• The number of bacteria in one human’s mouth is greater than the total number of people who ever lived

• Each year more than 200 million people become infected with malaria.

• Bacterial fermentation is used to produce cheese, yogurt, buttermilk, and many types of sausage

• More than half of our antibiotics come from soil bacteria of the genus *Streptomyces.*
During the fall of 2001, five Americans died from the disease anthrax in a presumed terrorist attack.

Animals, plants, fungi, and viruses have all served as weapons, but the most frequently employed biowarfare agents have been bacteria. History provides many examples of the use of biological agents as weapons:

- The practical difficulties of controlling such weapons—and a measure of ethical repugnance—led the United States to end its bioweapons program in 1969 and to destroy its products.
- Although not all signatories have honored it, 103 nations have signed the Biological Weapons Convention, pledging never to develop or store biological weapons.

Not all bacteria are harmful to humans:

- Nearly all life on Earth depends on bacteria and other microbial life in one way or another.
MAJOR EPISODES IN THE HISTORY OF LIFE

• Earth was born 4.5 billion years ago.

• Prokaryotes
  – Appeared about 3.5 billion years ago

• Oxygen production
  – Began about 2.5 billion years ago

• Single-celled eukaryotic organisms
  – Evolved about 1.7 billion years ago.

• Multicellular eukaryotes
  – Evolved about 1 billion years ago

• All the major phyla of animals
  – Evolved by the end of the Cambrian explosion, which began about 570 million years ago

• About 475 million years ago
  – Plants and fungi colonized land
  – Amphibians evolved from fish, and vertebrate life moved onto land.
Some major episodes in the history of life.

- First humans
- Extinction of dinosaurs
- Plants and symbiotic fungi colonize land
- Oldest animal fossils
- Origin of multicellular organisms
- Oldest eukaryotic fossils
- Accumulation of atmospheric oxygen by photosynthetic prokaryotes
- Earth cool enough for water to exist in liquid form
- Origin of Earth

THE ORIGIN OF LIFE

- We may never know how life began on Earth.
Resolving the Biogenesis Paradox

• All life today arises by the reproduction of preexisting life, or biogenesis.

Most biologists now think it is possible that chemical and physical processes on the early Earth produced simple cells.

A Four-Stage Hypothesis for the Origin of Life

• According to one hypothetical scenario, the first organisms were products of chemical evolution in four stages.
Stage 1: Abiotic Synthesis of Organic Monomers

- Stanley Miller
  - Devised an experiment that produced small organic molecules in 1953.

Stage 2: Abiotic Synthesis of Polymers

- Researchers have observed polymerization of organic monomers in various situations.

Stage 3: Origin of Self-Replicating Molecules

- Laboratory experiments have shown that short RNA molecules can assemble spontaneously.
Stage 4: Formation of Pre-Cells

- The properties of life emerge from an interaction of molecules organized into higher levels of order.

Laboratory experiments demonstrate that pre-cells could have formed spontaneously from abiotically produced organic compounds.

From Chemical Evolution to Darwinian Evolution

- Over millions of years
  - Natural selection favored the most efficient pre-cells
  - The first prokaryotic cells evolved.
Prokaryotes

- Prokaryotes
  - Lived and evolved all alone on Earth for 2 billion years.

They're Everywhere!

- Prokaryotes
  - Are found wherever there is life
  - Outnumber all eukaryotes combined
  - Can cause disease
  - Can be beneficial.

The Two Main Branches of Prokaryotic Evolution: Bacteria and Archaea

- The majority of prokaryotes are bacteria.
Some archaea are “extremophiles”
- Extreme halophiles thrive in salty environments.

Extreme thermophiles
- Inhabit very hot water

Methanogens
- Inhabit the bottoms of lakes and swamps.

The Structure, Function, and Reproduction of Prokaryotes

Prokaryotic cells
- Lack nuclei
- Lack other membrane-enclosed organelles
- Have cell walls exterior to their plasma membranes.
• Prokaryotes come in several shapes
  – Cocci
  – Bacilli
  – Spirochetes.

• Most prokaryotes are unicellular and very small.

• Some prokaryotes
  – Form true colonies
  – Show specialization of cells
  – Are very large.
• About half of all prokaryotes are motile, using flagella.

• Some prokaryotes
  – Can survive extended periods of very harsh conditions
  – Form endospores.

• Most prokaryotes can reproduce by binary fission at very high rates if conditions are favorable.
The Nutritional Diversity of Prokaryotes

Prokaryotes exhibit four major modes of nutrition.

<table>
<thead>
<tr>
<th>Nutritional Type</th>
<th>Energy Source</th>
<th>Carbon Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photoautotroph (photosynthesis)</td>
<td>Sunlight</td>
<td>CO₂</td>
</tr>
<tr>
<td>Chemoautotroph</td>
<td>Inorganic chemicals</td>
<td>CO₂</td>
</tr>
<tr>
<td>Photoheterotroph</td>
<td>Sunlight</td>
<td>Organic compounds</td>
</tr>
<tr>
<td>Chemoheterotroph</td>
<td>Organic compounds</td>
<td>Organic compounds</td>
</tr>
</tbody>
</table>

- **Photoautotrophs**
  - Are photosynthetic organisms
  - Include the cyanobacteria
- **Chemoautotrophs**
  - Need CO₂ as a carbon source
  - Extract energy from inorganic substances.

- **Photoheterotrophs**
  - Use light to generate ATP
  - Must obtain their carbon in organic form
- **Chemoheterotrophs**
  - Must consume organic molecules for both energy and carbon.
The Ecological Impact of Prokaryotes

- Prokaryotes
  - Have a major impact on the Earth and its inhabitants.

Bacteria That Cause Disease

- Pathogens
  - Are bacteria and other microorganisms that cause disease.

- Most pathogenic bacteria
  - Cause disease by producing poisons

- Exotoxins
  - Are poisonous proteins secreted by bacterial cells

- Endotoxins
  - Are chemical components of the cell walls of certain bacteria.
The best defenses against bacterial disease are
- Sanitation
- Antibiotics
- Education.

Lyme disease
- Is caused by bacteria carried by ticks.

Prokaryotes and Chemical Recycling
- Prokaryotes play essential roles
  - In chemical cycles in the environment
  - In the breakdown of organic wastes and dead organisms.
Bioremediation is the use of organisms to remove pollutants from water, air, and soil

- A familiar example is use of prokaryotic decomposers in sewage treatment.

Certain bacteria can decompose petroleum and are useful in cleaning up oil spills.
**PROTISTS**

- Protists
  - Are eukaryotic
  - Evolved from prokaryotes.

---

**The Origin of Eukaryotic Cells**

- Eukaryotic cells evolved through the combination of two processes.

---

- In one process, the eukaryotic cell’s endomembrane system evolved from inward folds of the plasma membrane of a prokaryotic cell.

![Image of cell structure](image_url)
• The second process, endosymbiosis, generated mitochondria and chloroplasts.

The Diversity of Protists

• All protists are eukaryotes
  – Most are unicellular.

Protozoans

• Protozoans
  – Live primarily by ingesting food.
• Protozoans include
  – Flagellates, with flagella.

  ![Trypanosomes (Flagellates)](Image)

  Figure 15.19a

• Amoebas, with pseudopodia

  ![An amoeba ingesting food](Image)

  Figure 15.19b

• Forams.

  ![A foram](Image)

  Figure 15.19c

• Apicomplexans

  ![An apicomplexan: Plasmodium](Image)

  Figure 15.19d

• Ciliates, with cilia.

  ![Paramecium](Image)

  Figure 15.19e
**Slime Molds**

- Slime molds
  - Resemble fungi in appearance and lifestyle.

- Plasmodial slime molds
  - Can be large.

- Cellular slime molds
  - Have an interesting and complex life cycle.
Unicellular Algae

- Algae
  - Are photosynthetic protists
  - Are found in plankton.

- Unicellular algae include
  - Dinoflagellates, components of phytoplankton
  - Diatoms, which have glassy walls.
- Green algae, unicellular and colonial.

Seaweeds
- Seaweeds
  - Are large, multicellular marine algae
  - Grow on rocky shores and just offshore
  - Are often edible.

- The three major groups of seaweeds.
EVOLUTION CONNECTION:
THE ORIGIN OF MULTICELLULAR LIFE

- Multicellular organisms
  - Are different from unicellular ones
  - Have specialized cells.

The evolutionary links between unicellular and multicellular organisms were probably colonial protists.

SUMMARY OF KEY CONCEPTS

- Major Episodes in the History of Life.

<table>
<thead>
<tr>
<th>Millions of years ago</th>
<th>Major Episode</th>
</tr>
</thead>
<tbody>
<tr>
<td>475</td>
<td>Plants and fungi colonize land</td>
</tr>
<tr>
<td>570</td>
<td>All major animal phyla established</td>
</tr>
<tr>
<td>1,000</td>
<td>First multicellular organisms</td>
</tr>
<tr>
<td>1,700</td>
<td>Oldest eukaryotic fossils</td>
</tr>
<tr>
<td>2,500</td>
<td>Accumulation of atmospheric $O_2$</td>
</tr>
<tr>
<td>3,500</td>
<td>Oldest prokaryotic fossils</td>
</tr>
<tr>
<td>4,500</td>
<td>Origin of Earth</td>
</tr>
</tbody>
</table>
• A Four-Stage Hypothesis for the Origin of Life.

1. Abiotic synthesis
2. Polymerization
3. Self-replication
4. Packaging

Membrane-enclosed compartment

• The Two Main Branches of Prokaryotic Evolution: Bacteria and Archaea.

Prokaryotes

Domain Bacteria

Domain Archaea (e.g., extremophiles)

• The Nutritional Diversity of Prokaryotes.

<table>
<thead>
<tr>
<th>Nutritional Mode</th>
<th>Energy Source</th>
<th>Carbon Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photoautotroph</td>
<td>Sunlight</td>
<td>CO₂</td>
</tr>
<tr>
<td>Chemoautotroph</td>
<td>Inorganic chemicals</td>
<td></td>
</tr>
<tr>
<td>Phototroph</td>
<td>Sunlight</td>
<td>Organic compounds</td>
</tr>
<tr>
<td>Chemoheterotroph</td>
<td>Organic compounds</td>
<td></td>
</tr>
</tbody>
</table>