Chapter 26.
Origin of Life
The history tree of life can be documented with evidence as already discussed.

The Origin of Life on Earth is another story
Origin of Life hypothesis

- Abiotic synthesis of organic molecules
  - amino acids & nucleotides

- Building polymers
  - joining molecules into polymers
  - proteins & nucleic acids

- Protobions
  - packaging polymers into membrane-bound droplets
  - maintain internal chemistry

- Origin of self-replicating molecules
  - makes inheritance possible
Conditions on early Earth

- Reducing atmosphere
  - electron-adding
  - water vapor, CO\textsubscript{2}, nitrogen, NO\textsubscript{x}, CH\textsubscript{4}, NH\textsubscript{3}, H\textsubscript{2}, H\textsubscript{2}S

- Energy source
  - lightning, UV radiation, volcanic
Abiotic synthesis

- **Testable hypothesis**
  - **1920**
    Oparin & Haldane propose reducing environment hypothesis
  - **1953**
    Miller & Urey test the hypothesis
It is unclear whether young Earth’s atmosphere contained enough methane and ammonia to be reducing. Growing evidence suggests that the early atmosphere was made up primarily of nitrogen and carbon dioxide and was neither reducing nor oxidizing (electron–removing). Miller–Urey–type experiments using such atmospheres have not produced organic molecules. Still, it is likely that small “pockets” of the early atmosphere—perhaps near volcanic openings—were reducing.

Instead of forming in the atmosphere, the first organic compounds on Earth may have been synthesized near submerged volcanoes and deep–sea vents—weak points in Earth’s crust where hot water and minerals gush into the ocean.
Life is defined partly by two properties: accurate replication and metabolism. Neither property can exist without the other. Self–replicating molecules and a metabolism–like source of the building blocks must have appeared together. How did that happen?

The necessary conditions for life may have been met by protobionts, aggregates of abiotically produced molecules surrounded by a membrane or membrane–like structure. Protobionts exhibit some of the properties associated with life, including simple reproduction and metabolism, as well as the maintenance of an internal chemical environment different from that of their surroundings.

Laboratory experiments demonstrate that protobionts could have formed spontaneously from abiotically produced organic compounds. For example, small membrane–bounded droplets called liposomes can form when lipids or other organic molecules are added to water.
RNA world

■ RNA is likely first genetic material
  ◆ multi-functional molecule
  ◆ codes information
  ◆ enzyme functions
    ▪ ribozymes
    ▪ replication
  ◆ regulatory molecule
  ◆ transport molecule

Dawn of natural selection

Why RNA?
RNA molecules are important catalysts in modern cells. Modern cells use RNA catalysts, called ribozymes, to remove introns from RNA. Ribozymes also help catalyze the synthesis of new RNA, notably rRNA, tRNA, and mRNA. Thus, RNA is autocatalytic, and in the prebiotic world, before there were enzymes (proteins) or DNA, RNA molecules may have been fully capable of ribozyme-catalyzed replication.
Key Events in Origin of Life

- Key events in evolutionary history of life on Earth
  - life originated 3.5–4.0 bya
Prokaryotes

Prokaryotes dominated life on Earth from 3.5–2.0 bya

3.5 billion year old fossil of bacteria

modern bacteria

Electron Transport Systems

The chemiosmotic mechanism of ATP synthesis, in which a complex set of membrane-bound proteins pass electrons to reducible electron acceptors with the generation of ATP from ADP, is common to all three domains of life—Bacteria, Archaea, and Eukarya. There is strong evidence that this electron transport mechanism actually originated in organisms that lived before the last common ancestor of all present-day life. The earliest of these electron transport systems likely evolved before there was any free oxygen in the environment and before the appearance of photosynthesis; the organisms that used it would have required a plentiful supply of energy-rich compounds such as molecular hydrogen, methane, and hydrogen sulfide. A great challenge facing scientists studying the origin of life is to determine the steps by which this electron transport mechanism originated, and how important early versions of it might have been in the emergence of the first cells.

So considerable metabolic diversity among prokaryotes living in various environments had already evolved more than 3 billion years ago. Most subsequent evolution has been more structural than metabolic.
Stromatolites
fossilized mats of prokaryotes resemble modern microbial colonies

Lynn Margulis
Oxygen atmosphere

- Oxygen begins to accumulate 2.7 bya
  - photosynthetic bacteria
    - cyanobacteria (blue-green algae)
  - reducing → oxidizing atmosphere
    - corrosive
      - banded iron in rocks = rusting
Endosymbiosis

- Evolution of eukaryotes
  - membrane bound organelles = 2.1 bya
Cambrian explosion

- **543 mya**
  - within 10–20 million years most of the major phyla of animals appear in fossil record
CAMBRIAN EXPLOSION was characterized by the sudden and roughly simultaneous appearance of many diverse animals from almost life within 30 million years ago. No other period in the history of animal life can match this remarkable burst of evolutionary activity. These early animal creatures, shown here, were some species extracted from fossils by Simon Conway Morris and Henry Wittingham of the University of Cambridge.
Diversity of life and periods of mass extinction. The fossil record of terrestrial and marine organisms reveals a general increase in the diversity of organisms over time (red line and right vertical axis). Mass extinctions, represented by peaks in the extinction rate (blue line and left vertical axis) interrupted the buildup of diversity. The extinction rate is the estimated percentage of extant taxonomic families that died out in each period of geologic time.

The fossil record chronicles a number of occasions when global environmental changes were so rapid and disruptive that a majority of species were swept away. Such mass extinctions are known primarily from the decimation of hard-bodied animals that lived in shallow seas, the organisms for which the fossil record is most complete. Two mass extinctions—the Permian and the Cretaceous—have received the most attention. The Permian mass extinction, which defines the boundary between the Paleozoic and Mesozoic eras, claimed about 96% of marine animal species. Terrestrial life was also affected. For example, 8 out of 27 orders of insects were wiped out. This mass extinction occurred in less than 5 million years, possibly much less—an instant in the context of geologic time. The Cretaceous mass extinction of 65 million years ago, which marks the boundary between the Mesozoic and Cenozoic eras, doomed more than half of all marine species and exterminated many families of terrestrial plants and animals, including most of the dinosaurs.
The Chicxulub impact crater in the Caribbean Sea near the Yucatan Peninsula of Mexico indicates an asteroid or comet struck the earth and changed conditions 65 million years ago.

Trauma for Earth and its Cretaceous life.

One clue to a possible cause of the Cretaceous mass extinction is a thin layer of clay enriched in iridium that separates sediments from the Mesozoic and Cenozoic eras. Iridium is an element very rare on Earth but common in many of the meteorites and other extraterrestrial objects that occasionally fall to Earth. Walter and Luis Alvarez and their colleagues at the University of California proposed that this clay is fallout from a huge cloud of debris that billowed into the atmosphere when an asteroid or a large comet collided with Earth. This cloud would have blocked sunlight and severely disturbed the global climate for several months.

Where did the asteroid or comet hit? Research has focused on the Chicxulub crater. The 65–million–year–old Chicxulub impact crater is located in the Caribbean Sea near the Yucatán Peninsula of Mexico. The horseshoe shape of the crater and the pattern of debris in sedimentary rocks indicate that an asteroid or comet struck at a low angle from the southeast. This artist’s interpretation represents the impact and its immediate effect—a cloud of hot vapor and debris that could have killed most of the plants and animals in North America within hours. About 180 km in diameter, the crater is the right size to have been caused by an object with a diameter of 10 km.
Classification

- Linnaeus used structural similarity
- 1969
  Robert Whittaker devised 5 Kingdom system
  - Monera
  - Protista
  - Plantae
  - Fungi
  - Animalia
Re-Classifying Life

- **New groupings**
  - molecular data challenges 5 Kingdoms
  - Monera is too diverse
    - 2 distinct lineages of prokaryotes
  - Protists are too diverse

(a) The five-kingdom system

(b) The three-domain system

(c) How many kingdoms?
3 Domain system

- **Super Kingdoms**
  - Bacteria
  - Archaea
    - extremophiles = live in extreme environments
  - Eukarya
    - eukaryotes
A New Tree of Life

1. Last common ancestor of all living things
2. Possible fusion of bacterium and archaeon, yielding ancestor of eukaryotic cells
3. Symbiosis of mitochondrial ancestor with ancestor of eukaryotes
4. Symbiosis of chloroplast, ancestor with ancestor of green plants