3, this situation is called *multiple alleles* and is very common in nature. For example, coat color in rabbits is determined by a single gene that has four, well-known alleles. In humans, multiple alleles exist for blood types and eye colors.

Polygenic Inheritance

Examples of Erminette Chickens



VOCABULARY

Co-dominance: genetic condition in which both dominant and recessive alleles are expressed

Erminette: black and white flecked, spotted—variable black and white feathers

Polygenic Inheritance: the additive effect of two or more genes which results in an inherited characteristic

Probability: the mathematical principle used to predict the chances or likelihood of certain events

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Many inherited traits are controlled by more than one gene. This is particularly true of the genes that control body shape and form. For example, although your facial appearance is inherited, no single gene determines the exact shape of your mouth or the position of your ears. Rather, these characteristics are determined by an interaction of genes on several chromosomes or at several places on one chromosome. This is called ***polygenic inheritance***.

Because polygenic traits are controlled by more than one gene, their inheritance can be complicated and often will show a very wide range of phenotypes. An example is the skin color of humans. Genes for skin color are located in many places, and depending upon which genes are present at these multiple locations, skin color will vary. A person with many genes for dark skin will have very dark skin color, and a person with multiple genes for light skin will have very light skin color. In addition, many conditions exist between very dark and very light skin color, depending on which genes are evident in an individual.

Probability

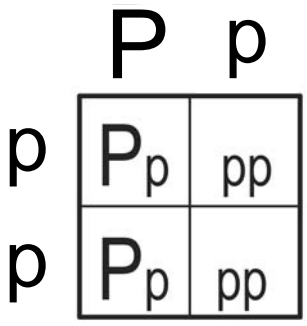
Geneticists have realized that one of the most useful aspects of genetics is that it allows great predictability. By using the mathematical principles of ***probability***, we can predict the chances of certain events.

For example, think about an ordinary event with an uncertain outcome, such as the flipping of a coin. Flipping a coin has two possible outcomes—the coin may land either heads up or tails up. Each outcome has an equal probability, or likelihood, of occurring. Therefore, the probability of a single coin flip landing heads up is one out of two, or ½.If you were to flip a coin four times in a row, you could calculate the probability of the coin landing heads up each time. Because each coin toss is an independent event, the probability of each coin landing heads up is 1 out of 2, or ½. Therefore, the probability of flipping four heads in a row is: ½ x ½ x ½ x ½ = 1/16, or one chance in 16. The fact that the individual probabilities were multiplied together illustrates an important point: past outcomes do not affect future outcomes. For example, even if you flipped three heads in a row, the probability of the fourth flip landing heads is still ½.

Probability applies to genetics because the formation of gametes during meiosis depends on a random division of genes. Like flipping a coin, if an organism has two different alleles for the same gene, the chances are 1 in 2, or ½, that one of its gametes will carry one of the alleles.

Purple Flowers vs. White Flowers

As an example, suppose we were to cross a plant that is heterozygous for purple flowers (Pp) with one that is homozygous for white flowers (pp). (White is the recessive allele.) By making a Punnett square, the probability of outcomes can be calculated



Genotype	Probability
Pp	1/2
pp	1/2

Phenotype	Probability
purple	1/2
white	1/2

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easily. The white flower produces gametes that contain only the allele for white flowers (p), while the purple flower produces two types of gametes—one with the allele for purple flowers (P) and one with the allele for white flowers (p). Therefore, half the seeds will be heterozygous for purple flowers (Pp) and half will be homozygous for white flowers (pp). The probability that an offspring will produce the phenotype for white flowers is therefore 1 out of 2, or ½.

Suppose we were to plant four seeds from the above cross. The probability of producing four plants with white flowers would be calculated just like the coin flip: ½ x ½ x ½ x ½ = 1/16.

If you plant four seeds from this cross, you would expect half to produce white flowers and half to produce purple flowers as shown in the Punnett square. However, that doesn't mean that the seeds will always produce in this ratio. As you have just seen, a probability of 1 in 16 exists that all four seeds will produce white flowers.

In the next lesson, we will briefly examine the marvelous and wondrous complexity of human genetics and inheritance.

WATCH VIDEO:
Mendelian Genetics

LIFE PRINCIPLE

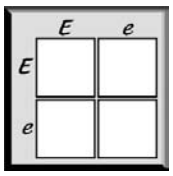


"Most of the things worth doing in the world had been declared impossible before they were done."

—Louis D. Brandeis (1856-1941)
First Jewish-American Supreme Court judge

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Lesson 5

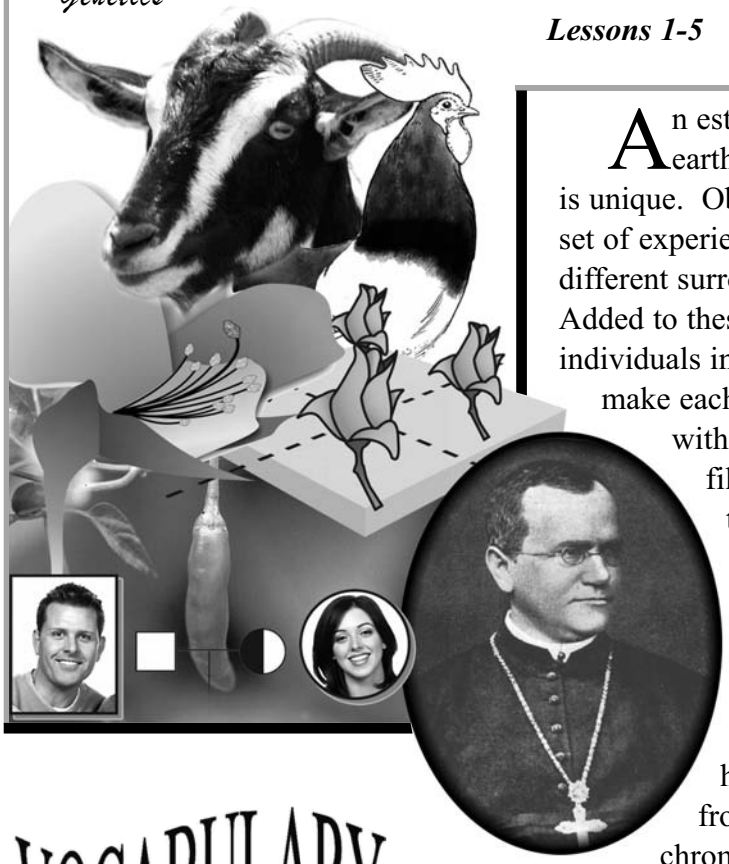
Mendelian Genetics

Chapter 3

HUMAN GENETICS

Section 1

Lessons 1-5



An estimated six billion people were alive on earth by 2002 AD. Each of these six billion is unique. Obviously, every individual has a different set of experiences. Each person grows up with different surroundings and with different viewpoints. Added to these are the biological differences that individuals inherit in their genes. These also help to make each person unique. Each one of us is born with enough personal, genetic information to fill all the books of a large library. We are truly wonderfully and marvelously made!

VOCABULARY

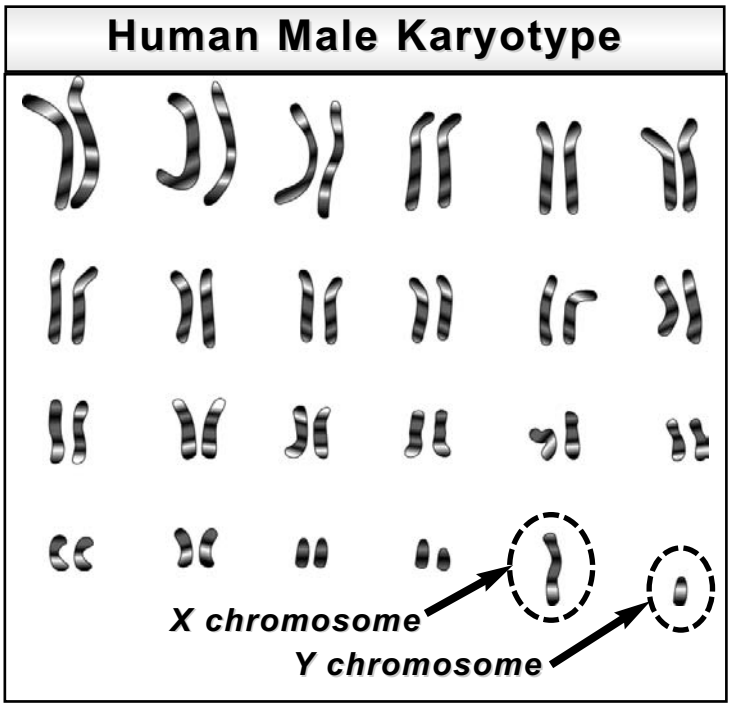
Colchicines: a poison that breaks down microtubules
Karyotype: diagrammatic representation of individual chromosomes cut out from a photograph and grouped together
Autosomes or ***Autosomal Chromosomes***: any chromosomes other than sex chromosome somatic cells; any cell in a multicellular organism except a sperm or egg

THE HUMAN CELL

As you have learned in a previous lesson, *diploid* human cells have a total of 46 chromosomes—23 from each parent. During mitosis, these chromosomes condense and are easy to see. Biologists have developed a special laboratory procedure in order to see all 46 chromosomes at once. This process involves growing a sample of cells in a substance called ***colchicines***, a poison that breaks down microtubules. This action prevents cells from completing mitosis. This way, biologists can trap the chromosomes during the phase in which the chromosomes are fully condensed. Once condensed, the chromosomes can be clearly seen and photographed. To analyze the chromosomes, a geneticist will cut the photograph in order to group the chromosomes together. A picture of chromosomes put together this way is called a ***karyotype***.

A human karyotype reveals that each cell has 22 pairs of homologous chromosomes that are numbered from 1 to 22 in order of decreasing size. The 22 pairs are called ***autosomes*** (or ***autosomal chromosomes***). In addition, each cell has one

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pair of sex chromosomes, called the ***X and Y chromosomes***. Female cells have two X chromosomes. Male cells have one X chromosome and one Y chromosome.

VOCABULARY

X and Y chromosomes: chromosomes that determine the sex of an individual
Zygote: a fertilized egg
Pedigree: diagram that tracks the inheritance of a single gene through several generations of a family
Colorblindness: a sex-linked genetic disorder which is the inability to see and discern certain colors; a recessive phenotype usually inherited by males
Hemophilia: a sex-linked genetic disorder in which the blood does not clot normally; a recessive trait that is usually exhibited by males
Antigens: molecules that stimulate the production of antibodies

HUMAN REPRODUCTIVE CELLS

The human reproductive cells—the sperm and the eggs—are produced by meiosis in the male and female reproductive systems. Sperm and eggs are both *haploid*. As you will recall, this means that they each contain 23 chromosomes—only half the total number of chromosomes in human body cells (*somatic cells*). Therefore, they usually carry just one sex chromosome each. During fertilization, a sperm and an egg unite to form a ***zygote*** that contains 46 chromosomes—the diploid number of chromosomes in humans.

Just like any other organism, human reproductive cells go through meiosis. During meiosis in males, the X and Y chromosomes pair and they are separated in the first meiotic division. This means that half of a male's sperm carries an X chromosome and half carries a Y chromosome. The female eggs, of course, contain only the X chromosome. It is therefore the male sperm that will determine if the offspring will be male or female. This also explains why males and females are born in approximately equal numbers worldwide.

PEDIGREE ANALYSIS

Because a human generation spans more than 20 years, geneticists must rely on family histories and medical records to provide inheritance patterns. One of the best ways to summarize this information is to construct a ***pedigree*** diagram which allows the inheritance of a single gene to be followed through several generations in a family.

In a pedigree, squares represent males and circles represent females. Vertical lines

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connect parents and their children, and horizontal lines connect male and female parents. In a family, the symbols for the children are placed from left to right, in birth order, with the oldest child on the extreme left. If a pedigree illustrates a homozygous trait, the squares or circles with this trait are circled. If a person is heterozygous for the trait, the square or circle is half shaded.

Sex-linked Genes in Humans

In humans, the Y chromosome is much shorter than the X chromosome. Because of this shortened size, a number of sex-linked conditions occur. When a gene occurs on an X chromosome, the other gene of the pair probably occurs on the other X chromosome. Therefore, a female with two X chromosomes will usually get two genes for this characteristic. In contrast, when a gene occurs on an X chromosome in a male, usually no other gene is present on the short Y chromosome. Because males have just one X chromosome, males are more likely than females to express the characteristic of a recessive gene on the X chromosome.

Colorblindness

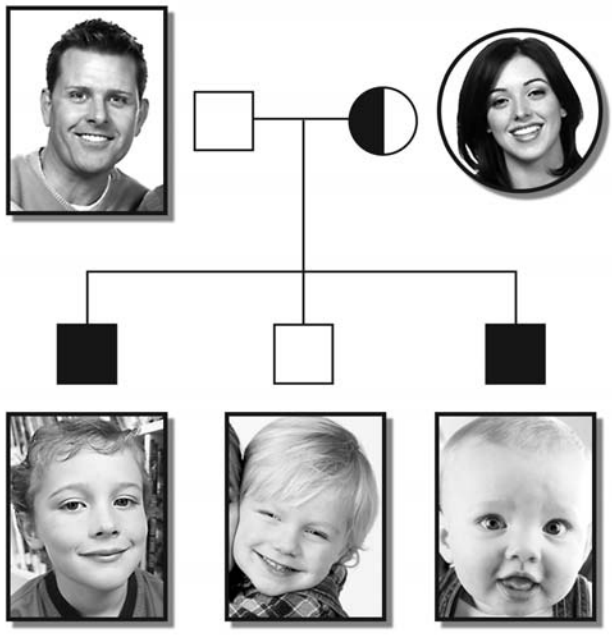
One of the most important genes carried on the X chromosome is responsible for normal color vision. The dominant allele produces color vision. The recessive allele causes ***colorblindness***. A woman is rarely colorblind because she usually has a dominant gene for vision on one of her X chromosomes. However, a male has the shortened Y chromosome; therefore, he has no gene to offset a gene for colorblindness on the X chromosome. As a result, if a male receives the recessive allele for colorblindness, he will be colorblind.

Hemophilia

Another example of sex-linked inheritance is a blood disease called ***hemophilia***. In hemophilia, the blood does not clot normally because an important blood-clotting protein is missing. The gene for hemophilia occurs on the X chromosome. As females have two X chromosomes, one X chromosome usually has the gene for normal blood clotting. Therefore, the female may carry the gene for hemophilia, but normally does not express hemophilia. In contrast, males have no offsetting gene on the shortened Y chromosome. Therefore, the gene for hemophilia expresses itself in the male.

Hemophilia affects approximately one male in every 10,000. On the other hand, few females—less than one in a million—suffer from this disorder. Although no cure has been developed, this blood disorder can be treated with injections of clotting factor proteins taken from the blood of healthy individuals.

Hemophilia Pedigree



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Blood Groups and Blood Types in Humans

Blood groups and types are very important, especially in medical procedures involving blood transfusions. Physicians must take care to be sure that the blood groups of the donor and the recipient are compatible. A transfusion of incompatible blood could lead to a violent reaction and even death.

Dominant and Recessive Alleles

The Rh blood group is one example of a trait that is determined by a single-gene, two-allele system—positive and negative. The positive allele (Rh+) is dominant, so persons who have two positive alleles (Rh+/Rh+), or one positive (Rh+) and one negative (Rh-), are said to be Rh-positive. Those with two negative alleles (Rh-/Rh-) are Rh-negative.

Blood Types and Multiple Alleles

Three basic human blood categories exist: *A*, *B*, and *O*. From these we get blood types *A*, *B*, *AB* and *O*, positive or negative. Recall from the previous lesson that a multiple allele is a type of gene that is determined by more than two alleles. The *ABO* blood group is an example of a multiple allele. This gene has three alleles—*IA*, *IB*, and *i*. To complicate matters further, the *IA* and *IB* alleles are codominant over the allele *i*. Alleles *IA* and *IB* are responsible for producing molecules called ***antigens***, which can be recognized by the immune system on the surface of the red blood cell. Allele *i* does not produce any antigens.

When medical workers describe blood groups, they usually mention both groups at the same time. For example, they may say that a patient has *AB*-negative blood, meaning that the person has both *A* and *B* antigens from the *ABO* gene and the negative allele from the *Rh* blood group. The most common blood type is *O*-positive; many people are *A*-positive, and some people have the rare *AB*-negative type of blood.

In the next section, we will begin to examine DNA and molecular genetics.

Multiple Alleles

Human ABO Blood Groups

Phenotype (blood group)	Genotype
A	I^AI^A or I^Ai
B	I^BI^B or I^Bi
AB	I^AI^B
O	ii

Career Bound

Phlebotomist—To become a phlebotomist, a person must have a high school education with classes in biology and chemistry. Further training in a medical assistant program at a technical school or junior college may also be required. Most phlebotomists work at hospitals or medical clinics taking blood samples from patients.

Life Principle



"Every human is marvelously and wonderfully fashioned as a unique individual of inestimable worth."

—Ronald E. Johnson, Ph.D.
Educator and author

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Discovery

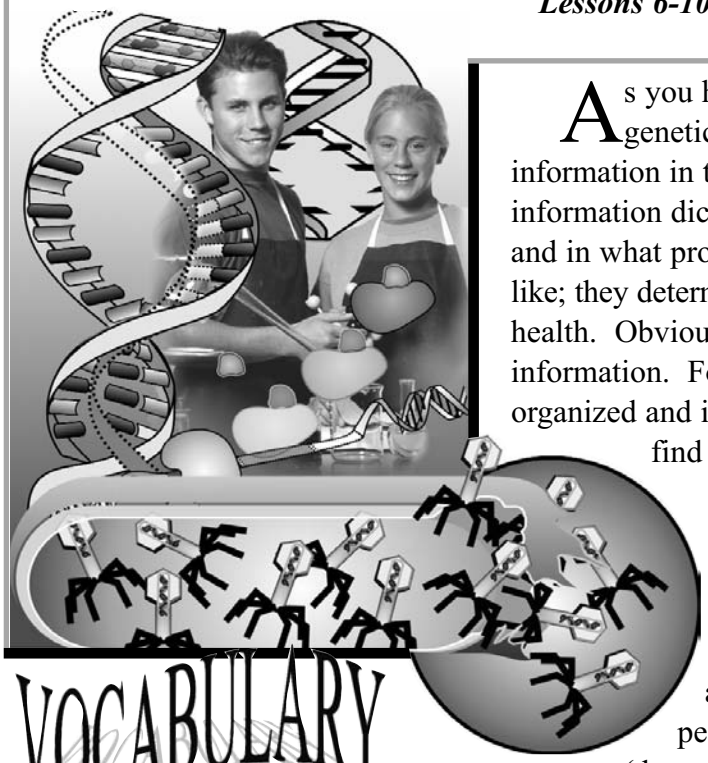
Lesson 6

Chapter 3

THE DISCOVERY OF DNA

Section 2

Lessons 6-10



As you have learned by studying Mendelian genetics, chromosomes are the bearers of genetic information in the form of genes. Genes contain information dictating what proteins our cells will make and in what proportions; they determine what we look like; they determine our predispositions to disease and health. Obviously, genes must contain a great deal of information. Fortunately, this information is highly organized and intelligently catalogued, just as you might find in a large library in a major university.

During the early part of the 20th century, scientists had already discovered that chromosomes were composed of two substances: DNA and protein. Scientists discovered that proteins were a diverse and complex group of molecules, but few people knew much about DNA (deoxyribonucleic acid). What has been discovered is that the structure of DNA is the most complex and elegant ***entity*** within the design of life.

The study of DNA structure and function has touched off a flurry of experiments into the molecular basis of inheritance, often called ***molecular genetics***. This is one of the most exciting fields of modern science. In less than 50 years, biologists have progressed from not even knowing that genes were made of DNA to the point that biologists can place a catalogue order for the ingredients needed to ***synthesize*** a particular gene in the laboratory.

VOCABULARY

Entity: something that has a distinct existence and objective reality

Molecular Genetics: science based on the activity of DNA (deoxyribonucleic acid) and the role of DNA in the production of proteins in the cell

Synthesize: to put together a substance chemically or biochemically

Virulent: disease producing and extremely dangerous

Transformation: process of reproduction in which genetic material is added to, or replaces portions of, a bacteria's DNA

BACTERIAL TRANSFORMATION

GRIFFITH'S EXPERIMENTS—1928

One of the most important steps in identifying DNA as the key to inheritance and genetics was an experiment done in 1928 by a British scientist named Fredrick Griffith. He was trying to identify a better way to fight pneumonia, a very

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serious disease of the lungs. In his experiment, Griffith isolated two types of bacteria that cause pneumonia. He called these types "smooth" and "rough" because of the appearance of the colonies that each type of bacteria produced. Griffith found that when samples of each type of bacteria were injected into laboratory mice, pneumonia (resulting in death) developed only in the mice injected with the smooth type of bacteria, whereas the mice injected with the rough type did not develop the disease.

In one experiment, Griffith heated a sample of smooth bacteria until they died, then injected the sample into some of the mice. These mice did not develop pneumonia, so Griffith concluded that the smooth bacteria needed to be alive to be ***virulent***. Griffith then mixed a sample of heat-killed, smooth bacteria with a sample of live, rough bacteria. By themselves, neither type of bacteria caused the mice to develop pneumonia. However, when he injected mice with this mixture of the two types, something unexpected happened. The mice became sick with pneumonia and died.

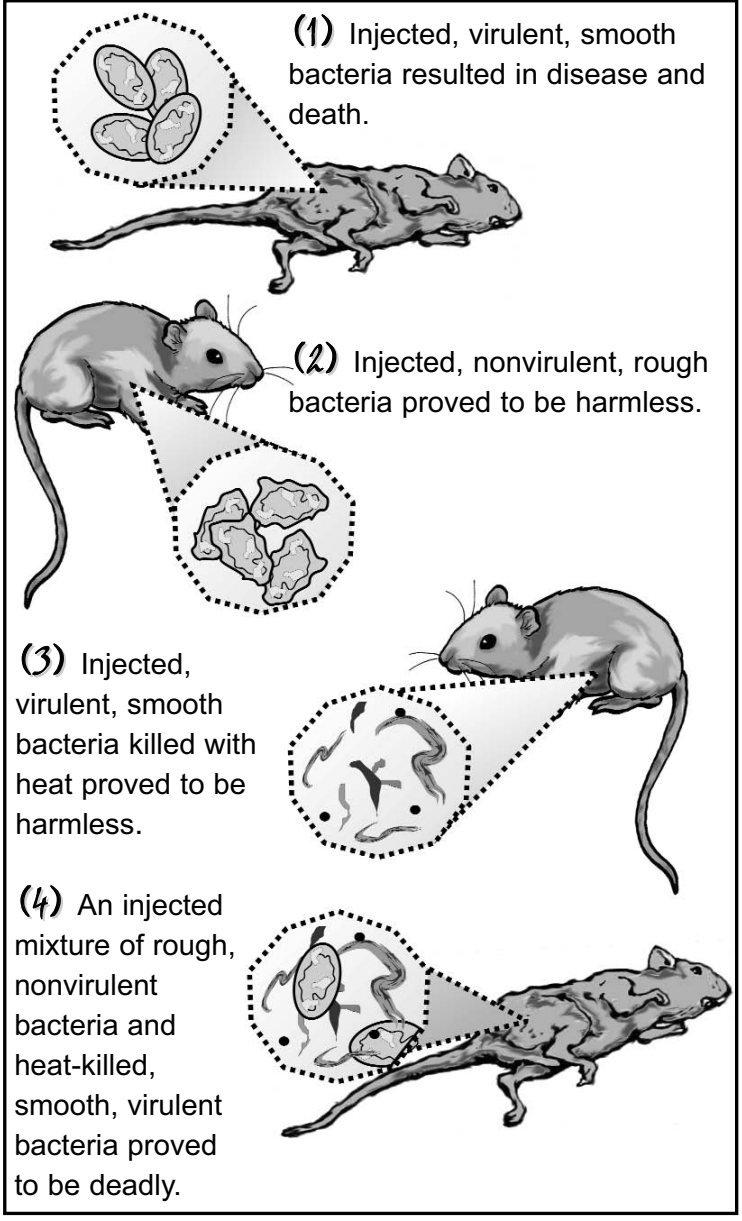
To determine which bacteria were responsible for causing the pneumonia, Griffith removed the lungs of the dead mice, recovered the live bacteria from them and grew colonies of the bacteria in laboratory culture dishes. The bacteria colonies that developed were the smooth, pneumonia-causing bacteria.

Griffith concluded that a mysterious molecule or group of molecules had changed the harmless, rough, live bacteria into virulent, smooth bacteria. Because one type

VOCABULARY

Bacteriophages: any virus that infects bacteria; also called a "phage."
Radioactive Isotopes: a form of an element that has a nucleus that gives off particles and energy; isotopes of an element vary in the number of neutrons
Radioactivity: the release of particles and energy from an isotope

Griffith's Experiments With Mice



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of bacteria was transformed into another, this process was called ***transformation***.

AVERY EXPERIMENTS—1944

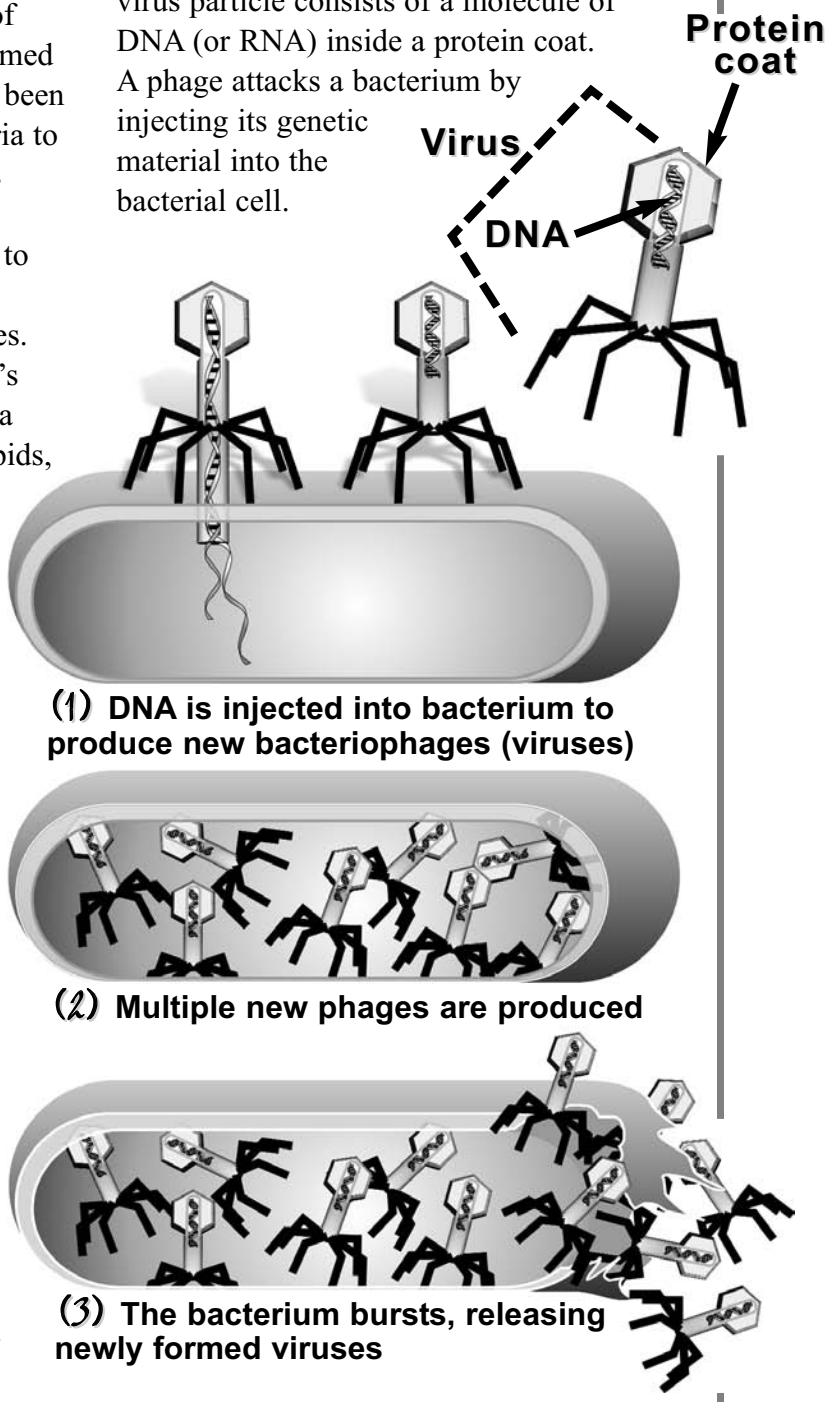
In 1944, Canadian biologist Oswald Avery realized that studying the process of transformation might be the key to identifying what we now call DNA—the molecule of heredity. Avery and his co-workers assumed that in Griffith's experiments, genes had been transferred from the dead, smooth bacteria to the live, rough bacteria. The researchers reasoned that if they discovered which molecule was needed for transformation to occur, lab technicians might be able to identify the molecules that make up genes.

In a series of experiments, Avery's team carefully treated heat-killed bacteria with enzymes that destroyed proteins, lipids, carbohydrates, and other molecules. None of these treatments affected the process of transformation. However, transformation was blocked when researchers destroyed a molecule called DNA—deoxyribonucleic acid. From these results, Avery concluded that *genes are made of DNA.*

This obvious conclusion—that DNA is the genetic material—was not widely accepted at that time, mainly because few biologists considered bacteria to be "real" organisms. Nearly ten years later, biologists realized that genetic information takes essentially the same form in viruses and in all organisms—from bacteria to plants to animals. We now know that during bacterial transformation, transforming DNA becomes incorporated into the genetic material (DNA) of the recipient bacterium and endows it with any genetic traits carried by the transforming DNA.

HERSHEY-CHASE EXPERIMENT—1952

In 1952, American scientists Alfred Hershey and Martha Chase carried out another experiment using ***bacteriophages*** that further supported the conclusion that genes are made of DNA. Bacteriophages (or *phage* for short) are viruses that attack bacteria. A virus particle consists of a molecule of DNA (or RNA) inside a protein coat. A phage attacks a bacterium by injecting its genetic material into the bacterial cell.



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The phage genetic material then "takes over" the genetic machinery of the bacterium, which causes the bacterium to make anywhere from a few to hundreds of new phages. Eventually, the bacterium bursts, releasing these newly formed viruses.

Hershey and Chase used ***radioactive isotopes*** in order to distinguish between the protein and the DNA of the phages. Most protein contains sulfur but not phosphorus, whereas DNA contains phosphorus but not sulfur. These scientists were able to label phage protein with radioactive sulfur, and phage DNA with radioactive phosphorus, and found that when the bacteria were infected with phage, the radioactive phosphorus in the phage always entered the bacterium, while all of the radioactive sulfur remained outside. This was strong evidence that the phage genetic material contained only DNA and no protein. This experiment convinced biologists around the world that genes were made of DNA.

RADIOACTIVE ISOTOPES

One way to trace molecules is to take advantage of an interesting property of matter—that not all of an element's atoms are identical. Elements have different isotopes, or atoms, that have the same numbers of protons but different numbers of neutrons in their nuclei. For example, while the nuclei of the different hydrogen isotopes each contain 1 proton, they contain 0, 1,or even 2 neutrons.

Although the common isotopes of many elements are stable, some isotopes are unstable, which means their nuclei release small particles or rays of energy. This release of particles, or energy, is called ***radioactivity***. Under the proper safety conditions, radioactivity can be readily observed in the science laboratory. As a result, radioactive isotopes provide biologists with a useful way to label molecules, allowing them to be identified as they move from one place to the next.

In the next lesson, we will be examining the elegant design of DNA and its powerful ability to replicate.

LIFE PRINCIPLE

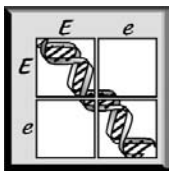


"To raise new questions, new possibilities, to regard old problems from a new angle, . . . requires creative imagination and marks real advance in science."

—Albert Einstein (1879-1955)
German-American physicist and mathematician

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Molecular Genetics

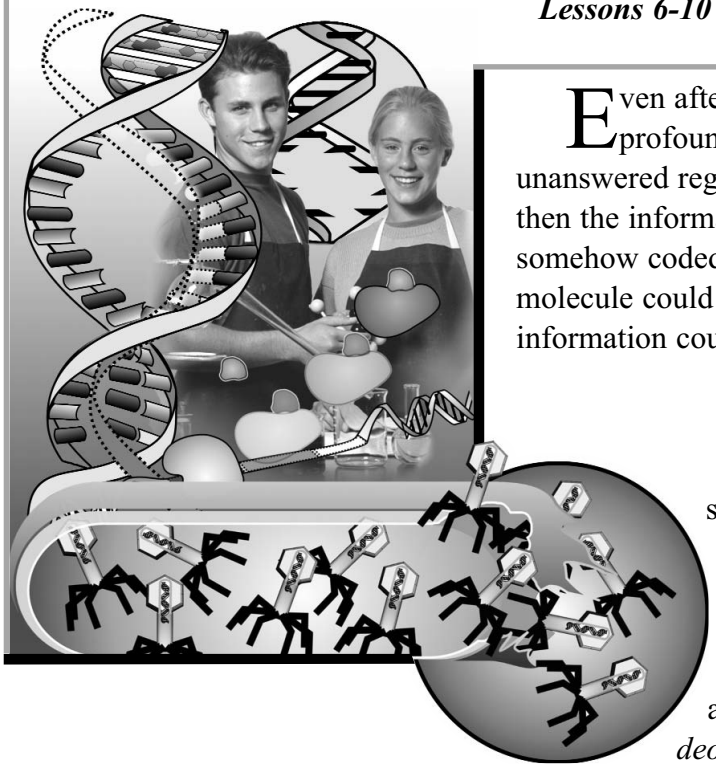
Lesson 7

Chapter 3

Section 2

Lessons 6-10

DNA STRUCTURE AND REPLICATION



Even after Hershey and Chase's simple but profound conclusions, questions still remained unanswered regarding DNA. If genes are made of DNA, then the information that genes contain must be somehow coded in the DNA. Scientists wondered how a molecule could carry information and how that information could be copied each time a cell divides.

DNA STRUCTURE

The first thing to examine was the structure of the DNA molecule. As you learned in chapter one, DNA is made up of ***nucleotides***. A nucleotide is made of three parts: a phosphate group, a nitrogenous (nitrogen-containing) base and a 5-carbon sugar which, in DNA, is *deoxyribose*.

DNA is made of four different types of molecules, called nucleotide *bases*. These are adenine, cytosine, guanine and thymine. Adenine and guanine are classified as *purines*, that pair with thymine and cytosine which are classified as *pyrimidines*.

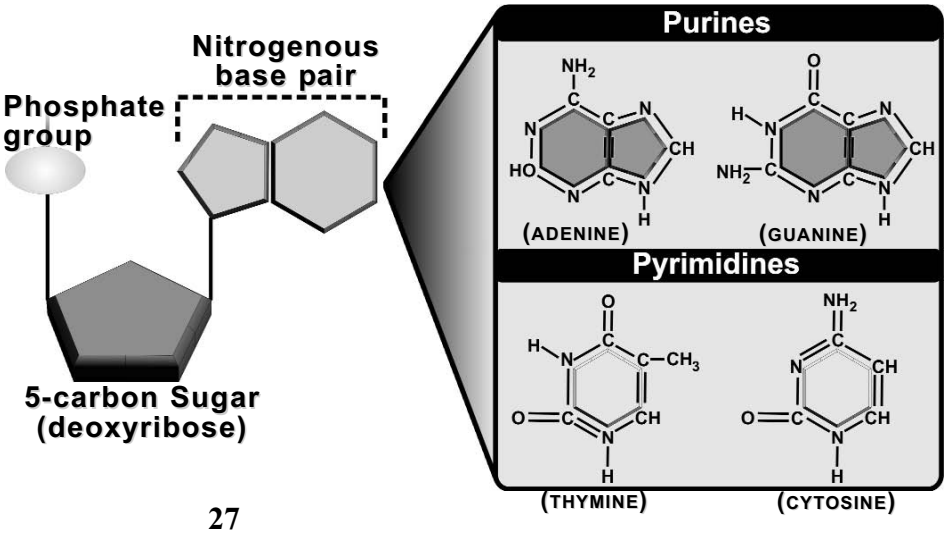
VOCABULARY

Nucleotide: compound made of a phosphate group, a nitrogenous base, and a 5-carbon sugar; forms the basic subunit of DNA

Chargaff's Rule: based on the discovery that DNA nucleotides contain equal amounts of cytosine and guanine, as well as adenine and thymine

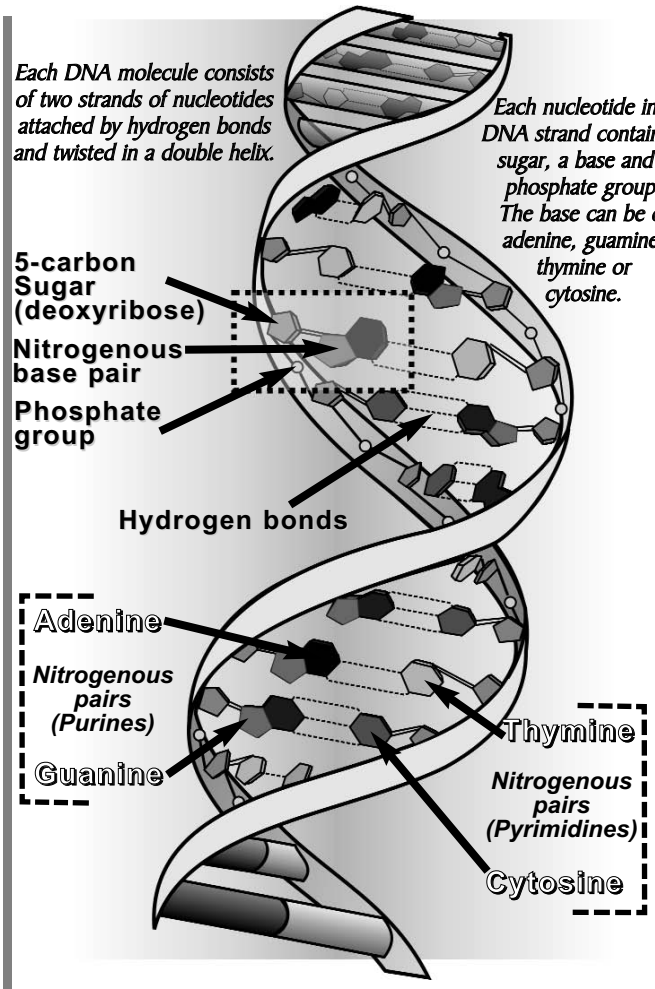
X-ray diffraction: a technique in which the scattering pattern of X-rays is recorded on film to be studied

Nucleotide Composition



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VOCABULARY

Double-helix: a term for the form of DNA, referring to its two adjacent nucleotide strands wound into a spiral shape
DNA replication: process in which DNA is copied
Chromatin: material of chromosomes that consists of DNA and proteins
Histones: proteins which are attached to chromosomes which may play a role in protecting and organizing DNA
Nucleosomes: tiny particle formed by histones which help to fold and package DNA
Propensity: natural inclination

CHARGAFF'S RULE

In 1950, American biochemist Erwin Chargaff discovered an interesting fact about the nucleotides in DNA. Chargaff studied the nucleotide composition of many different samples of DNA and found that the amount of each type of nucleotide differed in each sample. However, the amounts also followed a distinct pattern. The amounts of adenine (A) and thymine (T) were almost always equal, as were the amounts of cytosine (C) and guanine (G). This pattern has been proven true for the DNA in most species and is now known as ***Chargaff's Rule***. This finding eventually became a major clue in determining the structure of DNA.

FRANKLIN'S X-RAY PATTERN OF DNA

In 1951, English scientists Rosaline Franklin and Maurice Wilkins were studying the DNA molecule with a technique called ***X-ray diffraction***. In this technique, a powerful X-ray beam is aimed at a sample, then the scattering pattern of the X-rays is recorded on film. By itself, these patterns did not reveal the actual structure of DNA. However, the patterns did contain important clues, just as did Chargaff's discovery.

THE WATSON AND CRICK MODEL

In the winter of 1953, American scientist James Watson and British scientist Francis Crick had been investigating the structure of DNA. When they saw the work of Franklin and Wilkins, Watson and Crick realized that the X-ray patterns contained important clues. Within a few weeks, Watson and Crick had solved the mystery of the DNA structure.

The X-ray patterns of Franklin and Wilkins suggested that DNA contained two

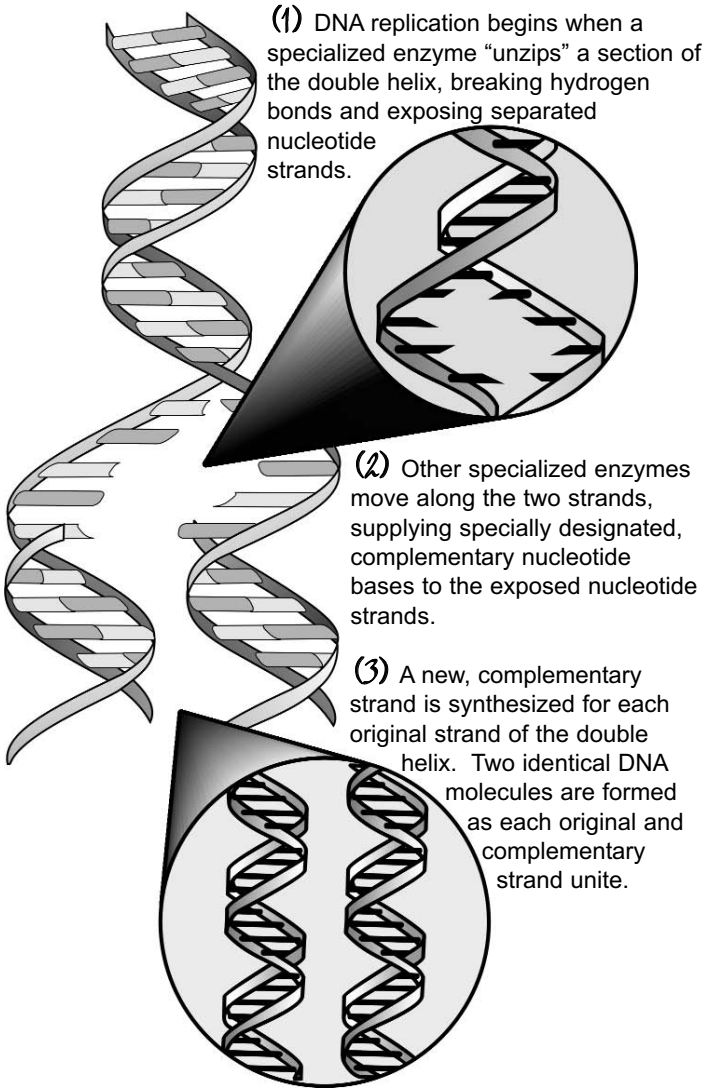
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strands, one twisted around the other. The structure worked out by Watson and Crick consists of two strands of DNA and is called the DNA ***double-helix***. The strands are arranged like a twisted, spiral ladder, with the sides being the sugar-phosphate "backbones" of the two strands, and the rungs being the nitrogenous bases linked together by bonds. The bases of each strand are arranged very close to each other. Watson and Crick discovered that hydrogen bonds could form between adenine (A) and thymine (T), and also between cytosine (C) and guanine (G). These pairs of nitrogenous bases are called *base pairs*, and the hydrogen bonds between the nitrogenous bases in a base pair provide the force needed to hold the strands together.

Everything seemed to fall into place at this point. The sequence of nucleotides on one strand matched perfectly the complementary sequence of the other strand. This base-pairing pattern also explained Chargaff's rules. Chargaff's rules had stated that DNA contains equal amounts of cytosine and guanine, as well as adenine and thymine. These are the pairs that form hydrogen bonds with each other. Therefore, for every adenine in a double-stranded DNA molecule, one thymine had to exist and for every cytosine, one guanine had to be present.

Watson and Crick became tremendously excited by the simple, yet elegant model they had constructed and quickly wrote up a two-page paper for publication. As Watson remarked, "It was too pretty not to be true." In 1962, Watson, Crick and Wilkins received the Nobel Prize—the highest award the international community can give for scientific discovery. (Franklin also might have been awarded this honor, but she died in 1958 and the Nobel prize is given only to living scientists.) In 1981, Crick published a book entitled *Life Itself, Its Nature and Origin.* Although a committed evolutionist, he wrote: "An honest man, armed with all the knowledge available to us now, could only state that, in some sense, the origin of life appears at the moment to be almost a miracle."

DNA Replication



DNA Replication

Before a cell divides, the DNA replicates, or duplicates itself, so that both the offspring of the cell receive the same genetic information as that of the parent cell. Before

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Watson and Crick had developed the double-helix model, biologists had difficulty imagining how any molecule could be duplicated. However, when biologists noticed that DNA had two strands bound to each other by base-pairing, scientists could easily see how DNA might be duplicated. If the two strands of DNA are separated, each strand can act as a "mold", or template, to produce a complementary strand.

DNA is copied in a process called ***DNA replication***. DNA replication takes place during the synthesis phase (S-phase) of the cell cycle, and the replication is carefully controlled by specialized enzymes. These enzymes separate or "unzip" the DNA double-helix, then begin to synthesize new strands that are complementary to the exposed bases. When DNA replication is complete, a cell has duplicated all its genetic information and is ready to begin cell division.

Structure of Chromosomes

Although chromosomes contain DNA, their structure is much more complex. Chromosomes are made of a material called ***chromatin***, which contains DNA and various different proteins. A very important class of these proteins is called ***histones***, a class of proteins that bind directly to DNA. Biologists believe that one possible role of histones is to protect the DNA from being broken down by enzymes in the cell nucleus that attack free DNA. Histones also form tiny particles, called ***nucleosomes***, which help to fold and package DNA. This is a very important process because DNA in a single chromosome may be as much as 10,000 times as long as the chromosome itself. Scientists have learned a great deal about the structure of DNA and the way DNA proteins are organized in chromosomes. However, much is still left to be learned about the workings of this incredibly complex DNA structure.

Think About This!

You have probably been frustrated by the ***propensity*** of cords or strings to weave themselves into incredible tangles! Suppose you were asked to take two long strands of fisherman's monofilament line—125 miles long—and then form it into a double helix structure and neatly fold and pack this line so it would fit into a basketball. Furthermore, you would need to ensure that the double-helix could be unzipped and duplicated along the length of this line, and the duplicate copy removed, and the master returned, all without tangling the line. You are probably saying to yourself "Impossible!"

This is exactly what happens in the billions of cells in your body every day. Scale the basketball down to the size of a human cell and the fisherman's line scales down to six feet of DNA. Although each cell is about one fifth of what the eye can see, it has to keep its six feet of DNA neatly coiled and free of knots, tightly packed into the tiny nucleus of the cell.*

This is an incredible accomplishment which happens over and over, without fail, as long as you live. We are truly wonderfully and marvelously made.

In the next lesson, we will examine more about the simple, yet sophisticated process by which DNA replicates.

*Used by permission of Chuck Missler in *Cosmic Codes*

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WATCH VIDEO:
DNA



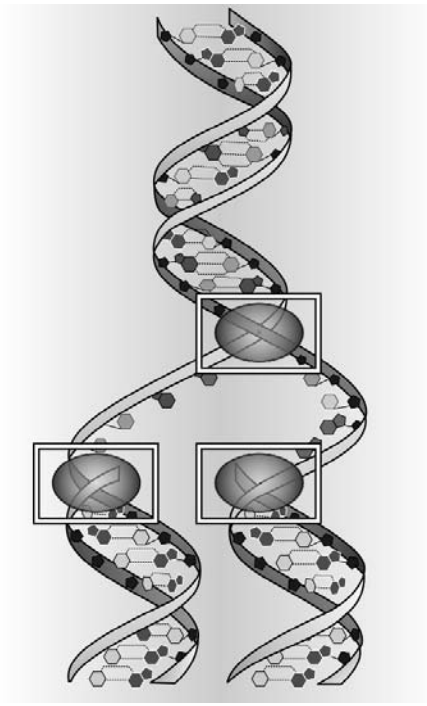
LIFE PRINCIPLE

"Science is complex and speculative, and it's ever changing."

—Sara Bernard
Author

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Molecular Genetics

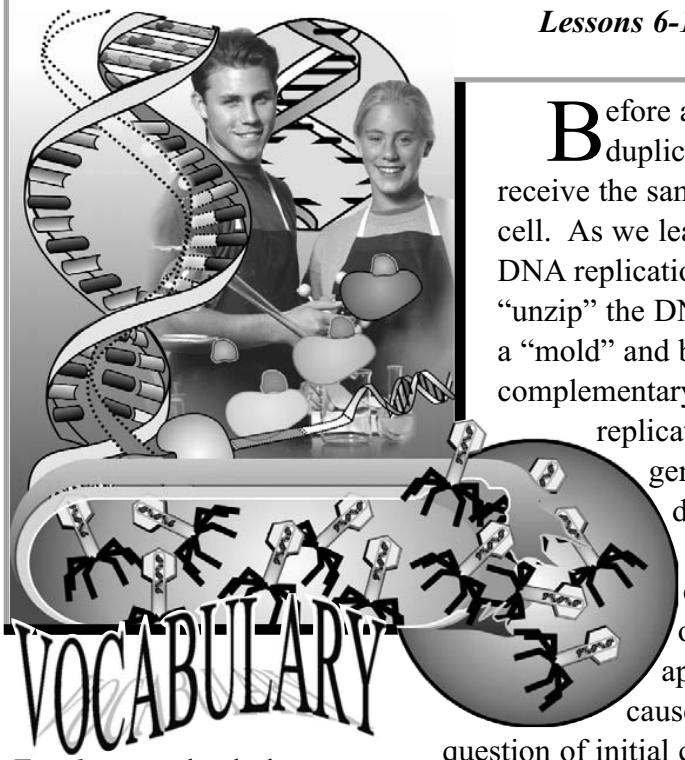
Lesson 8

Chapter 3

THE DNA REPLICATION PROCESS

Section 2

Lessons 6-10



Before a cell divides, the DNA replicates, or duplicates, itself so that both offspring of the cell receive the same genetic information as that of the parent cell. As we learned in the previous lesson, the process of DNA replication begins when specialized enzymes "unzip" the DNA double-helix. Each of the strands acts as a "mold" and begins to synthesize new strands that are complementary to the exposed bases. When DNA replication is complete, a cell has duplicated all its genetic information and is ready to begin cell division.

Discovery of the properties of DNA expanded scientific discussion of the origin of life. The complex structure and application of DNA to reproduction of life caused many biologists to reflect on the question of initial cause and the possibility of intelligent design. Discovery of the precision and predictability of DNA replication caused many other scientists to question and reconsider the theory that life began by accident and evolved by chance through the passage of time. Biologists began to hypothesize about the design of DNA.

In 1958, before the exact mechanism of DNA was known, two scientists, Matthew Meselson and Franklin Stahl, developed some experiments to show the process by which DNA duplicated itself. Meselson and Stahl formulated three hypotheses that attempted to explain what was already known about DNA replication:

CONSERVATIVE REPLICATION

This hypothesis suggested that the two strands of the parent DNA molecule act as ***templates*** for a completely new double-stranded molecule. The parent DNA is preserved intact and unites with one daughter cell while the new molecule unites with the other daughter cell.

VOCABULARY

Template: a molecule that serves as a pattern for another macromolecule

Semi-conservative replication: the method by which DNA is replicated; each daughter cell receives one strand of the original DNA

DNA polymerase: the enzyme which is responsible for joining the nucleotides together during DNA replication

Okazaki fragments: new fragments of DNA that are joined together by the enzyme *DNA ligase*

DNA ligase: the enzyme which joins the Okazaki fragments together to form a new strand of DNA

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Semi-Conservative Replication

According to this hypothesis, the two strands of the parental molecule separate like the two sides of a zipper, and each acts as the template for formation of one new strand which then becomes bound to it to form a complete molecule. Each daughter cell inherits a DNA molecule that is a hybrid, consisting of one new and one parental strand.

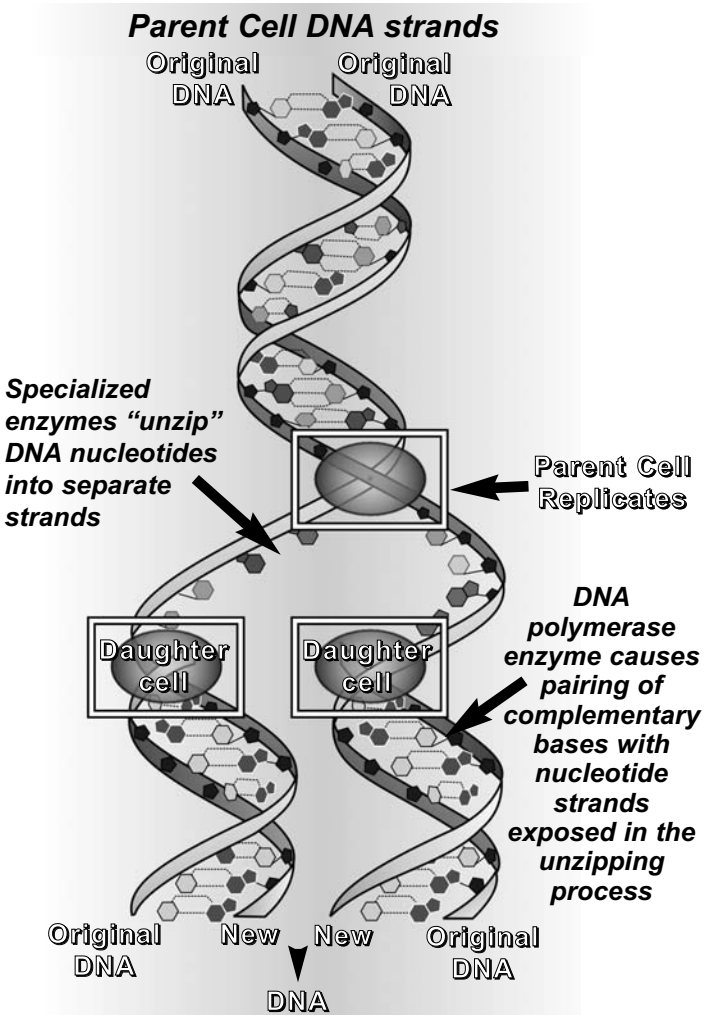
Dispersive replication

This hypothesis suggests that the parental DNA is broken up into short segments and used as templates for the formation of two, new double helixes which are then somehow joined together.

In some very simple experiments using radioisotopes, Meselson and Stahl showed that the first and third of these hypotheses could be disproved, and their results provided strong support for the theory of ***semi-conservative replication***. (Note that a hypothesis is a tentative assumption made to test its logical or empirical consequences which are based on observation or experience. Therefore, it is possible to *disprove* a hypothesis if the data does not agree with predictions of what should have happened if the hypothesis were true.)

What Meselson and Stahl concluded is that DNA replication begins with the separation of the two strands along the weak hydrogen bonds linking the paired bases. As the two strands separate, the nucleotide bases on each strand are exposed. The exposed bases then attract their complementary bases, which are available in the nucleus. The enzyme ***DNA polymerase*** joins all the nucleotide components to one another, forming a long strand of nucleotides. Thus, the old strand of DNA directs the synthesis of a new strand of DNA through what is called

DNA Replication



complementary base pairing. The old strand then unites with the new strand to form a double helix.

Researchers have found what they call ***Okazaki fragments*** (named after their discoverer) which are short pieces of DNA. Apparently, DNA is replicated to form these Okazaki fragments which are then joined together by an enzyme known as ***DNA ligase.***

In the next lesson, we will examine how RNA acts as a very "special agent" for DNA to carry out protein synthesis.

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LIFE PRINCIPLE



"There are only two ways to live your life. One is as though nothing is a miracle. The other is as though everything is a miracle."

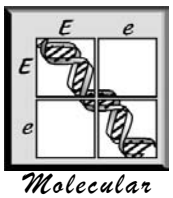
—Albert Einstein (1879-1955)
German-American physicist and mathematician

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Molecular Genetics

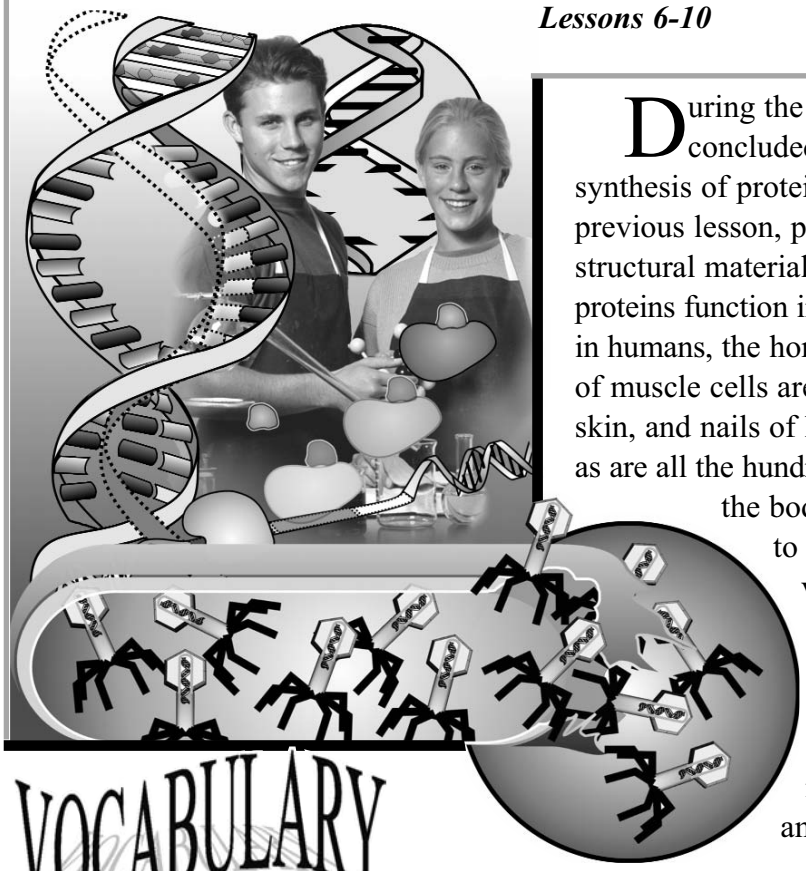
Lesson 9

Chapter 3

PROTEIN SYNTHESIS

Section 2

Lessons 6-10



During the 1950s and the 1960s, biologists concluded that DNA is essential in the synthesis of proteins. As you have learned in a previous lesson, proteins are used in enzymes and as structural materials in cells. Many specialized proteins function in cellular activities. For example, in humans, the hormone, insulin, and the filaments of muscle cells are composed of proteins. The hair, skin, and nails of humans are composed of proteins, as are all the hundreds of thousands of enzymes in the body. Obviously, proteins are critical to life, and how they are made is a very important function for the continuation of life.

For protein synthesis to occur, several essential materials must be present. One essential material is a supply of the twenty amino acids which comprise most

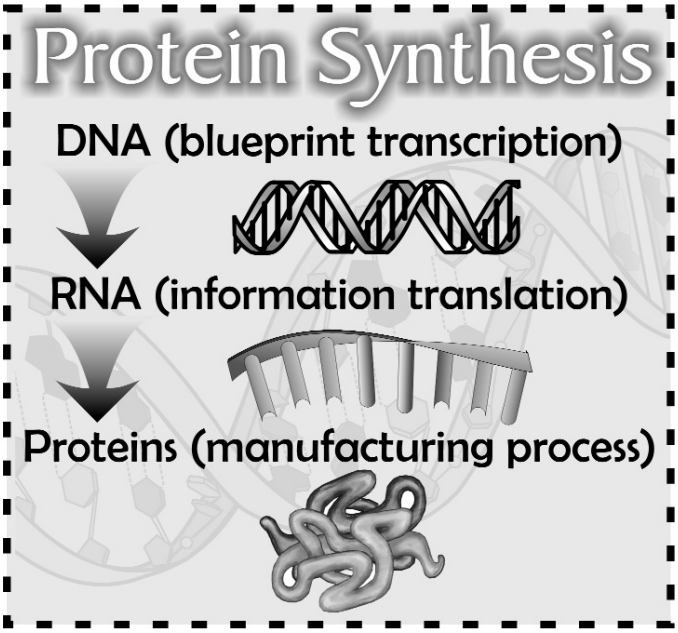
VOCABULARY

RNA (ribonucleic acid): a principal type of nucleic acid that carries out the instructions coded in DNA.

Messenger RNA (mRNA): a form of RNA that carries genetic information from the DNA in the nucleus to the ribosomes in the cytoplasm

Ribosomal RNA (rRNA): a form of RNA molecule that carries out the instructions coded in DNA

Ribosomes: small particles in the cell that are made of RNA and protein; sites of protein assembly



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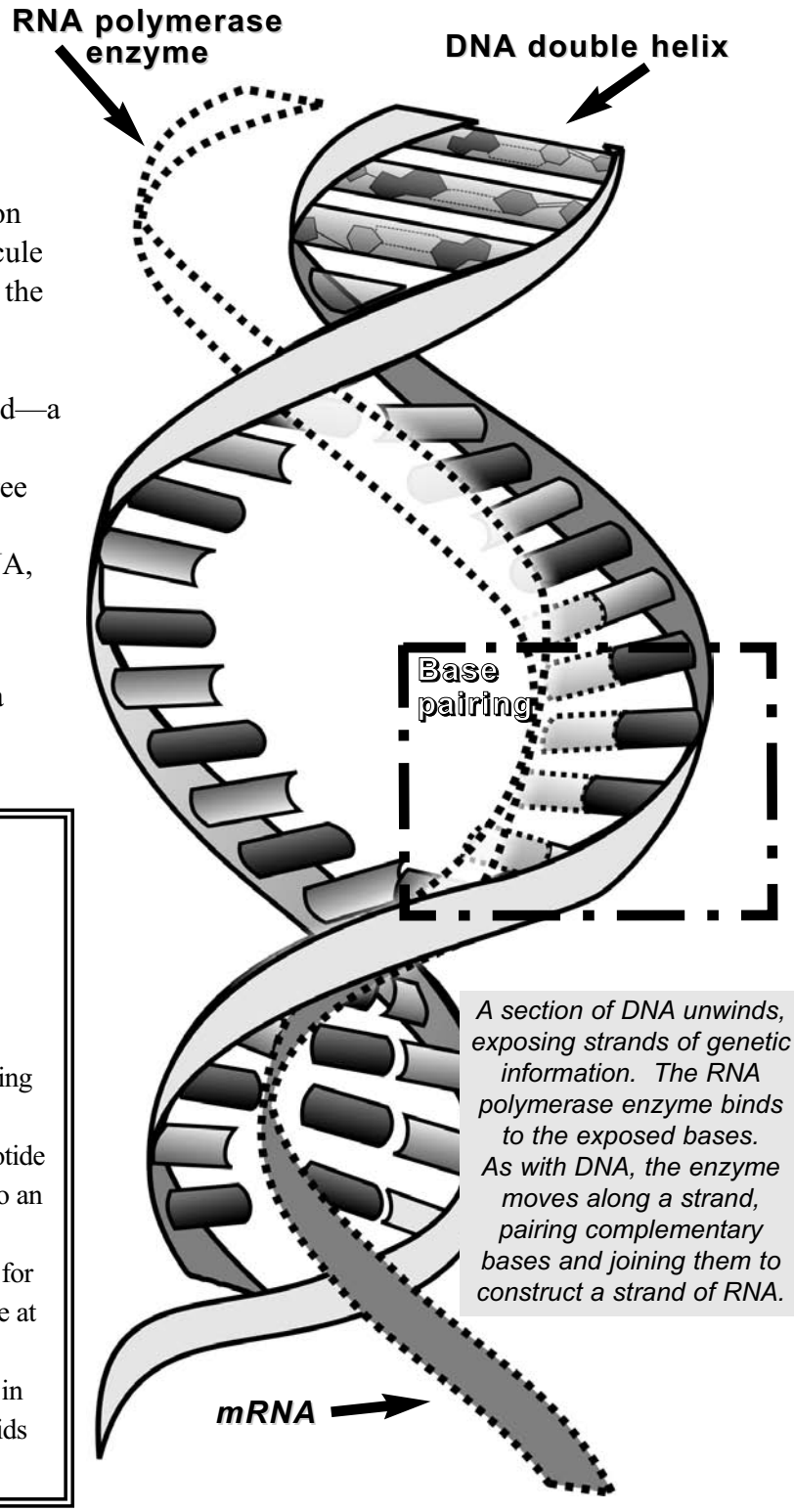
proteins. Another essential element is a series of enzymes that will function in the process. Of course, something in DNA must be present to carry the code for making protein. The component that must be present in DNA is the decoding agent, ***RNA (ribonucleic acid)***.

RNA Structure

To decode the genetic information contained in DNA, the cell uses a molecule called RNA—ribonucleic acid. RNA is the principal molecule that carries out the instructions coded in DNA.

Like DNA, RNA is a nucleic acid—a macromolecule formed by nucleotides. However, RNA differs from DNA in three main ways:

1. The sugar in RNA is *ribose*. In DNA, the sugar is *deoxyribose*.
2. RNA is generally *single-stranded*. Recall that the structure of DNA is a *double-stranded helix*.
3. RNA contains uracil instead of thiamine. Like thiamine, uracil can form hydrogen bonds with adenine.



A section of DNA unwinds, exposing strands of genetic information. The RNA polymerase enzyme binds to the exposed bases. As with DNA, the enzyme moves along a strand, pairing complementary bases and joining them to construct a strand of RNA.

VOCABULARY

Transfer RNA (tRNA): form of RNA that carries an amino acid to the ribosomes during the assembly of a protein

Transcription: process in which the nucleotide sequence of a DNA molecule is copied into an RNA molecule

RNA polymerase: the enzyme responsible for producing RNA from DNA, one nucleotide at a time

Genetic code: language of the instructions in DNA and RNA that code for the amino acids in proteins

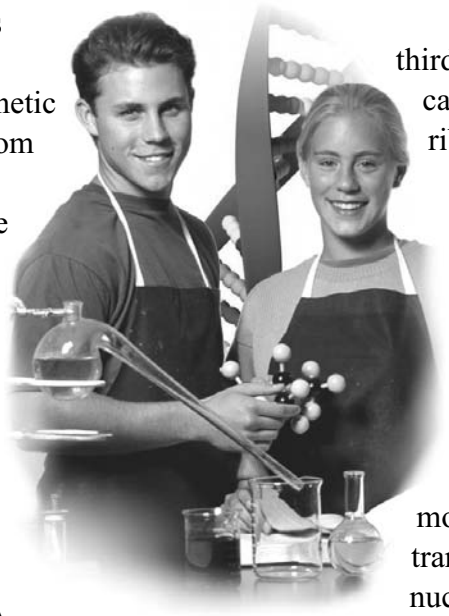
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TYPES OF RNA

Three types of RNA are involved in the synthesis of protein. As you will see in this lesson, each form of RNA plays a distinct role in the production of proteins.

Messenger RNA (mRNA) is synthesized in the nucleus from the DNA molecules. During the synthesis, the genetic information is transferred from the DNA molecule to the *mRNA* molecule. As its name implies, *messenger RNA* then carries copies of these instructions to the rest of the cell. The messenger process is absolutely faultless in precision. The intricate and delicate process overwhelms human understanding. This discussion of DNA and RNA may seem too abstract for youth; however, the purpose of these lessons is to express the complex and sophisticated manner in which life reproduces according to incredible, yet mysterious principles.



Ribosomal RNA (rRNA) is used to manufacture ***ribosomes***. Ribosomes are tiny particles of *rRNA* and protein, and are the "chemical workbenches" where amino acids are linked to one another to synthesize proteins. Ribosomes are each composed of two subunits, the smaller one fitting into the larger one much like a baseball fits into a cupped baseball glove.

Transfer RNA (tRNA) is a third type of RNA which is used to carry amino acids to the ribosomes for protein synthesis.

The *mRNA*, *rRNA*, and *tRNA* in a cell are each produced through transcription by genes in the DNA.

TRANSCRIPTION

Transcription is the process by which RNA molecules are made. In transcription, *part* of the nucleotide sequence of a DNA molecule is copied into RNA. For this reason, DNA is said to act as a template for RNA. A template is a pattern, or guide, from which a copy can be made.

To begin, the enzyme ***RNA polymerase*** binds to an area of one of the DNA molecules in the double helix. (The other strand remains dormant.) The enzyme moves along the DNA strand and "reads" the nucleotides one by one. It selects complementary bases from available nucleotides and positions them in an RNA molecule according to the principle of *complementary base pairing*. You have learned that DNA and RNA contain four different nucleotide bases. Base *A* (adenine) always pairs whith base *T* (thymine), and base *C* (cytosine) always pairs with base *G* (guanine). However, RNA contains *uracil* (*U*), rather than *thymine* found in DNA. The DNA *A's* would normally become *T's*; but in transcription, DNA *T's* become RNA *U's*.

VOCABULARY

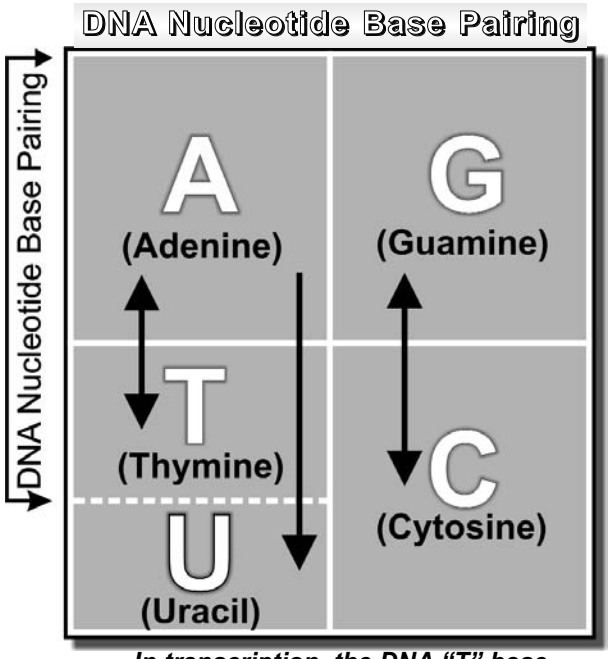
Codon: group of three nucleotides that codes for one of the twenty amino acids

Translation: process by which the nucleotides in mRNA are decoded into a sequence of amino acids in a polypeptide.

Anticodon: three complementary nucleotides in transfer RNA that bind to a codon in mRNA

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In transcription, the DNA "T" base becomes a "U" in RNA

Thus, a nucleotide sequence of *AACT* in DNA would be copied as *UUGA* in RNA. This careful base-pairing ensures that each RNA molecule carries a copy of the coded instructions in the DNA sequence. The RNA polymerase knows where to begin and end transcription because of a special "start" and "stop" sequence in the DNA code.

The Genetic Code

The study of the genetic code is fascinating. The following paragraphs are admittedly a bit bewildering. They are, however, wonderful evidence that the genetic code is a mystery which a growing number of scientists argue cannot be explained by theories of chance and accident. These scientists maintain that the simultaneous manufacturing of proteins and amino acids are too precise to be the result of chance over eons of time.

Proteins are made from polypeptides; polypeptides are made from 20 different amino acids. The order of the amino acids determines the polypeptide's characteristics.

The instructions encoded in DNA specify the order in which the 20 different amino acids are put together for each specific protein. The language of the instructions in DNA and RNA is called the ***genetic code***. It consists of the sequence of nitrogenous bases in the DNA.

The number of nucleotides is read in groups of three, so that each "word" of the genetic code is three letters long. Thus, in theory, the genetic code could express 64 different words, or ***codons***, which are more than enough to produce a unique code for

Genetic Code Codons Chart

Each amino acid has a 3-letter code, is designated by the first letters of the mRNA bases and is arranged in a precise sequence

(1) ***The first letter, or base, in a codon is placed vertically down the left side of the chart.***

(2) ***The second letter, or base, of the codon is placed horizontally along the top of the chart.***

(3) ***The third letter, or base, of the codon is listed vertically down the right side of the chart.***

1st \ 2nd	*Uracil*	*Cytosine*	*Adenine*	*Guanine*	
U	Phenylalanine Phenylalanine Leucine Leucine	Serine Serine Serine Serine	Tyrosine Tyrosine *Stop* *Stop*	Cysteine Cysteine *Stop* Tryptophan	U C A G
C	Leucine Leucine Leucine Leucine	Proline Proline Proline Proline	Histidine Histidine Glutamine Glutamine	Arginine Arginine Arginine Arginine	U C A G
A	Isoleucine Isoleucine Isoleucine Methionine	Threonine Threonine Threonine Threonine	Asparagine Asparagine Lysine Lysine	Serine Serine Arginine Arginine	U C A G
G	Valine Valine Valine Valine	Alanine Alanine Alanine Alanine	Aspartic acid Aspartic acid Glutamic acid Glutamic acid	Glycine Glycine Glycine Glycine	U C A G

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each of the twenty amino acids. In fact, researchers have discovered that more than one code exists for most of the amino acids. Scientists have discovered 64 possible codons of the genetic code. You will notice that six different codons specify the amino acid *leucine*, and six others specify the amino acid *arginine*.

In most molecules of *mRNA*, the AUG codon is the "start" codon. Notice that AUG is also the codon for methionine, which means that methionine is usually the first amino acid to be used when a polypeptide chain is assembled.

Three codons—UAA, UAG, and UGA—serve as stop signals. Like a period at the end of a sentence, these codons signify the end of a genetic message and the end of a polypeptide.

TRANSLATION

Translation is the process by which the genetic code is used to produce a protein. This process begins with the arrival of the *mRNA* molecule at the "workbench" ribosome, made of *rRNA* and protein. While *mRNA* was being synthesized at the DNA site, *tRNA* molecules were uniting with their specific amino acids.

After it arrives at the ribosomes, the *mRNA* molecule exposes its bases in sets of three, the codons. Each codon has a complementary codon called an ***anticodon*** on a *tRNA* molecule. The *tRNA* molecule matches its anticodon with the *mRNA* codon and then deposits the appropriate amino acid. The next codon of the *mRNA* is exposed, and the complementary anticodon of a *tRNA* molecule is positioned next to the first amino acid and the two are linked. The ribosomes are responsible for joining the two amino acids and cutting the bond between the amino acid and its *tRNA* molecule. After the *tRNA* has released its amino acid to this growing polypeptide chain, the *tRNA* molecule is free to go back into the cytoplasm to link up with new molecules of amino acids.

The ribosome advances along the *mRNA*, attracting new *tRNA* molecules and amino acids. This process continues until the ribosome reaches one of the three stop codons. The result is a complete polypeptide. Scientists who understand this intricate, precise and predictable, life-sustaining process simply exclaim, "Wow!"

Dr. Richard Dawkins, Oxford University evolutionary zoologist, noted: "The machine code of the genes is uncannily computer-like!".

In the next lesson, we will explore the amazing microworld of gene expression, transcription and specialization.

LIFE PRINCIPLE

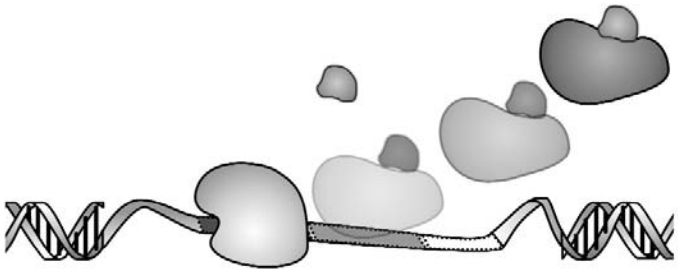


"A little science estranges a man from God; a lot of science brings him back."

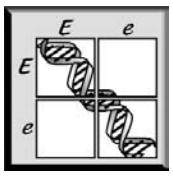
—Sir Francis Bacon (1561-1626)
English statesman and scientist

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Molecular Genetics

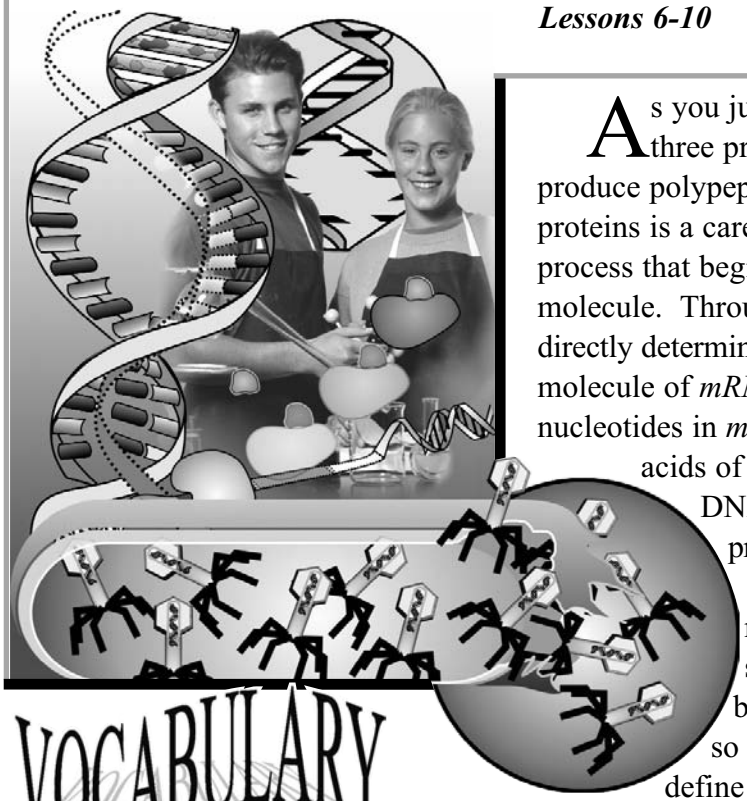
Lesson 10

Chapter 3

GENE EXPRESSION

Section 2

Lessons 6-10



As you just learned in the previous lesson, the three principal forms of RNA work together to produce polypeptide proteins. The synthesis of proteins is a carefully orchestrated, fabulously designed process that begins with a coded message on a DNA molecule. Through transcription, a section of DNA directly determines the sequence of nucleotides in a molecule of *mRNA*. Then, through translation, the nucleotides in *mRNA* are translated into the amino acids of a protein. In this way, a section of DNA—a gene—directs the synthesis of proteins.

Reproduction of the cell represents a complex effort to synthesize proteins correctly. You may be wondering why all these proteins are so important to life. Recall that genes define everything about an organism—the color of flowers, the height of plants, the type of human blood, the sex of a newborn baby. Your genes define your human characteristics.

Remember that many proteins are enzymes that catalyze and carefully regulate chemical reactions. Thus, a gene could control flower color by coding for an enzyme that helps to produce a pigment. Another gene could determine blood type by coding for an enzyme that helps to produce complex molecules in red blood cells. Proteins from other genes regulate the rate and pattern of growth throughout an organism, controlling its size and shape.

In fact, proteins are the keys to almost everything that living cells do. In addition, by coding for all the proteins of life, DNA is the molecular key to all of life.



VOCABULARY

Operon: a region of the DNA molecule used for gene regulation processes

Repressor: the repressor gene codes for the repressor protein; the repressor protein blocks a gene's transcription by binding to the operator

Operator: special region of DNA to which the repressor binds

Inducer: something that prompts another entity to action; specifically, a substance capable of activating a structural gene by combining with and inactivating a genetic repressor

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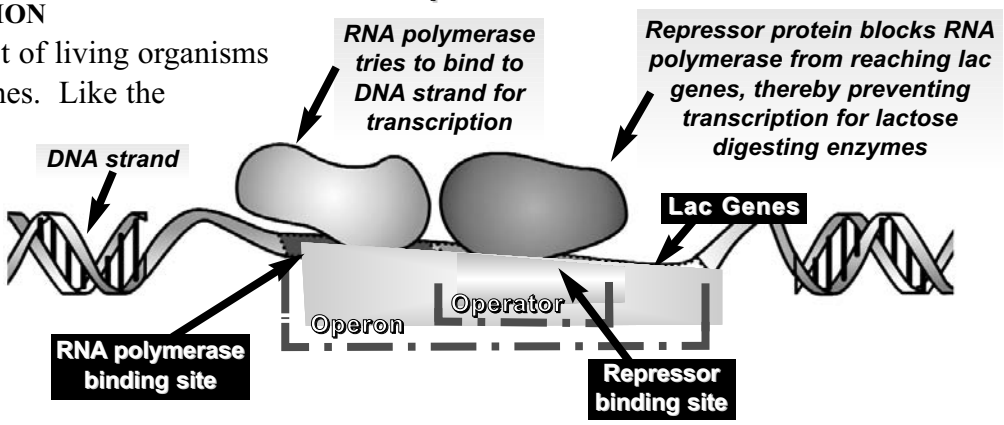
Gene Expression

Even the simplest of living organisms contain thousands of genes. Like the thousands of books in a library, not all genes in the cell's chromosomes are read at the same time. In fact, only a small fraction of the cell's genes are active at any given time.

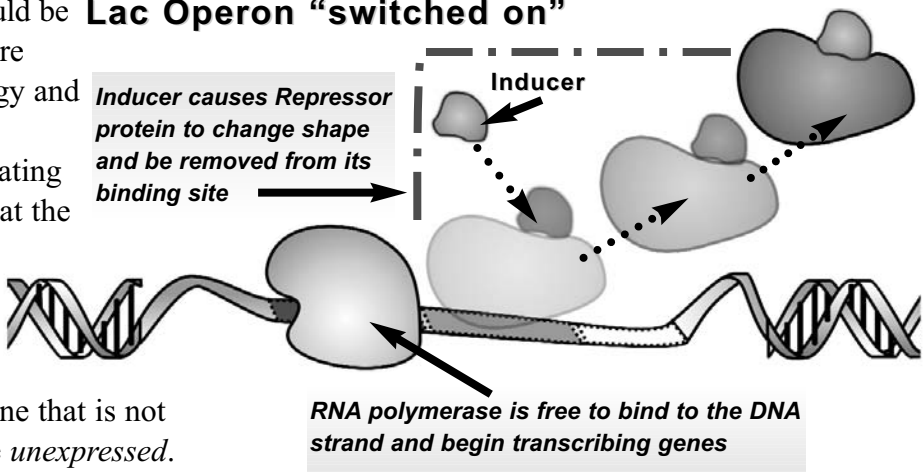
A cell that transcribed all its genes at the same time would be making many proteins that were not needed, thus wasting energy and raw materials. Fortunately, a sophisticated method of regulating gene transcription exists so that the cells function very efficiently.

A gene that is transcribed into *mRNA* is said to be *expressed*, and a gene that is not being transcribed is said to be *unexpressed*. An expressed gene is sometimes referred to as being "turned on", and an unexpressed gene is referred to as being "turned off."

Lactose Absent: Transcription Halted: Lac Operon "switched off"



Lactose Present: Transcription Proceeds: Lac Operon "switched on"



Many questions that researchers have had about gene expression and control have been answered by studying a bacterium called *Escherichia coli* or *E-coli* for short. *E-coli* contains about 2000 genes. *E-coli* uses three enzymes to digest *lactose*, the primary sugar found in milk products. To operate at optimum efficiency, *E-coli* would make these enzymes only when needed, such as when lactose is present. Amazingly, researchers have verified that is exactly what this little bacterium does.

A region of DNA known as an ***operon*** controls the gene regulation process. In *E-coli*, the operon includes at least five genes which operate as follows:

1. Three genes, called *lac genes*, code for the enzymes which digest lactose.

VOCABULARY

Introns: intervening sequence that is removed from *mRNA* and therefore not expressed

Exons: expressed sequence of *mRNA*; a region that remains in *mRNA* after the introns are removed

Human genome: the complete set of genes in an individual (perhaps as many as 10 million)

Orchestrate: to direct and coordinate an activity (such as a symphony orchestra); to ensure a harmonious or efficient outcome

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2. One gene, called a ***repressor***, encodes for a regulatory repressor protein that can sense the presence or absence of lactose.
3. One gene, called an ***operator***, activates transcription for the synthesis of the lactose-digesting enzymes.

In the *absence of lactose*, the repressor protein is synthesized by the repressor gene and then binds with the operator gene on the DNA to block transcription. Specifically, the repressor protein blocks RNA polymerase from reaching the *lac* genes, so transcription for the lactose-digesting enzymes stops. Like a lock on the library door, the repressor protein blocks the expression of the *lac* genes and transcription is halted.

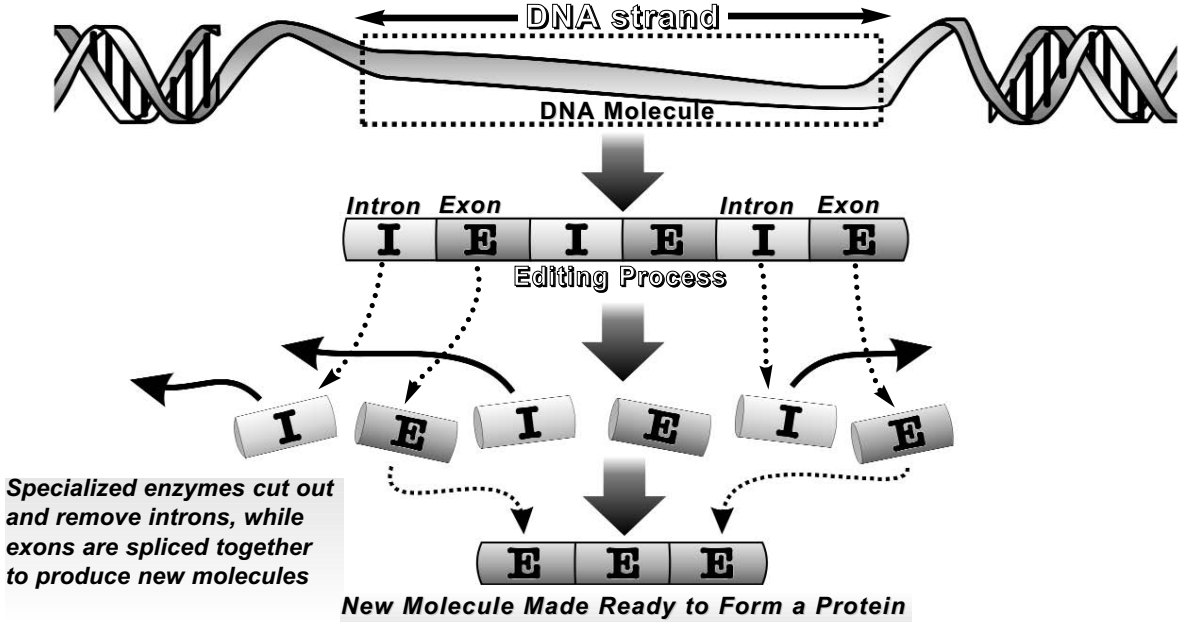
When *lactose is present* in bacteria, something remarkable happens. The lactose acts as an ***inducer*** that binds to the repressor protein, causing it to change shape and be removed from its binding site on the DNA. Therefore, with the presence of lactose, the "lock" is gone and the *lac* genes are ready to be transcribed by RNA polymerase.

Not all genes work exactly as the *lac* genes work. In eukaryotic cells, the control of gene expression is much more complicated. However, many genes follow the pattern just described, controlling when and where transcription happens.

Gene Editing

In 1976, scientists Philip Sharp and Susan Berget made a surprising discovery about gene expression in eukaryotes. The scientists carefully compared the DNA sequence of a gene with the base sequence of *mRNA* for the very same gene. They expected the two sequences to match perfectly—but they were surprised to find something quite different.

The researchers found that *mRNA* often undergoes a process similar to editing, in which parts of the molecule are removed and discarded. The discarded parts are called ***introns***—short for *intervening sequences*. After introns are removed, the remaining parts are spliced together to form the final version of *mRNA*. The remaining parts are called ***exons***—short for *expressed sequences*. Scientists do not really understand this process or why it occurs. It does appear,



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however, that with introns and exons the cell can manage gene expression more efficiently.

Specialization and Coordination, The Unsolved Dilemma

Scientists' understanding of DNA is still far from complete. Active pursuits are taking place attempting to create a comprehensive map of the ***human genome***.

The DNA mechanisms are beginning to be understood regarding the production of proteins. Much more interesting dimensions of the DNA model appear to be on the scientific horizon. An area least understood has to do with the *specialization* of tissues.

To illustrate, let's look at the human egg. When it is fertilized by a sperm, it becomes a zygote and mitosis begins. The single cell splits to become two identical cells. They, in turn, split to become four—then eight, then 16, and so forth. The process continues until the embryo is formed.

Soon, a dark line begins to develop down the center of the zygote and, ultimately, becomes the spine. Gradually, the dividing cells are no longer identical to one another. They begin to specialize into various tissues: bone, muscle, organ, nerve, etc. What baffles scientists is how these cells know what they are to become, because they were all identical in earlier stages! While this amazing specialization is taking place, development progresses in a coordinated, perfectly-timed fashion. An increasing number of scientists realize that this precise development reflects design, order and governance by some kind of intelligence.

To picture the awesome process that is taking place during cell specialization and embryo development, visualize the following. Imagine a group of 50 people, each of whom is skilled at playing every instrument in an orchestra. Suppose that each one is provided with a comprehensive set of musical instruments for a symphony. However, a symphony would occur only if someone directed and coordinated the process. Someone would have to decide who would be first violin, who would play the trumpet, percussion instruments, and so forth. A knowledgeable, intelligent conductor would be needed to ***orchestrate*** the various instruments and movements to provide a perfectly coordinated and harmonious result. Simply because each component has the total information or instrumentation needed does not produce efficient or harmonious results.

In similar fashion, the logical mind speculates that intelligent orchestration would be required for a fertilized egg to become a fully developed, highly-complex organism.

In the next section, we will begin examining some selected topics in genetics—with a special emphasis on genetic engineering.



Life Principle

"What we see depends mainly on what we look for."

—John Lubbock (1834-1913)
British archaeologist, biologist, author, member of Parliament

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Lesson 11

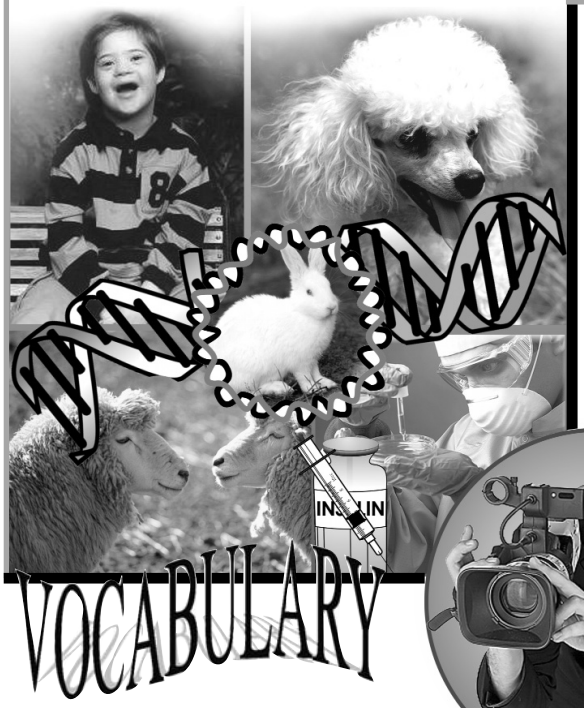
Mutation Mechanics

Chapter 3

MUTATIONS AND HUMAN GENETIC DISORDERS

Section 3

Lessons 11-15



VOCABULARY

Mutation: inheritable alteration in the genetic information of a cell

Melanin: brown pigment that gives skin and hair their color

Vitiligo: sporatic absence of pigment in various body parts

Hemoglobin: iron-containing protein found in red blood cells that helps to transport oxygen to all parts of the body

Nondisjunction: failure of chromosome pair to separate correctly during meiosis

Trisomy: condition caused by cells that contain three copies of a chromosome rather than two copies

MUTATIONS

As you have learned in earlier lessons, a cell copies its DNA before dividing. Although the copying process usually works perfectly, every now and then a "mistake" occurs. These mistakes are called ***mutations***—from the Latin word meaning, "change." A mutation is an inheritable change in genetic information.



Mutations may occur in any cell and in any gene. At the molecular level, a mutation consists of an alteration, deletion, or insertion of one or more DNA nucleotides. Once a change has occurred, the altered genes continue to replicate in their changed form unless another mutation occurs. Although mutations may occur in any living cell, they are most important when they occur in gametes because the change affects the traits of following generations.

Most laboratory mutations have been induced artificially by chemicals, heat and radiation, or other such disturbing influences. Fortunately, mutations in nature are quite rare, and when they do occur they usually tend to disappear rather quickly. Mutations, however, are usually harmful. In humans and animals, mutations are classified as "birth defects" or human genetic disorders.

AUTOSOMAL GENETIC DISORDERS

Earlier, we studied that some genetic disorders such as colorblindness and hemophilia are carried on the sex chromosome. These disorders often show up in the male because recessive traits will be inherited on the X chromosome. The majority of human genes, and therefore the

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majority of genetic disorders, are carried on the *autosomes*. (Recall that autosomes are the non-sex chromosomes).

Albinism

Albinism is a genetic disorder caused by a *recessive* allele on chromosome number eleven (which is believed to result from a lack of the enzyme *tyrosinase*). Individuals who have two copies of this allele are unable to produce ***melanin***, the pigment responsible for most human skin color. People or animals with total albinism have no pigment in their fur, hair, skin or eyes. Albino eyes have pink irises and red pupils. Albinos are very sensitive to light, and therefore must avoid exposure to bright sunlight. Related conditions in humans include *partial albinism* and ***vitiligo***, the latter occuring in one to three percent of the population.

Albino Rabbit



Cystic Fibrosis (CF)

In the United States, cystic fibrosis is the most common, fatal genetic disease. Cystic fibrosis is caused by a *recessive* allele on chromosome number seven. People with two copies of this allele produce a defective cell membrane protein that interferes with the movement of chloride ions in and out of the cells. This results in the secretion of thick mucus that can clog the lungs and the ducts of the pancreas and liver. Cystic fibrosis usually results in death before the twentieth birthday.

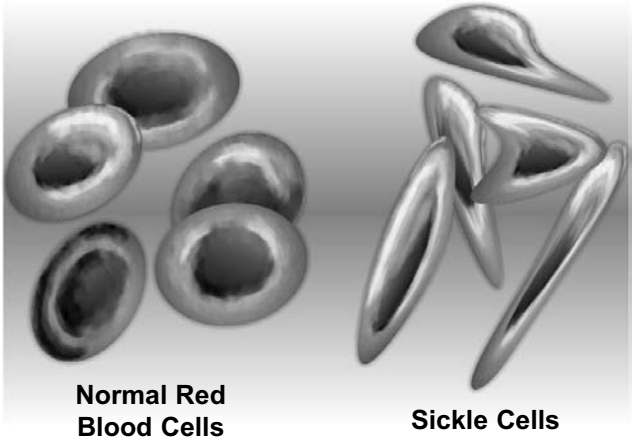
Tay-Sachs Disease

Like cystic fibrosis, Tay-Sachs disease is a fatal genetic disorder caused by the occurrence of two *recessive* alleles. Tay-Sachs disease is most common in Jewish families of Eastern European ancestry. Children who are born with Tay-Sachs disease suffer from a rapid breakdown of the nervous system beginning at age 2 or 3.

Sickle Cell Anemia

Sickle cell anemia is a blood disorder that is characterized by a crescent or sickle-shaped red blood cell. Sickle cell anemia is caused by a *recessive* allele that produces a mutated (abnormal) form of ***hemoglobin*** molecules. The amino acid sequence distinguishing normal hemoglobin from the sickle-cell form is only a single amino acid. This shows how a very simple mutation can have significant, negative effects on humans.

Individuals with two copies of the sickle cell allele will have sickle cell anemia



Normal Red Blood Cells **Sickle Cells**

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which is characterized by poor blood circulation, shortness of breath and periodic, severe pain in the abdomen, muscle and bones. In the United States, sickle cell anemia is most common among people of African ancestry.

Huntington Disease

Not all genetic disorders are carried on recessive alleles. Huntington disease, for example, is a rare genetic disorder caused by a *dominant* allele located on chromosome number four. Most individuals with this disorder have no symptoms until their late 30's or 40's when they begin to lose control of their muscles. As the disease progresses, brain tissue deteriorates. Most patients die within 15 years after symptoms of the disorder appear.

Because Huntington disease appears in middle age, most people who are at risk for the disorder have already had children by the time they find out that they carry the allele. Because the allele is dominant, a heterozygous person with Huntington disease has a 50 percent chance of passing this disorder along to one of his or her children.

Chromosome Number Disorders

Every human life begins with a single cell called the *zygote*, which is formed by the union of a sperm and an egg. Normally, a human sperm and egg each contain 22 autosomes and 1 sex chromosome. Recall that when these sex cells are formed in meiosis, each chromosome pair separates during the first meiotic division.

Occasionally, something goes wrong and a chromosome pair fails to separate correctly. The most common error of this type in meiosis is called ***nondisjunction***, which literally means, "not coming apart." When nondisjunction occurs, abnormal numbers of chromosomes are produced in the sex cells. If one of these sex cells fuses and become a zygote, a genetic disorder will occur.

Turner Syndrome

One type of nondisjunction in which sex chromosomes fail to separate in meiosis can result in *Turner syndrome*. During meiosis, either a sperm or an egg is produced without a sex chromosome. When such a cell fuses with a sex cell carrying a single *X* chromosome, the zygote will be *XO*. The *O* indicates that a sex chromosome is missing. Only females can be afflicted with Turner syndrome. Because their sex organs do not fully develop, these females are unable to conceive children. Otherwise, most females with Turner syndrome are able to lead full and productive lives.

Klinefelter Syndrome

Nondisjunction can also produce males whose cells contain an extra sex chromosome. This abnormality is called Klinefelter syndrome. Mental retardation is often associated with this syndrome, although its extent varies from one person to the next.


Child with Down Syndrome

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Down Syndrome

Nondisjunction may occur in autosomes as well as in sex chromosomes. If the two copies of an autosome do not separate correctly during meiosis, an individual can be born with cells that contain three copies of a chromosome. This condition is called ***trisomy***. The most common form of trisomy is *Down syndrome*.

Down syndrome results in heart and circulatory problems, a weakened immune system, and mental retardation. The degree of retardation varies greatly. Although some people who have Down syndrome are severely retarded, others are able to function quite well in society. Down syndrome people who are treated kindly and lovingly function at their best and respond in like manner, but rarely live into their twenties.

DNA Precision

The DNA/RNA coding system arranges amino acids into a specific sequence to form a specific protein. While similar to letters of an alphabet in sentences, only a specific sequence of amino acids will produce the essential proteins.

One of the most important proteins for human life is hemoglobin. It is responsible for both the red color of our blood and for the oxygen chemistry of our breathing. Only one specific sequence of amino acids is truly hemoglobin. Physical problems occur, and sometimes death, if even one amino acid is replaced. Sickle cell anemia is but one example.

Given all the amino acids present in the hemoglobin molecule, 10^{650} possible sequences exist, yet only one of these sequences is hemoglobin! The mathematical probability of this very important, life-giving molecule occuring by chance seems rather unlikely, given scientists' estimations of the existence of only 10^{66} atoms in the entire universe. The precision with which life reproduces, and the negative effects of mutations, cause many scientists to question theories of molecular accidents.

In the next lesson, we will examine some of the mechanisms of mutations.



Life Principle

"Our duty is to believe that for which we have sufficient evidence, and to suspend our judgement when we have not."

—John Lubbock (1834-1913)
British archaeologist, biologist,
author, member of Parliament

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Mutation Mechanics

Lesson 12

Chapter 3

Section 3

Lessons 11-15

SPECIAL TOPICS IN GENETICS



Agents that cause mutations, called ***mutagens***, such as radon gas or ultraviolet radiation can occur naturally in the environment. Other mutagens, such as some pesticides and pollutants, can be introduced by the action of humans. Such mutagens affect not only people, but also wildlife in the area. In most cases, mutations caused by exposure to mutagens are harmful to an organism. Common mutagenic effects include cancer, tumors, and abnormal cell or organ growth and development.



VOCABULARY

Mutagens: agents which cause mutations

Chromosomal mutations: change in the number or structure of a cell's chromosomes; a mutation that affects the entire chromosome

Polyploid: the condition in which a cell has three or more sets of chromosomes

Polyploidy: the condition of being polyploid

Gene mutation: mutation that involves only a single gene

Point mutation: gene mutation that involves a single nucleotide

MECHANISMS OF MUTATIONS

Chromosomal Mutations

Changes involving the number or structure of a cell's chromosomes are called ***chromosomal mutations***. This type of mutation may move a gene's location on a chromosome or change the number of copies of a gene.

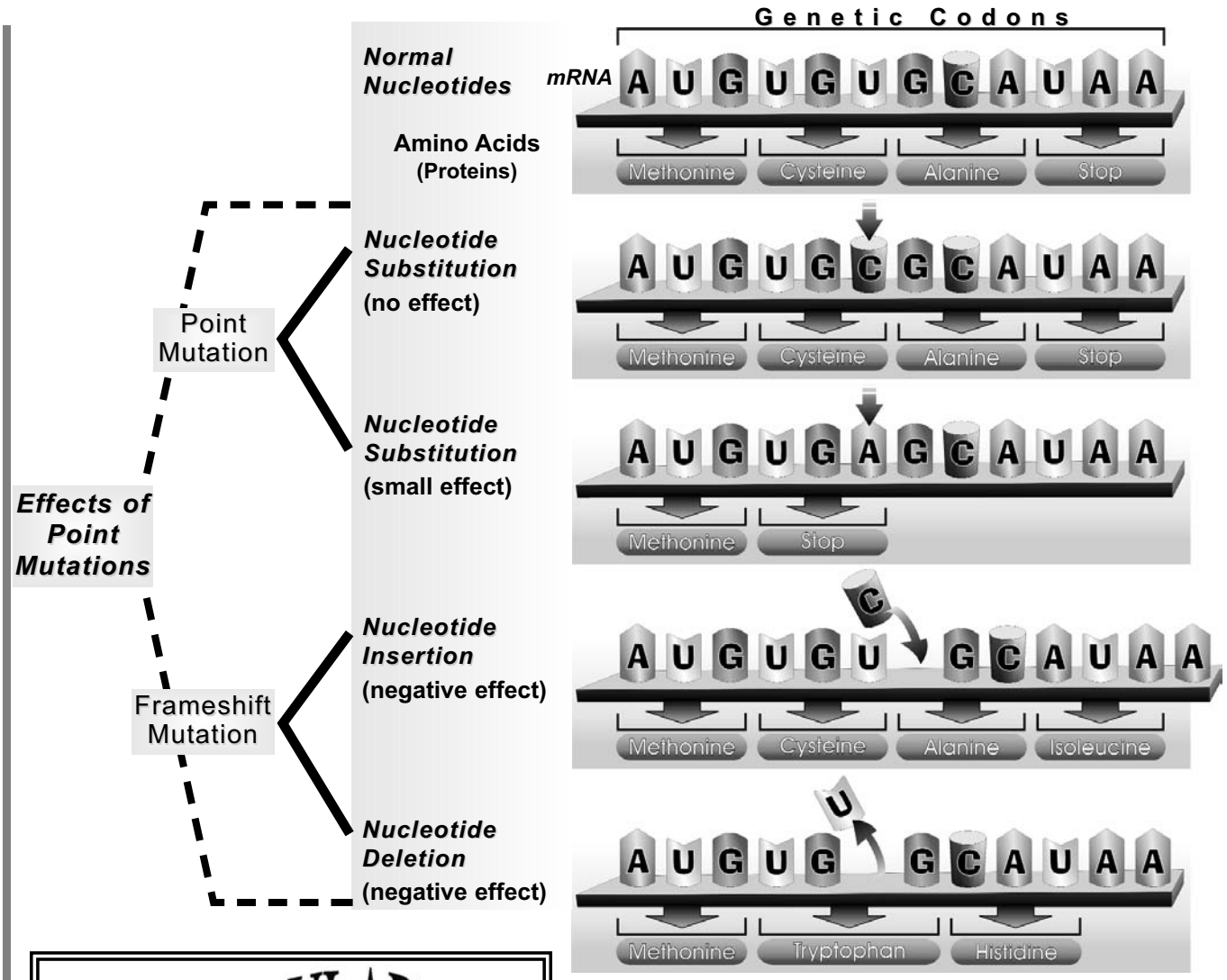
Some chromosomal mutations take place during meiosis. When a whole set of chromosomes fails to separate during meiosis, gametes with extra sets of chromosomes can be produced. These gametes may produce cells with three sets (3n) or four sets (4n) of chromosomes. An organism with three or more sets of chromosomes in its cells is said to be ***polyploid***.

In humans and animals, ***polyploidy*** is usually fatal. However, plants tolerate this condition much better than do animals or people. In fact, polyploidy can often produce larger and stronger plants than the normal diploid *(2n)* form. Crops such as bananas, wheat, and citrus fruits are each produced from polyploid plants.

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Normal vs "Broken" Chromosomes



VOCABULARY

Frameshift mutation: gene mutation that involves the insertion or deletion of a nucleotide, thus changing the grouping of codons
Transposition: gene mutation in which long stretches of DNA (containing one or more genes) move from one chromosome to another
Transposons: the genes which are involved in transposition mutation; can disrupt transcription and change the type of amino acids inserted into a protein
Happenstance: a circumstance regarded as being due to chance

Gene Mutations

A change that affects only an individual gene is known as a ***gene mutation***. A gene mutation may involve only one nucleotide or many nucleotides, and can have dramatic consequences for an organism.

A gene mutation that involves a single nucleotide—such as the substitution of one nucleotide for another—is called a ***point mutation***. Although a point mutation produces a small change to the DNA sequence, it may cause a change in the amino acid sequence and thus affect the function of a protein.

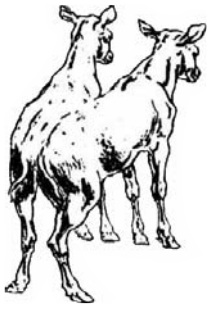
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Far more serious are mutations that involve the addition or deletion of one or more bases from a DNA molecule. Recall that the genetic code is read in groups of three nucleotides known as *codons*. Adding or subtracting even a single base from a normal sequence during transcription can disrupt translation by shifting the entire code. This type of mutation is called a ***frameshift mutation*** and could result in the production of a protein with no real function, or one with a harmful effect.

Sometimes mutations are caused by ***transposition***, in which long stretches of DNA (containing one or more genes) move from one chromosome to another. These "jumping genes", called ***transposons***, can disrupt transcription and change the type of amino acids inserted into a protein.

Every cell has highly effective self-repair mechanisms designed to correct the harmful changes made by mutations, and to prevent some mutations from being passed on to offspring. Some 50 specialized enzymes locate different types of faulty sequences in the DNA and clip out those flaws. Another repair mechanism scans DNA after replication and marks mismatched base pairs for repair.

Mutations and Breeding



Most mutations are harmful, or at least non-beneficial, such as a 2-headed calf or a 3-legged dog. However, mutations occasionally produce some desirable results. For this reason, breeders trying to improve on an animal or plant will try to increase the rates at which mutations occur, thus increasing the chance of producing a beneficial one. X-rays, ultraviolet light, and certain chemicals often increase an organism's mutation rate. The probability of obtaining beneficial mutations requires working with large numbers of organisms. Bacteria can be grown in the millions, allowing researchers to study even the rarest mutations in bacterial genes.

Unparalleled Cellular Complexity*

Consider a make believe model of a "simple" cell as follows: Imagine a model 1,000 million times larger than the actual size of a cell. In this model cell, each atom would be about the size of a tennis ball. We would need ten million million atoms (10^{13}) and our model would have to be over ten miles in diameter. If we counted the atoms at one per minute, the process would take 50 years to complete. This make-believe model illustrates the complexity of a single cell.

This "simple" cell is of unparalleled complexity and adaptive design. It is filled with automated factories and assembly plants with processing units connected to a central memory bank. Hundreds of thousands of specific types of robot machines (protein molecules) are everywhere, each composed of over 3,000 parts. Elegant control systems regulate the automated assembly of components. We even discover error-correcting, fail-safe coding and proofreading devices for quality control.

The technology in the "simple cell" is unequaled in any factory on earth. What is even more staggering is that it is capable of duplicating the entire structure within a matter of a few hours! This is the "simple cell" that some think happened by unaided chance.

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The complexity of the simple cell argues strongly against cellular ***happenstance***. As British evolutionary zoologist Dr. Richard Dawkins of Oxford University, UK, stated: "The more statistically improbable a thing is, the less we can believe that it just happened by blind chance".

In the next lesson, we will begin to examine some advances in the field of genetic engineering.

LIFE PRINCIPLE



"Our scientific power has outrun our spiritual power. We have guided missles and misguided men."

—Martin Luther King, Jr. (1929-1968)
American Civil Rights leader

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Special Topics in Molecular Genetics

Lesson 13

Chapter 3

Section 3

Lessons 11-15

GENETIC ENGINEERING: PART I



Genetic Engineering is the science of altering an organism's genetic material to eliminate undesirable characteristics and/or to produce desirable new ones. Biological techniques are used to increase plant and animal food production, to diagnose disease, improve medical treatment and to help dispose of industrial waste. This area of biology is a large, rapidly-growing field, encompassing many different facets of life in which many new careers are being developed.



VOCABULARY

Genetic engineering: manipulation and insertion of genes and DNA from different sources into an organism

Selective breeding: producing a new generation by mating individuals with desired characteristics

Hybridization: mating of two organisms with dissimilar genetic characteristics

Inbreeding: mating of organisms with similar genetic characteristics

Restriction enzyme: protein that cuts DNA at a specific sequence of nucleotides

SELECTIVE BREEDING

The first genetic engineering technique practiced, which is still in use today, was the ***selective breeding*** of plants and animals, usually for increased food production. In selective breeding, only those plants or animals with desirable characteristics are used for further breeding. Corn has been selectively bred for several thousand years for increased kernel size and number and for nutritional content. More recently, selective breeding of wheat and rice has helped produce higher yields in order to supply the world's ever-increasing demand for food. Selective breeding has produced nearly all domestic animals—including cats, dogs, and horses.

HYBRIDIZATION

A cross between dissimilar plants or animals is known as ***hybridization*** and is one of the breeder's most important tools because it provides a way to combine the best characteristics of two organisms. For example, hybridization

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could be used to combine the disease resistance of one plant with the food-producing capacity of another plant.

Inbreeding



When a breed of organisms has been established, the breeder must try to maintain the breed. This is often done with ***inbreeding***—the mating of breeds with similar characteristics. The many breeds of dogs—from beagles to poodles to schnauzers—are maintained by inbreeding.

Inbreeding helps to ensure that the defining characteristics which make each breed special will be preserved. However, inbreeding also carries a special set of problems. Because most members of a breed are genetically similar, crossing individuals of the same breed may bring together two recessive alleles for a genetic defect. Excessive inbreeding has caused several problems in many dog breeds, such as blindness and joint deformities in German shepherds and retrievers.

Manipulating the Genes

Selective breeding is a simple way to influence which genes are passed on to new plants and animals. However, many generations of selective breeding are necessary to produce the proper gene combinations. New techniques have enabled scientists to select the desired gene combinations by simply "cutting and pasting." Scientists no longer need many generations to produce the desired results.

Techniques of Gene "Editing"

Biologists have techniques to cut, separate, and read DNA sequences and to splice together these sequences in almost any order. The techniques can be likened to those used by film editors who will often cut and separate sections of videotapes. Then, they will splice the videotape back together in order to get the finished product they desire.



VOCABULARY

Electrophoresis: technique used in which electric fields are used to separate biological material

Recombinant DNA: pieces of DNA from two or more sources that are reassembled to act as a single DNA molecule

Technique #1—Cutting the DNA

DNA can be cut at specific places by proteins known as ***restriction enzymes***. More than 100 restriction enzymes are known, and each one cuts DNA at a specific sequence of nucleotides. Restriction enzymes are very precise, and like a key that fits only one lock, these enzymes will cut a DNA sequence only if it matches the sequence perfectly.

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Restriction enzymes allow biologists to cut large DNA molecules into smaller, precisely sized fragments. Biologists can then work on pieces of DNA that contain a few hundred nucleotides instead of millions.

Technique #2—Separating DNA

DNA fragments can be separated by a technique known as ***electrophoresis***. During this process, DNA fragments separate from each other as they move through a special gel—a watery solid with a consistency similar to dessert gelatin.

First, DNA fragments are placed at one end of the gel. Then the gel is placed in an electric field. Because DNA fragments carry negative charges, they move toward the positively charged electrode. Smaller fragments move more quickly through the gel than larger fragments which results in separation of larger and smaller fragments.

Technique #3—Reading DNA

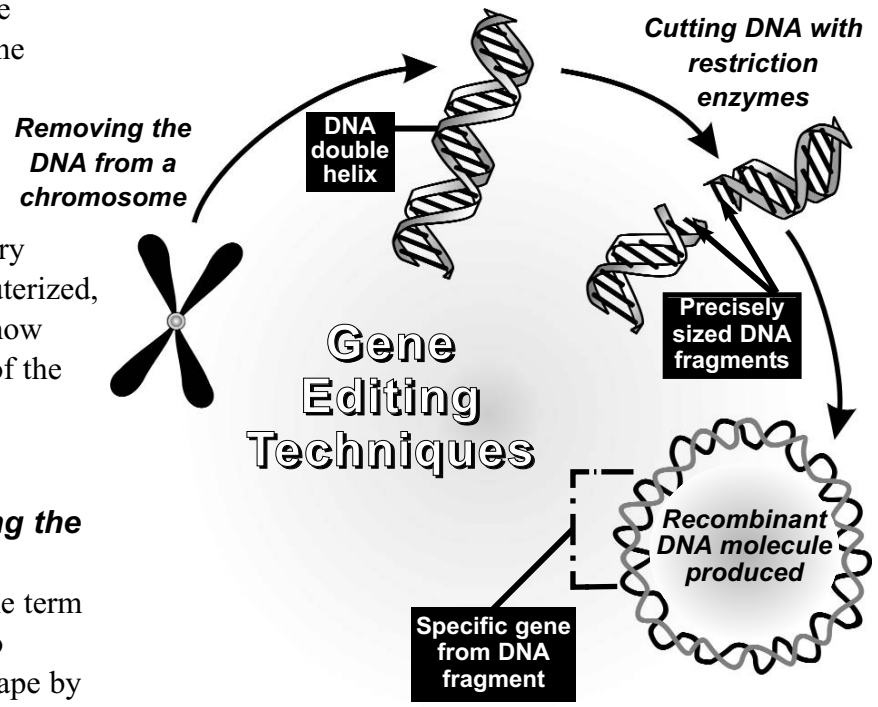
Within the past few decades, biological researchers have developed a way to read the sequence of DNA fragments as they separate in the gels. Today, sequencing has become a routine laboratory procedure. In fact, computerized, automated machines can now carry out the sequencing of the nucleotides in the gels.

Technique #4—Splicing the DNA

To a film editor, the term *splicing* means to join two sections of film or video tape by taping their ends together. DNA can be spliced together in a similar fashion.

When some restriction enzymes cut DNA, a short, single-stranded region remains on each side of the cut and these regions act like the sticky side of a piece of tape. By mixing two strands of DNA fragments cut with the same enzyme, the single-stranded regions hold the ends of the fragments together. Other enzymes can be used to join the fragments permanently.

The joined piece of DNA acts like a single DNA molecule. This kind of DNA is known as ***recombinant DNA*** because it is made by combining DNA from two different sources. This process allows biologists to design a DNA molecule for many different and special purposes. For example, recombinant DNA can be used to form proteins not normally produced in a cell, or to produce drugs or vaccines. In the next two lessons, we will be learning about many ways these techniques are being used in the rapidly expanding field of genetic engineering.



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In the next lesson, we will learn more about cell transformation and the manipulation of genes.

WATCH VIDEO: Hybridization

LIFE PRINCIPLE



"To know the facts, to reason in reality and live wisely: these are essential to success in life."

–Anonymous

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Special Topics in Molecular Genetics

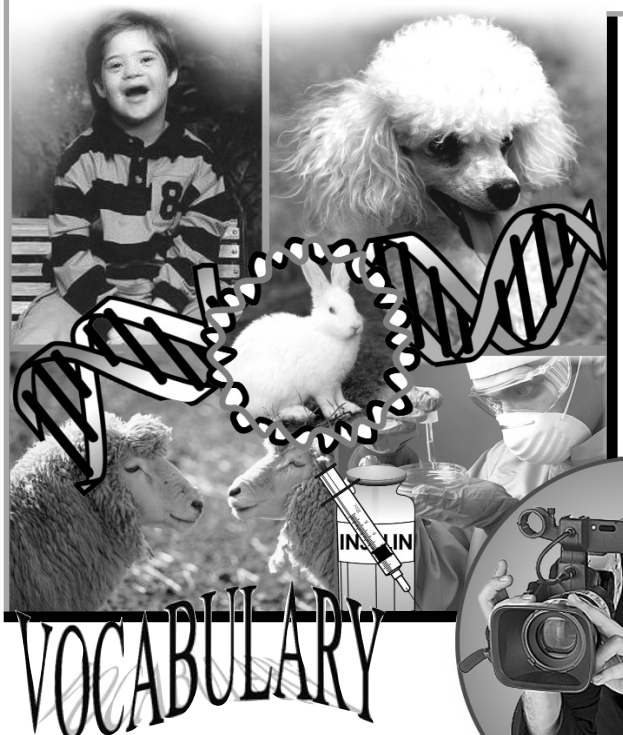
Lesson 14

Chapter 3

Section 3

Lessons 11-15

GENETIC ENGINEERING: PART II

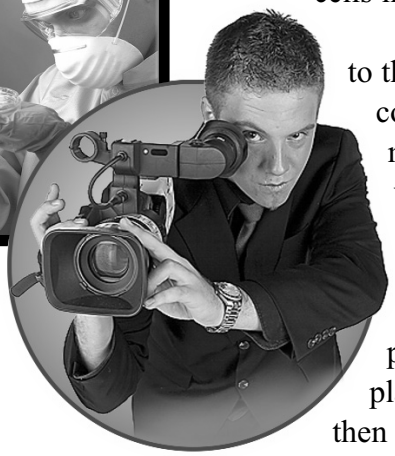


VOCABULARY

Cell transformation: the changing of a cell's genetic makeup by the insertion of DNA
Plasmids: small, circular DNA molecules in some bacteria that can be used in cell transformation
Vectors: recombinant DNA plasmids that serve as delivery agents or gene carriers
Transgenic: description of an organism that has been transformed or altered with genes from another organism
Insulin: a hormone that regulates metabolism of sugar and carbohydrates in the body; needed by many patients with diabetes

CELL TRANSFORMATION

After a recombinant DNA molecule is synthesized, the next step is cell transformation, which involves putting the recombinant DNA into a live cell. In ***cell transformation*** new genes are inserted into a cell, thus changing the cell's genetic makeup. Recombinant DNA can be used to transform cells in many ways.



Some bacteria, in addition to their regular chromosomes, contain small circular DNA molecules called ***plasmids*** which can be used as agents of cell transformation. First, pieces of DNA are joined to isolated plasmid molecules, producing recombinant plasmids, or ***vectors***, which are then mixed with a culture of bacteria that do not contain plasmids. Under the right conditions, a few of the bacteria in the culture will take up the plasmids. These few can be isolated and then used to grow millions of transformed bacteria. Each of the bacteria inherits both the plasmid and the recombinant DNA.

Eukaryotes are much more complex than the prokaryotic bacteria, and it is significantly more difficult to make eukaryotic cells accept new DNA. Yeasts, which are single-cell eukaryotes, have plasmids of their own. Yeast plasmids are used to transform cells in a way that is very similar to bacterial transformation.

In addition, biologists have developed ways to transform animal and plant cells which do not have plasmids. One way is to use a tiny needle to inject new DNA into a cell. Sometimes the cell breaks down and destroys the new pieces of DNA, but at other times the cell takes the pieces into the

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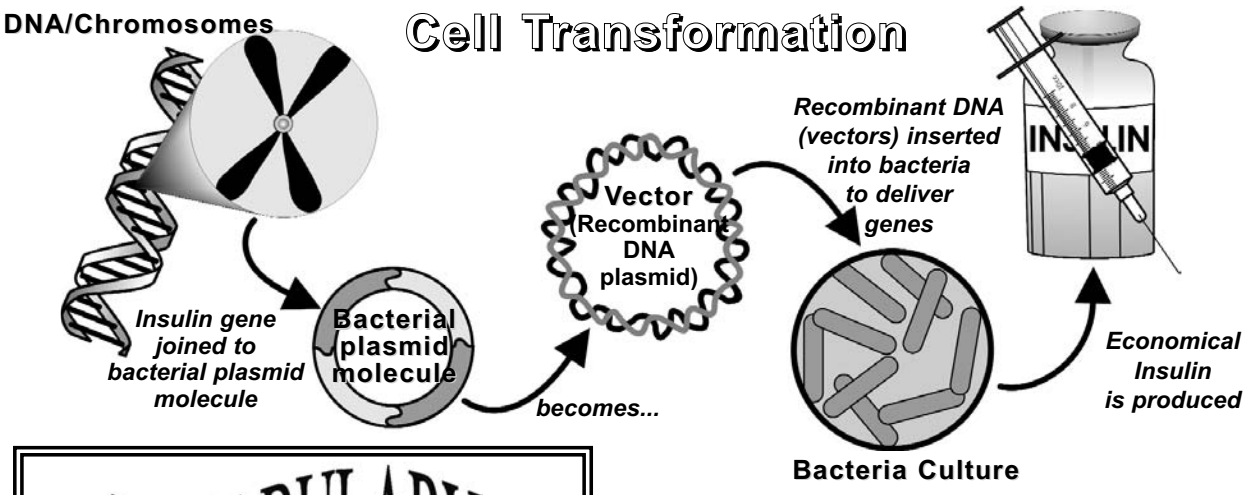
nucleus and inserts them into the chromosomes. The result is a transformed eukaryotic cell.

APPLICATIONS

Using recombinant DNA, researchers are able to insert new genes into almost any organism. Organisms that have been transformed with genes from other organisms are said to be ***transgenic***. As you have just learned, plasmids can be used to produce transgenic bacteria and yeasts. If a complete organism is grown from a transformed animal or plant cell, the result is a transgenic animal or transgenic plant. Genetic manipulation techniques have opened the doors to some possibly frightening and very controversial results.

PHARMACEUTICAL PRODUCTS

If a gene is properly inserted into yeast or a bacterium, the yeast or bacterium is "fooled" into producing large amounts of the protein for which the gene codes. For example, transgenic bacteria can produce a human protein called ***insulin***. People with a disease called *diabetes* do not produce enough insulin of their own to process dietary sugars and carbohydrates and thus may require insulin injections. Insulin produced by transgenic bacteria is both inexpensive and effective.



Another important, genetic engineered pharmaceutical is called ***interferon***, a chemical that is produced naturally in the body in tiny amounts. Interferon is an anti-viral agent currently used to fight certain types of cancers and for certain skin diseases.

Transgenic cells are also used to make proteins for treating numerous diseases and disorders. Vaccines are being produced with

VOCABULARY

Interferon: a chemical that is produced in the body in tiny amounts; an anti-viral agent used against certain types of cancers and for certain skin diseases

Cloning: the process of artificially producing an organism genetically identical to a biological organism

Ethical: pertaining to accepted moral principles of conduct

Gene therapy: a process in which a healthy gene can be directly inserted into a person with a malfunctioning gene; the goal is to provide the cell information needed to produce the lacking protein

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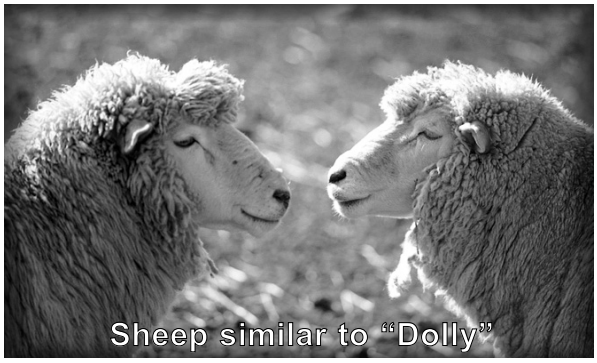
transgenics. Genetically altered vaccines are also being used to fight hepatitis, influenza, and herpes.

Food and Animal Production

Biology researchers have found ways to stimulate transformed plant cells to grow into transgenic plants. Laboratory results include a tomato that stays fresher longer than other tomatoes and a strain of soybeans that is highly resistant to weed-killing chemicals. Scientists have also developed transgenic potato and strawberry plants that are frost-resistant; vegetables, such as potatoes and corn, have been developed to resist attacks by certain insect pests.

To produce a transgenic animal, researchers first transform an animal's egg cell and then allow the egg to be fertilized and mature. For example, the growth hormone in rainbow trout has been transferred directly into carp eggs. The resultant transgenic carp can produce both carp and rainbow trout growth hormone and grow to be one-third larger than normal carp. Another example is a transgenic pig that has been produced with the ability to synthesize human hemoglobin for use as a blood substitute.

Recombinant DNA has also been used to make the cattle growth hormone called bovine somatotrophin (BST) in the bacterium *E. coli*. The hormone is then extracted from the bacterium, purified, and injected into dairy cows which result in 10-15% increase in milk production.


Sheep similar to "Dolly"

Cloning

A related technique performed specifically with animals is known as ***cloning***. In cloning, scientists remove the DNA-containing nucleus from a female's egg and replace it with a nucleus from a different animal. The scientists then place the egg in the uterus of a third animal. This was first demonstrated in Great Britain with the birth of a cloned sheep named "Dolly" in 1997. The resultant animal was nearly genetically identical to the animal from which the nucleus was obtained, but genetically unrelated to the mother who gave birth. Dolly, however, developed numerous negative side-effects which eventually caused her death. Cloning is still in its infancy and is an ***ethical*** issue that has resulted in much controversy among scientists, legislators, theologians and others.

Industry

Cell transformation has also been applied in the management of industrial wastes. Genetically altered bacteria have been used to decompose many forms of garbage and to break down petroleum products. This is especially helpful with the removal of oil spills caused by ruptured pipelines and damaged cargo ships.

Gene Therapy

Gene therapy, in which a healthy gene can be inserted directly into a person with a malfunctioning gene, is perhaps the most revolutionary recombinant DNA technology. Many problems, however, remain to be solved in introducing the healthy gene into human cells. The use of

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gene therapy has been approved in more than 400 clinical trials in an attempt to cure diseases such as cystic fibrosis, emphysema, and muscular dystrophy. Although some results seem to be beneficial, no actual cures have been developed.

Controversies Surrounding Genetic Engineering

Public reactions to the use of genetic engineering techniques have been mixed. Generally, the production of medicines by these genetically-based procedures has been welcomed. However, critics fear that pathogenic or disease-producing organisms used in some recombinant DNA experiments might develop into extremely infectious forms that could cause worldwide epidemics.



The use of genetically engineered bovine somatotrophin (BST) to increase the milk yield of dairy cows is particularly controversial. Some critics question the safety of BST, both for the cows that are injected with BST and the humans who drink the genetically engineered milk. In the United States, a large percentage of dairy cows are treated with BST. In Canada, BST cannot be sold legally. Canadian scientists claim that many health concerns are still unanswered about this hormone.

Environmentalists fear that transgenic plants may interbreed with weeds, producing vegetation with unwanted characteristics, such as resistance to herbicides. Insects seem to develop quick resistance to plants that have been engineered to incorporate biological pesticides.

Opponents of genetic engineering warn that the use of genetically modified food crops could result in unforeseen agricultural problems. For example, a 1999 laboratory study found that genetically modified corn produced pollen that killed monarch butterfly caterpillars.

Many European and developing nations have voiced concerns about the health and environmental risks associated with imported, genetically modified food crops from the United States and other countries. Many countries have refused to buy any products that have been genetically altered.

As the years go by, genetic engineering will affect everyone. Therefore, you would be wise to pay close attention to what is happening, specifically with regard to public policies about these procedures. You will be called on to apply your knowledge of biology and your ethical, moral training to address these and other important issues that will be raised during your lifetime.

In the next lesson, we will learn about a new and revolutionary technique called DNA fingerprinting.

WATCH VIDEO: Genetically Engineered Food

Life Principle



"I may disagree with what you have to say, but I shall defend, to the death, your right to say it."

—Voltaire (1694-1778), French author

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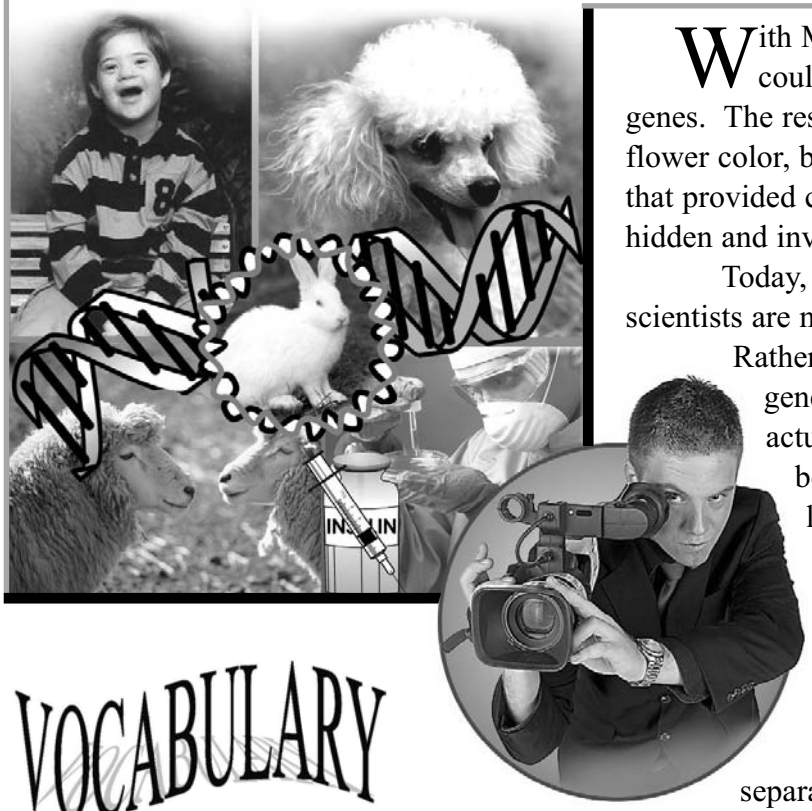
Lesson 15

Chapter 3

Section 3

Lessons 11-15

DNA FINGER-PRINTING, DISEASE AND JUSTICE



With Mendelian genetics, researchers could observe only the effects of genes. The researchers studied plant size, flower color, blood type, and anything visual that provided clues about the genes that were hidden and invisible within the cell.

Today, with advances in genetics, scientists are not restricted to indirect clues. Rather than looking for the effects of genes, biologists now can look at the actual genes. This new genetics is beginning to affect many areas of life and will continue to be a growing part of our culture for years to come.

VOCABULARY

DNA fingerprinting: technique used to identify an individual from the unique pattern of DNA

Restriction Fragment Length Polymorphisms (RFLPs): dark bands revealed when pieces of DNA are separated and identified by electrophoresis; can be used to identify and classify an individual's unique DNA.

Forensic medical science: a science dealing with the relation and application of medical facts to legal problems

DNA FINGERPRINTING

The development of separation and identification techniques for DNA has enabled researchers to match DNA molecules to one another for identification purposes. This process has been used in a procedure called ***DNA fingerprinting***.

DNA fingerprinting focuses on the large amount of "junk" DNA—repeating units of DNA that do not code for protein synthesis in the human genome. The number of repeats between genes varies from individual to individual. The greater the number of repeated units, the longer the strand of DNA between the genes. The repeating sequences are called ***Restriction Fragment Length Polymorphisms (RFLPs)***. As the pattern of RFLPs is unique for each



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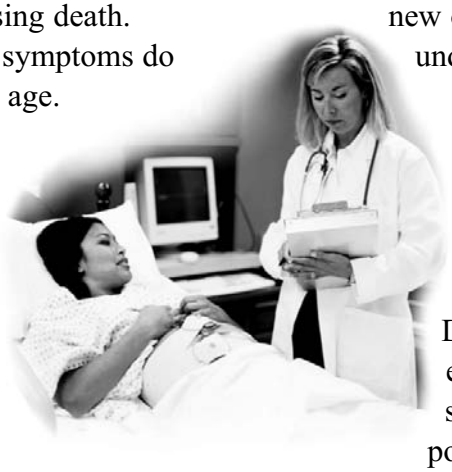
individual, it can be used as a molecular fingerprint.

To perform DNA fingerprinting, DNA is obtained from an individual's blood cells, hair fibers, skin fragments, or other tissue. The DNA is then extracted from the cell. During analysis, the DNA is split into fragments with the use of restriction enzymes. Then the DNA fragments are injected into a gel, in which these fragments can be separated by their lengths through the electrophoresis process. Radioactive probes match up to the repeat units and adhere to them. The radioactivity is then detected in order to allow the number of repeat units to be measured. The separated DNA fragments are then identified and used to develop a fingerprint. Several applications of this procedure are now in use in both the medical and law enforcement fields which often overlap in ***forensic medical science***.

Genetic Diseases

Consider the situation of people at risk for Huntington disease—a serious genetic disease caused by an autosomal dominant allele. Huntington disease, as we saw in an earlier lesson, slowly damages the nervous system, eventually causing death. However, the disease's symptoms do not appear until middle age.

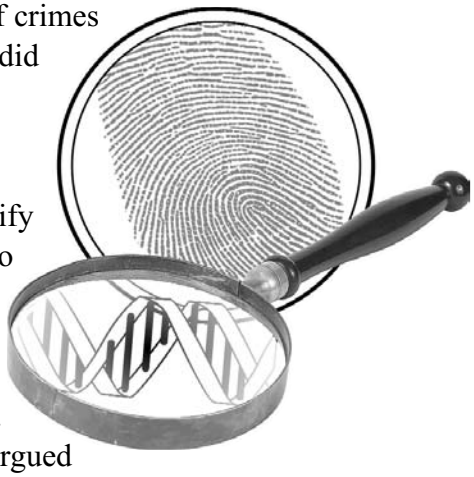
Before genetic testing, the children of people who had Huntington disease had to wait many years before learning whether they also would suffer from this condition. Today, with RFLP techniques, researchers have identified the DNA sequences which identify Huntington disease. Thus, geneticists can determine whether a person carries this allele.



Similar tests have been developed for other genetic disorders, including cystic fibrosis, sickle cell anemia, and Tay-Sachs disease. Tests for these diseases are particularly useful for couples deciding whether to conceive children.

Criminal Justice

The most controversial applications of DNA fingerprinting have been in the criminal justice system. DNA fingerprinting can identify suspects of serious crimes—as well as clear people of crimes that the suspects did not commit. Although police often use DNA evidence to identify suspects, juries do not always accept DNA evidence when a case goes to trial. Observers have argued that many jury members do not trust DNA fingerprints because the technology is too new or it is simply too hard to understand.



Future Possibilities

Many applications have been suggested for DNA fingerprinting. Some social scientists believe that DNA techniques could provide an excellent way for each individual in society to be identified. Some politicians have suggested that DNA information should be incorporated into an ID card or into a small computer chip that

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would be placed within a person's body. Although DNA fingerprinting impresses some social scientists, others argue that, at best, DNA fingerprinting is an imperfect means of identification. The strengths and weaknesses of DNA fingerprinting are sure to be debated and tested in the years ahead.

One of the most ambitious scientific endeavors of this century is the Human Genome Project—an effort to sequence all the nitrogenous bases in the human genome. Begun in 1990, this huge effort is expected to encompass fifteen years of work at a cost of approximately $3 billion. Knowing the content of the human genome will help researchers devise new diagnostics and treatments for genetic diseases. Information from the project has already identified a host of genes associated with genetic disorders. It has provided clues to the genetic basis of cancer and heart disease.

In the next chapter we will discuss various aspects of the theory of evolution.

LIFE PRINCIPLE



"The past should be appreciated by everyone; the door to the future should be guarded by people of moral character."

—Ron Johnson, Ph.D.
Educator and author

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