1. __________________ hypothesized that species evolve through use and disuse of body parts
2. __________________’s principle of uniformitarianism
3. ____________, a French scientist, advocated catastrophism
4. ____________: thought species were unchanged
5. ______________: interpreted organismal adaptations as evidence that the Creator had designed each species for a specific purpose
1. **Lamark** hypothesized that species evolve through use and disuse of body parts
2. **Lyell**’s principle of uniformitarianism
3. **Cuvier** a French scientist, advocated catastrophism
4. **Aristotle**: thought species were unchanged
5. **Carolus Linnaeus** interpreted organismal adaptations as evidence that the Creator had designed each species for a specific purpose
DO NOW

- How do adaptations help an individual survive?
NAME THAT ADAPTATION

- Living organisms are adapted to their environment
CHAPTER 22-24
EVOLUTION
ALBATROSS

- 12 foot wingspan
- Spend most of their lives in flight
- Sleep while flying
ANTEATER

• Sleep 12 hours a day
• Long tongues to capture Termites
**Camel**

- Long eyelashes
- Nostrils that open/close
- Fat stored in hump
- Wide feet
- Tan color
- Fluctuating body temperature
CRICKET

- Can freeze solid in winter
- Hard exoskeleton
CHEETAH

• Lean body
• Light bone structure
DOLPHIN

• Streamlined body
• Excellent hearing
• Intelligent
• Travel in Pods
GIRAFFE

• Long neck
• Extra heart
GREENLAND SHARK

• Natural antifreeze in blood that makes them poisonous to humans
LION

• Frontal eye position for depth perception
• Fur color
Polar Bear

- White fur
- Layer of blubber
WOODPECKER

• Cushioning in skull to protect brain from hammering
Snakes

- Bones in mouth loosely connected
- Teeth curved backwards
- Windpipe moves
WATER SPIDER

• Lives under water
• Uses air bubble to breath
CHAPTER 22: WHAT YOU NEED TO KNOW!

- Homework: Read 22.1
  - Quiz tomorrow on 22.1, be sure you know Linnaeus, Cuvier, Lyell, and Lamarck (be able to identify the differences between Lamarck’s view of the mechanisms of evolution from Darwin’s.)

- Examples of Evidence of Evolution
- Homologous & Analogous Structures, and how they relate to Evolution.
- The role of adaptations, variation, time, reproductive success, and heritability in evolution.
Began in 1831 on HMS Beagle (ship)
During this five year long voyage Darwin documented his findings regarding the natural world
Collected specimens to study
- Use Darwin’s findings not only to understand the past, but to also predict the future of Earth and the organisms that live on it (including diseases)
In 1859, Darwin published *On the Origin of Species by Means of Natural Selection*, presenting a strong, logical explanation of descent with modification, evolution by the mechanism of natural selection.
The **Galapagos** Islands: An isolated group of islands off the coast of **South America** where Darwin found considerable specimens.

- Found many groups of **finches**, each with their own **niche**, eating habits, and physical distinctions.
Darwin discovered 13 distinct species of finch on the islands. Hypothesized each species adapted to their environment.
What is Evolution?

**Evolution** is change over time.
Darwin observed that

- Organisms produce more offspring than the environment can support
- Organisms vary in many traits
Darwin reasoned that traits that increase their chance of surviving and reproducing in their environment tend to leave more offspring than others.

- As a result, favorable traits accumulate in a population over generations.

DARWIN PROPOSED NATURAL SELECTION AS THE MECHANISM OF EVOLUTION
Natural Selection:

The name Darwin gave to process by which adaptations are shaped.

The natural selection theory has 4 main points:
1. There is variation within populations.
2. Some of those variations are favorable.
3. Not all young produced in a generation will survive.
4. Individuals that survive & reproduce are those with favorable variations.
The offspring of the survivors will inherit the favorable variations.

for each new generations, a progressively larger number of offspring will have the favorable variations.
Darwin found convincing evidence for his ideas in the results of artificial selection, the selective breeding of domesticated plants and animals.
Terminal bud
Lateral buds

Cabbage
Brussels sprouts

Cauliflower
Leaves
Kale

Flower clusters

Wild mustard

Stem

Wild mustard

Broccoli
Kohlrabi

Flowers and stems
NATURAL SELECTION:

- Some important points
  - Individuals do not evolve; populations evolve
  - Natural selection can amplify or diminish only heritable traits; acquired characteristics cannot be passed on to offspring
  - Evolution is not goal directed and does not lead to perfection; favorable traits vary as environments change
Will natural selection act on variation in hair style in a human population?

No
Hair style is not a heritable trait.
Will natural selection act on tongue rolling in a human population?
(Note: Tongue rolling is an inherited trait, caused by a dominant allele)

Probably not. Even though it is a heritable trait, the ability to roll the tongue likely has not fitness benefits. It does not increase an individual's chances at breeding.
Chapter 22.3

EVIDENCE OF EVOLUTION
EVIDENCE OF EVOLUTION

- Direct Observations
- The Fossil Record
- Homology (Convergent Evolution)
- Biogeography
Development of pesticide resistance in insects

- Initial use of pesticides favors those few insects that have genes for pesticide resistance
- With continued use of pesticides, resistant insects flourish and vulnerable insects die
- Proportion of resistant insects increases over time
Chromosome with allele conferring resistance to pesticide

Additional applications will be less effective, and the frequency of resistant insects in the population will grow.
Soapberry bugs use their “beak” to feed on seeds within fruits

- In southern Florida soapberry bugs feed on balloon vine with larger fruit; they have longer beaks

- In central Florida they feed on goldenrain tree with smaller fruit; they have shorter beaks

Correlation between fruit size and beak size has also been observed in Louisiana, Oklahoma, and Australia

- In Florida this evolution in beak size occurred in less than 35 years
On native species, southern Florida

On introduced species, central Florida

Soapberry Bug Beak Size

Number of individuals

Beak length (mm)

Museum-specimen average

Example of Natural Selection

Soapberry Bug Beak Size
Soapberry bug with beak inserted in balloon vine fruit
On native species, southern Florida

Museum-specimen average

On introduced species, central Florida

Beak length (mm)

Number of individuals

RESULTS
The bacterium *Staphylococcus aureus* is commonly found on people

- Several strains naturally found on human skin, with no effects
- One strain, methicillin-resistant *S. aureus* (MRSA) is a dangerous pathogen

*S. aureus* became resistant to penicillin in 1945, two years after it was first widely used

*S. aureus* became resistant to methicillin in 1961, two years after it was first widely used
Methicillin works by inhibiting a protein used by bacteria in their cell walls

- So, the MRSA bacteria use a different protein in their cell walls

When exposed to methicillin, MRSA strains are more likely to survive and reproduce than nonresistant *S. aureus* strains

- Bacteria strains can change genes with members of their own members and other species

MRSA strains are now resistant to many antibiotics
Chromosome map of *S. aureus* clone USA300

Key to adaptations
- Methicillin resistance
- Ability to colonize hosts
- Increased disease severity
- Increased gene exchange (within species) and toxin production
The fossil record shows that organisms have evolved in a historical sequence:
- The oldest known fossils are prokaryote cells
- The oldest eukaryotic fossils are a billion years younger
- Multicellular fossils are even more recent

The study of fossils is known as **paleontology**.
Fossils can document important transitions

For example, the transition from land to sea in the ancestors of cetaceans
Other even-toed ungulates

Hippopotamuses

†Pakicetus

†Rodhocetus

†Dorudon

Living cetaceans

Common ancestor of cetaceans

Millions of years ago

Key: Pelvis, Tibia, Femur, Foot

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**Tappania**, a unicellular eukaryote

*Skull of Homo erectus*

*Ammonite casts*
Biogeography, the geographic distribution of species, suggested to Darwin that organisms evolve from common ancestors.
**BIOGEOGRAPHY:** ENDEMIC SPECIES

- **Endemic Species:** species found at a certain geographic location and nowhere else.

  - Can you think of any?

  - **Marsupials** are a sub-class of mammals that are thought to have evolved concurrently with their placental cousins. Distinguishable by their child rearing pouches.

  - Most marsupials are **endemic** to Australia
Marsupial fossils are found in North America, but why don’t we see Kangaroos?
PANGEA
Continental Drift

200 million years ago

135 million years ago

35 million years ago

Present day
MORE EVIDENCE FOR THE EVOLUTIONARY VIEW OF LIFE

- **Comparative anatomy** is the comparison of body structures in different species.

- **Homology** is the similarity in characteristics that result from common ancestry.
  - Vertebrate forelimbs
Homologous Structures

- Humerus
- Radius
- Ulna
- Carpals
- Metacarpals
- Phalanges

Human

Cat

Whale

Bat
HOMOLOGOUS STRUCTURES

Which of the following pairs are homologous structures?

- Human limb and whale flipper
- Insect wing and bat wing
- Human thumb and chimpanzee thumb
Which of the following are homologous structures?
- Oak leaf and oak root
- Oak leaf and lichen
- Oak leaf and maple leaf
- There are no homologous plant structures
Distantly related organisms sometimes have characteristics that are similar in function but different in structure.

Structures that are similar in function, but are not inherited from a common ancestor.

The **wings** of an **insect**, a **pterodactyl**, a **bird**, and a **bat** all serve the same function, but differ in structure and have evolved from different ancestors.
Birds wing, bat wing & insects wing are all examples of __________ structures.

A human are and whale fin are examples of __________ structures.

Explain how each of these 2 types of structures could come to exist in different species.
MORE EVIDENCE THAT REINFORCES THE
EVOLUTIONARY VIEW OF LIFE

**Comparative embryology** is the comparison of early stages of development among different organisms

- Many vertebrates have common embryonic structures, revealing homologies
- When you were an embryo, you had a tail and pharyngeal pouches (just like an embryonic fish)
Pharyngeal pouches
Post-anal tail

Chick embryo

Human embryo
MORE EVIDENCE THAT REINFORCES THE EVOLUTIONARY VIEW OF LIFE

- Some **homologous structures** are **vestigial** organs
  - For example, the pelvic and hind-leg bones of some modern whales
VESTIGIAL STRUCTURES

- Structures that are **inherited**, but **reduced in size and often unused**.
- Are remnants of functional structures that have been inherited from an ancestor.
The femur fits into the hip making a ball and socket joint.
Does a whale need a femur?
Pelvis and hind limb

Pakicetus (terrestrial)

Rhodocetus (predominantly aquatic)

Pelvis and hind limb

Dorudon (fully aquatic)

Pelvis and hind limb

Balaena (recent whale ancestor)
Do we need...?
Molecular biology: Comparisons of DNA and amino acid sequences between different organisms reveal evolutionary relationships

- All living things share a common DNA code for the proteins found in living cells
- We share genes with bacteria, yeast, and fruit flies
HOMOLOGIES INDICATE PATTERNS OF DESCENT THAT CAN BE SHOWN ON AN EVOLUTIONARY TREE

- Darwin was the first to represent the history of life as a tree
Homologous structures and genes can be used to determine the branching sequence of an evolutionary tree.
JUST TO RECAP

- Evolution is the change in a species over time.
- There is overproduction of offspring, which leads to competition for resources.
- Heritable variations exist within a population.
- These variations can result in differential reproductive success.
- Over generation, this can result in changes in the genetic composition of the population.
- ... & POPULATIONS EVOLVE, NOT Individuals.
Chapter 23

THE EVOLUTION OF POPULATIONS
THE EVOLUTION OF POPULATIONS

You Need to Know:

- FOR EVOLUTION TO OCCUR, there **MUST** be **GENETIC VARIATION**!
- How **mutation** and **sexual reproduction** each produce genetic variation
- The conditions for **Hardy-Weinberg Equilibrium**
- How to use the **Hardy-Weinberg equation** to calculate allele frequencies and to test whether a population is evolving.
One misconception is that organisms evolve during their lifetimes.

- Natural selection acts on individuals, but only populations evolve.
A **population** is a group of individuals of the **same species** living in the **same place** at the **same time**.
Evolution is the change in heritable traits in a population over generations.

- Populations may be isolated from one another (with little interbreeding), or individuals within populations may interbreed.
Microevolution is a change in the relative frequencies of alleles (or allele frequencies) of a population over generations.

- Evolution on its smallest scale
- Changes occur in a population’s gene pool
- A gene pool is the total collection of genes in a population at any one time
MICROEVOLUTION IS A CHANGE IN ALLELE FREQUENCIES IN A POPULATION OVER GENERATIONS

- Three mechanisms cause allele frequency change:
  1. Natural selection
  2. Genetic drift
  3. Gene flow

- Only natural selection causes adaptive evolution
GENETIC VARIATION- EXPLAIN THE FOLLOWING:

- **Genetic Variation** (or differences in heritable traits) is a prerequisite for evolution to occur.

- **Phenotype** is the product of inherited *genotype* and environmental influences.

- **Natural selection** can only act on variation with a genetic component.
POPULATIONS ARE THE UNITS OF EVOLUTION

- **Population genetics** studies how populations change genetically over time.
VARIATION WITHIN A POPULATION

Both discrete and quantitative characters contribute to variation within a population

- **Discrete characters** can be classified on an either-or basis (tall or short)
- **Quantitative characters** vary along a continuum within a population (various degrees of height)
  - Quantitative are more common.
Genetic variation can be measured as **gene variability** or **nucleotide variability**

- For gene variability, **average heterozygosity** measures the **average percent** of loci that are **heterozygous** in a population
  - **For example:** A fruit fly has about 13,700 loci.
  - **On average about 14% of** fruit flies loci (or 1,920) are heterozygous.
  - This provides enough variation for natural selection to occur.
Nucleotide variability is measured by comparing the DNA sequences of pairs of individuals, and then averaging the results.

**Example:**
- Fruit fly’s have about 180 million nucleotides.
- On average, the sequence of any two *D. melanogaster* (fruit flies) differ by about 1.8 million (1%) nucleotides.

How is it between two *Drosophila melanogaster*, on average only 1% of the genome varies, but 14% of the genes vary?

Genes only make up a small fraction of the entire genome.
Most species exhibit **geographic variation**, differences between gene pools of separate populations.

For example, Madeira is home to several isolated populations of mice.

- Chromosomal variations are **neutral** (no phenotypic effect), so variations among populations is due to **drift** (random chance), not natural selection.
Figure 23.4 Geographic variation in isolated mouse populations on Madeira.

Some chromosomes have fused. The genome has changed, but the genes are intact, so no phenotypic changes have occurred.
Some examples of geographic variation occur as a **cline**, which is a **graded change** in a trait along a **geographic axis**

- For example, mummichog fish vary in a cold-adaptive allele along a temperature gradient
  - *Ldh-B^b* allele codes for the metabolic enzyme lactate dehydrogenase-B, is a better catalyst in cold water than other forms of the enzyme.

- This variation results from **natural selection**
What do you think the this graph might look like?
Maine
Cold (6°C)

Georgia
Warm (21°C)
Sources of Genetic Variation

**Mutation and Sexual Reproduction** produce **Genetic Variation**, making **Evolution Possible**
Mutation, or changes in the nucleotide sequence of DNA, is the ultimate source of new alleles. Occasionally, mutant alleles improve the adaptation of an individual to its environment and increase its survival and reproductive success (for example, DDT resistance in insects).
Chromosomal duplication is an important source of genetic variation. If a gene is duplicated, the new copy can undergo mutation without affecting the function of the original copy. For example, an early ancestor of mammals had a single gene for an olfactory receptor (smell). The gene has been duplicated many times, and humans now have 1,000 different olfactory receptor genes.
RAPID REPRODUCTION

- Mutation rates are low in animals and plants.
- The average is about one mutation in every 100,000 genes per generation.
- Mutations rates are often lower in prokaryotes and higher in viruses.
SEXUAL REPRODUCTION

- Sexual reproduction shuffles alleles to produce new combinations
Parents

Offspring, with new combinations of alleles

Gametes

Meiosis

Random fertilization

Offspring, with new combinations of alleles
Animation: Genetic Variation from Sexual Recombination
Right-click slide / select “Play”
THE HARDY-WEINBERG EQUATION

CAN BE USED TO TEST WHETHER A POPULATION IS EVOLVING
POP QUIZ HOT SHOT

- There are 5 conditions for Hardy-Weinberg Equilibrium, Name 4 of them (if you name more and they are wrong you will lose points)
- Give an example of genetic drift.
- The following is an example of natural selection: Birth weights of most humans lie in a narrow range, as those babies that are very large or very small have higher mortality, this is an example of _____ natural selection.
THE HARDY-WEINBERG EQUATION

- Sexual reproduction alone does not lead to evolutionary change in a population
  - Although alleles are shuffled, the frequency of alleles and genotypes in the population does not change
    - Similarly, if you shuffle a pack of cards, you’ll deal out different hands, but the cards and suits in the deck do not change
The Hardy Weinberg principle states that allele and genotype frequencies within a sexually reproducing, diploid population will remain in equilibrium unless outside forces act to change those frequencies.
Imagine that there are two alleles in a blue-footed booby population: \( W \) and \( w \)
- \( W \) is a dominant allele for a nonwebbed booby foot
- \( w \) is a recessive allele for a webbed booby foot
THE HARDY-WEINBERG EQUATION

- Consider the gene pool of a population of 500 boobies
  - 320 (64%) are homozygous dominant (WW)
  - 160 (32%) are heterozygous (Ww)
  - 20 (4%) are homozygous recessive (ww)
<table>
<thead>
<tr>
<th>Phenotypes</th>
<th>Genotypes</th>
<th>Number of animals (total = 500)</th>
<th>Genotype frequencies</th>
<th>Number of alleles in gene pool (total = 1,000)</th>
<th>Allele frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WW</td>
<td>320</td>
<td>$\frac{320}{500} = 0.64$</td>
<td>640 $W$</td>
<td>$\frac{800}{1,000} = 0.8$ $W$</td>
</tr>
<tr>
<td></td>
<td>Ww</td>
<td>160</td>
<td>$\frac{160}{500} = 0.32$</td>
<td>160 $W$ + 160 $w$</td>
<td>$\frac{200}{1,000} = 0.2$ $w$</td>
</tr>
<tr>
<td></td>
<td>ww</td>
<td>20</td>
<td>$\frac{20}{500} = 0.04$</td>
<td>40 $w$</td>
<td></td>
</tr>
</tbody>
</table>

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THE HARDY-WEINBERG EQUATION

- Frequency of dominant allele ($W$) = 80% = $p$
  - 80% of alleles in the booby population are $W$
- Frequency of recessive allele ($w$) = 20% = $q$
  - 20% of alleles in the booby population are $w$
THE HARDY-WEINBERG EQUATION

- Frequency of all three genotypes must be 100% or 1.0
  - \( p^2 + 2pq + q^2 = 100\% = 1.0 \)
  - homozygous dominant + heterozygous + homozygous recessive = 100%

\[ p^2 + 2pq + q^2 = 100\% = 1.0 \]

Homozygous Dominant + Heterozygous + Homozygous Recessive = 100%
THE HARDY-WEINBERG EQUATION

- What about the next generation of boobies?
  - Probability that a booby sperm or egg carries $W = 0.8$ or 80%
  - Probability that a sperm or egg carries $w = 0.2$ or 20%
Gametes reflect allele frequencies of parental gene pool

**Eggs**
- $W$ egg $p = 0.8$
- $w$ egg $q = 0.2$

**Sperm**
- $W$ sperm $p = 0.8$
- $w$ sperm $q = 0.2$

Next generation:

**Genotype frequencies**
- $WW \ p^2 = 0.64$
- $Ww \ pq = 0.16$
- $wW \ qp = 0.16$
- $ww \ q^2 = 0.04$

**Allele frequencies**
- $0.8 \ W$
- $0.2 \ w$
THE HARDY-WEINBERG EQUATION

- What is the probability of a booby chick with a homozygous dominant genotype (WW)?

- What is the probability of a booby chick with a homozygous recessive genotype (ww)?

- What is the probability of a booby chick with a heterozygous genotype (Ww)?
THE HARDY-WEINBERG EQUATION

- If a population is in Hardy-Weinberg equilibrium, allele and genotype frequencies will not change unless something acts to change the gene pool.
The Hardy-Weinberg theorem describes a hypothetical population that is not evolving.

In real populations, allele and genotype frequencies do change over time.
For a population to remain in Hardy-Weinberg equilibrium for a specific trait, it must satisfy five conditions:

1. **Very large population**
2. **No gene flow** between populations
3. **No mutations**
4. **Random mating**
5. **No natural selection**
Phenylketonuria (PKU)

Phenylketonuria (PKU) is an autosomal recessive metabolic genetic disorder characterized by a mutation in the gene for the enzyme phenylalanine hydroxylase (PAH), rendering it nonfunctional.

- This enzyme metabolizes the amino acid phenylalanine (Phe) to the amino acid tyrosine.
- When PAH activity is reduced, phenylalanine accumulates and is converted into phenylpyruvate (also known as phenylketone), which can be detected in the urine.

Untreated PKU can lead to intellectual disability, seizures, and other serious medical problems.

The mainstream treatment for classic PKU patients is a strict PHE-restricted diet.
APPLYING THE HARDY-WEINBERG PRINCIPLE

- We can assume the locus that causes phenylketonuria (PKU) (metabolic disorder) is in Hardy-Weinberg equilibrium given that:

1. There is a very large population
2. Migration has no effect as many other populations have similar allele frequencies
3. The PKU gene mutation rate is low
4. Mate selection is random with respect to whether or not an individual is a carrier for the PKU allele
5. Natural selection can only act on rare homozygous individuals who do not follow dietary restrictions
The occurrence of PKU is 1 per 10,000 births
We want to know the frequency of the allele in the US population.
What is the percentage of carriers for the trait?

- Write out the Hardy-Weinberg Equation
- We know that PKU is a recessive trait
- Which variable represents recessive traits?
- What is the genotype of individuals with PKU?
- What component of the HW Eqn represents those individuals?
- What do we know that component to be equal to?
The occurrence of PKU is 1 per 10,000 births
- \( q^2 = 0.0001 \)
- \( q = 0.01 \)

The frequency of normal alleles is
- \( p = 1 - q = 1 - 0.01 = 0.99 \)

The frequency of carriers is
- \( 2pq = 2 \times 0.99 \times 0.01 = 0.0198 \)
  - or approximately 2% of the U.S. population

Check it
- \( p^2 + 2pq + q^2 = 1.0 \)
  - \( 0.9801 + 0.0198 + 0.0001 = 1.0 \)
MECHANISMS OF MICROEVOLUTION

What could cause changes in allele frequency?
Think about your lab (the lab we will be doing).
1. Give an example of genetic drift.

2. The following is an example of natural selection: Birth weights of most humans lies in a narrow range, as those babies that are very large or very small have higher mortality, this is an example of _______ selection.

3. This type of selection is when natural selection shifts the overall makeup of the population by favoring variants that are at one extreme of the phenotypes distribution.

4. This is an the term given to the post-zygotic species barrier in which 2 species mate & produce a viable, fertile hybrids, however, when the hybrids mate, their offspring are weak or sterile.

5. This is one of the 2 main types of speciation in which a population forms a new species because it is geographically isolated from the parent population.
NATURAL SELECTION, GENETIC DRIFT, AND GENE FLOW CAN ALTER ALLELE FREQUENCIES IN A POPULATION
If the five conditions for the Hardy-Weinberg equilibrium are not met in a population, the population’s gene pool may change

- **Mutations** are rare and random and have little effect on the gene pool
- If **mating is nonrandom**, allele frequencies won’t change much (although genotype frequencies may)
3 MAIN CAUSES OF EVOLUTION

The three main causes of evolutionary change are

- Natural selection
- Genetic drift
- Gene flow
Natural selection

- If individuals differ in their survival and reproductive success, natural selection will alter allele frequencies
  - Consider the boobies: Would webbed or nonwebbed boobies be more successful at swimming and capturing fish?
GENETIC DRIFT

Genetic drift

- **Genetic drift** is a change in the gene pool of a population due to chance
- In a small population, chance events may lead to the loss of genetic diversity
Animation: Causes of Evolutionary Change

Right-click slide / select “Play”
Generation 1

$p$ (frequency of $C^R$) = 0.7
$q$ (frequency of $C^W$) = 0.3

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5 plants leave offspring

Generation 1

\[ p \text{ (frequency of } CR) = 0.7 \]
\[ q \text{ (frequency of } CW) = 0.3 \]

Generation 2

\[ p = 0.5 \]
\[ q = 0.5 \]
Generation 1
\[ p \text{ (frequency of } \text{C} \text{R}) = 0.7 \]
\[ q \text{ (frequency of } \text{C} \text{W}) = 0.3 \]

5 plants leave offspring

Generation 2
\[ p = 0.5 \]
\[ q = 0.5 \]

2 plants leave offspring

Generation 3
\[ p = 1.0 \]
\[ q = 0.0 \]
THE FOUNDER EFFECT

- The **founder effect** occurs when a few individuals become isolated from a larger population.

- Allele frequencies in the small founder population can be different from those in the larger parent population.
GENETIC DRIFT

Genetic drift

- The bottleneck effect leads to a loss of genetic diversity when a population is greatly reduced
  - For example, the northern elephant seal was hunted to near extinction in the 1700s and 1800s
  - A remnant population of fewer than 100 seals was discovered and protected; the current population of 175,000 descended from those few seals and has virtually no genetic diversity
Original population → Bottlenecking event
Original population → Bottlenecking event → Surviving population
Genetic drift

- Genetic drift produces the **founder effect** when a few individuals **colonize a new habitat**
  - The smaller the group, the more different the gene pool of the new population will be from the gene pool of the original population
EFFECTS OF GENETIC DRIFT: A SUMMARY

1. Genetic drift is significant in small populations
2. Genetic drift causes allele frequencies to change at random
3. Genetic drift can lead to a loss of genetic variation within populations
4. Genetic drift can cause harmful alleles to become fixed
Gene flow consists of the movement of alleles among populations.

- Alleles can be transferred through the movement of fertile individuals or gametes (for example, pollen).
- Gene flow tends to reduce variation among populations over time.
Four moose were taken from the Canadian mainland to Newfoundland in 1904. These two males and two females rapidly formed a large population of moose that now flourishes in Newfoundland. Which mechanism is most likely to have contributed to the genetic differences between the mainland and Newfoundland moose?

- Gene flow
- **Founder effect**
- Novel mutations
The fossil remains of pygmy (or dwarf) mammoths (1.5 m to 2 m tall) have been found on Santa Rosa and San Miguel Islands off the coast of California. This population of pygmy mammoths is descended from a population of mammoths of normal size (4 m tall). Dwarfing is common in island populations and is not the result of chance events. What mechanism do you think best accounts for the decrease in mammoth size on these islands?

- Gene flow
- Genetic drift
- Natural selection
Adaptive Radiation is the emergence of new species.

An individual’s fitness is the contribution it makes to the gene pool of the next and subsequent generations.

The fittest individuals are those that pass on the most genes to the next generation.
NATURAL SELECTION CAN ALTER VARIATION IN A POPULATION IN 3 WAYS

- Stabilizing selection favors intermediate phenotypes, acting against extreme phenotypes.
- Stabilizing selection is very common, especially when environments are stable.
**Stabilizing selection**

- **Original population**
- **Evolved population**

**Directional selection**

- **Original population**
- **Evolved population**

**Disruptive selection**

- **Original population**
- **Evolved population**

**Phenotypes (fur color)**

- Stabilizing selection
- Directional selection
- Disruptive selection
NATURAL SELECTION CAN ALTER VARIATION IN A POPULATION IN 3 WAYS

- **Directional selection** acts against individuals at one of the phenotypic extremes. Common during:
  - Periods of *environmental change*
  - Population *migration* to a new and different habitat
Disruptive selection favors individuals at both extremes of the phenotypic range.
- This form of selection may occur in patchy habitats.
Disruptive Selection:

- When selection does not favor the most common variation within a population, leading to a favorable selection for extreme phenotypes.
SEXUAL SELECTION MAY LEAD TO PHENOTYPIC DIFFERENCES BETWEEN MALES AND FEMALES

- In many animal species, males and females show distinctly different appearance, called sexual dimorphism.
- Intrasetosexual competition involves competition for mates, usually by males.
SEXUAL SELECTION MAY LEAD TO PHENOTYPIC DIFFERENCES BETWEEN MALES AND FEMALES

In intersexual competition (or mate choice), individuals of one sex (usually females) are choosy in picking their mates, often selecting flashy or colorful mates.
THE PRESERVATION OF GENETIC VARIATION

- **Neutral variation** is genetic variation that does not confer a selective advantage or disadvantage
  - Various mechanisms help to preserve genetic variation in a population
DIPLOIDY

- Diploidy maintains genetic variation in the form of hidden recessive alleles.
- Heterozygotes can carry recessive alleles that are hidden from the effects of selection.
Balancing selection occurs when natural selection maintains stable frequencies of two or more phenotypic forms in a population.

Balancing selection includes:
- Heterozygote advantage
- Frequency-dependent selection
Heterozygote Advantage

- **Heterozygote advantage** occurs when heterozygotes have a higher fitness than do both homozygotes.
- Natural selection will tend to maintain two or more alleles at that locus.
- The sickle-cell allele causes mutations in hemoglobin but also confers malaria resistance.
Distribution of malaria caused by *Plasmodium falciparum* (a parasitic unicellular eukaryote)

**Key**

Frequencies of the sickle-cell allele

- 0–2.5%
- 2.5–5.0%
- 5.0–7.5%
- 7.5–10.0%
- 10.0–12.5%
- >12.5%

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Frequency-Dependent Selection

- In frequency-dependent selection, the fitness of a phenotype declines if it becomes too common in the population.
- Selection can favor whichever phenotype is less common in a population.
  - For example, frequency-dependent selection selects for approximately equal numbers of "right-mouthed" and "left-mouthed" scale-eating fish.
FIGURE 23.18

**“Left-mouthed”**
*P. microlepis*

**“Right-mouthed”**
*P. microlepis*

**Frequency of “left-mouthed” individuals**

<table>
<thead>
<tr>
<th>Sample year</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>0.6</td>
</tr>
<tr>
<td>1982</td>
<td>0.7</td>
</tr>
<tr>
<td>1983</td>
<td>0.5</td>
</tr>
<tr>
<td>1984</td>
<td>0.6</td>
</tr>
<tr>
<td>1985</td>
<td>0.7</td>
</tr>
<tr>
<td>1986</td>
<td>0.5</td>
</tr>
<tr>
<td>1987</td>
<td>0.6</td>
</tr>
<tr>
<td>1988</td>
<td>0.7</td>
</tr>
<tr>
<td>1989</td>
<td>0.5</td>
</tr>
<tr>
<td>1990</td>
<td>0.6</td>
</tr>
</tbody>
</table>
1. Describe Darwin’s concept of natural selection
2. Describe an example of natural selection known to occur in nature
3. Explain how the fossil record, biogeography, comparative anatomy, comparative embryology, and molecular biology support evolution
4. Explain how mutation and sexual recombination produce genetic variation
5. Describe the five conditions required for a population to be in Hardy-Weinberg equilibrium
YOU SHOULD NOW BE ABLE TO

6. Explain the significance of the Hardy-Weinberg equilibrium to natural populations and to public health science

7. Define genetic drift and gene flow

8. Explain why natural selection is the only mechanism that leads to adaptive evolution

9. Distinguish between stabilizing selection, directional selection, and disruptive selection, and describe an example of each
10. Distinguish between intrasexual selection and intersexual selection

11. Describe how antibiotic resistance has evolved

12. Explain how genetic variation is maintained in populations
Chapter 24

THE ORIGIN OF SPECIES
Speciation: One species splits from another. (emergence of a new species)

Microevolution: Change in allele frequency

Macroevolution: Broad change in an entire species over time

The Biological Species Concept defines a Species as: a group of populations whose members have the potential to interbreed in nature and produce viable, fertile offspring.
Reproductive isolation:
- Hybrids
- Prezygotic Barriers
- Postzygotic Barriers
REPRODUCTIVE ISOLATION

- **Reproductive isolation** is the existence of biological factors (barriers) that impede two species from producing viable, fertile offspring.

- **Hybrids** are the offspring of crosses between different species.

- Reproductive isolation can be classified by whether factors act before or after fertilization.
**REPRODUCTIVE ISOLATION**

- **Prezygotic barriers** block fertilization from occurring by:
  - Impeding different species from attempting to mate
  - Preventing the successful completion of mating
  - Hindering fertilization if mating is successful
Prezygotic barriers

- Habitat Isolation
- Temporal Isolation
- Behavioral Isolation
- Mechanical Isolation
- Gametic Isolation

Individuals of different species → Habitat Isolation → Temporal Isolation → Behavioral Isolation → Mechanical Isolation → Gametic Isolation → Fertilization

(a) (c) (e) (f) (g)
Postzygotic barriers prevent the hybrid zygote from developing into a viable, fertile adult:

- Reduced hybrid viability
- Reduced hybrid fertility
- Hybrid breakdown
Postzygotic barriers

Reduced Hybrid Viability  Reduced Hybrid Fertility  Hybrid Breakdown

FERTILIZATION ➔ VIABLE, FERTILE OFFSPRING

(h) (i) (j) (l)
Prezygotic barriers

- Habitat Isolation
- Temporal Isolation
- Behavioral Isolation
- Mechanical Isolation
- Gametic Isolation

Postzygotic barriers

- Reduced Hybrid Viability
- Reduced Hybrid Fertility
- Hybrid Breakdown

Individuals of different species attempt mating, but due to prezygotic barriers, fertilization is prevented. Once fertilization occurs, postzygotic barriers may still prevent viable, fertile offspring.
OTHER SPECIES CONCEPTS:

- Compare
  - Biological species concept
  - Morphological species concept
  - Ecological species concept
  - Phylogenetic species concept
LIMITATIONS OF THE BIOLOGICAL SPECIES CONCEPT

- The biological species concept cannot be applied to fossils or asexual organisms (including all prokaryotes).
- The biological species concept emphasizes absence of gene flow.
- However, gene flow can occur between distinct species.
  - For example, grizzly bears and polar bears can mate to produce “grolar bears”
Grizzly bear \((U.\ arctos)\)

Polar bear \((U.\ maritimus)\)

Hybrid “grolar bear”
OTHER DEFINITIONS OF SPECIES

- Other species concepts emphasize the unity within a species rather than the separateness of different species.

- The **morphological species concept** defines a species by structural features:
  - It applies to sexual and asexual species but relies on subjective criteria.
The ecological species concept views a species in terms of its ecological niche
- It applies to sexual and asexual species and emphasizes the role of disruptive selection

The phylogenetic species concept defines a species as the smallest group of individuals on a phylogenetic tree
- It applies to sexual and asexual species, but it can be difficult to determine the degree of difference required for separate species
SPECIATION OCCURS WITH AND WITHOUT GEOGRAPHIC SEPARATION

- **Allopatric** *(Other Country)* Speciation
- **Sympatric** *(Same County)* Speciation

- Polyploidy
- Autoploidy
- Allopolyploid
(a) Allopatric speciation. A population forms a new species while geographically isolated from its parent population.

(b) Sympatric speciation. A subset of a population forms a new species without geographic separation.
In allopatric speciation, gene flow is interrupted or reduced when a population is divided into geographically isolated subpopulations.

For example, the flightless cormorant of the Galápagos likely originated from a flying species on the mainland.
SYMPATRIC ("SAME COUNTRY") SPECIATION

In sympatric speciation, speciation takes place in geographically overlapping populations.
Polyploidy is the presence of extra sets of chromosomes due to accidents during cell division.

Polyploidy is much more common in plants than in animals.

An autopolyploid is an individual with more than two chromosome sets, derived from one species.
An **allopolyploid** is a species with multiple sets of chromosomes derived from different species.
Species A
$2n = 6$

Normal gamete
$n = 3$

Species B
$2n = 4$

Meiotic error; chromosome number not reduced from $2n$ to $n$

Unreduced gamete with 4 chromosomes
Species A  
$2n = 6$

Species B  
$2n = 4$

Meiotic error; chromosome number not reduced from $2n$ to $n$

Normal gamete  
$n = 3$

Unreduced gamete with 4 chromosomes

Hybrid with 7 chromosomes
Species A
2n = 6

Species B
2n = 4

Meiotic error; chromosome number not reduced from 2n to n

Unreduced gamete with 4 chromosomes

Hybrid with 7 chromosomes

Normal gamete
n = 3

Normal gamete
n = 3

Unreduced gamete with 7 chromosomes

Normal gamete
n = 3
Species A
$2n = 6$

Species B
$2n = 4$

Normal gamete
$n = 3$

Meiotic error; chromosome number not reduced from $2n$ to $n$

Unreduced gamete with 4 chromosomes

Hybrid with 7 chromosomes

Unreduced gamete with 7 chromosomes

Normal gamete
$n = 3$

New species: viable fertile hybrid (allopolyploid) $2n = 10$
Many important crops (oats, cotton, potatoes, tobacco, and wheat) are polyploids.
Sympatric speciation can also result from the appearance of new ecological niches.
Sexual selection can drive sympatric speciation.

Sexual selection for mates of different colors has likely contributed to speciation in cichlid fish in Lake Victoria.
EXPERIMENT

Normal light

Monochromatic orange light

*P. pundamilia*

*P. nyererei*
In allopatric speciation, geographic isolation restricts gene flow between populations.

- Reproductive isolation may then arise by natural selection, genetic drift, or sexual selection in the isolated populations.
- Even if contact is restored between populations, interbreeding is prevented.
In sympatric speciation, a reproductive barrier isolates a subset of a population without geographic separation from the parent species.

Sympatric speciation can result from polyploidy, natural selection, or sexual selection.
A hybrid zone is a region in which members of different species mate and produce hybrids.

- Hybrids are the result of mating between species with incomplete reproductive barriers.
A hybrid zone can occur in a single band where adjacent species meet.

For example, two species of toad in the genus *Bombina* interbreed in a long and narrow hybrid zone.
EUROPE

Yellow-bellied toad, *Bombina variegata*

Fire-bellied toad range

Hybrid zone

Yellow-bellied toad range

Fire-bellied toad, *Bombina bombina*

Distance from hybrid zone center (km)

Frequency of *B. variegata*-specific allele

0.99

0.9

0.5

0.1

0.01

40

30

20

10

0

10

20

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Hybrids often have reduced fitness compared with parent species.

The distribution of hybrid zones can be more complex if parent species are found in patches within the same region.
When closely related species meet in a hybrid zone, there are three possible outcomes:

- Reinforcement
- Fusion
- Stability
Gene flow

Population

Barrier to gene flow

Isolated population diverges

Hybrid zone

Hybrid individual

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Gene flow

Population

Barrier to gene flow

Isolated population diverges

Hybrid zone

Hybrid individual

Possible outcomes:

- Reinforcement
- Fusion
- Stability

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The **reinforcement** of barriers occurs when hybrids are less fit than the parent species.

Over time, the rate of hybridization decreases.

Where reinforcement occurs, reproductive barriers should be stronger for sympatric than allopatric species.

- For example, in populations of flycatchers, males are more similar in allopatric populations than sympatric populations.
Females choosing between these males:

<table>
<thead>
<tr>
<th></th>
<th>Own species</th>
<th>Other species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sympatric pied male</td>
<td>28</td>
<td>(none)</td>
</tr>
<tr>
<td>Sympatric collared male</td>
<td>24</td>
<td></td>
</tr>
</tbody>
</table>

Females choosing between these males:

<table>
<thead>
<tr>
<th></th>
<th>Own species</th>
<th>Other species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allopatric pied male</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Allopatric collared male</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

Number of females: 28, 24, 20, 16, 12, 8, 4, 0
FUSION: WEAKENING REPRODUCTIVE BARRIERS

- If hybrids are as fit as parents, there can be substantial gene flow between species.
- If gene flow is great enough, the parent species can fuse into a single species.
- For example, researchers think that pollution in Lake Victoria has reduced the ability of female cichlids to distinguish males of different species.
- This might be causing the fusion of many species.
Pundamilia nyererei

Pundamilia pundamilia

Pundamilia “turbid water,” hybrid offspring from a location with turbid water
STABILITY: CONTINUED FORMATION OF HYBRID INDIVIDUALS

- Extensive gene flow from outside the hybrid zone can overwhelm selection for increased reproductive isolation inside the hybrid zone.
Broad patterns in speciation can be studied using the fossil record, morphological data, or molecular data.
The fossil record includes examples of species that appear suddenly, persist essentially unchanged for some time, and then apparently disappear.

**Punctuated equilibria**: describes periods of apparent stasis punctuated by sudden change.

The punctuated equilibrium model contrasts with a model of gradual change in a species’ existence.
(a) Punctuated pattern

(b) Gradual pattern
The punctuated pattern in the fossil record and evidence from lab studies suggest that speciation can be rapid. For example, the sunflower *Helianthus anomalus* originated from the hybridization of two other sunflower species.
EXPERIMENT

H. annuus gamete

H. petiolarus gamete

F₁ experimental hybrid (4 of the 2n = 34 chromosomes are shown)

RESULTS

H. anomalus

Chromosome 1

Experimental hybrid

H. anomalus

Chromosome 2

Experimental hybrid
The interval between speciation events can range from 4,000 years (some cichlids) to 40 million years (some beetles), with an average of 6.5 million years.
A fundamental question of evolutionary biology persists: **How many genes change when a new species forms?**

Depending on the species in question, speciation might require the change of only a single allele or many alleles.

- For example, in Japanese *Euhadra* snails, the direction of shell spiral affects mating and is controlled by a single gene.
In monkey flowers (*Mimulus*), two loci affect flower color, which influences pollinator preference.

Pollination that is dominated by either hummingbirds or bees can lead to reproductive isolation of the flowers.

In other species, speciation can be influenced by larger numbers of genes and gene interactions.
Typical *Mimulus lewisii* (a)

*M. lewisii* with an *M. cardinalis* flower-color allele (b)

Typical *Mimulus cardinalis* (c)

*M. cardinalis* with an *M. lewisii* flower-color allele (d)
FROM SPECIATION TO MACROEVOLUTION

- Macroevolution is the cumulative effect of many speciation and extinction events.