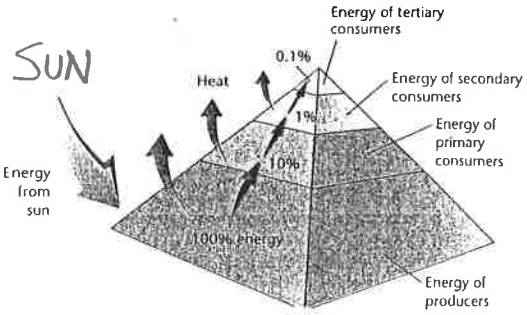
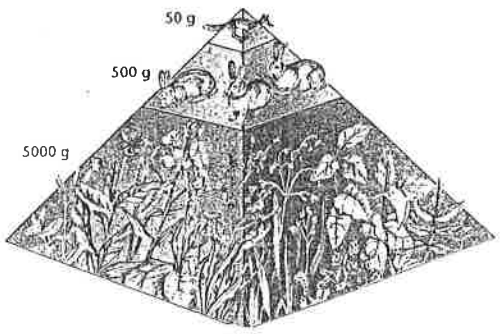
Standard 2 - Interactions --- The student will investigate the interactions of organisms with their environment through different relationships, population dynamics, and patterns of behavior.

Performance Indicators:

1. **Identify commensalism, parasitism, and mutualism, given a scenario with examples**
   a. **Commensalism** -- a type of symbiotic relationship in which one organism **benefits** from the association and the other is **not affected** (ex. = barnacles on whales)
   b. **Parasitism** -- a type of symbiotic relationship in which one organism **benefits** from the association and the other is **harmed** (ex. = tapeworms in an animal's digestive tract)
   c. **Mutualism** -- a type of symbiotic relationship in which **both organisms benefit** from the association (ex. = microorganisms in the digestive tract of termites)
2. **Classify organisms as producers, consumers, or decomposers, given their behaviors and environment**
   a. **Producers** -- organisms, such as plants, the produce organic compounds (food) from inorganic compounds; are called autotrophs
   b. **Consumers** -- organisms, such as animals, that obtain nutrients from other organisms; are called heterotrophs (primary, secondary, tertiary consumers; scavengers)
   c. **Decomposers** -- organisms, such as bacteria, that feed on dead organic material (they serve as "recyclers," releasing important substances back into the environment
   d. **Scavenger** -- a consumer that feeds on the remains of dead organisms
3. **Identify abiotic and biotic factors, given a description or an illustration of an ecosystem**
   a. **Biotic factors** -- all the **living** organisms in an environment and their effect on other living things
   b. **Abiotic factors** -- physical factors (**nonliving**) of the environment (exs. = water, air, temperature)
4. **Make inferences about how environmental factors would affect population growth, given a scenario**
   a. **Carrying capacity** -- the number of organisms that can be supported by the environmental resources in a given ecosystem
   b. **Limiting factor** -- any condition of the environment that limits the size of a population
   exs. = climate, disease, pollution, availability of water, predation, parasitism, competition for food
5. **Examine the energy flow and loss through the trophic levels of an ecosystem, given an illustration of an energy pyramid**
   a. **Energy (ecological) pyramid**-- shows the relationships between producers and consumers at different trophic levels in an ecosystem
   b. **Biomass** -- the total mass of organic matter at each trophic level
   c. The total amount of energy available decreases with each higher feeding level up the pyramid
   d. The greatest amount of energy is available at the bottom of the pyramid with the producers; the amount decreases the higher up the pyramid; thus, fewer organisms can be supported at each level up the pyramid



◀ Figure 46.8 As you move from the base of the pyramid toward the top, the amount of energy at each trophic level decreases.



◀ Figure 46.7 An ecological pyramid shows that biomass is greatest at the beginning of the food chain.

Life Science Chpt. 18 Study Guide

Section 1 - Everything is connected

- Ecology is the study of the interactions between organisms and their environment.
- All environments consist of biotic and abiotic parts.
  - Biotic - the part of the environment consisting of all living organisms
  - Abiotic - the part of the environment consisting of all the non-living things
- All organisms in an environment are organized into the 5 Levels of Environmental Organization.
  1. Organism - a single living thing
  2. Population - group of similar organisms of the same species living together in an environment
  3. Community - various populations of different species that live in a single environment and interact
  4. Ecosystem - various communities and all the abiotic things in a single environment
  5. Biosphere - All ecosystems, collectively, on Earth or the part of the Earth where life exists.

Section 2 - Living Things Need Energy

- Organisms in any environment can be classified into 3 groups based on how the organisms obtain energy:
  1. Producers - organisms capable of making their own food (also called autotrophs) - usually through photosynthesis
  2. Consumers - organisms that obtain their energy from the things they eat
     - A. Herbivore - consumer that eats only plants
     - B. Carnivore - consumer that eats only animals
     - C. Omnivores - consumer that eats both plants and animals
     - D. Scavengers - animals that feed on the bodies of other dead animals
  3. Decomposers - organisms (usually not animals) that get energy by breaking down the remains of dead organisms
     - often are bacteria or fungi
- Scientists use food chains to illustrate how energy in food molecules flows from one organism to another
- Scientists use food webs to illustrate how energy in food molecules flows between many organisms in multiple food chains (more accurate and realistic than a food chain)
- Energy isn't transferred with 100% efficiency between any organisms in any environment
- As consumers eat other organisms for food, some energy is inevitably lost.
- Most energy is either used by the consumer or lost as heat.

Life Science Chpt. 18 Study Guide cont'd.

- An energy pyramid is a diagram showing the energy lost at each level of a food chain as consumers eat organisms
- Habitat - the environment in which an organism lives
- Niche - an organism's way of life within an ecosystem

Section 3 - Types of Interactions

- A limiting factor is an environmental resource needed by organisms for survival that is scarce. The amount present of a limiting factor determines the number of organisms that the environment can support.
- The carrying capacity is the largest population that a given environment can support over a long period of time.
- Organisms in any environment interact in 4 main ways:
  1. Competition - when 2 or more individuals or populations try to use the same limited resource
  2. Predator/Prey - when one organism (predator) eats another organism (prey)
  3. Symbiosis - close long-term relationship between 2 or more species

Types of Symbiosis:

A. Mutualism - symbiotic relationship in which both organisms benefit

B. Commensalism - symbiotic relationship in which one organism benefits and the other is unaffected

C. Parasitism - symbiotic relationship in which one organism benefits and the other organism is harmed
- parasite = organism that benefits
- host = organism that is harmed

- Coevolution is a long-term change that takes place in 2 species because of their close interactions with one another.

Life Science Chpt. 20 Study Guide

Section 1 - Land Ecosystems

- A biome is a geographic area characterized by certain types of plant and animal communities. The following are the major Land ecosystems and biomes:

FORESTS

3 Main Types

1. Temperate Deciduous Forests - characterized by
   - Trees whose leaves change colors in Autumn
   - Trees that lose leaves in Winter
   - Avg. rainfall 75-125 cm or 29.5-49 inches per year
   - Avg. Temperatures Summer = 28°C or 82.4°F
     Winter = 6°C or 42.8°F
   - Variety of animals including mammals, birds, and reptiles
2. Coniferous Forests - characterized by
   - consist mainly of evergreen trees that do not lose leaves in autumn or winter
   - many of the trees are conifers = trees that produce seeds in cones
   - most trees' leaves are compact, needle-like leaves with waxy coating
   - Avg. rainfall 35-75 cm or 14-29.5 inches per year
   - Avg. Temperatures Summer = 14°C or 57.2°F
     Winter = -10°C or 14°F
   - Herbivores include moose, deer, porcupine, chipmunk
   - Carnivores include foxes and lynxes

3. Tropical Rain Forests - characterized by
- more biological diversity than any other biome
- Trees create a canopy for many animals and plants to live in
- Thin and poor topsoil
- Most nutrients are contained in the plants
- Avg. Rainfall - up to 400 cm or 157.5 inches per year
- Avg. Temperatures Daytime = 34°C or 93°F
  Nighttime = 20°C or 68°F

GRASSLANDS

1. Temperate grasslands - characterized by
- vegetation is mainly grasses mixed with a variety of flowering plants
- Few trees
- Fires prevent growth of slow-growing plants
- Avg. Rainfall 25-75 cm or 10-29.5 inches per year
- Avg. Temperatures Summer = 30°C or 86°F
  Winter = 0°C or 32°F
- home to prairie dogs, mice, large herbivores like bison

2. Savanna - characterized by
- tropical grassland with scattered clumps of trees
- grasses with deep roots
- grasses die during the dry season
- large herbivores include elephants, giraffes, zebras, gazelles, wildebeests
- Carnivores include lions, leopards
- Avg yearly rainfall = 150 cm or 59 inches
- Avg. temp. Dry season = 34°C or 93°F Wet Season = 16°C or 61°F

Deserts

- hot, dry regions
- most water that falls to the ground evaporates
- plants with either shallow, widespread roots or very deep roots
- Many nocturnal animals (active only at night)
- Avg. yearly rainfall = less than 25 cm or 10 inches
- Avg. Temperatures Summer = 38°C or 100°F Winter = 7°C or 45°F
- cactus plants
- animals include jack rabbits, kangaroo rats, tortoises, reptiles

Tundra

2 major types:

1. Arctic Tundra - characterized by
   - permafrost (frozen soil)
   - only the surface of the soil thaws during summer
   - Permafrost prevents rainfall from draining and soil surface stays wet and soggy
   - little rainfall
   - lakes and ponds are common
   - plants include grasses, sedges, rushes, and small woody shrubs, mosses and lichens
   - few to no deep-rooted plants like trees
   - Animals include caribou, musk ox, wolves, lemmings, shrews, hares, and migratory birds
   - Avg. yearly rainfall = 30-50 cm or 12-20 inches
   - Avg. Temp. Summer = 12°C or 53.6°F Winter = -26°C or -14°F

2. Alpine Tundra - characterized by
   - found above treeline of very high mountains
   - receive a lot of sunlight
   - receive a lot of precipitation (usually snow)

MAJOR AQUATIC ECOSYSTEMS

Marine (salt water) Ecosystems

- cover 3/4 of Earth
- largest animals on Earth live in them
- Governed by abiotic factors such as
  - Temperature
  - amount of sunlight penetrating the water
  - distance from land
  - depth of the water
- contain phytoplankton which are microscopic photosynthetic organisms that float near the surface of the water. Phytoplankton are the most abundant producers in the oceans and many marine ecosystem food chains depend on phytoplankton.
- Contain Zooplankton which are microscopic consumers that feed on phytoplankton. They are tiny animals. Along with phytoplankton, Zooplankton form the bases of many marine food chains.

MARINE ECOSYSTEMS CONT'D.

- Many consist of 4 main areas:

1. Intertidal Zone - area where ocean meets land.
   - Above water and exposed to direct sunlight during low tide
   - battered by waves
   - include mud flats, rocky shores, sandy beaches
   - plants include sea grasses
   - animals include snails, herons, sea stars, anemones, clams, crabs,

2. Neritic Zone - seaward just beyond intertidal Zone where water is less than 200 m deep.
   - receives much sunlight
   - contain coral reefs
   - water may be warm, clear, sunny
   - Plants include phytoplankton (major producers in this area), seaweeds
   - Animals include sea turtles, dolphin, coral, sponges, colorful fish
   - includes region over the continental shelf

3. Oceanic Zone - past continental shelf seaward into deep water of the open ocean
   - Phytoplankton are major producers to a depth of 200 m
   - Below 200 m very little light penetrates,
   - animals include whales, squid, glowing fish
   - includes deep water that is dark and under high pressure

4. Benthic Zone - sea floor
- organisms here obtain food mostly by consuming material that falls from above
- chemosynthetic bacteria live here (obtain energy by using chemicals instead of sunlight in a process much like photosynthesis)
- organisms include bacteria, worms, sea urchins
- contain thermal vent communities which are places where organisms live in groups around cracks in the Earth's crust that release extreme amounts of heat and chemicals from deep within the Earth

Special Oceanic Environments

Coral Reefs

- composed of coral animals living in a mutualistic relationship with algae. The algae make food for both through photosynthesis, and the coral provide a sunny home for the algae.
- Foundation of a reef is made from coral skeletons that accumulate over many years
- contain almost as much biological diversity as a rain forest

Special Oceanic Environments cont'd. (7)

The Sargasso Sea

- located in the middle of the Atlantic Ocean
- has no land boundaries
- Contains huge floating rafts of Sargassum which is a type of algae usually found attached to rocks on North American shores
- Animals live among the Sargassum

Polar Ice

- includes ice
- waters rich in nutrients from surrounding landmasses
- large plankton populations
- home to diverse animals such as fish, birds, and mammals such as penguins and sea lions.
- includes the Arctic Ocean (around North Pole) and the waters surrounding Antarctica

Estuaries

- area where fresh water from streams and rivers spills into the ocean
- Amount of salt in these areas changes frequently with the tide. High tide increases the amount of salt in this environment, and low tide decreases the amount of salt present.
- Fresh water running into estuary is rich in nutrients.
- Waters support large numbers of plankton
- many marine animals use estuaries as nurseries for their young because of abundant nutrients and few large predators

Intertidal Areas

- includes mud flats, sandy beaches, rocky shores
  Mud flats are home to many worms and crabs and shorebirds.
  Sandy beaches are home to worms, clams, crabs, and plankton living among the sand grains.
  Rocky shores contain organisms that either use tough hold fasts or cement themselves to rocks to avoid being swept away by crashing waves.

Freshwater Ecosystems

- characterized by abiotic factors such as (primarily) speed at which water moves

Moving Freshwater Ecosystems

- water may come from melting ice or snow, or a spring
- includes tributaries which are trickles or streams of water joining larger trickles or streams of water

Tyes of Moving Freshwater Ecosystems

1. Fast Moving Water
   - organisms living here require special adaptations to avoid being swept away by the current. Some cling to rocks, live under rocks, or use suction discs to hold to the rocks, or burrow in the mud
   - Producers include algae and moss.
   - Animals include insects or insect larvae, tadpoles, burrowing clams and mussels, and fish

2. Slow moving water
- organic material and sediment may be deposited on the bottom - building deltas
- water eventually empties into ocean
- animals include dragonflies, water striders, and other invertebrates

Still Freshwater Ecosystems

- examples include ponds and lakes
- may be divided into 3 zones:

1. Littoral zone - where freshwater meets the land.
   - plants include cattails, rushes, floating leaf plants like water lilies, and pond weeds
   - Animals include snails, small arthropods, insect larvae, clams, worms, frogs, salamanders, water turtles, fishes, water snakes
2. Open-water zone - extends from the littoral zone across the top of the water.
   - extends only as deep as light can reach
   - phytoplankton are the most numerous photosynthetic organisms
   - animals include bass, blue gills, lake trout
3. Deep-water zone - below the open-water zone
   - no light reaches here
   - animals include catfish, carp, worms, insect larvae, crustaceans, fungi, bacteria
   - organisms feed on dead organic material that falls down from above

Wetlands

- area of land where the water level is near or above the surface of the ground for most of the year
- play an important role in flood control
- soak up large amounts of water during heavy rains or spring snowmelt
- water seeps into ground replenishing groundwater supplies
- support variety of plant and animal life
- include 2 main types:

1. Marsh - treeless wetland ecosystem
   - plants vary with depth of the water and marsh location, but they include cattails, rushes, grasses, reeds, bulrushes, wild rice
   - Animals include muskrats, turtles, frogs, redwing blackbirds
   - found in shallow waters along shores of lakes, ponds, rivers, streams
2. Swamps - wetland ecosystem where trees and vines grow.
   - occur in low-lying areas and beside slow moving rivers
   - most are flooded for part of the year
   - plants include willow, bald cypress, water tupelo, oak, and elm trees... poison ivy, spanish moss, water lilies
   - Animals include fish, snakes, birds

FROM LAKE TO FOREST

- A lake may become a forest over a long period of time. The steps involved in changing a lake to a forest are as follows:

1. Water entering the lake (rivers or streams) carries mud, dirt, and sediment into the lake.
2. The sediment accumulates on the bottom of the lake slowly making the lake more shallow.
3. Eventually the lake is so shallow that it is classified as a marsh.
4. More plants grow in the shallow marsh.
5. As more plants begin to grow in the marsh they slowly absorb all the standing water and the marsh becomes a forest.

Succession

Primary and Secondary Succession

How do communities change over time?

Ecosystems change over time, especially after disturbances, as some species die out and new species move in.

Primary and Secondary Succession

Ecological succession is a series of more-or-less predictable changes that occur in a community over time.

Ecosystems change over time, especially after disturbances, as some species die out and new species move in.

Over the course of succession, the number of different species present typically increases.

Primary Succession

Volcanic explosions can create new land or sterilize existing areas.

Retreating glaciers can have the same effect, leaving only exposed bare rock behind them.

Succession that begins in an area with no remnants of an older community is called **primary succession.**

Primary Succession

For example, in Glacier Bay, Alaska, a retreating glacier exposed barren rock.

Over the course of more than 100 years, a series of changes has led to the hemlock and spruce forest currently found in the area.

Changes in this community will continue for centuries.

Primary Succession

The first species to colonize barren areas are called **pioneer species.**

One ecological pioneer that grows on bare rock is lichen—a mutualistic symbiosis between a fungus and an alga.

Primary Succession

Over time, lichens convert, or fix, atmospheric nitrogen into useful forms for other organisms, break down rock, and add organic material to form soil.

Certain grasses, like those that colonized Krakatau early on, are also pioneer species.

Secondary Succession

Sometimes, existing communities are not completely destroyed by disturbances. In these situations, **secondary succession** occurs.

Secondary succession proceeds faster than primary succession, in part because soil survives the disturbance. As a result, new and surviving vegetation can regrow rapidly.

Secondary Succession

Secondary succession often follows a wildfire, hurricane, or other natural disturbance.

We think of these events as disasters, but many species are adapted to them. Although forest fires kill some trees, for example, other trees are spared, and fire can stimulate their seeds to germinate.

Secondary succession can also follow human activities like logging and farming.

Why Succession Occurs

Every organism changes the environment it lives in.

One model of succession suggests that as one species alters its environment, other species find it easier to compete for resources and survive.

For example, as lichens add organic matter and form soil, mosses and other plants can colonize and grow.

As organic matter continues to accumulate, other species move in and change the environment further.

Over time, more and more species can find suitable niches and survive.

Climax Communities

Do ecosystems return to “normal” following a disturbance?

Secondary succession in healthy ecosystems following natural disturbances often reproduces the original climax community.

Ecosystems may or may not recover from extensive human-caused disturbances.

Climax Communities

Ecologists used to think that succession in a given area always proceeds through the same stages to produce a specific and stable climax community.

Recent studies, however, have shown that succession doesn’t always follow the same path, and that climax communities are not always uniform and stable.

Succession After Natural Disturbances

Secondary succession in healthy ecosystems following natural disturbances often reproduces the original climax community.

Healthy coral reefs and tropical rain forests often recover from storms, and healthy temperate forests and grasslands recover from wildfires.

Succession After Natural Disturbances

However, detailed studies show that some climax communities are not uniform.

Often, they have areas in varying stages of secondary succession following multiple disturbances that took place at different times.

Some climax communities are disturbed so often that they can’t really be called stable.

Succession After Human-Caused Disturbances

Ecosystems may or may not recover from extensive human-caused disturbances.

Clearing and farming of tropical rain forests, for example, can change the microclimate and soil enough to prevent regrowth of the original community.

Recombinant DNA

Polymerase Chain Reaction

Once biologists find a gene, a technique known as **polymerase chain reaction (PCR)** allows them to make many copies of it.

1. A piece of DNA is heated, which separates its two strands.

Polymerase Chain Reaction

2. At each end of the original piece of DNA, a biologist adds a short piece of DNA that complements a portion of the sequence.

These short pieces are known as primers because they prepare, or prime, a place for DNA polymerase to start working.

Polymerase Chain Reaction

3. DNA polymerase copies the region between the primers. These copies then serve as templates to make more copies.

4. In this way, just a few dozen cycles of replication can produce billions of copies of the DNA between the primers.

Changing DNA

How is recombinant DNA used?

Recombinant-DNA technology—joining together DNA from two or more sources—makes it possible to change the genetic composition of living organisms.

Changing DNA

Scientists began wondering if it might be possible to change the DNA of a living cell, and many of them realized this had already been accomplished decades earlier in Frederick Griffith's bacterial transformation experiments.

During transformation, a cell takes in DNA from outside the cell, and that added DNA becomes a component of the cell's own genome.

Griffith's extract of heat-killed bacteria contained DNA fragments, which were taken up by live bacteria, transforming the live bacteria and changing their characteristics.

Combining DNA Fragments

Today, scientists can produce custom-built DNA molecules in the lab and then insert those molecules—along with the genes they carry—into living cells.

Machines known as DNA synthesizers are used to produce short pieces of DNA, up to several hundred bases in length.

These synthetic sequences can then be joined to natural sequences using DNA ligase or other enzymes that splice DNA together.

Combining DNA Fragments

A gene from one organism can be attached to the DNA of another organism.

Restriction enzymes cut DNA at specific sequences, producing "sticky ends," which are single-stranded overhangs of DNA.

Combining DNA Fragments

If two DNA molecules are cut with the same restriction enzyme, their sticky ends will bond to a DNA fragment that has the complementary base sequence. DNA ligase then joins the two fragments.

The resulting molecules are called **recombinant DNA.**

Combining DNA Fragments

Recombinant-DNA technology—joining together DNA from two or more sources—makes it possible to change the genetic composition of living organisms.

By manipulating DNA in this way, scientists can investigate the structure and functions of genes.

Plasmids and Genetic Markers

Scientists working with recombinant DNA soon discovered that many of the DNA molecules they tried to insert into host cells simply vanished because the cells often did not copy, or replicate, the added DNA.

Today scientists join recombinant DNA to another piece of DNA containing a replication "start" signal. This way, whenever the cell copies its own DNA, it copies the recombinant DNA too.

Plasmids and Genetic Markers

In addition to their own large chromosomes, some bacteria contain small circular DNA molecules known as **plasmids.**

Joining DNA to a plasmid, and then using the recombinant plasmid to transform bacteria, results in the replication of the newly added DNA along with the rest of the cell's genome.

Plasmids and Genetic Markers

Plasmids used for genetic engineering typically contain a replication start signal, called the origin of replication (*ori*), and a restriction enzyme cutting site, such as EcoRI.

Plasmids and Genetic Markers

Plasmids are also found in yeasts, which are single-celled eukaryotes that can be transformed with recombinant DNA as well.

Biologists working with yeasts can construct artificial chromosomes containing centromeres, telomeres, and replication start sites.

These artificial chromosomes greatly simplify the process of introducing recombinant DNA into the yeast genome.

Plasmids and Genetic Markers

Bacteria can be transformed using recombinant plasmids.

Scientists can insert a piece of DNA into a plasmid if both the plasmid and the target DNA have been cut by the same restriction enzymes to create sticky ends.

Plasmids and Genetic Markers

The new combination of genes is then returned to a bacterial cell, which replicates the recombinant DNA over and over again and produces human growth hormone.

Plasmids and Genetic Markers

The recombinant plasmid has a genetic marker, such as a gene for antibiotic resistance. A **genetic marker** is a gene that makes it possible to distinguish bacteria that carry the plasmid from those that don't.

Transgenic Organisms

How can genes from one organism be inserted into another organism?

Transgenic organisms can be produced by the insertion of recombinant DNA into the genome of a host organism.

Transgenic Organisms

The universal nature of the genetic code makes it possible to construct organisms that are **transgenic**, containing genes from other species.

Transgenic organisms can be produced by the insertion of recombinant DNA into the genome of a host organism.

Like bacterial plasmids, the DNA molecules used for transformation of plant and animal cells contain genetic markers that help scientists identify which cells have been transformed.

Transgenic Organisms

Transgenic technology was perfected using mice in the 1980s.

Genetic engineers can now produce transgenic plants, animals, and microorganisms.

By examining the traits of a genetically modified organism, it is possible to learn about the function of the transferred gene.

Transgenic Plants

Many plant cells can be transformed using *Agrobacterium.*

In nature this bacterium inserts a small DNA plasmid that produces tumors in a plant's cells.

Scientists can deactivate the plasmid's tumor-producing gene and replace it with a piece of recombinant DNA.The recombinant plasmid can then be used to infect and transform plant cells.

The transformed cells can be cultured to produce adult plants.

Transgenic Plants

There are other ways to produce transgenic plants as well.

When their cell walls are removed, plant cells in culture will sometimes take up DNA on their own.

DNA can also be injected directly into some cells.

If transformation is successful, the recombinant DNA is integrated into one of the plant cell's chromosomes.

Transgenic Animals

Scientists can transform animal cells using some of the same techniques used for plant cells.

The egg cells of many animals are large enough that DNA can be injected directly into the nucleus.

Once the DNA is in the nucleus, enzymes that are normally responsible for DNA repair and recombination may help insert the foreign DNA into the chromosomes of the injected cell.

Transgenic Animals

Recently it has become possible to eliminate particular genes by constructing DNA molecules with two ends that will sometimes recombine with specific sequences in the host chromosome.

Once they recombine, the host gene normally found between those two sequences may be lost or specifically replaced with a new gene.

This kind of gene replacement has made it possible to pinpoint the specific functions of genes in many organisms, including mice.

Cloning

A **clone** is a member of a population of genetically identical cells produced from a single cell

The technique of cloning uses a single cell from an adult organism to grow an entirely new individual that is genetically identical to the organism from which the cell was taken.

Clones of animals were first produced in 1952 using amphibian tadpoles.

In 1997, Scottish scientist Ian Wilmut announced that he had produced a sheep, called Dolly, by cloning.

Cloning

Animal cloning uses a procedure called nuclear transplantation.

The process combines an egg cell with a donor nucleus to produce an embryo.

First, the nucleus of an unfertilized egg cell is removed.

Cloning

Next, the egg cell is fused with a donor cell that contains a nucleus, taken from an adult.

The resulting diploid egg develops into an embryo, which is then implanted in the uterine wall of a foster mother, where it develops until birth.

Cloned cows, pigs, mice, and even cats have since been produced using similar techniques.

Applications of Genetic Engineering

Agriculture and Industry

How can genetic engineering benefit agriculture and industry?
Ideally, genetic modification could lead to better, less expensive, and more nutritious food as well as less harmful manufacturing processes.

Agriculture and Industry

Almost everything we eat and much of what we wear come from living organisms.
Researchers have used genetic engineering to try to improve the products we get from plants and animals.
Genetic modification could lead to better, less expensive, and more nutritious food as well as less harmful manufacturing processes.

GM Crops

Since their introduction in 1996, genetically modified (GM) plants have become an important component of our food supply.
One genetic modification uses bacterial genes that produce a protein known as Bt toxin.
This toxin is harmless to humans and most other animals, but enzymes in the digestive systems of insects convert Bt to a form that kills the insects.
Plants with the Bt gene do not have to be sprayed with pesticides.
In addition, they produce higher yields of crops.

GM Crops

Other useful genetic modifications include resistance to herbicides, which are chemicals that destroy weeds, and resistance to viral infections.

GM Crops

Some transgenic plants may soon produce foods that are resistant to rot and spoilage.
Engineers are currently developing GM plants that may produce plastics for the manufacturing industry.

GM Animals

Transgenic animals are becoming more important to our food supply.
About 30 percent of the milk in U.S. markets comes from cows that have been injected with hormones made by recombinant-DNA techniques to increase milk production.
Pigs can be genetically modified to produce more lean meat or high levels of healthy omega-3 acids.
Using growth-hormone genes, scientists have developed transgenic salmon that grow much more quickly than wild salmon.

GM Animals

Scientists in Canada combined spider genes into the cells of lactating goats.
The goats began to produce silk along with their milk.
The silk can be extracted from the milk and woven into a thread that can be used to create a light, tough, and flexible material.

GM Animals

Scientists are working to combine a gene for lysozyme—an antibacterial protein found in human tears and breast milk—into the DNA of goats.

Milk from these goats may help prevent infections in young children who drink it.

GM Animals

Researchers hope that cloning will enable them to make copies of transgenic animals, which would increase the food supply and could help save endangered species.

In 2008, the U.S. government approved the sale of meat and milk from cloned animals.

Cloning technology could allow farmers to duplicate the best qualities of prize animals without the time and complications of traditional breeding.

Health and Medicine

How can recombinant-DNA technology improve human health?

Today, recombinant-DNA technology is the source of some of the most important and exciting advances in the prevention and treatment of disease.

Preventing Disease

Golden rice is a GM plant that contains increased amounts of provitamin A, also known as beta-carotene—a nutrient that is essential for human health.

Two genes engineered into the rice genome help the grains produce and accumulate beta-carotene.

Provitamin A deficiencies produce serious medical problems, including infant blindness. There is hope that provitamin A–rich golden rice will help prevent these problems.

Other scientists are developing transgenic plants and animals that produce human antibodies to fight disease.

Preventing Disease

In the future, transgenic animals may provide us with an ample supply of our own proteins.

Several laboratories have engineered transgenic sheep and pigs that produce human proteins in their milk, making it easy to collect and refine the proteins.

Many of these proteins can be used in disease prevention.

Medical Research

Transgenic animals are often used as test subjects in medical research.

They can simulate human diseases in which defective genes play a role.

Scientists use models based on these simulations to follow the onset and progression of diseases and to construct tests of new drugs that may be useful for treatment.

This approach has been used to develop models for disorders like Alzheimer’s disease and arthritis.

Treating Disease

Recombinant-DNA technology can be used to make important proteins that could prolong and even save human lives.

For example, human growth hormone, which is used to treat patients suffering from pituitary dwarfism, is now widely available because it is mass-produced by recombinant bacteria.

Other products now made in genetically engineered bacteria include insulin to treat diabetes, blood-clotting factors for hemophiliacs, and potential cancer-fighting molecules such as interleukin-2 and interferon.

Treating Disease

Gene therapy is the process of changing a gene to treat a medical disease or disorder.

In gene therapy, an absent or faulty gene is replaced by a normal, working gene.

This process allows the body to make the protein or enzyme it needs, which eliminates the cause of the disorder.

Treating Disease —

One Example of Gene Therapy

To deliver therapeutic genes to target cells researchers engineer a virus that cannot reproduce or cause harm.

The DNA containing the therapeutic gene is inserted into the modified virus.

The patient's cells are then infected with the genetically engineered virus.

In theory the virus will insert the healthy gene into the target cell and correct the defect.

Treating Disease

Gene therapy can be risky.

In 1999, 18-year-old Jesse Gelsinger volunteered for a gene therapy experiment designed to treat a genetic disorder of his liver. He suffered a massive reaction from the viruses used to carry genes into his liver cells, and he died a few days later.

For gene therapy to become an accepted treatment, we need more reliable ways to insert working genes and to ensure that the DNA used in the therapy does no harm.

Genetic Testing

Genetic testing can be used to determine if two prospective parents are carrying the alleles for a genetic disorder such as cystic fibrosis (CF).

Because the CF allele has slightly different DNA sequences from its normal counterpart, genetic tests use labeled DNA probes that can detect and distinguish the complementary base sequences found in the disease-causing alleles.

Some genetic tests search for changes in cutting sites of restriction enzymes, while others use PCR to detect differences between the lengths of normal and abnormal alleles.

Genetic tests are now available for diagnosing hundreds of disorders.

Personal Identification

How is DNA used to identify individuals?

DNA fingerprinting analyzes sections of DNA that may have little or no function but that vary widely from one individual to another.

Personal Identification

No individual is exactly like any other genetically—except for identical twins, who share the same genome.

Chromosomes contain many regions with repeated DNA sequences that do not code for proteins. These vary from person to person. Here, one sample has 12 repeats between genes A and B, while the second has 9 repeats between the same genes.

DNA fingerprinting can be used to identify individuals by analyzing these sections of DNA that may have little or no function but that vary widely from one individual to another.

Personal Identification

In DNA fingerprinting, restriction enzymes first cut a small sample of human DNA into fragments containing genes and repeats. Note that the repeat fragments from these two samples are of different lengths.

Next, gel electrophoresis separates the restriction fragments by size.

Personal Identification

A DNA probe then detects the fragments that have highly variable regions, revealing a series of variously sized DNA bands.

Personal Identification

If enough combinations of enzymes and probes are used, the resulting pattern of bands can be distinguished statistically from that of any other individual in the world.

DNA samples can be obtained from blood, sperm, or tissue—even from a hair strand if it has tissue at the root.

Forensic Science

The precision and reliability of DNA fingerprinting has revolutionized **forensics**—the scientific study of crime scene evidence.

DNA fingerprinting has helped solve crimes, convict criminals, and even overturn wrongful convictions.

To date, DNA evidence has saved more than 110 wrongfully convicted prisoners from death sentences.

Forensic Science

DNA forensics is used in wildlife conservation as well.

African elephants are a highly vulnerable species. Poachers, who slaughter the animals mainly for their precious tusks, have reduced their population dramatically.

To stop the ivory trade, African officials now use DNA fingerprinting to identify the herds from which black-market ivory has been taken.

Establishing Relationships

When genes are passed from parent to child, genetic recombination scrambles the molecular markers used for DNA fingerprinting, so ancestry can be difficult to trace.

The Y chromosome, however, never undergoes crossing over, and only males carry it. Therefore, Y chromosomes pass directly from father to son with few changes.

Establishing Relationships

Similarly, the small DNA molecules found in mitochondria are passed, with very few changes, from mother to child in the cytoplasm of the egg cell.

Because mitochondrial DNA (mtDNA) is passed directly from mother to child, your mtDNA is the same as your mother’s mtDNA, which is the same as her mother’s mtDNA.

This means that if two people have an exact match in their mtDNA, then there is a very good chance that they share a common maternal ancestor.

Establishing Relationships

Y-chromosome analysis has helped researchers settle longstanding historical questions.

One such question—did President Thomas Jefferson father the child of a slave?—may have been answered in 1998.

DNA testing showed that descendants of the son of Sally Hemings, a slave on Jefferson’s Virginia estate, carried his Y chromosome.

This result suggests Jefferson was the child’s father, although the Thomas Jefferson Foundation continues to challenge that conclusion.

Ethics and Impacts of Biotechnology

Profits and Privacy

What privacy issues does biotechnology raise?

What if the government wants to use an individual's DNA for another purpose, in a criminal investigation or a paternity suit? What if health-insurance providers manage their healthcare policies based on a genetic predisposition to disease?

Profits and Privacy

Private biotechnology and pharmaceutical companies do much of the research involving GM plants and animals. Their goal is largely to develop profitable new crops, drugs, tests, or other products.

Like most inventors, they protect their discoveries and innovations with patents, a legal tool that gives an individual or company the exclusive right to profit from its innovations for a number of years.

Patenting Life

Molecules and DNA sequences can be patented. In fact, roughly one fifth of the known genes in the human genome are now patented commercially.

Patenting Life

Patenting Life

Laboratory techniques like PCR have also been patented. When a scientist wants to run a PCR test, he or she must pay a fee for the license to use this process.

Patenting Life

The ability to patent is meant to spur discovery and advancements in medicine and industry, but sometimes patent holders demand high fees that block other scientists from exploring certain lines of research.

In the case of the development of provitamin A–enriched golden rice, patent disputes kept the rice out of the hands of farmers for years.

Patenting Life

When it comes to your own DNA, how much privacy are you entitled to?

Do you have exclusive rights to your DNA?

Should you, like patent holders, be able to keep your genetic information confidential?

Genetic Ownership

The Tomb of the Unknowns in Arlington National Cemetery, near Washington, D.C., holds the remains of unknown American soldiers who fought our nation's wars.

In order to avoid more unknown soldiers, the U.S. military now requires all personnel to give a DNA sample when they begin their service.

Those DNA samples are kept on file and used, if needed, to identify the remains of individuals who perish in the line of duty.

Genetic Ownership

What if the government wants to use an individual's DNA sample for a criminal investigation or a paternity suit?

What if health-insurance providers manage their healthcare policies based on a genetic predisposition to disease?

Suppose that, years after giving a DNA sample, an individual is barred from employment or rejected for health insurance because of a genetic defect detected in the sample. Would this be a fair and reasonable use of genetic information?

In 2008, the United States Congress passed the Genetic Information Nondiscrimination Act, which protects Americans against discrimination based on their genetic information.

Safety of Transgenics

Are GM foods safe?

Careful studies of such foods have provided no scientific support for concerns about their safety, and it does seem that foods made from GM plants are safe to eat.

Pros of GM Foods

Farmers choose GM crops because they produce higher yields, reducing the amount of land and energy that must be devoted to agriculture and lowering the cost of food for everyone.

Insect-resistant GM plants need little, if any, insecticide to grow successfully, reducing the chance that chemical residues will enter the food supply and lessening damage to the environment.

Pros of GM Foods

Careful studies of GM foods have provided no scientific support for concerns about their safety, and it does seem that foods made from GM plants are safe to eat.

Cons of GM Foods

Critics point out that no long-term studies have been made of the hazards these foods might present.

Some worry that the insect resistance engineered into GM plants may threaten beneficial insects, killing them as well as crop pests.

Others express concerns that use of plants resistant to chemical herbicides may lead to overuse of these weed-killing compounds.

Another concern is that the patents held on GM seeds by the companies that produce them may prove costly enough to force small farmers out of business, especially in the developing world.

Cons of GM Foods

In the United States, current federal regulations treat GM foods and non-GM foods equally.

GM foods are not required to undergo special safety testing before entering the market.

No additional labeling is required to identify a product as genetically modified unless its ingredients are significantly different from its conventional counterpart.

The possibility that meat from GM animals may soon enter the food supply has heightened concerns about labeling. As a result, some states have begun to consider legislation to require the labeling of GM foods, thereby providing consumers with an informed choice.

Ethics of the New Biology

Should genetic modifications to humans and other organisms be closely regulated?

Just because we have the technology to modify an organism's characteristics, are we justified in doing so?

Ethics of the New Biology

Biotechnology has given us the ability to know ourselves more and more. With this knowledge, however, comes responsibility.

You've seen how the GFP gene can easily be extracted from a jellyfish and spliced onto genes coding for important cellular proteins.

This ability has led to significant new discoveries about how cells function.

Ethics of the New Biology

The same GFP technology was used to create fluorescent zebra fish.

These fish—along with fluorescent mice, tadpoles, rabbits, and even cats—have all contributed to our understanding of cells and proteins.

Ethics of the New Biology

But the ability to alter life forms for any purpose, scientific or nonscientific, raises important questions. Just because we have the technology to modify an organism's characteristics, are we justified in doing so?

Ethics of the New Biology

If human cells can be manipulated to cure disease, should biologists try to engineer taller people or change their eye color, hair texture, sex, blood group, or appearance?

What will happen to the human species when we gain the opportunity to design our bodies or those of our children?

What will be the consequences if biologists develop the ability to clone human beings by making identical copies of their cells?

These are questions with which society must come to grips.

Ethics of the New Biology

The goal of biology is to gain a better understanding of the nature of life.

As our knowledge increases, however, so does our ability to manipulate the genetics of living things, including ourselves.

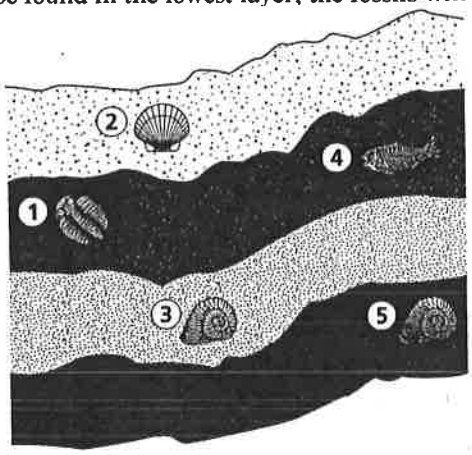
In a democratic nation, all citizens are responsible for ensuring that the tools science has given us are used wisely.

We should all be prepared to help develop a thoughtful and ethical consensus of what should and should not be done with the human genome.

Standard 6 - Biological Evolution --- The student will investigate the forces of natural selection on the development of organisms and examine the evidence for biological evolution.

Performance Indicators:

1. **Differentiate between the relative age of various fossils in sedimentary rock, given a diagram of rock strata**
   a. **Relative dating** – methods used to determine the order/sequence of events
   b. **Relative age** – is the age of an object in relationship/relative to another object
   c. The oldest fossils will be found in the lowest layer; the fossils will become progressively younger toward the upper layers



2. **Predict how environmental changes will encourage or discourage the formation of a new species or extinction of an existing species, given a written scenario**

3. **Transfer knowledge of divergent evolution, as in Darwin's finches, to determine why species with a common ancestor have adapted differently, given a diagram of the various species**
   a. **Divergent evolution** ---type of evolution in which isolated populations evolve independently

4. **Compare homologous structures in species to determine the relatedness of certain species, given diagrams or pictures of each**
   a. **Homologous structures** -- parts of different organisms that have similar structures and embryonic development, but have different forms and functions
   b. The structures are similar because they were inherited from a common ancestor
   c. Ex. = wings of birds and insects

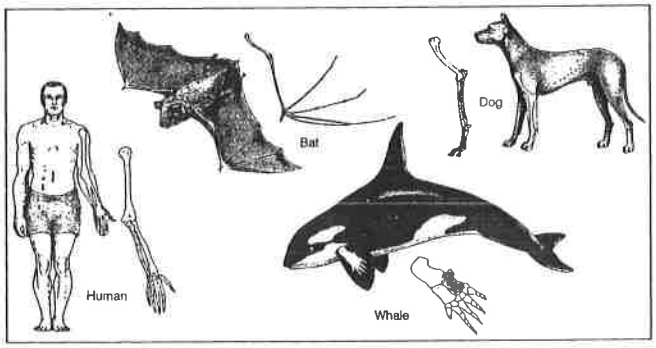
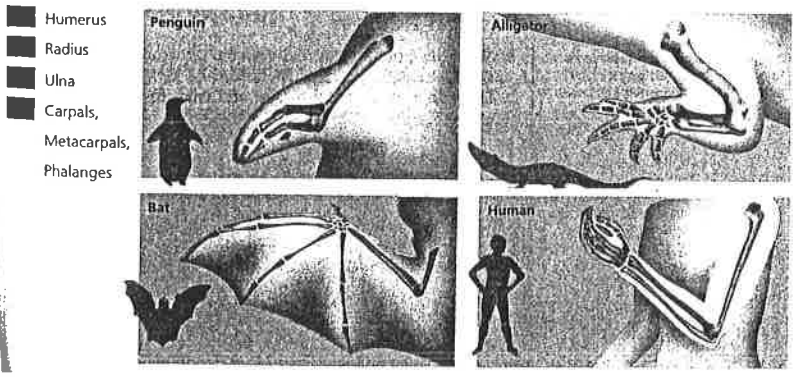


Figure 13–17 Superbly adapted to performing different tasks, the limbs of various organisms are remarkably similar in structure. Here you can see the homologous limbs of four mammals. How is the form of each limb adapted for different movements?

Figure 15-4 The forelimbs of the penguin, the alligator, the bat, and the human are all derived from the same embryological structure.



Life Science Chpt. 7 Study Guide

Section 1 - Change Over Time

Key Terms:

- Adaptation
- Species
- Evolution
- Fossil
- Fossil Record
- Vestigial Structure
- Homologous Structure
- Fitness
- Selective breeding
- Artificial Selection
- Natural Selection
- Analogous Structure

- Scientists used to think that living organisms on Earth never changed.
- Scientists now believe that new species of living organisms emerge from older existing species through evolution.
- Scientists even believe that all living organisms descended from a common ancestor. The ancient common ancestor evolved through genetic mutations that resulted in different physical characteristics and thus different species.
- Scientists use fossils as evidence for evolution.
- Fossils show organisms that once existed. Some of those species have descendants alive today, and some fossil species are now extinct.
- Scientists arrange fossils of similar organisms in order from oldest to youngest to create a fossil record.
- The fossil record shows how organisms have changed as time passed by illustrating the similarities and differences between the old fossils, the new fossils, and current living organisms.

Evidence of Evolution:

- Similar arrangements of bones in the skeletons of different species indicates evolutionary relationships
- Similarities in DNA from different species indicates the relationships between the different species. In the same way that your DNA is most similar to your closest relatives' DNA (parents / siblings), species that have similar DNA are also related to one another. The more similar the DNA between different species, the more closely related the species are. Evolution suggests the species have similar DNA because they inherited the DNA from a common ancestor - just like you and your siblings have similar DNA because you and your siblings inherited your DNA from common ancestors (your parents).
- The embryos (in early stages of development) of many different species are similar in many ways. Evolution suggests that different species develop in similar ways as embryos because the different species originated as a single species many years ago.

Life Science Chpt. 7 Study Guide

Section 2 - How does Evolution Happen?

- Prior to the 1800's, people believed that nothing living on Earth changed. People believed that all life on Earth had always been the same and always would be the same. People also believed that the Earth was very young (less than 10,000 years old).
- Charles Lyell published Principles of Geology. In this book he proposed that the Earth was very old - much older than people previously believed.
- Thomas Malthus published his Essay on the Principle of Population. In this essay, Malthus proposed that humans may reproduce beyond their natural resources. Humans may have more babies than they can support.
- Charles Darwin sailed around the world on a ship called the H.M.S. Beagle. While on this trip Darwin collected many different species of animals and plants. One of the most important places Darwin visited was the Galapagos Islands. By observing the many species of animals & plants, Darwin developed his concept of Evolution by Natural selection.

Evolution by Natural selection:

1. Each species produces more offspring than will survive to adulthood.

over ⇨

2. All the individuals in a population possess different physical traits because they have slightly different genes.

3. A natural environment doesn't have enough resources (food, space, etc.) to support every individual in a population. Thus, the individuals of a population will compete with each other for the resources necessary to survive.

4. The individuals with the physical traits (and thus genes) that help them get more resources (food, space, etc.) will be more healthy, will live longer, and will have more babies. Their babies will then have the genes (passed to them from their parents) that code for the physical traits that help them survive better.

- Scientists now believe that the different physical traits observed in the different organisms arise from mutations in organisms' DNA. The mutations that help organisms survive better and live longer are then called adaptations.

Life Science Chpt. 7 Study Guide

Section 3 - Natural Selection in Action

- One example of natural selection may be found in the problem of pesticide resistance in insects. As humans have sprayed insect populations with pesticides, most of the sprayed insects died. However a few of the insects sprayed have genetic traits that enabled them to survive the pesticides. Because most of the other insects died, the few insects that remained (due to genetic adaptations) bred more and produced whole new populations of insects with the genetic trait (passed to them from their parents who survived the pesticides) that enabled them to resist pesticides. Thus, when the pesticides are sprayed a 2nd time to kill the new populations of insects, the pesticides are ineffective.
- Another example of natural selection is evident in the populations of peppered moths in Europe. Due to their genetic traits in their DNA, peppered moths have 2 possible colorations = dark peppered and light-peppered. Before industries in Europe began polluting the air, the trees were light-colored. Thus, the light peppered moths blended in well on light-colored trees. Predators had a more difficult time seeing the light peppered moths and so the predators ate more dark peppered moths. The dark moths were easily seen on light trees. So most of the peppered moth population consisted of light peppered moths. However, when industries began polluting the air, the air pollution turned the light-colored trees dark as the soot and smoke clung to the trees. Now predators noticed the light peppered moths more on the

darkened trees and the predators began eating more of the light moths. Once pollution turned the trees dark, the dark moths blended in better with the trees and the dark moths were eaten less often by predators. After pollution turned the trees dark, the dark peppered moths survived longer and produced more offspring. Therefore the majority of the peppered moth population after the trees turned dark consisted of dark peppered moths. A change in the color of the trees produced a shift in the coloration of the peppered moth population.

- Steps in the formation of a new species through evolution by natural selection:
  1. Separation - a single population becomes separated into 2 groups by a geographic barrier.
  2. Adaptation - each of the 2 separated groups adapts to their 2 unique environments
  3. Division - through the development of new genetic traits (adaptations) over many years, the 2 separated groups develop into 2 different species that are genetically different enough to prevent successful interbreeding

Lesson Overview 8.1 Energy and Life

Chemical Energy and ATP

One of the most important compounds that cells use to store and release energy is **adenosine triphosphate (ATP).**

ATP consists of adenine, a 5-carbon sugar called ribose, and three phosphate groups.

Storing Energy

Adenosine diphosphate (ADP) has two phosphate groups instead of three. ADP contains some energy, but not as much as ATP.

Storing Energy

When a cell has energy available, it can store small amounts of it by adding phosphate groups to ADP, producing ATP.

Releasing Energy

Cells can release the energy stored in ATP by breaking the bonds between the second and third phosphate groups.

Chemical Energy and ATP

Because a cell can add or subtract these phosphate groups, it has an efficient way of storing and releasing energy as needed.

ATP is like a rechargeable battery that powers the machinery of the cell.

Using Biochemical Energy

ATP is not good for storing large amounts of energy for a long time.

It is more efficient for cells to keep only a small supply of ATP on hand.

Cells can regenerate ATP from ADP as needed.

Heterotrophs and Autotrophs

In photosynthesis, plants convert the sun's energy into chemical energy stored in the bonds of carbohydrates.

The energy in carbohydrates is used to make ATP as needed or stored in other molecules.

8.2 Photosynthesis: An Overview

Light

Energy from the sun travels to Earth in the form of light.

Sunlight is a mixture of different wavelengths

Light

Our eyes see the different wavelengths of the visible spectrum as different colors: red, orange, yellow, green, blue, indigo, and violet.

Pigments

Plants gather the sun's energy with light-absorbing molecules called **pigments.**

The plants' main pigment is **chlorophyll.**

Pigments

two types of chlorophyll

1. chlorophyll *a*
2. chlorophyll *b*

Both absorb light very well in the blue-violet and red regions of the visible spectrum, but not in the green region.

Pigments

Plants also contain red and orange pigments such as carotene that absorb light in other regions of the spectrum.

Pigments

Most of the time, the green color of the chlorophyll overwhelms the other pigments, but as temperatures drop and chlorophyll molecules break down, the red and orange pigments may be seen.

Chloroplasts

Photosynthesis takes place inside organelles called chloroplasts.

Chloroplasts contain saclike photosynthetic membranes called **thylakoids**, which are interconnected and arranged in stacks known as grana.

Chloroplasts

Pigments are located in the thylakoid membranes.

The fluid portion outside of the thylakoids is known as the **stroma.**

Energy Collection

Because light is a form of energy, any compound that absorbs light absorbs energy.

When chlorophyll absorbs light, some of the light energy is transferred to electrons. These high-energy electrons make photosynthesis work.

High-Energy Electrons

The high-energy electrons produced by chlorophyll are highly reactive and require a special "carrier."

High-Energy Electrons

Think of a high-energy electron as being similar to a hot potato. If you wanted to move the potato from one place to another, you would use an oven mitt—a carrier—to transport it.

Plants use electron carriers to transport high-energy electrons from chlorophyll to other molecules.

High-Energy Electrons

$NADP^+$ (nicotinamide adenine dinucleotide phosphate) is a carrier molecule.

$NADP^+$ accepts and holds two high-energy electrons, along with a hydrogen ion (H^+). In this way, it is converted into NADPH.

The NADPH can then carry the high-energy electrons to chemical reactions elsewhere in the cell.

An Overview of Photosynthesis

Photosynthesis uses the energy of sunlight to convert water and carbon dioxide into high-energy sugars and oxygen.

word equation:

chemical equation:

An Overview of Photosynthesis

Plants use the sugars generated by photosynthesis to produce complex carbohydrates such as starches, and to provide energy for the synthesis of other compounds, including proteins and lipids.

Light-Dependent Reactions

Photosynthesis involves two sets of reactions.

The first set of reactions is known as the **light-dependent reactions** because they require the direct involvement of light and light-absorbing pigments.

Light-Dependent Reactions

The light-dependent reactions use energy from sunlight to produce ATP and NADPH.

These reactions take place within the thylakoid membranes of the chloroplast.

Light-Dependent Reactions

Water is required as a source of electrons and hydrogen ions. Oxygen is released as a byproduct.

Light-Independent Reactions

Plants absorb carbon dioxide from the atmosphere and complete the process of photosynthesis by producing sugars and other carbohydrates.

During **light-independent reactions**, ATP and NADPH molecules produced in the light-dependent reactions are used to produce high-energy sugars from carbon dioxide.

Light-Independent Reactions

No light is required to power the light-independent reactions.

The light-independent reactions take place outside the thylakoids, in the stroma.

8.3 The Process of Photosynthesis

The Light-Dependent Reactions: Generating ATP and NADPH

The light-dependent reactions encompass the steps of photosynthesis that directly involve sunlight.

The light-dependent reactions occur in the thylakoids of chloroplasts.

The Light-Dependent Reactions: Generating ATP and NADPH

Thylakoids contain clusters of chlorophyll and proteins known as **photosystems.**

Photosystems absorb sunlight and generate high-energy electrons.

Photosystem II

Light energy is absorbed by electrons in the pigments within photosystem II, increasing the electrons' energy level.

The high-energy electrons are passed to the **electron transport chain**, a series of electron carriers that shuttle high-energy electrons during ATP-generating reactions.

Photosystem II

The thylakoid membrane provides new electrons to chlorophyll from water molecules.

Enzymes of the inner surface of the thylakoid break up water molecules into 2 electrons, 2 H^+ ions, and 1 oxygen atom.

Photosystem II

The 2 electrons replace the high-energy electrons that have been lost to the electron transport chain.

Oxygen is released into the air. This reaction is the source of nearly all of the oxygen in Earth's atmosphere.

The H^+ ions are released inside the thylakoid.

Electron Transport Chain

Energy from the electrons is used by proteins in the electron transport chain to pump H^+ ions from the stroma into the thylakoid space.

Electron Transport Chain

At the end of the electron transport chain, the electrons pass to photosystem I.

Photosystem I

Because some energy has been used to pump H^+ ions across the thylakoid membrane, electrons do not contain as much energy when they reach photosystem I.

Pigments in photosystem I use energy from light to reenergize the electrons.

Photosystem I

At the end of a short second electron transport chain, $NADP^+$ molecules in the stroma pick up the high-energy electrons and H^+ ions at the outer surface of the thylakoid membrane to become NADPH.

Hydrogen Ion Movement and ATP Formation

H^+ ions accumulate within the thylakoid space from the splitting of water and from being pumped in from the stroma.

The buildup of H^+ ions makes the stroma negatively charged relative to the space within the thylakoids.

Hydrogen Ion Movement and ATP Formation

This gradient, the difference in both charge and H^+ ion concentration across the membrane, provides the energy to make ATP.

Hydrogen Ion Movement and ATP Formation

H^+ ions cannot directly cross the thylakoid membane. However, the thylakoid membrane contains a protein called **ATP synthase t**hat spans the membrane and allows H^+ ions to pass through it.

Hydrogen Ion Movement and ATP Formation

Powered by the gradient, H^+ ions pass through ATP synthase and force it to rotate.

As it rotates, ATP synthase binds ADP and a phosphate group together to produce ATP.

Hydrogen Ion Movement and ATP Formation

This process, called **chemiosmosis**, enables light-dependent electron transport to produce not only NADPH (at the end of the electron transport chain), but ATP as well.

The Light-Independent Reactions: Producing Sugars

During the light-independent reactions, also known as the **Calvin cycle**, plants use the energy that ATP and NADPH contains to build carbohydrates.

Carbon Dioxide Enters the Cycle

Carbon dioxide molecules enter the Calvin cycle from the atmosphere.

An enzyme in the stroma of the chloroplast combines carbon dioxide molecules with 5-carbon compounds that are already present in the organelle, producing 3-carbon compounds that continue into the cycle.

Carbon Dioxide Enters the Cycle

For every 6 carbon dioxide molecules that enter the cycle, a total of twelve 3-carbon compounds are produced.

Carbon Dioxide Enters the Cycle

Other enzymes in the chloroplast then convert the 3-carbon compounds into higher-energy forms in the rest of the cycle, using energy from ATP and high-energy electrons from NADPH.

Sugar Production

At midcycle, two of the twelve 3-carbon molecules are removed from the cycle.

These molecules become the building blocks that the plant cell uses to produce sugars, lipids, amino acids, and other compounds.

Sugar Production

The remaining ten 3-carbon molecules are converted back into six 5-carbon molecules that combine with six new carbon dioxide molecules to begin the next cycle.

Summary of the Calvin Cycle

The **Calvin cycle** uses 6 molecules of carbon dioxide to produce a single 6-carbon sugar molecule.

Summary of the Calvin Cycle

The energy for the reactions is supplied by compounds produced in the light-dependent reactions.

Summary of the Calvin Cycle

The plant uses the sugars produced by the Calvin cycle to meet its energy needs and to build macromolecules needed for growth and development.

Temperature, Light, and Water

The reactions of photosynthesis are made possible by enzymes that function best between 0°C and 35°C.

Temperatures above or below this range may affect those enzymes, slowing down the rate of photosynthesis or stopping it entirely.

Temperature, Light, and Water

High light intensity increases the rate of photosynthesis.

After the light intensity reaches a certain level, the plant reaches its maximum rate of photosynthesis.

Temperature, Light, and Water

a shortage of water can slow or even stop photosynthesis.

Water loss can also damage plant tissues.

Photosynthesis Under Extreme Conditions

C4 and CAM plants have biochemical adaptations that minimize water loss while still allowing photosynthesis to take place in intense sunlight.

C4 Photosynthesis

C4 plants have a specialized chemical pathway that allows them to capture even very low levels of carbon dioxide and pass it to the Calvin cycle.

The name “C4 plant” comes from the fact that the first compound formed in this pathway contains 4 carbon atoms.

The C4 pathway requires extra energy in the form of ATP to function.

C4 organisms include crop plants like corn, sugar cane, and sorghum.

CAM Plants

CAM (**Crassulacean Acid Metabolism)** plants admit air into their leaves only at night, where carbon dioxide is combined with existing molecules to produce organic acids, “trapping” the carbon within the leaves.

During the daytime, when leaves are tightly sealed to prevent water loss, these compounds release carbon dioxide, enabling carbohydrate production.

CAM plants include pineapple trees, many desert cacti, and “ice plants”.

Lesson Overview 9.1 Cellular Respiration: An Overview

Chemical Energy and Food

Food provides living things with the chemical building blocks they need.

Cells break down food molecules and use the energy stored in the chemical bonds to produce compounds such as ATP that power the activities of the cell.

Chemical Energy and Food

Energy stored in food is expressed in units of calories.

A **Calorie** is the amount of energy needed to raise the temperature of 1 gram of water by 1 degree Celsius. 1000 calories = 1 kilocalorie, or Calorie.

Overview of Cellular Respiration

If oxygen is available, organisms can obtain energy from food by **cellular respiration.**

In symbols:

$6\ O_2 + C_6H_{12}O_6 \rightarrow 6\ CO_2 + 6\ H_2O + \text{Energy}$

In words:

Oxygen + Glucose → Carbon dioxide + Water + Energy

chemical energy in food must be released gradually, otherwise most of the energy would be lost in the form of heat and light.

Stages of Cellular Respiration

three main stages:

1. glycolysis
2. Krebs cycle
3. electron transport chain (ETC)

Oxygen and Energy

Pathways that require oxygen are **aerobic.**

The Krebs cycle and ETC are aerobic processes.

Both occur inside the mitochondria.

Oxygen and Energy

Gylcolysis is an **anaerobic** process.

It does not directly require or rely on oxygen.

Glycolysis occurs in the cell cytoplasm.

Comparing Photosynthesis and Cellular Respiration

Photosynthesis removes carbon dioxide from the air,
Cell respiration puts it back.

Photosynthesis releases oxygen,
cell respiration uses that oxygen to release energy from food.

Photosynthesis and Cellular Respiration

Photosynthesis and cell respiration are opposite processes.

The energy flows in opposite directions. Photosynthesis “deposits” energy, and cell respiration “withdraws” energy.

Photosynthesis: $6\ CO_2 + 6\ H_2O \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6\ O_2$

Respiration: $6\ O_2 + C_6H_{12}O_6 \rightarrow 6\ CO_2 + 6\ H_2O + \text{Energy}$

Comparing Photosynthesis and Cellular Respiration

cell respiration occurs in plants, animals, fungi, protists, and most bacteria.

photosynthesis occurs only in plants, algae, and some bacteria.

Lesson Overview 9.2 The Process of Cellular Respiration

Glycolysis

During glycolysis, glucose is broken down into 2 molecules of the 3-carbon molecule pyruvic acid.

Pyruvic acid is a reactant in the **Krebs cycle**.

ATP and NADH are produced as part of the process.

ATP Production

2 ATP are used in glycolysis.

Glycolysis produces 4 ATP

Thus a net gain of 2 ATP molecules for each glucose in glycolysis.

NADH Production

During glycolysis, the electron carrier **NAD^+** (nicotinamide adenine dinucleotide) accepts a pair of high-energy electrons, becoming NADH and it carries them to the electron transport chain to produce more ATP.

2 NADH molecules are produced for every molecule of glucose.

Advantages of Glycolysis

produces ATP very fast

Glycolysis does not require oxygen, so it can quickly supply energy to cells when oxygen is unavailable.

Disadvantages:
requires 2 ATP to be used
only gain 2 net ATP

The Krebs Cycle

pyruvic acid (made in glycolysis) is broken down into carbon dioxide

also known as citric acid cycle because citric acid is the first compound formed.

Citric Acid Production

Pyruvic acid from glycolysis enters the **matrix**, the innermost compartment of the mitochondrion.

Citric Acid Production

Once pyruvic acid is in the mitochondrial matrix, NAD^+ accepts 2 high-energy electrons to form NADH. One molecule of CO_2 is also produced.

The remaining 2 carbon atoms react to form acetyl-CoA.

Cycle Overview

Acetyl-CoA combines with a 4-carbon molecule to produce citric acid.
Citric acid is changed into a 5-carbon compound and then a 4-carbon compound.

Two molecules of CO_2 are released.

The 4-carbon compound can then start the cycle again by combining with acetyl-CoA.

Energy Extraction

Energy released by the breaking and rearranging of carbon bonds is captured in the forms of ATP, NADH, and $FADH_2$.

For each turn of the cycle, one ADP molecule is converted into ATP.

NADH and $FADH_2$ are used in the electron transport chain to generate ATP.

Energy Extraction

Each glucose results in 2 molecules of pyruvic acid, which enter the Krebs cycle. So each molecule of glucose results in two complete "turns" of the Krebs cycle.

For each glucose molecule,

6 CO_2
2 ATP
8 NADH
2 $FADH_2$ are produced.

Electron Transport

NADH and $FADH_2$ pass high-energy electrons to electron carrier proteins in the electron transport chain.

Electron Transport

At the end of the ETC, the electrons combine with H^+ ions and oxygen to form water.

Electron Transport

Energy made by the ETC is used to move H+ ions against a concentration gradient across the inner mitochondrial membrane into the intermembrane space.

ATP Production

H+ ions diffuse back across the mitochondrial membrane through the ATP synthase, causing the ATP synthase molecule to spin. With each rotation, the ATP synthase produces ATP.

Energy Totals

With oxygen, the complete breakdown of glucose makes 36 -38 ATP.

Which is about 36 % of the total energy of glucose.

The other 64% is released as heat**.**

Energy Totals

A cell can make ATP from nearly any source. Complex carbs are broken into simple sugars like glucose. Lipids and proteins can be broken down into molecules that enter the Krebs cycle or glycolysis at one of several places.

Lesson Overview 9.3 Fermentation

Fermentation

Fermentation - process by which energy is released from food without oxygen.

- occurs in cytoplasm

Fermentation

1. Glycolysis
2. cells convert NADH made by glycolysis back into NAD^+
3. NAD+ used to do glycolysis again

Alcoholic Fermentation

Some organisms produce ethyl alcohol and carbon dioxide through fermentation.

- used to produce alcoholic beverages
- causes bread dough to rise.

Alcoholic Fermentation

Chemical equation:

Pyruvic acid + NADH → Alcohol + CO_2 + NAD^+

Lactic Acid Fermentation

Some organisms convert pyruvic acid to lactic acid during fermentation.

Chemical equation:

Pyruvic acid + NADH → Lactic acid + NAD^+

Energy and Exercise

For short, quick bursts of energy, the body uses ATP already in muscles as well as ATP made by lactic acid fermentation.

For exercise longer than about 90 seconds, aerobic cellular respiration is the only way to continue generating a supply of ATP.

* Fermentation makes 2 net ATP.

Cell respiration makes 36-38 net ATP.

Competition

How does competition shape communities?

By causing species to divide resources, competition helps determine the number and kinds of species in a community and the niche each species occupies.

Competition

How one organism interacts with other organisms is an important part of defining its niche.

Competition occurs when organisms attempt to use the same limited ecological resource in the same place at the same time.

Competition

In a forest, for example, plant roots compete for resources such as water and nutrients in the soil.

Animals **compete** for resources such as food, mates, and places to live and raise their young.

Competition can occur both between members of the same species (known as intraspecific competition) and between members of different species (known as interspecific competition).

The Competitive Exclusion Principle

The **competitive exclusion principle** states that no two species can occupy exactly the same niche in exactly the same habitat at exactly the same time.

If two species attempt to occupy the same niche, one species will be better at competing for limited resources and will eventually exclude the other species.

As a result of competitive exclusion, natural communities rarely have niches that overlap significantly.

Dividing Resources

Instead of competing for similar resources, species usually divide them.

For example, the three species of North American warblers shown all live in the same trees and feed on insects.

But one species feeds on high branches; another feeds on low branches, and another feeds in the middle.

Dividing Resources

The resources utilized by these species are similar yet different. Therefore, each species has its own niche and competition is minimized.

This division of resources was likely brought about by past competition among the birds.

By causing species to divide resources, competition helps determine the number and kinds of species in a community and the niche each species occupies

Predation, Herbivory, and Keystone Species

How do predation and herbivory shape communities?

Predators can affect the size of prey populations in a community and determine the places prey can live and feed.

Herbivores can affect both the size and distribution of plant populations in a community and determine the places that certain plants can survive and grow.

Predator-Prey Relationships

An interaction in which one animal (the predator) captures and feeds on another animal (the prey) is called **predation.**

Predators can affect the size of prey populations in a community and determine the places prey can live and feed.

Birds of prey, for example, can play an important role in regulating the population sizes of mice, voles, and other small mammals.

Predator-Prey Relationships

This graph shows an idealized computer model of changes in predator and prey populations over time.

Herbivore-Plant Relationships

An interaction in which one animal (the herbivore) feeds on producers (such as plants) is called **herbivory.**

Herbivores, like a ring-tailed lemur, can affect both the size and distribution of plant populations in a community and determine the places that certain plants can survive and grow.

For example, very dense populations of white-tailed deer are eliminating their favorite food plants from many places across the United States.

Keystone Species

Sometimes changes in the population of a single species, often called a **keystone species,** can cause dramatic changes in the structure of a community.

In the cold waters off the Pacific coast of North America, for example, sea otters devour large quantities of sea urchins.

Urchins are herbivores whose favorite food is kelp, giant algae that grow in undersea “forests.”

Keystone Species

A century ago, sea otters were nearly eliminated by hunting. Unexpectedly, the kelp forest nearly vanished.

Without otters as predators, the sea urchin population skyrocketed, and armies of urchins devoured kelp down to bare rock.

Without kelp to provide habitat, many other animals, including seabirds, disappeared.

Otters were a keystone species in this community.

Keystone Species

After otters were protected as an endangered species, their population began to recover.

As otters returned, the urchin populations dropped, and kelp forests began to thrive again.

Recently, however, the otter population has been falling again, and no one knows why.

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.

43 **Gene Linkage and Gene Maps**

How can two alleles from different genes be inherited together?

44 **Gene Linkage and Gene Maps**

How can two alleles from different genes be inherited together?

Alleles of different genes tend to be inherited together from one generation to the next when those genes are located on the same chromosome.

45 **Gene Linkage**

Thomas Hunt Morgan's research on fruit flies led him to the principle of gene linkage.

After identifying more than 50 *Drosophila* (fruit fly) genes, Morgan discovered that many of them appeared to be "linked" together in ways that seemed to violate the principle of independent assortment.

46 **Gene Linkage**

For example, Morgan used a fly with reddish-orange eyes and miniature wings in a series of test crosses.

His results showed that the genes for those two traits were almost always inherited together.

Only rarely did the genes separate from each other.

47 **Gene Linkage**

Morgan and his associates observed so many genes that were inherited together that, before long, they could group all of the fly's genes into four linkage groups.

The linkage groups assorted independently, but all of the genes in one group were inherited together.

As it turns out, *Drosophila* has four linkage groups and four pairs of chromosomes.

48 **Gene Linkage**

Morgan's findings led to two remarkable conclusions:

First, each chromosome is actually a group of linked genes.

Second, it is the chromosomes that assort independently, not individual genes.

Alleles of different genes tend to be inherited together when those genes are located on the same chromosome.

49 **Gene Mapping**

In 1911, Columbia University student Alfred Sturtevant wondered if the frequency of crossing-over between genes during meiosis might be a clue to the genes' locations.

Sturtevant reasoned that the farther apart two genes were on a chromosome, the more likely it would be that a crossover event would occur between them.

If two genes are close together, then crossovers between them should be rare. If two genes are far apart, then crossovers between them should be more common.

50 **Gene Mapping**

By this reasoning, he could use the frequency of crossing-over between genes to determine their distances from each other.

Sturtevant gathered lab data and presented a gene map showing the relative locations of each known gene on one of the *Drosophila* chromosomes.

Sturtevant's method has been used to construct gene maps ever since this discovery.

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.

26 **X-Chromosome Inactivation**

If just one X chromosome is enough for cells in males, how does the cell "adjust" to the

extra X chromosome in female cells?

In female cells, most of the genes in one of the X chromosomes are randomly switched off, forming a dense region in the nucleus known as a Barr body.

Barr bodies are generally not found in males because their single X chromosome is still active.

27 **X-Chromosome Inactivation**

X-chromosome inactivation also happens in other mammals.

In cats, a gene that controls the color of coat spots is located on the X chromosome.

28 **X-Chromosome Inactivation**

One X chromosome may have an allele for orange spots and the other X chromosome may have an allele for black spots.

In cells in some parts of the body, one X chromosome is switched off. In other parts of the body, the other X chromosome is switched off. As a result, the cat's fur has a mixture of orange and black spots.

29 **X-Chromosome Inactivation**

Male cats, which have just one X chromosome, can have spots of only one color.

If a cat's fur has three colors—white with orange and black spots, for example—you can almost be certain that the cat is female.

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.

Sickle Cell Disease

This disorder is caused by a defective allele for beta-globin, one of two polypeptides in hemoglobin, the oxygen-carrying protein in red blood cells.

The defective polypeptide makes hemoglobin less soluble, causing hemoglobin molecules to stick together when the blood's oxygen level decreases.

The molecules clump into long fibers, forcing cells into a distinctive sickle shape, which gives the disorder its name.

9 **Sickle Cell Disease**

Sickle-shaped cells are more rigid than normal red blood cells, and they tend to get stuck in the capillaries.

If the blood stops moving through the capillaries, damage to cells, tissues, and even organs can result.

10 **Cystic Fibrosis**

Cystic fibrosis (CF) is most common among people of European ancestry.

Most cases result from the deletion of just three bases in the gene for a protein called cystic fibrosis transmembrane conductance regulator (CFTR). As a result, the amino acid phenylalanine is missing from the protein.

11 **Cystic Fibrosis**

CFTR normally allows chloride ions (Cl^-) to pass across cell membranes.

The loss of these bases removes a single amino acid—phenylalanine—from CFTR, causing the protein to fold improperly.

The misfolded protein is then destroyed.

12 **Cystic Fibrosis**

With cell membranes unable to transport chloride ions, tissues throughout the body malfunction. Children with CF have serious digestive problems and produce thick, heavy mucus that clogs their lungs and breathing passageways.

13 **Cystic Fibrosis**

People with one normal copy of the CF allele are unaffected by CF, because they can produce enough CFTR to allow their cells to work properly.

Two copies of the defective allele are needed to produce the disorder, which means the CF allele is recessive.

14 **Huntington's Disease**

Huntington's disease is caused by a dominant allele for a protein found in brain cells.

The allele for this disease contains a long string of bases in which the codon CAG—

coding for the amino acid glutamine—repeats over and over again, more than 40 times.

Despite intensive study, the reason why these long strings of glutamine cause disease is still not clear.

The symptoms of Huntington's disease, namely mental deterioration and uncontrollable movements, usually do not appear until middle age.

The greater the number of codon repeats, the earlier the disease appears, and the more severe are its symptoms.

15 **Genetic Advantages**

Disorders such as sickle cell disease and CF are still common in human populations.

In the United States, the sickle cell allele is carried by approximately 1 person in 12 of African ancestry, and the CF allele is carried by roughly 1 person in 25 of European ancestry.

Why are these alleles still around if they can be fatal for those who carry them?

16 **Genetic Advantages**

Most African Americans today are descended from populations that originally lived in west central Africa, where malaria is common.

Malaria is a mosquito-borne infection caused by a parasite that lives inside red blood cells.

17 **Genetic Advantages**

Individuals with just one copy of the sickle cell allele are generally healthy, and are also highly resistant to the parasite, giving them a great advantage against malaria.

The upper map shows the parts of the world where malaria is common. The lower map shows regions where people have the sickle cell allele.

18 **Genetic Advantages**

More than 1000 years ago, the cities of medieval Europe were ravaged by epidemics of typhoid fever.

Typhoid is caused by a bacterium that enters the body through cells in the digestive system.

The protein produced by the CF allele helps block the entry of this bacterium.

Individuals heterozygous for CF would have had an advantage when living in cities with

poor sanitation and polluted water, and—because they also carried a normal allele—these individuals would not have suffered from cystic fibrosis.

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.