The scientific method is a systematic method to problem solving. The seven steps in the scientific method are:

(1)STATING THE PROBLEM.
(2)GATHER INFORMATION ON THE PROBLEM. A suggested solution is called a HYPOTHESIS. A HYPOTHESIS is sometimes called a "educated guess".
(3)FORM A HYPOTHESIS. A suggested solution is called a HYPOTHESIS. A HYPOTHESIS is sometimes called an "educated guess".
(4)EXPERIMENT TO TEST THE HYPOTHESIS. An EXPERIMENT is a method of testing a hypothesis. The factor being tested in an experiment is called the VARIABLE. In any experiment, only one variable is tested at a time.

An experiment has two groups, an EXPERIMENTAL GROUP and a CONTROL GROUP. A CONTROL EXPERIMENT is run in exactly the same way as the experiment with the variable, but the variable is left out.
(5)RECORD AND ANALYZE DATA. DATA includes observations such as measurements.
(6)STATE THE CONCLUSION. After analyzing the recorded data, the scientists come to a conclusion.
(7)REPEATING THE WORK. Before the conclusion is accepted, the work is repeated many times by other scientists to verify that the conclusion is true.

1-3 THE METRIC SYSTEM.
The common language of measurement in science used all over the world is the METRIC SYSTEM.

The METRIC SYSTEM is the standard system used by all scientists.

The METRIC SYSTEM is a decimal system, that is based on units of ten.

THE METRIC PREFIXES ARE:	MILLI- 1/1000th	KILO - 1000
	CENTI- 1/100th	HECTA- 100
	DECI- 1/10th	DECA - 10

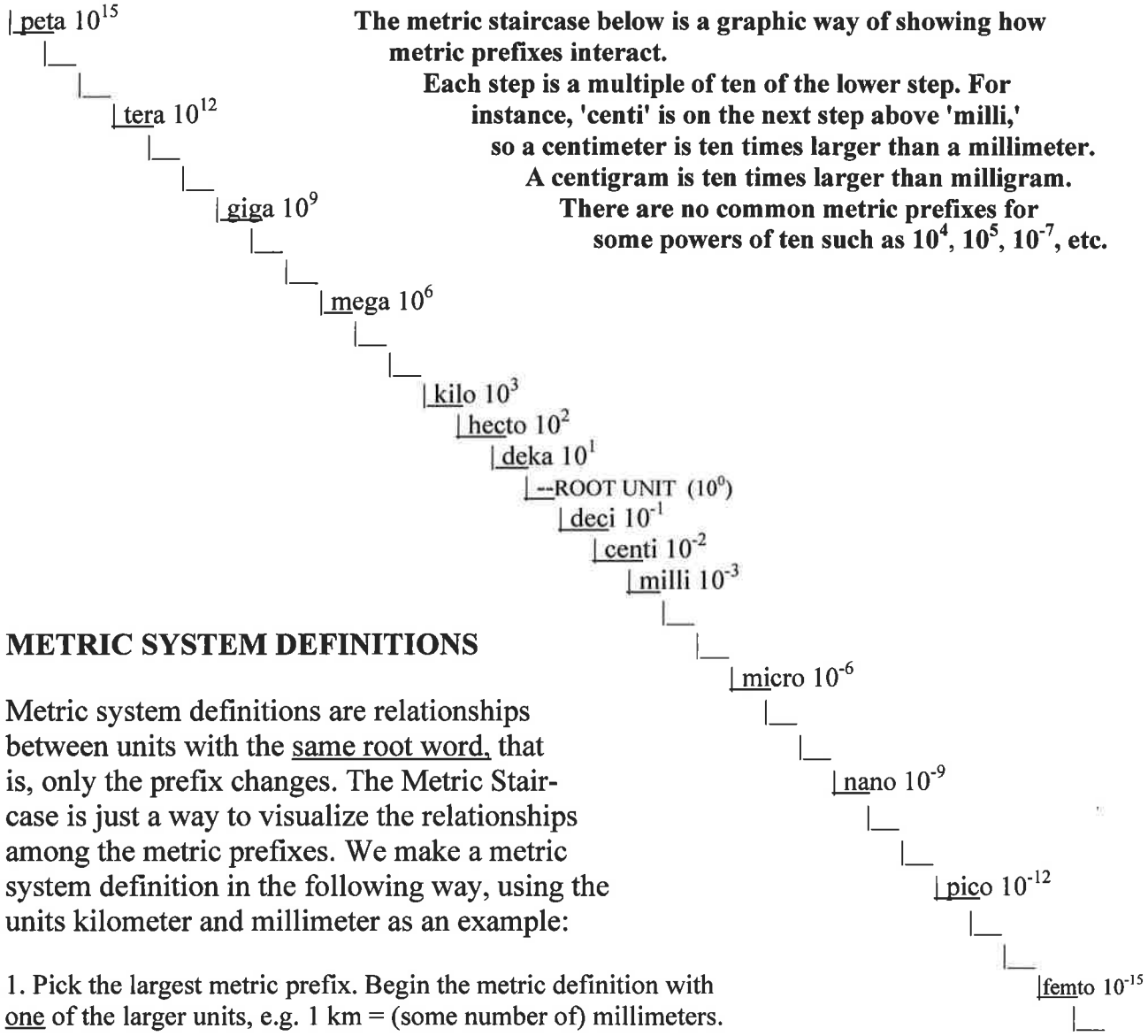
The basic unit of length in the metric system is the METER. The meter is equal to 39.4 inches.

The basic unit of volume in the metric system is the LITER. The amount of space an object takes up is called its VOLUME.

The basic unit of mass in the metric system is the KILOGRAM. One KILOGRAM is 2.2 pounds. MASS is the amount of matter in an object. AN object with a mass of 1 kilogram is pulled toward the Earth with a force of 9.8 newtons.

THE METRIC STAIRCASE

Adapted from http://www.chemtutor.com/unit.htm



The metric staircase below is a graphic way of showing how metric prefixes interact.

Each step is a multiple of ten of the lower step. For instance, 'centi' is on the next step above 'milli,' so a centimeter is ten times larger than a millimeter. A centigram is ten times larger than milligram.

There are no common metric prefixes for some powers of ten such as 10^{4}, 10^{5}, 10^{-7}, etc.

METRIC SYSTEM DEFINITIONS

Metric system definitions are relationships between units with the same root word, that is, only the prefix changes. The Metric Staircase is just a way to visualize the relationships among the metric prefixes. We make a metric system definition in the following way, using the units kilometer and millimeter as an example:

1. Pick the largest metric prefix. Begin the metric definition with one of the larger units, e.g. 1 km = (some number of) millimeters.

2. Count the number of 'steps' down the metric staircase between the two metric prefixes. For instance, kilo- to milli- is six steps.

3. The number of the smaller unit is ten to the power of the number of steps between the metric prefixes. In our example, 1 km = 1x 10^{6} mm. Another way to think of it is that the number of spaces you move the decimal point is the number of steps, so six steps is six decimal places, which means that 1 km = 1,000,000 mm. Or if you went from the smaller to the larger unit, 1mm = .000001km

One reason for stating the metric system definitions this way is to make calculations easier and make the sense of the definition more obvious. It is easier to use 1 km = 1x 10^{6}mm (or 1 km = E6 mm) than to use 1 mm = 1x 10^{-6} km, (or .000001km or 1/1,000,000 km) in computations, even though they are both correct.

VI. LIVING THINGS REPRODUCE

There are two types of reproduction:

(1) SEXUAL REPRODUCTION usually requires two parents. Most multicellular forms of plants and animals reprodcue sexually. 3

(2) ASEXUAL REPRODUCTION only requires one parent. When an organism divides into two parts, it is reproducing asexually. Bacteria reproduce in this way. (Binary fission) Yeast forms growths called buds, which break off and then form new yeast plants. (Budding)

Sexual and asexual reproduction have an important function in common. In each case, the offspring receive a set of special chemical "blueprints," or plans. These blueprints determine the characteristics of that living thing and are passed from one generation to the next.

I. Living things are made up of basic units called cells, are based on a universal genetic code, obtain and use materials and energy, grow and develop, reproduce, respond to their environment, maintain a stable internal environment, and change over time.

Homeostasis is the ability of an organism to maintain a relatively constant internal environment.

1 **Lesson Overview**

1.2 Science in Context

2 **THINK ABOUT IT**

Scientific methodology is the heart of science. But that vital "heart" is only part of the full "body" of science.

Science and scientists operate in the context of the scientific community and society at large.

3 **Exploration and Discovery: Where Ideas Come From**

What scientific attitudes help generate new ideas?

4 **Exploration and Discovery: Where Ideas Come From**

What scientific attitudes help generate new ideas?

Curiosity, skepticism, open-mindedness, and creativity help scientists generate new ideas.

5 **Exploration and Discovery: Where Ideas Come From**

Scientific methodology is closely linked to exploration and discovery.

Scientific methodology starts with observations and questions that may be inspired by scientific attitudes, practical problems, and new technology.

6 **Scientific Attitudes**

Good scientists share scientific attitudes, or habits of mind, that lead them to exploration and discovery.

Curiosity, skepticism, open-mindedness, and creativity help scientists generate new ideas.

7 **Curiosity**

A curious researcher, for example, may look at a salt marsh and immediately ask, "What's that plant? Why is it growing here?"

Often, results from previous studies also spark curiosity and lead to new questions.

8 **Skepticism**

Good scientists are skeptics, which means that they question existing ideas and hypotheses, and they refuse to accept explanations without evidence.

Scientists who disagree with hypotheses design experiments to test them.

Supporters of hypotheses also undertake rigorous testing of their ideas to confirm them and to address any valid questions raised.

9 **Open-Mindedness**

Scientists must remain open-minded, meaning that they are willing to accept different ideas that may not agree with their hypothesis.

10 **Creativity**

Researchers need to think creatively to design experiments that yield accurate data.

11 **Practical Problems**

Sometimes, ideas for scientific investigations arise from practical problems. For example, people living on a strip of land along a coast may face flooding and other problems.

These practical questions and issues inspire scientific questions, hypotheses, and experiments.

12 **The Role of Technology**

Technology, science, and society are closely linked.

13 **The Role of Technology**

Discoveries in one field of science may lead to new technologies, which enable scientists in other fields to ask new questions or to gather data in new ways.

Technological advances can also have big impacts on daily life. In the field of genetics and biotechnology, for instance, it is now possible to mass-produce complex substances—such as vitamins, antibiotics, and hormones—that before were only available naturally.

14 **Communicating Results: Reviewing and Sharing Ideas**

Why is peer review important?

15 **Communicating Results: Reviewing and Sharing Ideas**

Why is peer review important?

Publishing peer-reviewed articles in scientific journals allows researchers to share ideas and to test and evaluate each other's work.

16 **Peer Review**

Scientists share their findings with the scientific community by publishing articles that have undergone peer review.

In peer review, scientific papers are reviewed by anonymous, independent experts.

Reviewers read them looking for oversights, unfair influences, fraud, or mistakes in techniques or reasoning. They provide expert assessment of the work to ensure that the highest standards of quality are met.

17 **Sharing Knowledge and New Ideas**

Once research has been published, it may spark new questions. Each logical and

important question leads to new hypotheses that must be independently confirmed by controlled experiments.

For example, the findings that growth of salt marsh grasses is limited by available nitrogen suggests that nitrogen might be a limiting nutrient for mangroves and other plants in similar habitats.

18 **Scientific Theories**

What is a scientific theory?

19 **Scientific Theories**

What is a scientific theory?

In science, the word theory applies to a well-tested explanation that unifies a broad range of observations and hypotheses and that enables scientists to make accurate predictions about new situations.

20 **Scientific Theories**

Evidence from many scientific studies may support several related hypotheses in a way that inspires researchers to propose a scientific theory that ties those hypotheses together.

In science, the word theory applies to a well-tested explanation that unifies a broad range of observations and hypotheses and that enables scientists to make accurate predictions about new situations.

A useful theory that has been thoroughly tested and supported by many lines of evidence may become the dominant view among the majority of scientists, but no theory is considered absolute truth. Science is always changing; as new evidence is uncovered, a theory may be revised or replaced by a more useful explanation.

21 **Science and Society**

What is the relationship between science and society?

22 **Science and Society**

What is the relationship between science and society?

Using science involves understanding its context in society and its limitations.

23 **Science and Society**

Many questions that affect our lives require scientific information to answer, and many have inspired important research. But none of these questions can be answered by science alone.

Scientific questions involve the society in which we live, our economy, and our laws and moral principles.

For example, researchers test shellfish for toxins that can poison humans. Should shellfish

be routinely screened for toxins?

24 **Science, Ethics, and Morality**

When scientists explain "why" something happens, their explanation involves only natural phenomena. Pure science does not include ethical or moral viewpoints.

For example, biologists try to explain in scientific terms what life is and how it operates, but science cannot answer questions about why life exists or what the meaning of life is.

Similarly, science can tell us how technology and scientific knowledge can be applied but not whether it should be applied in particular ways.

25 **Avoiding Bias**

The way that science is applied in society can be affected by bias, which is a particular preference or point of view that is personal, rather than scientific.

Science aims to be objective, but scientists are human, too. Sometimes scientific data can be misinterpreted or misapplied by scientists who want to prove a particular point.

Recommendations made by scientists with personal biases may or may not be in the public interest. But if enough of us understand science, we can help make certain that science is applied in ways that benefit humanity.

26 **Understanding and Using Science**

Don't just memorize today's scientific facts and ideas. Instead, try to *understand* how scientists developed those ideas. Try to see the thinking behind the experiments and try to pose the kinds of questions scientists ask.

Understanding science will help you be comfortable in a world that will keep changing, and will help you make complex decisions that also involve cultural customs, values, and ethical standards.

27 **Understanding and Using Science**

Understanding biology will help you realize that we humans can predict the consequences of our actions and take an active role in directing our future and that of our planet.

28 **Understanding and Using Science**

Scientists make recommendations about big public policy decisions, but it is the voting citizens who influence public policy by casting ballots.

In a few years, you will be able to exercise the right to vote. That's why it is important that you understand how science works and appreciate both the power and the limitations of science.

1 **Lesson Overview**

1.3 Studying Life

2 **Characteristics of Living Things**

What characteristics do all living things share?

Living things are made up of basic units called cells, are based on a universal genetic code, obtain and use materials and energy, grow and develop, reproduce, respond to their environment, maintain a stable internal environment, and change over time.

3 **Characteristics of Living Things**

Biology is the study of life. But what is life?

No single characteristic is enough to describe a living thing. Also, some nonliving things share one or more traits with organisms.

Some things, such as viruses, exist at the border between organisms and nonliving things.

4 **Characteristics of Living Things**

Living things are based on a universal genetic code.

All organisms store the complex information they need to live, grow, and reproduce in a genetic code written in a molecule called DNA.

That information is copied and passed from parent to offspring and is almost identical in every organism on Earth.

5 **Characteristics of Living Things**

Living things grow and develop.

During development, a single fertilized egg divides again and again.

As these cells divide, they differentiate, which means they begin to look different from one another and to perform different functions.

6 **Characteristics of Living Things**

Living things respond to their environment.

A stimulus is a signal to which an organism responds.

For example, some plants can produce unsavory chemicals to ward off caterpillars that feed on their leaves.

7 **Characteristics of Living Things**

Living things reproduce, which means that they produce new similar organisms.

Most plants and animals engage in sexual reproduction, in which cells from two parents unite to form the first cell of a new organism.

8 **Characteristics of Living Things**

Other organisms reproduce through asexual reproduction, in which a single organism produces offspring identical to itself.

Beautiful blossoms are part of an apple tree's cycle of sexual reproduction.

9 **Characteristics of Living Things**

Living things maintain a relatively stable internal environment, even when external conditions change dramatically.

All living organisms expend energy to keep conditions inside their cells within certain limits. This conditionprocess is called homeostasis.

For example, specialized cells help leaves regulate gases that enter and leave the plant.

10 **Characteristics of Living Things**

Living things obtain and use material and energy to grow, develop, and reproduce.

The combination of chemical reactions through which an organism builds up or breaks down materials is called metabolism.

For example, leaves obtain energy from the sun and gases from the air. These materials then take part in various metabolic reactions within the leaves.

11 **Characteristics of Living Things**

Living things are made up of one or more cells—the smallest units considered fully alive.

Cells can grow, respond to their surroundings, and reproduce.

Despite their small size, cells are complex and highly organized.

For example, a single branch of a tree contains millions of cells.

12 **Characteristics of Living Things**

Over generations, groups of organisms evolve, or change over time.

Evolutionary change links all forms of life to a common origin more than 3.5 billion years ago.

13 **Big Ideas in Biology**

What are the central themes of biology?

The study of biology revolves around several interlocking big ideas: The cellular basis of life; information and heredity; matter and energy; growth, development, and reproduction; homeostasis; evolution; structure and function; unity and diversity of life; interdependence in nature; and science as a way of knowing.

14 **Cellular Basis of Life**

Living things are made of cells.

Many living things consist of only a single cell and are called unicellular organisms.

Plants and animals are multicellular. Cells in multicellular organisms display many different sizes, shapes, and functions.

15 **Information and Heredity**

Living things are based on a universal genetic code.

The information coded in your DNA is similar to organisms that lived 3.5 billion years ago.

The DNA inside your cells right now can influence your future—your risk of getting cancer, the amount of cholesterol in your blood, and the color of your children's hair.

16 **Matter and Energy**

Life requires matter that serves as nutrients to build body structures, and energy that fuels life's processes.

Some organisms, such as plants, obtain energy from sunlight and take up nutrients from air, water, and soil.

Other organisms, including most animals, eat plants or other animals to obtain both nutrients and energy.

The need for matter and energy link all living things on Earth in a web of interdependent relationships.

17 **Growth, Development, and Reproduction**

All living things reproduce. Newly produced individuals grow and develop as they mature.

During growth and development, generalized cells typically become more different and specialized for particular functions.

Specialized cells build tissues, such as brains, muscles, and digestive organs, that serve various functions.

18 **Homeostasis**

Living things maintain a relatively stable internal environment.

For most organisms, any breakdown of homeostasis may have serious or even fatal consequences.

Specialized plant cells help leaves regulate gases that enter and leave the plant.

19 **Evolution**

Groups of living things evolve. Evolutionary change links all forms of life to a common origin more than 3.5 billion years ago.

20 **Structure and Function**

Each major group of organisms has evolved its own collection of structures that have evolved in ways that make particular functions possible.

Organisms use structures that have evolved into different forms as species have adapted to life in different environments.

21 **Unity and Diversity of Life**

Life takes a variety of forms. Yet, all living things are fundamentally similar at the molecular level.

All organisms are composed of a common set of carbon-based molecules, store information in a common genetic code, and use proteins to build their structures and carry out their functions.

Evolutionary theory explains both this unity of life and its diversity.

22 **Interdependence in Nature**

All forms of life on Earth are connected into a biosphere, or “living planet.”

Within the biosphere, organisms are linked to one another and to the land, water, and air around them.

Relationships between organisms and their environments depend on the cycling of matter and the flow of energy.

23 **Fields of Biology**

How do different fields of biology differ in their approach to studying life?

Biology includes many overlapping fields that use different tools to study life from the level of molecules to the entire planet.

24 **Global Ecology**

Global ecological studies are enabling us to learn about our global impact, which affects all life on Earth.

For example, an ecologist may monitor lichens in a forest in efforts to study the effects of air pollution on forest health.

25 **Biotechnology**

The field of biotechnology is based on our ability to "edit" and rewrite the genetic code. We may soon learn to correct or replace damaged genes that cause inherited diseases or genetically engineer bacteria to clean up toxic wastes.

Biotechnology raises enormous ethical, legal, and social questions.

26 **Ecology and Evolution of Infectious Diseases**

The relationships between hosts and pathogens are dynamic and constantly changing.

Organisms that cause human disease have their own ecology, which involves our bodies, medicines we take, and our interactions with each other and the environment. Understanding these interactions is crucial to safeguarding our future.

27 **Genomics and Molecular Biology**

These fields focus on studies of DNA and other molecules inside cells. Genomics is now looking at the entire sets of DNA code contained in a wide range of organisms.

Computer analyses enable researchers to compare vast databases of genetic information in search of keys to the mysteries of growth, development, aging, cancer, and the history of life on Earth.

28 **Performing Biological Investigations**

How is the metric system important in science?

Most scientists use the metric system when collecting data and performing experiments.

29 **Scientific Measurement**

Most scientists use the metric system when collecting data and performing experiments.

The metric system is a decimal system of measurement whose units are based on certain physical standards and are scaled on multiples of 10.

30 **Scientific Measurement:**
Common Metric Units

31 **Scientific Measurement**

The basic unit of length, the meter, can be multiplied or divided to measure objects and distances much larger or smaller than a meter. The same process can be used when

measuring volume and mass.

For example, scientists in Alaska want to measure the mass of a polar bear. What unit of measurement should the scientists use to express the mass?

32 **Safety**

Scientists working in a laboratory or in the field are trained to use safe procedures when carrying out investigations.

Whenever you work in your biology laboratory, you must follow safe practices as well.

Before you start each activity, read all the steps and make sure that you understand the entire procedure, including any safety precautions.

The single most important safety rule is to always follow your teacher's instructions. Any time you are in doubt about any part of an activity, ask your teacher for an explanation.

33 **Safety**

Because you may come in contact with organisms you cannot see, it is essential that you wash your hands thoroughly after every scientific activity. Wearing appropriate protective gear is also important while working in a laboratory.

Remember that you are responsible for your own safety and that of your teacher and classmates. If you are handling live animals, you are responsible for their safety too.

ORGANIC COMPOUNDS that are basic to life include:
(1) CARBOHYDRATES. (2) Lipids (3) PROTEINS (4 Nucleic acids.

CARBOHYDRATES are the main source of energy for living things.
CARBOHYDRATES are made of the elements carbon, hydrogen, and oxygen. SUGARS and STARCHES are two important carbohydrates. CARBOHYDRATES are broken down inside the body into a simple sugar called GLUCOSE. The body then uses the glucose to produce the energy needed for life activities. If a plant has more sugar than it needs for its energy requirements, it will store the sugar for later use. The sugar is stored as STARCH. Animals store extra sugar as glycogen.

FATS AND OILS are another group of energy-rich compounds made of carbon, hydrogen, and oxygen. The more proper scientific term for these compounds are LIPIDS. FATS are solid at room temperature and OILS are liquid at room temperature.

PROTEINS, like carbohydrates and fats, are organic compounds made up of carbon, hydrogen, and oxygen. But proteins also contain the elements nitrogen and sometimes the elements sulfur and phosphorus. they may have primary, secondary, tertiary, quaternary structures.

The building blocks of proteins are AMINO ACIDS. There are about 20 different amino acids.

PROTEINS are necessary for the growth and repair of body structures. Proteins are used to build body parts such as hair and muscles. Proteins provide energy. Some proteins such as in blood carry oxygen throughout the body. Other proteins fight germs that invade the body.

ENZYMES are a special type of protein that regulates chemical activities within the body. Enzymes act as a CATALYSTS. A CATALYST is a substance that speeds up or slows down chemical reactions but is not itself changed by the reaction. Without enzymes, the chemical reactions of metabolism could not take place or would take place so slowly that they would be of little value to the organism.

NUCLEIC ACIDS are the organic chemical blueprints. NUCLEIC ACIDS, which are very large compounds, store information that helps the body make the proteins it needs.

There are two types of nucleic acids:
(1) DNA (DEOXYRIBONUCLEIC ACID) - stores the information needed to build protein. DNA also carries messages about the organism that are passed from parent to offspring. DNA is called the "blueprint of life".
(2) RNA (RIBONUCLEIC ACID) - reads the message or blueprint carried by the DNA and guides the protein making process.

Together these two nucleic acids contain the information and carry out the steps that make each organism what it is.

****

II. Biochemistry

1. Organic: contains carbon
2. Inorganic: does not contain carbon
2. 4 main organic compounds:

(a.) Carbohydrates: contain carbon (C) hydrogen (H) oxygen (O)

Ex. sugar (glucose - $C_6H_{12}O_6$ sucrose - $C_{12}H_{22}O_{11}$)
starch

3 Types of Carbohydrates

1. monosaccharides - glucose $C_6H_{12}O_6$ 2:1 ratio H to O
2. disaccharides - sucrose $C_{12}H_{22}O_{11}$ = glucose + glucose (water released)
3. polysaccharides - most complex Starch Cellulose Glycogen

Lab: Iodine

	Iodine	Benedicts Solution
Mono	stays red orange	turns green, yellow, orange, red
Di	stays red orange	stays blue (no change)
Poly	blue black	stays blue (no change)

(b) Lipids: contain Carbon Hydrogen Oxygen (H:O - not in a 2:1 ratio)

Ex. Fats - Oils made up of fatty acids and glycerol

store more energy than any other type of molecule

(c) Proteins: contain Carbon Hydrogen Oxygen Nitrogen

Made up of amino acids held by peptide bonds

There are 20 different amino acids

Enzyme: protein that acts as a catalyst. Lowers activation energy needed to make chemical reactions occur.

(d.) Nucleic Acids: contain carbon (C) hydrogen (H) oxygen (O) nitrogen (N) phosphorous (P)

Ex. DNA and RNA — Heredity material
— Carry instructions for protein synthesis

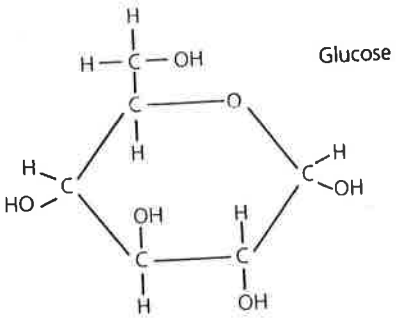
Biochem Quick Lab Guide

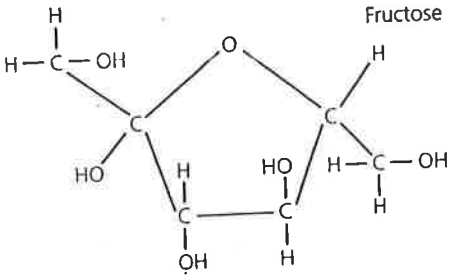
Table below shows positive test results only

Test	*Simple Carbs*	*Complex Carbs*	*Proteins*	*Lipids*
Benedict's Test	Turns various colors - does not stay blue			
Biuret Reagent			Turns purple or pink	
Iodine		Turns dark purple or black		
Paper bag				Leaves greasy stain that may be transparent
Sudan IV				Turns red

6. Distinguish proteins, carbohydrates, lipids, and nucleic acids, given structural diagrams

Carbohydrates





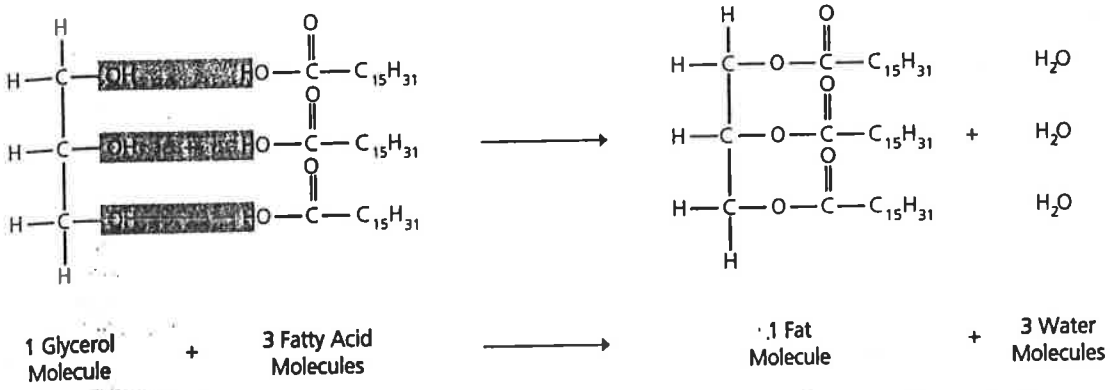
a. **Carbohydrates** (C,H,O) have a 1:2:1 ratio of carbon, hydrogen, oxygen; ex. - glucose

b. **Lipids** (C,H,O) have fewer carbon atoms

c. **Proteins** are long chains of amino acids enzymes - proteins controlling most cell activity

d. **Nucleic acids** (DNA, RNA) consist of a sugar, a base, and a phosphate group

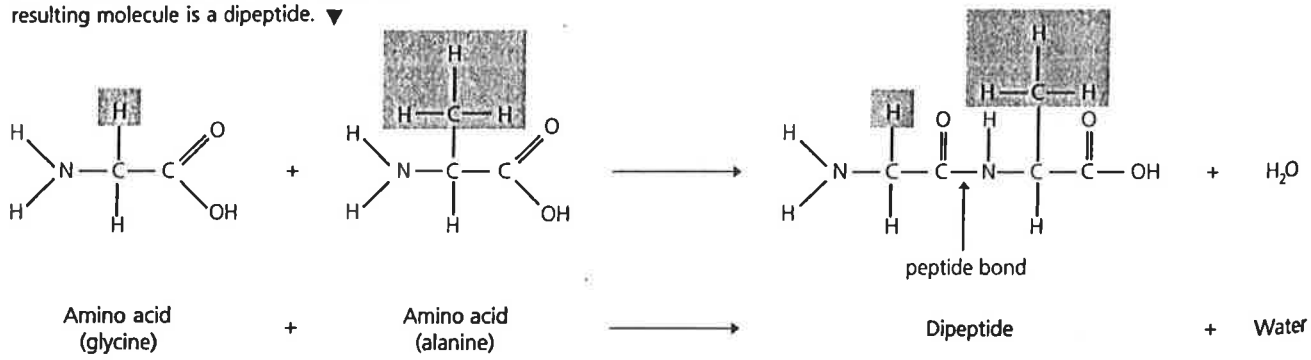
Lipids



▲ **Figure 4–10**
Synthesis of a Fat. A molecule of fat is formed by the dehydration synthesis of three fatty acid molecules and one glycerol molecule.

Protcins

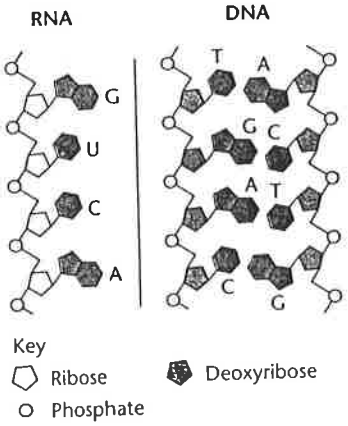
Formation of a Peptide Bond. In this dehydration synthesis reaction, a peptide bond forms between two amino acids. The resulting molecule is a dipeptide. ▼



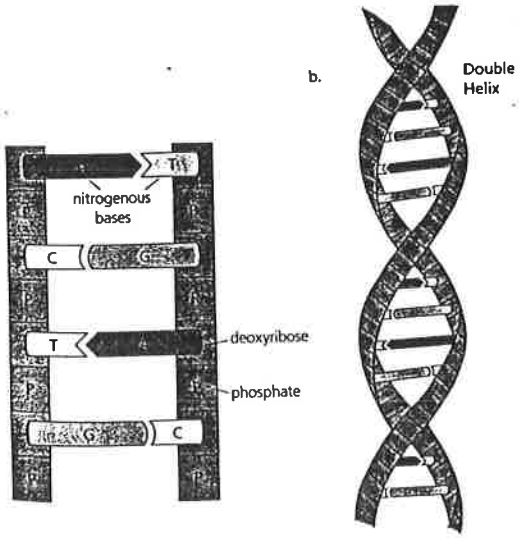
Nucleic acids

a. **DNA**
a double-stranded helix
has thymine but not uracil

b. **RNA**
is single stranded
has uracil but not thymine



▲ Figure 4.13 DNA and RNA both have nitrogen bases attached to the sugar molecules in the sugar-phosphate chains. Here, the bases are represented by letters.



Lesson Overview 12.1 Identifying the Substance of Genes

- **The Role of DNA**

  What is the role of DNA in heredity?

  The DNA that makes up genes must be capable of storing, copying, and transmitting the genetic information in a cell.

- **The Role of DNA**

  The DNA that makes up genes must be capable of storing, copying, and transmitting the genetic information in a cell.

  These three functions are analogous to the way in which you might share a treasured book, as pictured in the figure.

- **Storing Information**

  The foremost job of DNA, as the molecule of heredity, is to store information.

  Genes control patterns of development, which means that the instructions that cause a single cell to develop into an oak tree, a sea urchin, or a dog must somehow be written into the DNA of each of these organisms.

- **Copying Information**

  Before a cell divides, it must make a complete copy of every one of its genes, similar to the way that a book is copied.

- **Copying Information**

  To many scientists, the most puzzling aspect of DNA was how it could be copied.

  Once the structure of the DNA molecule was discovered, a copying mechanism for the genetic material was soon put forward.

- **Transmitting Information**

  When a cell divides, each daughter cell must receive a complete copy of the genetic information.

  Careful sorting is especially important during the formation of reproductive cells in meiosis.

  The loss of any DNA during meiosis might mean a loss of valuable genetic information from one generation to the next.

Lesson Overview 12.2 The Structure of DNA

The Components of DNA

What are the chemical components of DNA?

DNA is a nucleic acid made up of nucleotides joined into long strands or chains by covalent bonds.

Nucleic Acids and Nucleotides

Nucleic acids are long, slightly acidic molecules originally identified in cell nuclei.

Nucleic acids are made up of nucleotides, linked together to form long chains.

The nucleotides that make up DNA are shown.

Nucleic Acids and Nucleotides

DNA's nucleotides are made up of three basic components: a 5-carbon sugar called deoxyribose, a phosphate group, and a nitrogenous base.

Nitrogenous Bases and Covalent Bonds

The nucleotides in a strand of DNA are joined by covalent bonds formed between their sugar and phosphate groups.

Nitrogenous Bases and Covalent Bonds

DNA has four kinds of nitrogenous bases: adenine (A), guanine (G), cytosine (C), and thymine (T).

The nitrogenous bases stick out sideways from the nucleotide chain.

Nitrogenous Bases and Covalent Bonds

The nucleotides can be joined together in any order, meaning that any sequence of bases is possible.

Solving the Structure of DNA

What clues helped scientists solve the structure of DNA?

The clues in Franklin's X-ray pattern enabled Watson and Crick to build a model that explained the specific structure and properties of DNA.

Chargaff's Rules

Erwin Chargaff discovered that the percentages of adenine [A] and thymine [T] bases are almost equal in any sample of DNA.

The same thing is true for the other two nucleotides, guanine [G] and cytosine [C].

The observation that [A] = [T] and [G] = [C] became known as one of "Chargaff's rules."

Franklin's X-Rays

In the 1950s, British scientist Rosalind Franklin used a technique called X-ray diffraction to get information about the structure of the DNA molecule.

Franklin's X-Rays

X-ray diffraction revealed an X-shaped pattern showing that the strands in DNA are twisted around each other like the coils of a spring.

The angle of the X-shaped pattern suggested that there are two strands in the structure.

Other clues suggest that the nitrogenous bases are near the center of the DNA molecule.

The Work of Watson and Crick

At the same time, James Watson, an American biologist, and Francis Crick, a British physicist, were also trying to understand the structure of DNA.

They built three-dimensional models of the molecule.

The Work of Watson and Crick

Early in 1953, Watson was shown a copy of Franklin's X-ray pattern.

The clues in Franklin's X-ray pattern enabled Watson and Crick to build a model that explained the specific structure and properties of DNA.

The Work of Watson and Crick

Watson and Crick's breakthrough model of DNA was a double helix, in which two strands were wound around each other.

The Double-Helix Model

What does the double-helix model tell us about DNA?

The double-helix model explains Chargaff's rule of **base pairing** and how the two strands of DNA are held together.

The Double-Helix Model

A double helix looks like a twisted ladder.

In the double-helix model of DNA, the two strands twist around each other like spiral staircases.

The double helix accounted for Franklin's X-ray pattern and explains Chargaff's rule of base pairing and how the two strands of DNA are held together.

Antiparallel Strands

In the double-helix model, the two strands of DNA are "antiparallel"—they run in opposite directions.

This arrangement enables the nitrogenous bases on both strands to come into contact at the center of the molecule.

It also allows each strand of the double helix to carry a sequence of nucleotides, arranged almost like letters in a four-letter alphabet.

Hydrogen Bonding

Watson and Crick discovered that hydrogen bonds could form between certain nitrogenous bases, providing just enough force to hold the two DNA strands together.

Hydrogen bonds are relatively weak chemical forces that allow the two strands of the helix to separate.

The ability of the two strands to separate is critical to DNA's functions.

Base Pairing

Watson and Crick's model showed that hydrogen bonds could create a nearly perfect fit between nitrogenous bases along the center of the molecule.

These bonds would form only between certain base pairs—adenine with thymine, and guanine with cytosine.

This nearly perfect fit between A–T and G–C nucleotides is known as base pairing, and is illustrated in the figure.

Base Pairing

Watson and Crick realized that base pairing explained Chargaff's rule. It gave a reason why [A] = [T] and [G] = [C].

For every adenine in a double-stranded DNA molecule, there had to be exactly one thymine. For each cytosine, there was one guanine.

Lesson Overview 12.3 DNA Replication

- **Copying the Code**

  Base pairing in the double helix explained how DNA could be copied, or replicated, because each base on one strand pairs with only one base on the opposite strand.

  Each strand of the double helix has all the information needed to reconstruct the other half by the mechanism of base pairing.

  Because each strand can be used to make the other strand, the strands are said to be complementary.

- **The Replication Process**

  Before a cell divides, it duplicates its DNA in a copying process called **replication**.

  This process ensures that each resulting cell has the same complete set of DNA molecules.

- **The Replication Process**

  During replication, the DNA molecule separates into two strands and then produces two new complementary strands following the rules of base pairing.

  Each strand of the double helix of DNA serves as a template, or model, for the new strand.

- **The Replication Process**

  The two strands of the double helix separate, or “unzip,” allowing two replication forks to form.

- **The Replication Process**

  As each new strand forms, new bases are added following the rules of base pairing.

  If the base on the old strand is adenine, then thymine is added to the newly forming strand.

  Likewise, guanine is always paired to cytosine.

- **The Replication Process**

  The result of replication is two DNA molecules identical to each other and to the original molecule.

  Each DNA molecule resulting from replication has one original strand and one new strand.

- **The Role of Enzymes**

DNA replication is carried out by a series of enzymes. **Helicase** is the enzyme that “unzips” a molecule of DNA by breaking the hydrogen bonds between base pairs and unwinding the two strands of the molecule.

Each strand then serves as a template for the attachment of complementary bases.

- **The Role of Enzymes**

  The principal enzyme involved in DNA replication is called **DNA polymerase.**

  DNA polymerase is an enzyme that joins individual nucleotides to produce a new strand of DNA.

  DNA polymerase also “proofreads” each new DNA strand, ensuring that each molecule is a perfect copy of the original.

- **Telomeres**

  The tips of chromosomes are known as **telomeres**.

  The ends of DNA molecules, located at the telomeres, are particularly difficult to copy.

  Over time, DNA may actually be lost from telomeres each time a chromosome is replicated.

  An enzyme called telomerase compensates for this problem by adding short, repeated DNA sequences to telomeres, lengthening the chromosomes slightly and making it less likely that important gene sequences will be lost from the telomeres during replication.

- **Replication in Living Cells**

  How does DNA replication differ in prokaryotic cells and eukaryotic cells?

  Replication in most **prokaryotic** cells starts from a **single point** and proceeds in **two directions** until the entire chromosome is copied.
  In **eukaryotic** cells, replication may **begin at dozens or even hundreds** of places on the DNA molecule, proceeding **in both directions** until each chromosome is completely copied

  The cells of most **prokaryotes** have a **single, circular DNA** molecule in the cytoplasm, containing nearly all the cell’s genetic information.

  Eukaryotic cells, on the other hand, can have up to 1000 times **more DNA** that is arranged **in linear form**. Nearly all of the DNA of eukaryotic cells is found in the nucleus

- **Prokaryotic DNA Replication**

In most prokaryotes, DNA replication does not start until regulatory proteins bind to a single starting point on the chromosome. This triggers the beginning of DNA replication.

Replication in most prokaryotic cells starts from a single point and proceeds in two directions until the entire chromosome is copied.

- **Prokaryotic DNA Replication**

  Often, the two chromosomes produced by replication are attached to different points inside the cell membrane and are separated when the cell splits to form two new cells.

- **Eukaryotic DNA Replication**

  Eukaryotic chromosomes are generally much bigger than those of prokaryotes.

  In eukaryotic cells, replication may begin at dozens or even hundreds of places on the DNA molecule, proceeding in both directions until each chromosome is completely copied.

- **Eukaryotic DNA Replication**

  The two copies of DNA produced by replication in each chromosome remain closely associated until the cell enters prophase of mitosis.

  At that point, the chromosomes condense, and the two chromatids in each chromosome become clearly visible.

  They separate from each other in anaphase of mitosis, producing two cells, each with a complete set of genes coded in DNA.

Lesson Overview 13.1 RNA

The Role of RNA

Genes contain coded DNA instructions that tell cells how to build proteins.

The first step in decoding these genetic instructions is to copy part of the base sequence from DNA into RNA.

RNA, like DNA, is a nucleic acid that consists of a long chain of nucleotides.

RNA then uses the base sequence copied from DNA to direct the production of proteins.

Comparing RNA and DNA

Each nucleotide in both DNA and RNA is made up of a 5-carbon sugar, a phosphate group, and a nitrogenous base.

There are three important differences between RNA and DNA:

(1) The sugar in RNA is ribose instead of deoxyribose.

(2) RNA is generally single-stranded and not double-stranded.

(3) RNA contains uracil in place of thymine.

These chemical differences make it easy for the enzymes in the cell to tell DNA and RNA apart.

Comparing RNA and DNA

The roles played by DNA and RNA are similar to the master plans and blueprints used by builders.

Comparing RNA and DNA

A master plan has all the information needed to construct a building. Builders never bring a valuable master plan to the building site, where it might be damaged or lost. Instead, they prepare inexpensive, disposable copies of the master plan called blueprints.

Comparing RNA and DNA

Similarly, the cell uses DNA “master plan” to prepare RNA “blueprints.”

The DNA molecule stays safely in the cell’s nucleus, while RNA molecules go to the protein-building sites in the cytoplasm—the ribosomes.

You can think of an RNA molecule, as a disposable copy of a segment of DNA, a working copy of a single gene

Functions of RNA

The three main types of RNA are messenger RNA, ribosomal RNA, and transfer RNA.

Messenger RNA

Most genes contain instructions for assembling amino acids into proteins.

The RNA molecules that carry copies of these instructions are known as **messenger RNA** (mRNA): They carry information from DNA to other parts of the cell.

Ribosomal RNA

Proteins are assembled on ribosomes, small organelles composed of two subunits.

These ribosome subunits are made up of several **ribosomal RNA** (rRNA) molecules and as many as 80 different proteins.

Transfer RNA

When a protein is built, a **transfer RNA** (tRNA) molecule transfers each amino acid to the ribosome as it is specified by the coded messages in mRNA.

Transcription

Most of the work of making RNA takes place during **transcription.** During transcription, segments of DNA serve as templates to produce complementary RNA molecules.

The base sequences of the transcribed RNA complement the base sequences of the template DNA.

Transcription

In prokaryotes, RNA synthesis and protein synthesis take place in the cytoplasm.

In eukaryotes, RNA is produced in the cell's nucleus and then moves to the cytoplasm to play a role in the production of proteins. Our focus will be on transcription in eukaryotic cells.

Transcription

Transcription requires an enzyme, known as **RNA polymerase**, that is similar to DNA polymerase.

Transcription

RNA polymerase binds to DNA during transcription and separates the DNA strands.

Transcription

RNA polymerase then uses one strand of DNA as a template from which to assemble nucleotides into a complementary strand of RNA.

Promoters

RNA polymerase binds only to **promoters**, regions of DNA that have specific base sequences.

Promoters are signals in the DNA molecule that show RNA polymerase exactly where to begin making RNA.

Similar signals in DNA cause transcription to stop when a new RNA molecule is completed.

RNA Editing

RNA molecules sometimes require bits and pieces to be cut out of them before they can go into action.

The portions that are cut out and discarded are called **introns.**

In eukaryotes, introns are taken out of pre-mRNA molecules while they are still in the nucleus.

The remaining pieces, known as **exons**, are then spliced back together to form the final mRNA.

RNA Editing

Biologists don't have a complete answer as to why cells use energy to make a large RNA molecule and then throw parts of that molecule away.

Some pre-mRNA molecules may be cut and spliced in different ways in different tissues, making it possible for a single gene to produce several different forms of RNA.

RNA Editing

Introns and exons may also play a role in evolution, making it possible for very small changes in DNA sequences to have dramatic effects on how genes affect cellular function.

Lesson Overview 13.2 Ribosomes and Protein Synthesis

The Genetic Code

The first step in decoding genetic messages is to transcribe a nucleotide base sequence from DNA to mRNA.

This transcribed information contains a code for making proteins.

The Genetic Code

Proteins are made by joining amino acids together into long chains, called **polypeptides.**

As many as 20 different amino acids are commonly found in polypeptides.

The Genetic Code

The specific amino acids in a polypeptide, and the order in which they are joined, determine the properties of different proteins.

The sequence of amino acids influences the shape of the protein, which in turn determines its function.

The Genetic Code

RNA contains four different bases: adenine, cytosine, guanine, and uracil.

These bases form a “language,” or **genetic code**, with just four “letters”: A, C, G, and U.

The Genetic Code

Each three-letter “word” in mRNA is known as a **codon.**

A codon consists of three consecutive bases that specify a single amino acid to be added to the polypeptide chain.

How to Read Codons

Because there are four different bases in RNA, there are 64 possible three-base codons ($4 \times 4 \times 4 = 64$) in the genetic code.

This circular table shows the amino acid to which each of the 64 codons corresponds. To read a codon, start at the middle of the circle and move outward.

How to Read Codons

Most amino acids can be specified by more than one codon.

For example, six different codons—UUA, UUG, CUU, CUC, CUA, and CUG—specify leucine. But only one codon—UGG—specifies the amino acid tryptophan.

Start and Stop Codons

The genetic code has punctuation marks.

The methionine codon AUG serves as the initiation, or “start,” codon for protein synthesis.

Following the start codon, mRNA is read, three bases at a time, until it reaches one of three different “stop” codons, which end translation.

Translation

The sequence of nucleotide bases in an mRNA molecule is a set of instructions that gives the order in which amino acids should be joined to produce a polypeptide.

The forming of a protein requires the folding of one or more polypeptide chains.

Ribosomes use the sequence of codons in mRNA to assemble amino acids into polypeptide chains.

The decoding of an mRNA message into a protein is a process known as **translation.**

Steps in Translation

Messenger RNA is transcribed in the nucleus and then enters the cytoplasm for translation.

Steps in Translation

Translation begins when a ribosome attaches to an mRNA molecule in the cytoplasm.

As the ribosome reads each codon of mRNA, it directs tRNA to bring the specified amino acid into the ribosome.

One at a time, the ribosome then attaches each amino acid to the growing chain.

Steps in Translation

Each tRNA molecule carries just one kind of amino acid.

In addition, each tRNA molecule has three unpaired bases, collectively called the **anticodon**—which is complementary to one mRNA codon.

The tRNA molecule for methionine has the anticodon UAC, which pairs with the methionine codon, AUG.

Steps in Translation

The ribosome has a second binding site for a tRNA molecule for the next codon.

If that next codon is UUC, a tRNA molecule with an AAG anticodon brings the amino acid phenylalanine into the ribosome.

Steps in Translation

The ribosome helps form a peptide bond between the first and second amino acids—methionine and phenylalanine.

At the same time, the bond holding the first tRNA molecule to its amino acid is broken.

Steps in Translation

That tRNA then moves into a third binding site, from which it exits the ribosome.

The ribosome then moves to the third codon, where tRNA brings it the amino acid specified by the third codon.

Steps in Translation

The polypeptide chain continues to grow until the ribosome reaches a “stop” codon on the mRNA molecule.

When the ribosome reaches a stop codon, it releases both the newly formed polypeptide and the mRNA molecule, completing the process of translation.

The Roles of tRNA and rRNA in Translation

Ribosomes are composed of roughly 80 proteins and three or four different rRNA molecules.

These rRNA molecules help hold ribosomal proteins in place and help locate the beginning of the mRNA message.

They may even carry out the chemical reaction that joins amino acids together.

The Molecular Basis of Heredity

Most genes contain instructions for assembling proteins.

The Molecular Basis of Heredity

Many proteins are enzymes, which catalyze and regulate chemical reactions.

A gene that codes for an enzyme to produce pigment can control the color of a flower. Another gene produces proteins that regulate patterns of tissue growth in a leaf. Yet another may trigger the female or male pattern of development in an embryo.

Proteins are microscopic tools, each specifically designed to build or operate a component of a living cell.

The Molecular Basis of Heredity

Molecular biology seeks to explain living organisms by studying them at the molecular level, using molecules like DNA and RNA.

The central dogma of molecular biology is that information is transferred from DNA to RNA to protein.

There are many exceptions to this “dogma,” but it serves as a useful generalization that helps explain how genes work.

The Molecular Basis of Heredity

Gene expression is the way in which DNA, RNA, and proteins are involved in putting genetic information into action in living cells.

DNA carries information for specifying the traits of an organism.

The cell uses the sequence of bases in DNA as a template for making mRNA.

The Molecular Basis of Heredity

The codons of mRNA specify the sequence of amino acids in a protein.

Proteins, in turn, play a key role in producing an organism's traits.

The Molecular Basis of Heredity

One of the most interesting discoveries of molecular biology is the near-universal nature of the genetic code.

Although some organisms show slight variations in the amino acids assigned to particular codons, the code is always read three bases at a time and in the same direction.

Despite their enormous diversity in form and function, living organisms display remarkable unity at life's most basic level, the molecular biology of the gene.

Lesson Overview 13.3 Mutations

Types of Mutations

Now and then cells make mistakes in copying their own DNA, inserting the wrong base or even skipping a base as a strand is put together.

These variations are called **mutations**, from the Latin word *mutare*, meaning "to change."

Mutations are heritable changes in genetic information.

Types of Mutations

All mutations fall into two basic categories:

Those that produce changes in a single gene are known as gene mutations.

Those that produce changes in whole chromosomes are known as chromosomal mutations.

Gene Mutations

Mutations that involve changes in one or a few nucleotides are known as **point mutations** because they occur at a single point in the DNA sequence. They generally occur during replication.

If a gene in one cell is altered, the alteration can be passed on to every cell that develops from the original one.

Point mutations include substitutions, insertions, and deletions.

Substitutions

In a substitution, one base is changed to a different base.

Substitutions usually affect no more than a single amino acid, and sometimes they have no effect at all.

Substitutions

In this example, the base cytosine is replaced by the base thymine, resulting in a change in the mRNA codon from CGU (arginine) to CAU (histidine).

However, a change in the last base of the codon, from CGU to CGA for example, would still specify the amino acid arginine.

Insertions and Deletions

Insertions and deletions are point mutations in which one base is inserted or removed from the DNA sequence.

If a nucleotide is added or deleted, the bases are still read in groups of three, but now those groupings shift in every codon that follows the mutation.

Insertions and Deletions

Insertions and deletions are also called **frameshift mutations** because they shift the "reading frame" of the genetic message.

Frameshift mutations can change every amino acid that follows the point of the mutation and can alter a protein so much that it is unable to perform its normal functions.

Chromosomal Mutations

Chromosomal mutations involve changes in the number or structure of chromosomes.

These mutations can change the location of genes on chromosomes and can even change the number of copies of some genes.

There are four types of chromosomal mutations: deletion, duplication, inversion, and translocation.

Chromosomal Mutations

Deletion involves the loss of all or part of a chromosome.

Chromosomal Mutations

Duplication produces an extra copy of all or part of a chromosome.

Chromosomal Mutations

Inversion reverses the direction of parts of a chromosome.

Chromosomal Mutations

Translocation occurs when part of one chromosome breaks off and attaches to another.

Mutagens

Some mutations arise from **mutagens**, chemical or physical agents in the environment.

Chemical mutagens include certain pesticides, a few natural plant alkaloids, tobacco smoke, and environmental pollutants.

Physical mutagens include some forms of electromagnetic radiation, such as X-rays and ultraviolet light.

Mutagens

If these mutagens interact with DNA, they can produce mutations at high rates.

Some compounds interfere with base-pairing, increasing the error rate of DNA replication.

Others weaken the DNA strand, causing breaks and inversions that produce chromosomal mutations.

Cells can sometimes repair the damage; but when they cannot, the DNA base sequence changes permanently.

Harmful and Helpful Mutations

The effects of mutations on genes vary widely. Some have little or no effect; and some produce beneficial variations. Some negatively disrupt gene function.

Whether a mutation is negative or beneficial depends on how its DNA changes relative to the organism's situation.

Mutations are often thought of as negative because they disrupt the normal function of genes.

However, without mutations, organisms cannot evolve, because mutations are the source of genetic variability in a species.

Harmful Effects

Some of the most harmful mutations are those that dramatically change protein structure or gene activity.

The defective proteins produced by these mutations can disrupt normal biological activities, and result in genetic disorders.

Some cancers, for example, are the product of mutations that cause the uncontrolled growth of cells.

Harmful Effects

Sickle cell disease is a disorder associated with changes in the shape of red blood cells. Normal red blood cells are round. Sickle cells appear long and pointed.

Sickle cell disease is caused by a point mutation in one of the polypeptides found in hemoglobin, the blood's principal oxygen-carrying protein.

Among the symptoms of the disease are anemia, severe pain, frequent infections, and stunted growth.

Beneficial Effects

Some of the variation produced by mutations can be highly advantageous to an organism or species.

Mutations often produce proteins with new or altered functions that can be useful to organisms in different or changing environments.

For example, mutations have helped many insects resist chemical pesticides.

Some mutations have enabled microorganisms to adapt to new chemicals in the environment.

Beneficial Effects

Plant and animal breeders often make use of "good" mutations.

For example, when a complete set of chromosomes fails to separate during meiosis, the gametes that result may produce triploid (3N) or tetraploid (4N) organisms.

The condition in which an organism has extra sets of chromosomes is called **polyploidy.**

Beneficial Effects

Polyploid plants are often larger and stronger than diploid plants.

Important crop plants—including bananas and limes—have been produced this way.

Polyploidy also occurs naturally in citrus plants, often through spontaneous mutations.

18.1 Binomial Nomenclature

In the 1730s, Swedish botanist Carolus Linnaeus developed a two-word naming system called binomial nomenclature. In deciding how to place organisms into larger groups, Linnaeus grouped species according to anatomical similarities and differences.

The scientific name usually is Latin. It is written in italics. The first word begins with a capital letter, and the second word is lowercased.

Binomial Nomenclature

The polar bear, for example, is called *Ursus maritimus.*

The first part of the name—*Ursus*—is the genus to which the organism belongs. A **genus** is a group of similar species. The genus *Ursus* contains five other species of bears, including *Ursus arctos,* the brown bear or grizzly bear.

The second part of a scientific name—*maritimus* for polar bears—is unique to each species and is often a description of the organism's habitat or of an important trait. The Latin word maritimus refers to the sea: polar bears often live on pack ice that floats in the sea.

Binomial Nomenclature

The scientific name of the red maple is *Acer rubrum.*

The genus *Acer* consists of all maple trees.

The species *rubrum* describes the red maple's color.

Classifying Species into Larger Groups

In addition to naming organisms, biologists try to organize, or classify, living and fossil species into larger groups that have biological meaning. Biologists often refer to these groups as taxa (singular: **taxon).**

The science of naming and grouping organisms is called **systematics or taxonomy.**

Seven Levels

Linnaeus identified just four levels in his original classification system.

Over time, Linnaeus's original classification system would expand to include seven taxa: species, genus, family, order, class, phylum, and kingdom.

Seven Levels

The scientific name of a camel with two humps is *Camelus bactrianus.*

This illustration shows how a Bactrian camel, *Camelus bactrianus*, is grouped within each Linnaean category.

The genus *Camelus* contains another species, *Camelus dromedarius,* the dromedary, with only one hump.

Family

The South American llama bears some resemblance to Bactrian camels and dromedaries. But the llama is more closely related to other South American species than it is to European and Asian camels.

Therefore, llamas are placed in a different genus, *Lama*; their species name is *Lama glama.*

Genera that share many similarities *are* grouped into a larger category, the **family**—in this case, Camelidae.

Order

Closely related families are grouped into the next larger rank—an **order.**

Camels and llamas (family Camelidae) are grouped with several other animal families, including deer (family Cervidae) and cattle (family Bovidae), into the order Artiodactyla, hoofed animals with an even number of toes.

Class

Closely related orders are grouped into the next larger rank, a **class.**

The order Artiodactyla is placed in the class Mammalia, which includes all animals that are warm-blooded, have body hair, and produce milk for their young.

Phylum

Classes are grouped into a **phylum.** A phylum includes organisms that are different but that share important characteristics.

The class Mammalia is grouped with birds (class Aves), reptiles (class Reptilia), amphibians (class Amphibia), and all classes of fish into the phylum Chordata. These organisms share important body-plan features, among them a nerve cord along the back.

Kingdom

The largest and most inclusive of Linnaeus's taxonomic categories is the **kingdom.**

All multicellular animals are placed in the kingdom Animalia.

Problems With Traditional Classification

In a way, members of a species determine which organisms belong to that species by deciding with whom they mate and produce fertile offspring.

Ranks above the level of species, however, are determined by researchers who decide how to define and describe genera, families, orders, classes, phyla, and kingdoms.

Linnaeus grouped organisms into larger taxa according to overall similarities and differences. But which similarities and differences are the most important?

Problems With Traditional Classification

For example, adult barnacles and limpets live attached to rocks and have similar-looking shells.

Adult crabs don't look anything like barnacles and limpets.

Based on these features, one would likely classify limpets and barnacles together and crabs in a different group. However, that would be wrong.

Modern classification schemes look beyond overall similarities and differences and group organisms based on evolutionary relationships.

18.2 Evolutionary Classification

The concept of descent with modification led to **phylogeny**—the study of how living and extinct organisms are related to one another.

Advances in phylogeny, in turn, led to phylogenetic systematics, or evolutionary classification. Phylogenetic systematics groups species into larger categories that reflect lines of evolutionary descent, rather than overall similarities and differences.

Common Ancestors

Phylogenetic systematics places organisms into higher taxa whose members are more closely related to one another than they are to members of any other group.

The larger a taxon is, the farther back in time all of its members shared a common ancestor.

Clades

A **clade** is a group of species that includes a single common ancestor and all descendants of that ancestor—living and extinct.

A clade must be a monophyletic group. A **monophyletic group** must include all species that are descended from a common ancestor, and cannot include any species that are not descended from that common ancestor.

Cladograms

Modern evolutionary classification uses a method called cladistic analysis to determine how clades are related to one another.

This information is used to link clades together into a **cladogram,** which illustrates how groups of organisms are related to one another by showing how evolutionary lines, or lineages, branched off from common ancestors.

Building Cladograms

A speciation event, in which an ancestral lineage branches into two new lineages, is the basis for each branch point, or node. Each node represents the last point at which the new lineages shared a common ancestor.

The bottom, or "root," of the tree represents the common ancestor shared by all organisms on the cladogram.

Building Cladograms

A cladogram's branching patterns indicate degrees of relatedness among organisms.

Because lineages 3 and 4 share a common ancestor more recently with each other than they do with lineage 2, you know that lineages 3 and 4 are more closely related to each other than they are with lineage 2.

Building Cladograms

Likewise, lineages 2, 3, and 4 are more closely related, in terms on ancestry, with each other than any of them is to lineage 1.

Building Cladograms

This cladogram represents current hypotheses about evolutionary relationships among vertebrates.

Note that in terms of ancestry, amphibians are more closely related to mammals than they are to ray-finned fish!

Derived Characters

In contrast to Linnaean classification, cladistic analysis focuses on certain kinds of characters, called derived characters, when assigning organisms into clades.

A **derived character** is a trait that arose in the most recent common ancestor of a particular lineage and was passed along to its descendants.

Derived Characters

Whether or not a character is derived depends on the level at which you're grouping organisms. Four limbs, for example, is a derived character for the clade tetrapoda. Hair is a derived character for the clade Mammalia, but four limbs is *not* derived for mammals. If it were, only mammals would have four limbs!

Derived Characters

Specialized shearing teeth is a derived character for the clade Carnivora—of which both the coyote and lion are members. Neither hair nor four limbs is a derived character for this clade.

Retractable claws is a derived character for the clade Felidae (the cats). Notice that lions have this trait, but coyotes do not.

Losing Traits

Because distantly related groups of organisms can lose the same character, systematists are cautious about using the absence of a trait as a derived character.

For example, both whales and snakes have lost the tetrapod character of four limbs—but they are not very closely related. Snakes are members of the clade Reptilia, while whales are members of the clade Mammalia.

.

Reading Cladograms

Each derived character defines a clade. Hair, for example, is a defining character for the clade Mammalia.

Reading Cladograms

Retractable claws is a derived character shared only by members of the clade Felidae.

Reading Cladograms

Derived characters that appear "lower" on the cladogram than the branch point for a clade are not derived for that particular clade. Hair, for example, is not a derived character for the clade Carnivora.

Reading Cladograms

Smaller clades are nested within the larger clades. Clade Amniota is part of the larger clade Tetrapoda.

Clades and Traditional Taxonomic Groups

A clade must be monophyletic. This means that it contains an ancestral species and all of its descendants, and no species that are not descendants of that ancestor.

Cladistic analysis shows that many traditional taxonomic groups do form valid clades. Linnaean class Mammalia, for example, corresponds to clade Mammalia.

Clades and Traditional Taxonomic Groups

In other cases, however, traditional groups do not form valid clades.

Today's reptiles are all descended from a common ancestor. Modern birds, however, are also descended from that ancestor.

Linnaean class Reptilia, which does not include birds, is therefore not a valid clade.

Clades and Traditional Taxonomic Groups

Clades and Traditional Taxonomic Groups

Two clades do include the birds: clade Aves, (the birds themselves), and clade Reptilia. Therefore, according to cladistics, a bird is a reptile!

DNA in Classification

How are DNA sequences used in classification?

In general, the more derived genetic characters two species share, the more recently they shared a common ancestor and the more closely they are related in evolutionary terms.

Genes as Derived Characters

All organisms carry genetic information in their DNA passed on from earlier generations.

A wide range of organisms share a number of genes and show important homologies that can be used to determine evolutionary relationships.

Genes as Derived Characters

All eukaryotic cells, for example, have mitochondria, and all mitochondria have their own genes.

Because all genes mutate over time, shared genes contain differences that can be treated as derived characters in cladistic analysis.

For that reason, similarities and differences in DNA can be used to develop hypotheses about evolutionary relationships.

This suggests that American vultures are more closely related to storks than to other vultures.

New Techniques Suggest New Trees

The use of DNA characters in cladistic analysis has helped to make evolutionary trees more accurate.

For example, traditionally African vultures and American vultures were classified together in the falcon family.

Molecular analysis, however, showed that DNA from American vultures is more similar to the DNA of storks than it is to the DNA of African vultures.

New Techniques Suggest New Trees

Often, scientists use DNA evidence when anatomical traits alone can't provide clear answers.

For example, giant pandas and red pandas share many characteristics with both bears and raccoons.

New Techniques Suggest New Trees

DNA analysis revealed that the giant panda shares a more recent common ancestor with bears than with raccoons. Therefore, the giant panda has been placed in a clade with bears.

Red pandas, however, are in a clade with raccoons and other animals like weasels and seals.

18.3 Changing Ideas About Kingdoms

This diagram shows some of the ways in which organisms have been classified into kingdoms since the 1700s.

Three Domains

Genetic analysis has revealed that the two main prokaryotic kingdoms are more different from each other, and from eukaryotes, than previously thought. So, biologists established a new taxonomic category—the domain. A **domain** is a larger, more inclusive category than a kingdom.

Under this system, there are three domains—domain Bacteria (corresponding to domain Eubacteria), domain Archaea (corresponding to kingdom Archaebacteria), and domain Eukarya (corresponding to kingdoms Fungi, Plantae, Animalia, and kingdom "Protista").

Quotes are put around kingdom "Protista" to indicate that it is not a monophyletic group.

Three Domains

The Tree of All Life

Modern evolutionary classification is a rapidly changing science with the difficult goal of presenting all life on a single evolutionary tree.

The tree of life shows current hypotheses regarding evolutionary relationships among the taxa within the three domains.

The Tree of All Life

Domain Bacteria

Members of the domain **Bacteria** are unicellular and prokaryotic. This domain corresponds to the kingdom Eubacteria.

Their cells have thick, rigid walls that surround a cell membrane and contain a substance known as peptidoglycan.

These bacteria are ecologically diverse, ranging from free-living soil organisms to deadly parasites. Some photosynthesize, while others do not. Some need oxygen to survive, while others are killed by oxygen.

Domain Archaea

The domain Archaea corresponds to the kingdom Archaebacteria.

Members of the domain **Archaea** are unicellular and prokaryotic, and they live in some extreme environments—in volcanic hot springs, brine pools, and black organic mud totally devoid of oxygen. Many of these bacteria can survive only in the absence of oxygen.

Their cell walls lack peptidoglycan, and their cell membranes contain unusual lipids that are not found in any other organism.

Domain Eukarya

The domain **Eukarya** consists of all organisms that have a nucleus. It comprises the four remaining kingdoms of the six-kingdom system: ‘‘Protista,’’ Fungi, Plantae, and Animalia.

The “Protists”: Unicellular Eukaryotes

The kingdom Protista has long been viewed by biologists as a ‘‘catchall’’ group of eukaryotes that could not be classified as fungi, plants, or animals.

Recent molecular studies and cladistic analyses have shown that ‘‘the eukaryotes formerly known as ‘‘Protista’’ do not form a single clade. Current cladistic analysis divides these organisms into at least five clades.

Since these organisms cannot be properly placed into a single taxon, we refer to them as ‘‘protists.’’

The “Protists”: Unicellular Eukaryotes

Most ‘‘protists’’ are unicellular, but one group, the brown algae, is multicellular.

Some ‘‘protists’’ are photosynthetic, while others are heterotrophic.

Some display characters that resemble those of fungi, plants, or animals.

Fungi

Members of the kingdom Fungi are heterotrophs with cell walls containing chitin.

Most fungi feed on dead or decaying organic matter. They secrete digestive enzymes into their food source, which break the food down into smaller molecules. The fungi then absorb these smaller molecules into their bodies.

Mushrooms and other recognizable fungi are multicellular, like the ghost fungus shown. Some fungi—yeasts, for example—are unicellular.

Plantae

Members of the kingdom Plantae are multicellular, have cell walls that contain cellulose, and are autotrophic.

Autotrophic plants are able to carry on photosynthesis using chlorophyll.

Plants are nonmotile—they cannot move from place to place.

The entire plant kingdom is the sister group to the red algae, which are "protists." The plant kingdom, therefore, includes the green algae along with mosses, ferns, cone-bearing plants, and flowering plants.

Animalia

Members of the kingdom Animalia are multicellular and heterotrophic.

Animal cells do not have cell walls.

Most animals can move about, at least for some part of their life cycle.

There is incredible diversity within the animal kingdom, and many species of animals exist in nearly every part of the planet.

Lesson Overview 10.1 Cell Growth, Division, and Reproduction

Information "Overload"

Living cells store information in DNA that is used to build molecules needed for cell growth.

As cell size increases, demands on that information increase.

If the cell gets too big, the DNA would not be able to serve the needs of the growing cell.

Exchanging Materials

Nutrients enter and waste leaves a cell through the cell membrane.

The rate at which this exchange occurs depends on the surface area of a cell.

The rate at which nutrients are used and waste products are produced depends on the cell's volume.

If a cell gets too large, the surface area of the membrane is not large enough to exchange nutrients and waste quickly enough.

Division of the Cell

Before a cell grows too large, it divides into two new "daughter" cells in a process called **cell division.**

Before cell division, the cell copies all of its DNA.

Each daughter cell receives a complete set of DNA.

Cell division reduces cell volume and results in a better surface area to volume ratio for each daughter cell.

In multicellular organisms, cell division leads to growth, body repair and maintenance.

In single-celled organisms, cell division is a form of reproduction.

Asexual reproduction involves a single parent producing an offspring.

- offspring usually identical to parent (clones)
- produce many offspring from 1 cell.

Both prokaryotic and eukaryotic single-celled organisms and many multicellular organisms can reproduce asexually.

sexual reproduction - offspring produced by the fusion of two sex cells – one sex cell from each of two parents.

offspring inherit some genes from both parents.

Most animals and plants, and many single-celled organisms, reproduce sexually.

Comparing Sexual and Asexual Reproduction

Asexual	Sexual
Produces genetically identical offspring	Produces genetically diverse offspring
Reproduction is quick and produces large number of offspring	Genetic diversity helps ensure survival of species when environment changes

Lesson Overview 10.2 The Process of Cell Division

genetic information passed from parent to offspring is carried by **chromosomes.**

Chromosomes enable precise DNA separation during cell division.

Every cell must copy its genetic information before cell division begins.

Each daughter cell gets its own copy of that genetic information.

Cells of every organism have a specific number of chromosomes.

Prokaryotic Chromosomes

prokaryotes contain a single, circular DNA molecule, or **chromosome**

Eukaryotic Chromosomes

eukaryotic chromosomes are in the nucleus, and are made of **chromatin.**

Chromatin is composed of DNA and histone proteins.

DNA coils around histone proteins to form nucleosomes.

nucleosomes form coils and supercoils that make chromosomes.

The Cell Cycle

During the cell cycle, a cell grows, prepares for division, and divides to form two daughter cells.

Occurs in prokaryotes and eukaryotes

At the end of their cell cycle, prokaryotes divide by binary fission.

Binary fission - form of asexual reproduction which produces 2 genetically identical cells

For example, bacteria reproduce by binary fission.

The Eukaryotic Cell Cycle

The eukaryotic cell cycle consists of four phases: G1, S, G2, and M.

Interphase - time between cell divisions.

- period of growth
- consists of the G1, S, and G2 phases.

M phase - period of cell division.

G_1 Phase: Cell Growth

cells increase in size and make new proteins and organelles.

S Phase: DNA Replication

DNA is made when the chromosomes are replicated.

G_2 Phase: Preparing for Cell Division

organelles and molecules required for cell division are made

M Phase: Cell Division

In eukaryotes, cell division occurs in two stages: mitosis and cytokinesis.

Mitosis - division of the cell nucleus.

Cytokinesis - division of the cytoplasm.

Important Cell Structures Involved in Mitosis

Chromatid – each strand of a **duplicated** chromosome

Centromere – the area where each pair of chromatids is joined

Centrioles – tiny structures located in the cytoplasm of animal cells that help organize the spindle

Spindle – a fanlike microtubule structure that helps separate the chromatids

Prophase

duplicated chromosome condenses and becomes visible.

centrioles move to opposite sides of nucleus and help organize the spindle.

spindle forms and DNA strands attach at their **centromere**.

nucleolus disappears and nuclear envelope breaks down.

Metaphase

centromeres of duplicated chromosomes line up in center of cell.

spindle fibers connect the centromere of each chromosome to the poles of the spindle.

Anaphase

centromeres pull apart and chromatids separate to become individual chromosomes.

chromosomes separate into two groups near the poles of the spindle.

Telophase

chromosomes form into chromatin.

nuclear envelopes re-form.

spindle breaks apart

nucleolus appears in each daughter nucleus.

- division of the cytoplasm.

In animal cells, the cell membrane pinches in and cytoplasm divides into two equal parts.

In plant cells, a cell plate forms and develops into cell membranes.

A cell wall then forms in between the two new membranes.

1 **Lesson Overview**

11.1 The Work of Gregor Mendel

2 **THINK ABOUT IT**

What is an inheritance?

- It is something we each receive from our parents—a contribution that determines our blood type, the color of our hair, and so much more.

What kind of inheritance makes a person's face round or hair curly?

3 **The Experiments of Gregor Mendel**

Where does an organism get its unique characteristics?

4 **The Experiments of Gregor Mendel**

Where does an organism get its unique characteristics?

An individual's characteristics are determined by factors that are passed from one parental generation to the next.

5 **The Experiments of Gregor Mendel**

Every living thing—plant or animal, microbe or human being—has a set of characteristics inherited from its parent or parents.

The delivery of characteristics from parent to offspring is called heredity.

The scientific study of heredity, known as genetics, is the key to understanding what makes each organism unique.

6 **The Experiments of Gregor Mendel**

The modern science of genetics was founded by an Austrian monk named Gregor Mendel.

Mendel was in charge of the monastery garden, where he was able to do the work that changed biology forever.

7 **The Experiments of Gregor Mendel**

Mendel carried out his work with ordinary garden peas, partly because peas are small and easy to grow. A single pea plant can produce hundreds of offspring.

Today we call peas a “model system.”

8 **The Experiments of Gregor Mendel**

Scientists use model systems because they are convenient to study and may tell us how other organisms, including humans, actually function.

9 **The Experiments of Gregor Mendel**

By using peas, Mendel was able to carry out, in just one or two growing seasons, experiments that would have been impossible to do with humans and that would have taken decades—if not centuries—to do with other large animals.

10 **The Role of Fertilization**

Mendel knew that the male part of each flower makes pollen, which contains sperm—the plant’s male reproductive cells.

11 **The Role of Fertilization**

Similarly, Mendel knew that the female portion of each flower produces reproductive cells called eggs.

12 **The Role of Fertilization**

During sexual reproduction, male and female reproductive cells join in a process known as fertilization to produce a new cell.

In peas, this new cell develops into a tiny embryo encased within a seed.

13 **The Role of Fertilization**

Pea flowers are normally self-pollinating, which means that sperm cells fertilize egg cells from within the same flower.

A plant grown from a seed produced by self-pollination inherits all of its characteristics from the single plant that bore it. In effect, it has a single parent.

14 **The Role of Fertilization**

Mendel’s garden had several stocks of pea plants that were “true-breeding,” meaning that they were self-pollinating, and would produce offspring with identical traits to themselves.

In other words, the traits of each successive generation would be the same.

A trait is a specific characteristic of an individual, such as seed color or plant height, and may vary from one individual to another.

15 **The Role of Fertilization**

Mendel decided to “cross” his stocks of true-breeding plants—he caused one plant to

reproduce with another plant.

16 **The Role of Fertilization**

To do this, he had to prevent self-pollination. He did so by cutting away the pollen-bearing male parts of a flower and then dusting the pollen from a different plant onto the female part of that flower, as shown in the figure.

17 **The Role of Fertilization**

This process, known as cross-pollination, produces a plant that has two different parents.

Cross-pollination allowed Mendel to breed plants with traits different from those of their parents and then study the results.

18 **The Role of Fertilization**

Mendel studied seven different traits of pea plants, each of which had two contrasting characteristics, such as green seed color or yellow seed color.

Mendel crossed plants with each of the seven contrasting characteristics and then studied their offspring.

The offspring of crosses between parents with different traits are called hybrids.

19 **Genes and Alleles**

When doing genetic crosses, we call the original pair of plants the P, or parental, generation.

20 **Genes and Alleles**

Their offspring are called the F_1, or "first filial," generation.

21 **Genes and Alleles**

For each trait studied in Mendel's experiments, all the offspring had the characteristics of only one of their parents, as shown in the table.

22 **Genes and Alleles**

In each cross, the nature of the other parent, with regard to each trait, seemed to have disappeared.

23 **Genes and Alleles**

From these results, Mendel drew two conclusions. His first conclusion formed the basis of our current understanding of inheritance.

An individual's characteristics are determined by factors that are passed from one parental generation to the next.

Scientists call the factors that are passed from parent to offspring genes.

24 **Genes and Alleles**

Each of the traits Mendel studied was controlled by one gene that occurred in two contrasting varieties.

These gene variations produced different expressions, or forms, of each trait.

The different forms of a gene are called alleles.

25 **Dominant and Recessive Traits**

Mendel's second conclusion is called the principle of dominance. This principle states that some alleles are dominant and others are recessive.

An organism with at least one dominant allele for a particular form of a trait will exhibit that form of the trait.

An organism with a recessive allele for a particular form of a trait will exhibit that form only when the dominant allele for the trait is not present.

26 **Dominant and Recessive Traits**

In Mendel's experiments, the allele for tall plants was dominant and the allele for short plants was recessive.

27 **Dominant and Recessive Traits**

In Mendel's experiments, the allele for tall plants was dominant and the allele for short plants was recessive. Likewise, the allele for yellow seeds was dominant over the recessive allele for green seeds

28 **Segregation**

How are different forms of a gene distributed to offspring?

29 **Segregation**

How are different forms of a gene distributed to offspring?

During gamete formation, the alleles for each gene segregate from each other, so that each gamete carries only one allele for each gene.

30 **Segregation**

Mendel wanted to find out what had happened to the recessive alleles.

To find out, Mendel allowed all seven kinds of F_1 hybrids to self-pollinate. The offspring of an F_1 cross are called the F_2 generation.

The F_2 offspring of Mendel's experiment are shown.

31 **The F1 Cross**

When Mendel compared the F_2 plants, he discovered the traits controlled by the recessive alleles reappeared in the second generation.

Roughly one fourth of the F_2 plants showed the trait controlled by the recessive allele.

32 **Explaining the F_1 Cross**

Mendel assumed that a dominant allele had masked the corresponding recessive allele in the F_1 generation.

The reappearance of the recessive trait in the F_2 generation indicated that, at some point, the allele for shortness had separated from the allele for tallness.

33 **Explaining the F1 Cross**

How did this separation, or segregation, of alleles occur?

Mendel suggested that the alleles for tallness and shortness in the F_1 plants must have segregated from each other during the formation of the sex cells, or gametes.

34

Let's assume that each F_1 plant—all of which were tall—inherited an allele for tallness from its tall parent and an allele for shortness from its short parent.

35

The Formation of Gametes

When each parent, or F_1 adult, produces gametes, the alleles for each gene segregate from one another, so that each gamete carries only one allele for each gene.

36

The Formation of Gametes

A capital letter represents a dominant allele. A lowercase letter represents a recessive allele.

Each F_1 plant in Mendel's cross produced two kinds of gametes—those with the allele for tallness (*T)* and those with the allele for shortness *(t)*.

37 **The Formation of Gametes**

Whenever each of two gametes carried the *t* allele and then paired with the other gamete to produce an F_2 plant, that plant was short.

Every time one or more gametes carried the *T* allele and paired together, they produced a tall plant.

The F_2 generation had new combinations of alleles.

1 **Lesson Overview**

11.2 Applying Mendel's Principles

2 **THINK ABOUT IT**

Nothing in life is certain.

If a parent carries two different alleles for a certain gene, we can't be sure which of those alleles will be inherited by one of the parent's offspring.

However, even if we can't predict the exact future, we can do something almost as useful—we can figure out the odds.

3 **Probability and Punnett Squares**

How can we use probability to predict traits?

4 **Probability and Punnett Squares**

How can we use probability to predict traits?

Punnett squares use mathematical probability to help predict the genotype and phenotype combinations in genetic crosses.

5 **Probability and Punnett Squares**

Whenever Mendel performed a cross with pea plants, he carefully categorized and counted the offspring.

For example, whenever he crossed two plants that were hybrid for stem height (*Tt),* about three fourths of the resulting plants were tall and about one fourth were short.

6 **Probability and Punnett Squares**

Mendel realized that the principles of probability could be used to explain the results of his genetic crosses.

Probability is the likelihood that a particular event will occur.

7 **Probability and Punnett Squares**

For example, there are two possible outcomes of a coin flip: The coin may land either heads up or tails up.

The chance, or probability, of either outcome is equal. Therefore, the probability that a single coin flip will land heads up is 1 chance in 2. This amounts to 1/2, or 50 percent.

8 **Probability and Punnett Squares**

If you flip a coin three times in a row, what is the probability that it will land heads up every time?

Each coin flip is an independent event, with a one chance in two probability of landing heads up.

9 **Probability and Punnett Squares**

Therefore, the probability of flipping three heads in a row is:

$1/2 \times 1/2 \times 1/2 = 1/8$

10 **Probability and Punnett Squares**

As you can see, you have 1 chance in 8 of flipping heads three times in a row.

Past outcomes do not affect future ones. Just because you've flipped 3 heads in a row does not mean that you're more likely to have a coin land tails up on the next flip.

11 **Using Segregation to Predict Outcomes**

The way in which alleles segregate during gamete formation is every bit as random as a coin flip.

Therefore, the principles of probability can be used to predict the outcomes of genetic crosses.

12 **Using Segregation to Predict Outcomes**

Mendel's cross produced a mixture of tall and short plants.

13 **Using Segregation to Predict Outcomes**

If each F_1 plant had one tall allele and one short allele (*Tt),* then 1/2 of the gametes they produced would carry the short allele (t).

14 **Using Segregation to Predict Outcomes**

Because the *t* allele is recessive, the only way to produce a short (*tt*) plant is for two gametes carrying the *t* allele to combine.

15 **Using Segregation to Predict Outcomes**

Each F_2 gamete has a one in two, or 1/2, chance of carrying the *t allele*.

16 **Using Segregation to Predict Outcomes**

There are two gametes, so the probability of both gametes carrying the *t* allele is:

½ x ½ = ¼

17 **Using Segregation to Predict Outcomes**

Roughly one fourth of the F_2 offspring should be short, and the remaining three fourths should be tall.

18 **Using Segregation to Predict Outcomes**

This predicted ratio—3 dominant to 1 recessive—showed up consistently in Mendel's experiments.

19 **Using Segregation to Predict Outcomes**

For each of his seven crosses, about 3/4 of the plants showed the trait controlled by the dominant allele.

20 **Using Segregation to Predict Outcomes**

About 1/4 of the plants showed the trait controlled by the recessive allele.

21 **Using Segregation to Predict Outcomes**

Not all organisms with the same characteristics have the same combinations of alleles.

22 **Using Segregation to Predict Outcomes**

In the F_1 cross, both the *TT* and *Tt* allele combinations resulted in tall pea plants. The tt allele combination produced a short pea plant.

23 **Using Segregation to Predict Outcomes**

Organisms that have two identical alleles for a particular gene—*TT* or *tt* in this example—are said to be homozygous.

24 **Using Segregation to Predict Outcomes**

Organisms that have two different alleles for the same gene—such as *Tt*—are heterozygous.

25 **Probabilities Predict Averages**

Probabilities predict the average outcome of a large number of events.

The larger the number of offspring, the closer the results will be to the predicted values.

If an F_2 generation contains just three or four offspring, it may not match Mendel's ratios.

When an F_2 generation contains hundreds or thousands of individuals, the ratios usually come very close to matching Mendel's predictions.

26 **Genotype and Phenotype**

Every organism has a genetic makeup as well as a set of observable characteristics.

All of the tall pea plants had the same phenotype, or physical traits.

They did not, however, have the same genotype, or genetic makeup.

27 **Genotype and Phenotype**

There are three different genotypes among the F2 plants: *Tt, TT,* and *tt*.

The genotype of an organism is inherited, whereas the phenotype is formed as a result of both the environment and the genotype.

Two organisms may have the same phenotype but different genotypes.

28 **Using Punnett Squares**

One of the best ways to predict the outcome of a genetic cross is by drawing a simple

diagram known as a Punnett square.

Punnett squares allow you to predict the genotype and phenotype combinations in genetic crosses using mathematical probability.

29 **How To Make a Punnett Square for a One-Factor Cross**

Write the genotypes of the two organisms that will serve as parents in a cross.

In this example we will cross a male and female osprey that are heterozygous for large beaks. They each have genotypes of *Bb*.

Bb and Bb

30 **How To Make a Punnett Square**

Determine what alleles would be found in all of the possible gametes that each parent could produce.

31 **How To Make a Punnett Square**

Draw a table with enough spaces for each pair of gametes from each parent.

Enter the genotypes of the gametes produced by both parents on the top and left sides of the table.

32 **How To Make a Punnett Square**

Fill in the table by combining the gametes' genotypes.

33 **How To Make a Punnett Square**

Determine the genotypes and phenotypes of each offspring.

Calculate the percentage of each. In this example, three fourths of the chicks will have large beaks, but only one in two will be heterozygous.

34 **Independent Assortment**

How do alleles segregate when more than one gene is involved?

35 **Independent Assortment**

How do alleles segregate when more than one gene is involved?

The principle of independent assortment states that genes for different traits can segregate independently during the formation of gametes.

36 **Independent Assortment**

Mendel wondered if the segregation of one pair of alleles affects another pair.

Mendel performed an experiment that followed two different genes as they passed from one generation to the next.

Because it involves two different genes, Mendel's experiment is known as a two-factor, or dihybrid, cross. Single-gene crosses are monohybrid *crosses*.

37 **The Two-Factor Cross: F1**

Mendel crossed true-breeding plants that produced only round yellow peas with plants that produced wrinkled green peas.

38 **The Two-Factor Cross: F1**

The round yellow peas had the genotype *RRYY,* which is homozygous dominant.

39 **The Two-Factor Cross: F1**

The wrinkled green peas had the genotype *rryy,* which is homozygous recessive.

40 **The Two-Factor Cross: F1**

All of the F_1 offspring produced round yellow peas. These results showed that the alleles for yellow and round peas are dominant over the alleles for green and wrinkled peas.

The Punnett square shows that the genotype of each F_1 offspring was *RrYy, heterozygous for both seed shape and seed color.*

41 **The Two-Factor Cross: F2**

Mendel then crossed the F_1 plants to produce F_2 offspring.

42 **The Two-Factor Cross: F2**

Mendel observed that 315 of the F_2 seeds were round and yellow, while another 32 seeds were wrinkled and green—the two parental phenotypes.

But 209 seeds had combinations of phenotypes, and therefore combinations of alleles, that were not found in either parent.

43 **The Two-Factor Cross: F2**

The alleles for seed shape segregated independently of those for seed color.

Genes that segregate independently—such as the genes for seed shape and seed color in pea plants—do not influence each other's inheritance.

44 **The Two-Factor Cross: F2**

Mendel's experimental results were very close to the 9:3:3:1 ratio that the Punnett square shown predicts.

Mendel had discovered the principle of independent assortment. The principle of independent assortment states that genes for different traits can segregate independently during gamete formation.

45 **A Summary of Mendel's Principles**

What did Mendel contribute to our understanding of genetics?

46 **A Summary of Mendel's Principles**

What did Mendel contribute to our understanding of genetics?

Mendel's principles of heredity, observed through patterns of inheritance, form the basis of modern genetics.

47 **A Summary of Mendel's Principles**

The inheritance of biological characteristics is determined by individual units called genes, which are passed from parents to offspring.

48 **A Summary of Mendel's Principles**

Where two or more forms (alleles) of the gene for a single trait exist, some forms of the gene may be dominant and others may be recessive.

49 **A Summary of Mendel's Principles**

In most sexually reproducing organisms, each adult has two copies of each gene—one from each parent. These genes segregate from each other when gametes are formed.

50 **A Summary of Mendel's Principles**

Alleles for different genes usually segregate independently of each other.

51 **A Summary of Mendel's Principles**

At the beginning of the 1900s, American geneticist Thomas Hunt Morgan decided to use the common fruit fly as a model organism in his genetics experiments.

The fruit fly was an ideal organism for genetics because it could produce plenty of offspring, and it did so quickly in the laboratory.

52 **A Summary of Mendel's Principles**

Before long, Morgan and other biologists had tested every one of Mendel's principles and learned that they applied not just to pea plants but to other organisms as well.

The basic principles of Mendelian genetics can be used to study the inheritance of human traits and to calculate the probability of certain traits appearing in the next generation.

1 **Lesson Overview**

11.3 Other Patterns of Inheritance

2 **THINK ABOUT IT**

Mendel's principles offer a set of rules with which to predict various patterns of inheritance.

There are exceptions to every rule, and exceptions to the exceptions.

What happens if one allele is not completely dominant over another? What if a gene has several alleles?

3 **Beyond Dominant and Recessive Alleles**

What are some exceptions to Mendel's principles?

4 **Beyond Dominant and Recessive Alleles**

What are some exceptions to Mendel's principles?

Some alleles are neither dominant nor recessive.

Many genes exist in several different forms, and are therefore said to have multiple alleles.

Many traits are produced by the interaction of several genes.

5 **Beyond Dominant and Recessive Alleles**

Despite the importance of Mendel's work, there are important exceptions to most of his principles.

In most organisms, genetics is more complicated, because the majority of genes have more than two alleles.

In addition, many important traits are controlled by more than one gene.

Mendel's principles alone cannot predict traits that are controlled by multiple alleles or multiple genes.

6 **Incomplete Dominance**

A cross between two four o'clock plants shows a common exception to Mendel's principles.

The F_1 generation produced by a cross between red-flowered *(RR)* and white-flowered *(WW)* plants consists of pink-colored flowers *(RW)*, as shown.

7 **Incomplete Dominance**

In this case, neither allele is dominant. Cases in which one allele is not completely dominant over another are called incomplete dominance.

In incomplete dominance, the heterozygous phenotype lies somewhere between the two homozygous phenotypes.

8 **Codominance**

Cases in which the phenotypes produced by both alleles are clearly expressed are called codominance.

For example, in certain varieties of chicken, the allele for black feathers is codominant with the allele for white feathers.

Heterozygous chickens have a color described as "erminette," speckled with black and white feathers.

9 **Multiple Alleles**

A single gene can have many possible alleles.

A gene with more than two alleles is said to have multiple alleles.

Many genes have multiple alleles, including the human genes for blood type. This chart shows the percentage of the U.S. population that shares each blood group.

10 **Polygenic Traits**

Traits controlled by two or more genes are said to be polygenic traits. *Polygenic* means "many genes."

Polygenic traits often show a wide range of phenotypes.

The variety of skin color in humans comes about partly because more than four different genes probably control this trait.

11 **Genes and the Environment**

Does the environment have a role in how genes determine traits?

12 **Genes and the Environment**

Does the environment have a role in how genes determine traits?

Environmental conditions can affect gene expression and influence genetically determined traits.

13 **Genes and the Environment**

The characteristics of any organism are not determined solely by the genes that organism inherits.

Genes provide a plan for development, but how that plan unfolds also depends on the

environment.

The phenotype of an organism is only partly determined by its genotype.

14 **Genes and the Environment**

For example, consider the Western white butterfly. Western white butterflies that hatch in the summer have different color patterns on their wings than those hatching in the spring.

Scientific studies revealed that butterflies hatching in springtime had greater levels of pigment in their wings than those hatching in the summer.

In other words, the environment in which the butterflies develop influences the expression of their genes for wing coloration.

15 **Genes and the Environment**

In order to fly effectively, the body temperature of the Western white butterfly needs to be 28–40°C.

More pigmentation allows a butterfly to reach the warm body temperature faster.

Similarly, in the hot summer months, less pigmentation prevents the butterflies from overheating.

1 **Lesson Overview**

11.4 Meiosis

2 **THINK ABOUT IT**

As geneticists in the early 1900s applied Mendel's laws, they wondered where genes might be located.

They expected genes to be carried on structures inside the cell, but *which* structures*?*

What cellular processes could account for segregation and independent assortment, as Mendel had described?

3 **Chromosome Number**

How many sets of genes do multicellular organisms inherit?

4 **Chromosome Number**

How many sets of genes do multicellular organisms inherit?

The diploid cells of most adult organisms contain two complete sets of inherited chromosomes and two complete sets of genes.

5 **Chromosome Number**

Chromosomes—those strands of DNA and protein inside the cell nucleus—are the carriers of genes.

The genes are located in specific positions on chromosomes.

6 **Diploid Cells**

A body cell in an adult fruit fly has eight chromosomes, as shown in the figure.

Four of the chromosomes come from its male parent, and four come from its female parent.

These two sets of chromosomes are homologous, meaning that each of the four chromosomes from the male parent has a corresponding chromosome from the female parent.

7 **Diploid Cells**

A cell that contains both sets of homologous chromosomes is diploid, meaning "two sets."

The diploid number of chromosomes is sometimes represented by the symbol 2N.

For the fruit fly, the diploid number is 8, which can be written as 2N = 8, where N represents twice the number of chromosomes in a sperm or egg cell.

8 **Haploid Cells**

Some cells contain only a single set of chromosomes, and therefore a single set of genes.

Such cells are haploid, meaning "one set."

The gametes of sexually reproducing organisms are haploid.

For fruit fly gametes, the haploid number is 4, which can be written as N = 4.

9 **Phases of Meiosis**

What events occur during each phase of meiosis?

10 **Phases of Meiosis**

What events occur during each phase of meiosis?

In prophase I of meiosis, each replicated chromosome pairs with its corresponding homologous chromosome.

During metaphase I of meiosis, paired homologous chromosomes line up across the center of the cell.

11 **Phases of Meiosis**

What events occur during each phase of meiosis?

During anaphase I, spindle fibers pull each homologous chromosome pair toward opposite ends of the cell.

In telophase I, a nuclear membrane forms around each cluster of chromosomes. Cytokinesis follows telophase I, forming two new cells.

12 **Phases of Meiosis**

What events occur during each phase of meiosis?

As the cells enter prophase II, their chromosomes—each consisting of two chromatids—become visible.

The final four phases of meiosis II are similar to those in meiosis I. However, the result is four haploid daughter cells.

13 **Phases of Meiosis**

Meiosis is a process in which the number of chromosomes per cell is cut in half through the separation of homologous chromosomes in a diploid cell.

Meiosis usually involves two distinct divisions, called meiosis I and meiosis II.

By the end of meiosis II, the diploid cell becomes four haploid cells.

14 **Meiosis I**

Just prior to meiosis I, the cell undergoes a round of chromosome replication called interphase I.

Each replicated chromosome consists of two identical chromatids joined at the center.

15 **Prophase I**

The cells begin to divide, and the chromosomes pair up, forming a structure called a tetrad, which contains four chromatids.

16 **Prophase I**

As homologous chromosomes pair up and form tetrads, they undergo a process called crossing-over.

First, the chromatids of the homologous chromosomes cross over one another.

17 **Prophase I**

Then, the crossed sections of the chromatids are exchanged.

Crossing-over is important because it produces new combinations of alleles in the cell.

18 **Metaphase I and Anaphase I**

As prophase I ends, a spindle forms and attaches to each tetrad.

During metaphase I of meiosis, paired homologous chromosomes line up across the center of the cell.

19 **Metaphase I and Anaphase I**

During anaphase I, spindle fibers pull each homologous chromosome pair toward opposite ends of the cell.

When anaphase I is complete, the separated chromosomes cluster at opposite ends of the cell.

20 **Telophase I and Cytokinesis**

During telophase I, a nuclear membrane forms around each cluster of chromosomes.

Cytokinesis follows telophase I, forming two new cells.

21 **Meiosis I**

Meiosis I results in two cells, called daughter cells, each of which has four chromatids, as it would after mitosis.

Because each pair of homologous chromosomes was separated, neither daughter cell has the two complete sets of chromosomes that it would have in a diploid cell.

The two cells produced by meiosis I have sets of chromosomes and alleles that are different from each other and from the diploid cell that entered meiosis I.

22 **Meiosis II**

The two cells produced by meiosis I now enter a second meiotic division.

Unlike the first division, neither cell goes through a round of chromosome replication before entering meiosis II.

23 **Prophase II**

As the cells enter prophase II, their chromosomes—each consisting of two chromatids—become visible.

The chromosomes do not pair to form tetrads, because the homologous pairs were already separated during meiosis I.

24 **Metaphase II**

During metaphase of meiosis II, chromosomes line up in the center of each cell.

25 **Anaphase II**

As the cell enters anaphase, the paired chromatids separate.

26 **Telophase II, and Cytokinesis**

In the example shown here, each of the four daughter cells produced in meiosis II receives two chromatids.

27 **Telophase II, and Cytokinesis**

These four daughter cells now contain the haploid number (N)—just two chromosomes each.

28 **Gametes to Zygotes**

The haploid cells produced by meiosis II are gametes.

In male animals, these gametes are called sperm. In some plants, pollen grains contain haploid sperm cells.

In female animals, generally only one of the cells produced by meiosis is involved in reproduction. The female gamete is called an egg in animals and an egg cell in some plants.

29 **Gametes to Zygotes**

Fertilization—the fusion of male and female gametes—generates new combinations of alleles in a zygote.

The zygote undergoes cell division by mitosis and eventually forms a new organism.

30 **Comparing Meiosis and Mitosis**

How is meiosis different from mitosis?

31 **Comparing Meiosis and Mitosis**

How is meiosis different from mitosis?

In mitosis, when the two sets of genetic material separate, each daughter cell receives one complete set of chromosomes. In meiosis, homologous chromosomes line up and then move to separate daughter cells.

32 **Comparing Meiosis and Mitosis**

How is meiosis different from mitosis?

Mitosis does not normally change the chromosome number of the original cell. This is not the case for meiosis, which reduces the chromosome number by half.

33 **Comparing Meiosis and Mitosis**

How is meiosis different from mitosis?

Mitosis results in the production of two genetically identical diploid cells, whereas meiosis produces four genetically different haploid cells.

34 **Comparing Meiosis and Mitosis**

Mitosis is a form of asexual reproduction, whereas meiosis is an early step in sexual reproduction.

There are three other ways in which these two processes differ.

35 **Replication and Separation of Genetic Material**

In mitosis, when the two sets of genetic material separate, each daughter cell receives one complete set of chromosomes.

36 **Replication and Separation of Genetic Material**

In meiosis, homologous chromosomes line up and then move to separate daughter cells.

As a result, the two alleles for each gene segregate from each other and end up in different cells.

37 **Replication and Separation of Genetic Material**

The sorting and recombination of genes in meiosis result in a greater variety of possible gene combinations than could result from mitosis.

38 **Changes in Chromosome Number**

Mitosis does not normally change the chromosome number of the original cell.

Meiosis reduces the chromosome number by half.

39 **Changes in Chromosome Number**

A diploid cell that enters mitosis with eight four chromosomes will divide to produce two diploid daughter cells, each of which also has eight four chromosomes.

40 **Changes in Chromosome Number**

On the other hand, a diploid cell that enters meiosis with eight four chromosomes will pass through two meiotic divisions to produce four haploid gamete cells, each with only four two chromosomes.

41 **Number of Cell Divisions**

Mitosis is a single cell division, resulting in the production of two genetically identical diploid daughter cells.

42 **Number of Cell Divisions**

Meiosis requires two rounds of cell division, and, in most organisms, produces a total of four genetically different haploid daughter cells.

1 **Lesson Overview**

14.1 Human Chromosomes

2 **THINK ABOUT IT**

If you had to pick an ideal organism for the study of genetics, would you choose one that produced lots of offspring, was easy to grow in the lab, and had a short life span that allowed you to do several crosses per month?

3 **THINK ABOUT IT**

You certainly would not choose an organism that produced very few offspring, had a long life span, and could not be grown in a lab. Yet, when we study human genetics, this is exactly the sort of organism we deal with.

Given all of these difficulties, it may seem a wonder that we know as much about human genetics as we do.

4 **Karyotypes**

What is a karyotype?

5 **Karyotypes**

What is a karyotype?

A karyotype shows the complete diploid set of chromosomes grouped together in pairs, arranged in order of decreasing size.

6 **Karyotypes**

To find what makes us uniquely human, we have to explore the human genome.

A genome is the full set of genetic information that an organism carries in its DNA.

A study of any genome starts with chromosomes, the bundles of DNA and protein found in the nuclei of eukaryotic cells.

7 **Karyotypes**

To see human chromosomes clearly, cell biologists photograph cells in mitosis, when the chromosomes are fully condensed and easy to view.

8 **Karyotypes**

Scientists then cut out the chromosomes from the photographs and arrange them in a picture known as a karyotype. It shows the complete diploid set of chromosomes grouped together in pairs, arranged in order of decreasing size.

A karyotype from a typical human cell, which contains 46 chromosomes, is arranged in 23 pairs.

9 **Sex Chromosomes**

Two of the 46 chromosomes in the human genome are known as sex chromosomes, because they determine an individual's sex.

Females have two copies of the X chromosome.

Males have one X chromosome and one Y chromosome.

10 **Sex Chromosomes**

This Punnett square illustrates why males and females are born in a roughly 50 : 50 ratio.

All human egg cells carry a single X chromosome (23,X).

However, half of all sperm cells carry an X chromosome (23,X) and half carry a Y chromosome (23,Y).

This ensures that just about half the zygotes will be males and half will be females.

11 **Sex Chromosomes**

More than 1200 genes are found on the X chromosome, some of which are shown.

The human Y chromosome is much smaller than the X chromosome and contains only about 140 genes, most of which are associated with male sex determination and sperm development.

12 **Autosomal Chromosomes**

The remaining 44 human chromosomes are known as autosomal chromosomes, or autosomes.

The complete human genome consists of 46 chromosomes, including 44 autosomes and 2 sex chromosomes.

To quickly summarize the total number of chromosomes present in a human cell, biologists write 46,XX for females and 46,XY for males.

13 **Transmission of Human Traits**

What patterns of inheritance do human traits follow?

14 **Transmission of Human Traits**

What patterns of inheritance do human traits follow?

Many human traits follow a pattern of simple dominance.

15 **Transmission of Human Traits**

What patterns of inheritance do human traits follow?

The alleles for many human genes display codominant inheritance.

16 **Transmission of Human Traits**

What patterns of inheritance do human traits follow?

Because the X and Y chromosomes determine sex, the genes located on them show a pattern of inheritance called sex-linked.

17 **Dominant and Recessive Alleles**

Many human traits follow a pattern of simple dominance.

For example, a gene known as *MC1R* helps determine skin and hair color.

Some of *MC1R's* recessive alleles produce red hair. An individual with red hair usually has two sets of these recessive alleles, inheriting a copy from each parent.

Dominant alleles for the *MC1R* gene help produce darker hair colors.

18 **Dominant and Recessive Alleles**

Another trait that displays simple dominance is the Rhesus, or Rh blood group.

The allele for Rh factor comes in two forms: Rh^+ and Rh^-.

Rh^+ is dominant, so an individual with both alleles (Rh^+/Rh^-) is said to have Rh positive blood.

Rh negative blood is found in individuals with two recessive alleles (Rh^+/Rh^-).

19 **Codominant and Multiple Alleles**

The alleles for many human genes display codominant inheritance.

One example is the ABO blood group, determined by a gene with three alleles: I^A, I^B, *and* i.

20 **Codominant and Multiple Alleles**

This table shows the relationship between genotype and phenotype for the ABO blood group.

It also shows which blood types can safely be transfused into people with other blood types.

If a patient has AB-negative blood, it means the individual has I^A and I^B alleles from the ABO gene and two Rh^- alleles from the Rh gene.

21 **Codominant and Multiple Alleles**

If a patient has AB-negative blood, it means the individual has I^A and I^B alleles from the ABO gene and two Rh^- alleles from the Rh gene.

22 **Codominant and Multiple Alleles**

Alleles I^A and I^B are codominant. They produce molecules known as antigens on the surface of red blood cells.

Individuals with alleles I^A and I^B produce both A and B antigens, making them blood type AB.

23 **Codominant and Multiple Alleles**

The *i* allele is recessive.

Individuals with alleles I^AI^A or I^Ai produce only the A antigen, making them blood type A.

Those with I^BI^B or I^Bi alleles are type B.

Those homozygous for the *i* allele (ii) produce no antigen and are said to have blood type O.

24 **Sex-Linked Inheritance**

The genes located on the X and Y chromosomes show a pattern of inheritance called sex-linked.

A sex-linked gene is a gene located on a sex chromosome.

Genes on the Y chromosome are found only in males and are passed directly from father to son.

Genes located on the X chromosome are found in both sexes, but the fact that men have just one X chromosome leads to some interesting consequences.

25 **Sex-Linked Inheritance**

For example, humans have three genes responsible for color vision, all located on the X chromosome.

In males, a defective allele for any of these genes results in colorblindness, an inability to distinguish certain colors. The most common form, red-green colorblindness, occurs in about 1 in 12 males.

Among females, however, colorblindness affects only about 1 in 200. In order for a recessive allele, like colorblindness, to be expressed in females, it must be present in two copies—one on each of the X chromosomes.

The recessive phenotype of a sex-linked genetic disorder tends to be much more common among males than among females.

30 **Human Pedigrees**

How can pedigrees be used to analyze human inheritance?

31 **Human Pedigrees**

How can pedigrees be used to analyze human inheritance?

The information gained from pedigree analysis makes it possible to determine the nature of genes and alleles associated with inherited human traits.

32 **Human Pedigrees**

To analyze the pattern of inheritance followed by a particular trait, you can use a chart, called a pedigree, which shows the relationships within a family.

A pedigree shows the presence or absence of a trait according to the relationships between parents, siblings, and offspring.

33 **Human Pedigrees**

This diagram shows what the symbols in a pedigree represent.

34 **Human Pedigrees**

This pedigree shows how one human trait—a white lock of hair just above the forehead—passes through three generations of a family.

The allele for the white forelock trait is dominant.

35 **Human Pedigrees**

At the top of the chart is a grandfather who had the white forelock trait.

Two of his three children inherited the trait.

Three grandchildren have the trait, but two do not.

36 **Human Pedigrees**

Because the white forelock trait is dominant, all the family members in the pedigree lacking this trait must have homozygous recessive alleles.

One of the grandfather's children lacks the white forelock trait, so the grandfather must be heterozygous for this trait.

37 **Human Pedigrees**

The information gained from pedigree analysis makes it possible to determine the nature of genes and alleles associated with inherited human traits.

Based on a pedigree, you can often determine if an allele for a trait is dominant or recessive, autosomal or sex-linked.

19 **Chromosomal Disorders**

What are the effects of errors in meiosis?

20 **Chromosomal Disorders**

What are the effects of errors in meiosis?

If nondisjunction occurs during meiosis, gametes with an abnormal number of chromosomes may result, leading to a disorder of chromosome numbers.

21 **Chromosomal Disorders**

The most common error in meiosis occurs when homologous chromosomes fail to separate. This mistake is known as nondisjunction, which means "not coming apart."

Nondisjunction may result in gametes with an abnormal number of chromosomes, which can lead to a disorder of chromosome numbers.

22 **Chromosomal Disorders**

If two copies of an autosomal chromosome fail to separate during meiosis, an individual may be born with three copies of that chromosome.

This condition is known as a trisomy, meaning "three bodies."

The most common form of trisomy, involving three copies of chromosome 21, is Down syndrome, which is often characterized by mild to severe mental retardation and a high frequency of certain birth defects.

23 **Chromosomal Disorders**

Nondisjunction of the X chromosomes can lead to a disorder known as Turner's syndrome.

A female with Turner's syndrome usually inherits only one X chromosome.

Women with Turner's syndrome are sterile, which means that they are unable to reproduce. Their sex organs do not develop properly at puberty.

24 **Chromosomal Disorders**

In males, nondisjunction may cause Klinefelter's syndrome, resulting from the inheritance of an extra X chromosome, which interferes with meiosis and usually prevents these individuals from reproducing.

There have been no reported instances of babies being born without an X chromosome, indicating that this chromosome contains genes that are vital for the survival and development of the embryo.