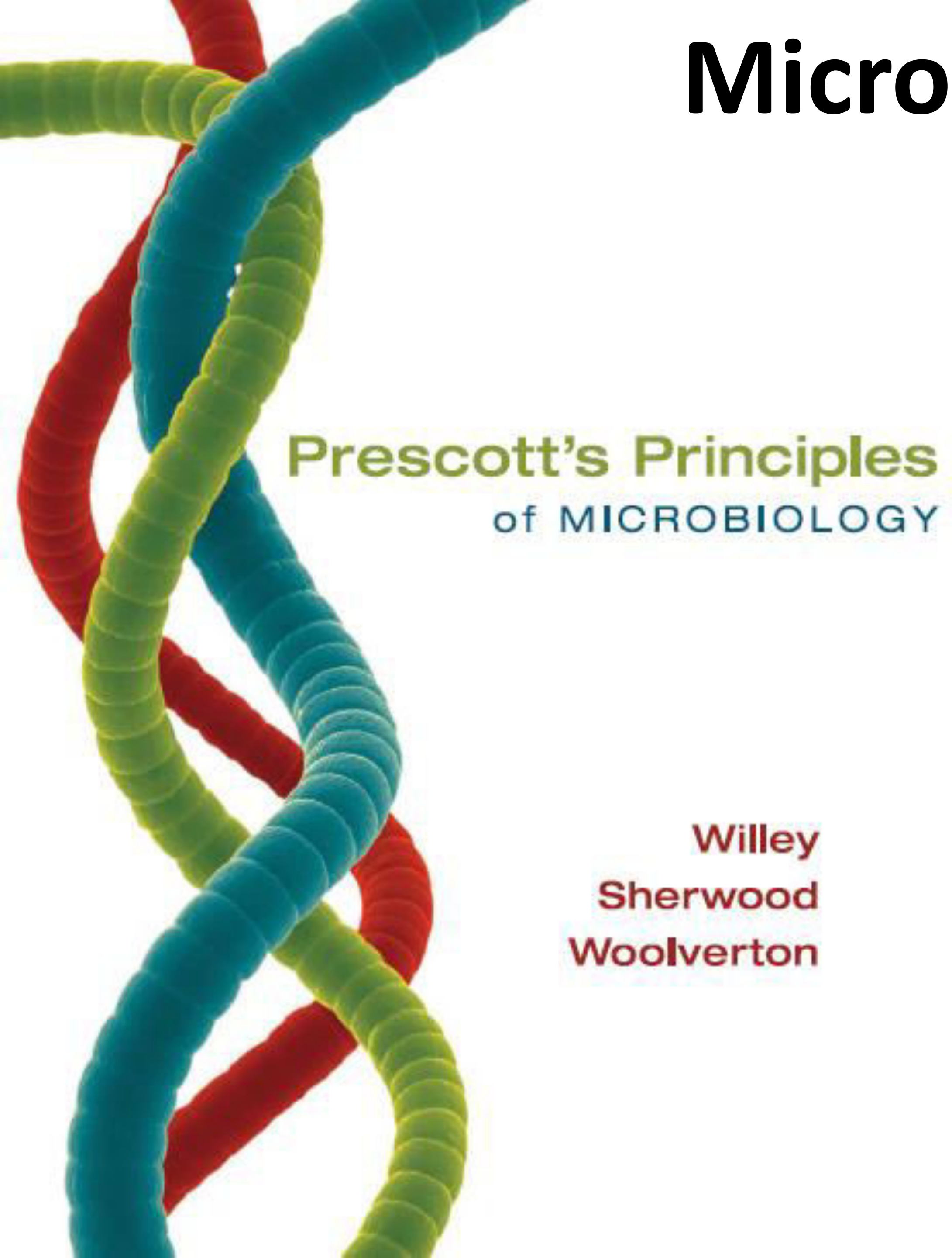
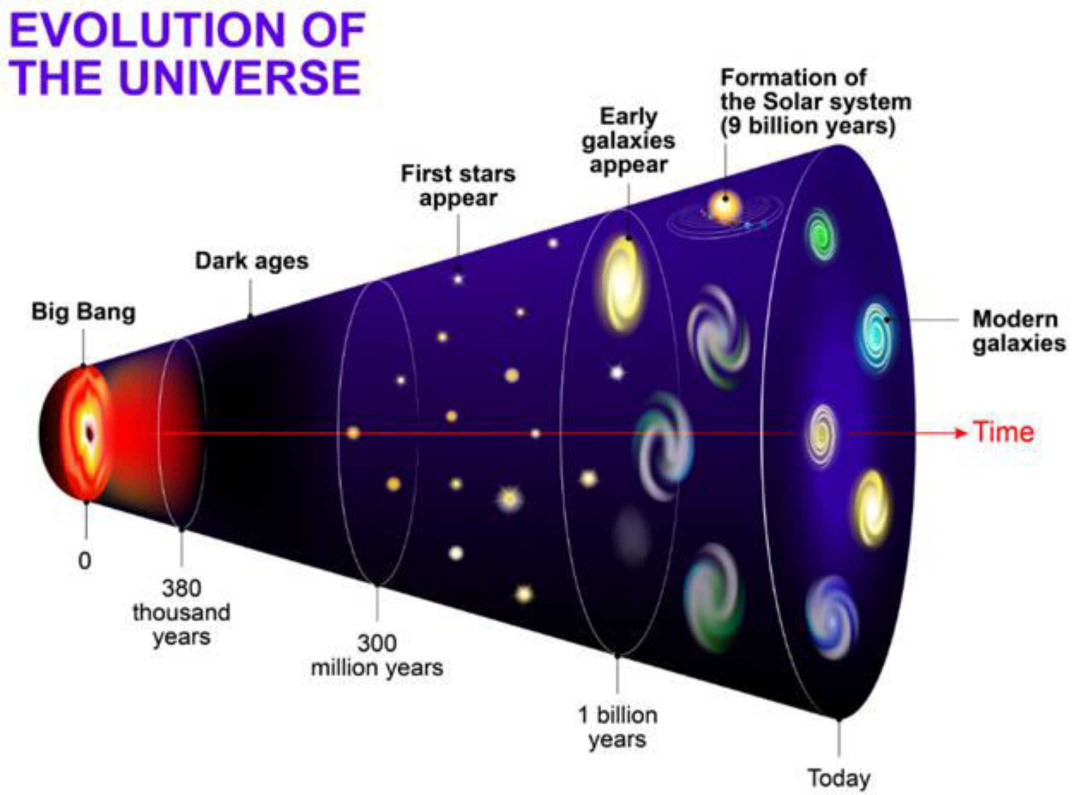
Microbial evolution



Dr. Akhilendra Pratap Bharati
Assistant Professor
Department of Life Science and Biotechnology



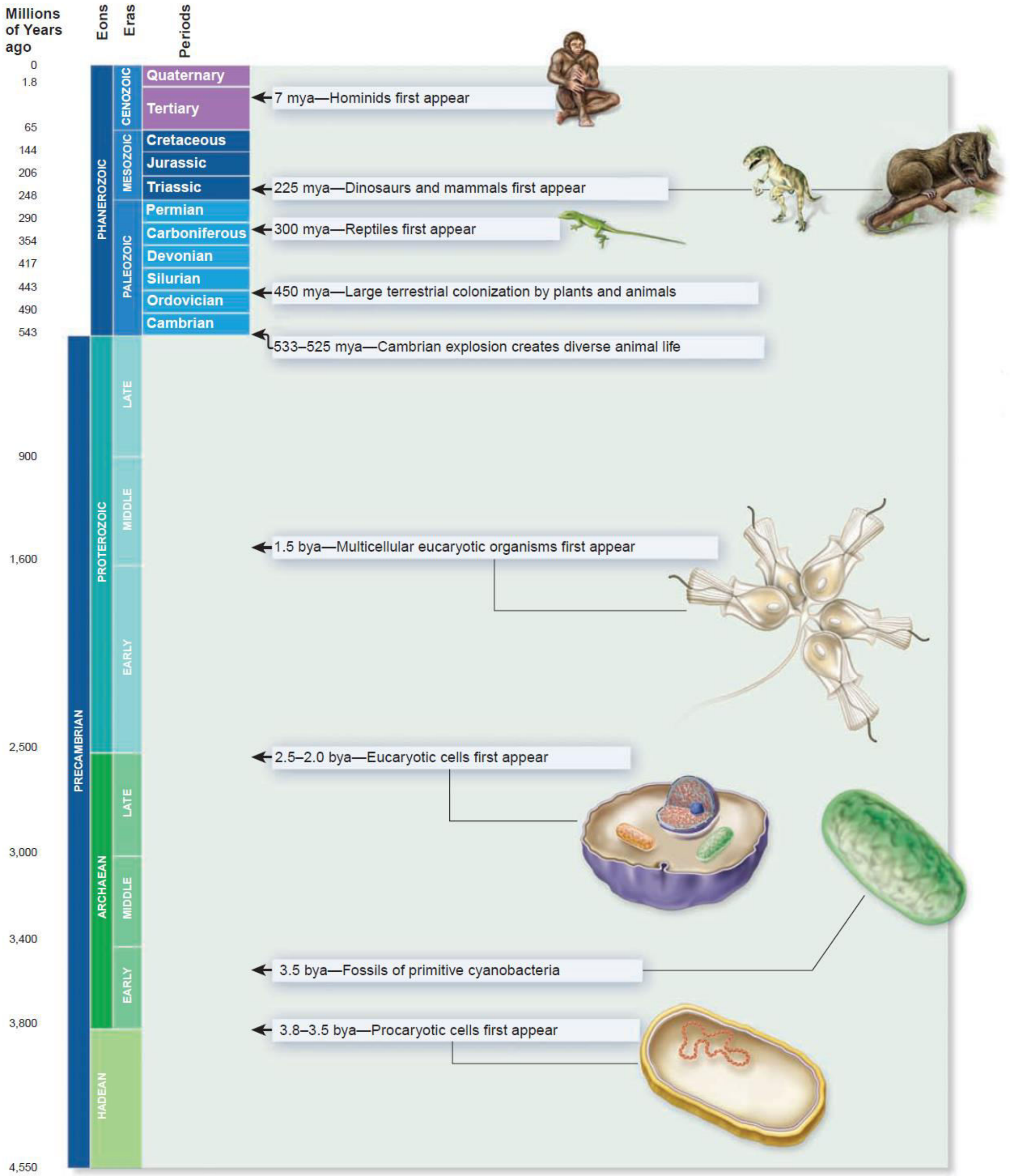


Figure 17.1 The Geological Timescale and an Overview of the History of Life on Earth. mya = million years ago; bya = billion years ago.

First Self-Replicating Entity: The RNA World hypothesis

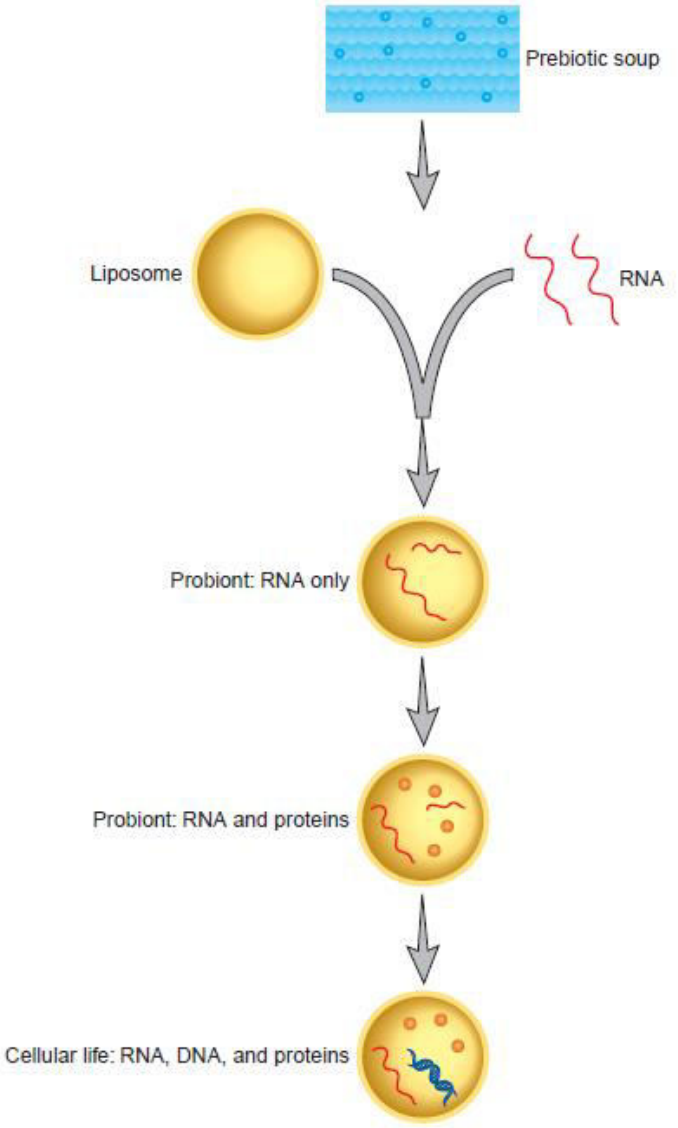


Figure 17.2 The RNA World Hypothesis for the Origin of Life.

- For life to evolve, a molecule was needed that could both replicate and perform work.
- An additional requirement for early cellular life was the development of a lipid membrane.

- When Earth was formed it was hot and anoxic, with an atmosphere rich in gases hydrogen, methane, carbon dioxide, nitrogen, and ammonia.
- For life to evolve, a molecule was needed that could both replicate and perform work. Proteins are capable of performing cellular work but cannot replicate, while just the opposite is true of DNA.
- A possible solution to this problem was suggested in 1981 when **Thomas Cech** discovered **self-splicing RNA** in the protist **Tetrahymena**.
- Three years later, **Sidney Altman** found that **RNaseP** in *Escherichia coli* is an RNA molecule that cleaves phosphodiester bonds.
- In this version of early life, various forms of molecules were assembled and destroyed over roughly half a billion years, until ultimately an entity, or **probiont**, something like modern RNA enclosed in a lipid vesicle was generated

Skeptical of the RNA world hypothesis

- Earth 4 billion years ago would have prevented the stable formation of ribose, phosphate, purines, and pyrimidines all needed to construct RNA.
- In fact purine bases have been generated abiotically in a heated mixture of hydrogen cyanide and ammonia, but unable to synthesize pyrimidines.
- Another problem with the RNA world hypothesis is the instability of RNA.
- In 1996 **James Ferris** and colleagues were able to overcome the problem of RNA degradation by adding the **clay mineral montmorillonite** to a solution of chemically charged nucleotides. They showed that the rate of RNA synthesis was faster than its degradation.
- Later it was shown that amino acids in solution with the minerals **hydroxyapatite and illite** could also polymerize into polypeptides of about 50 amino acid residues.

- However, one additional problem with the RNA world hypothesis concerns the ability of early RNA to **self-replicate**.

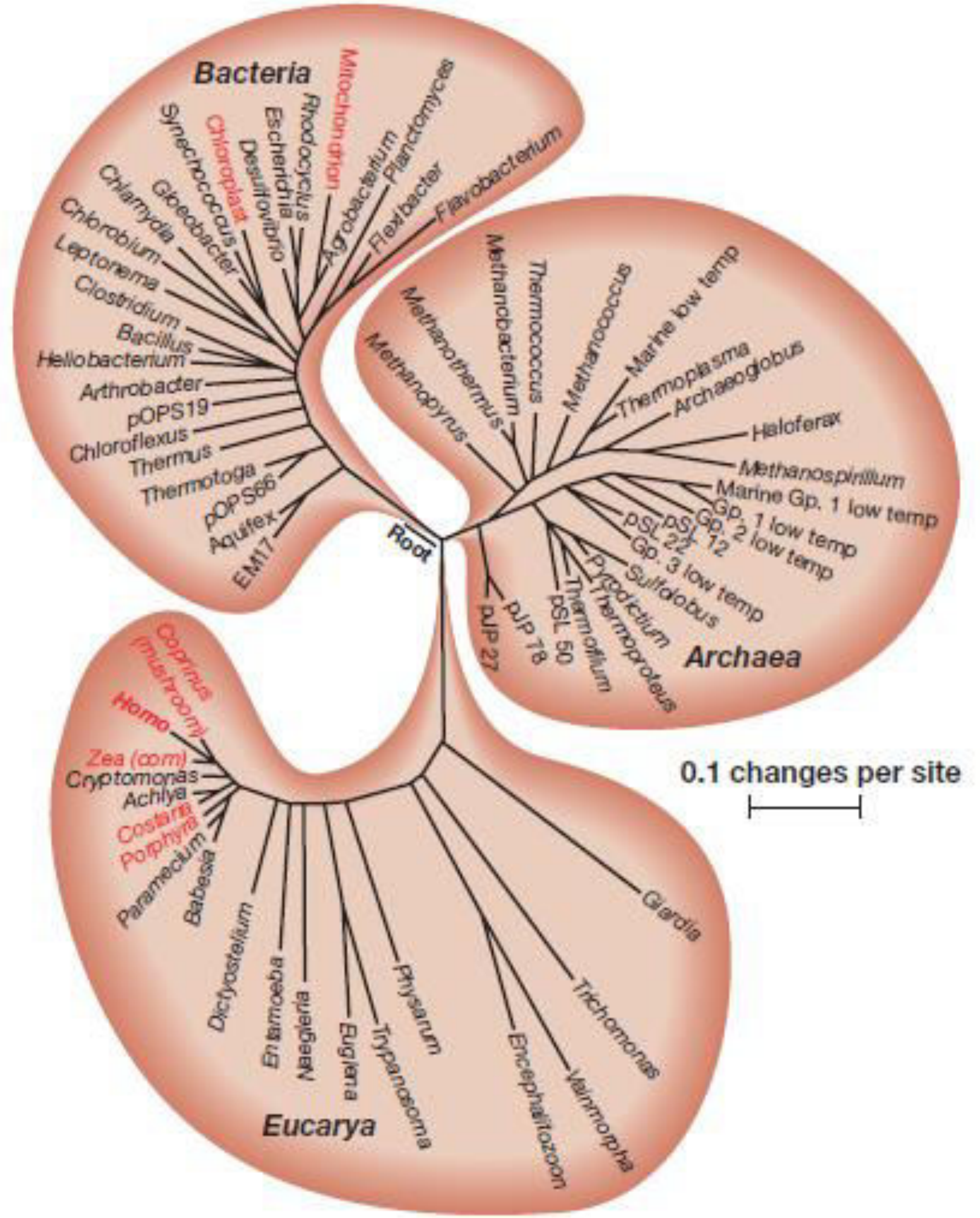
- Thus although it is clear that microbial life ultimately emerged from a random mixture of chemicals, the actual mechanism by which the first cell-like entity arose is a controversy that may never be resolved

Three Domains of Life

The most important sequence-based investigation was initiated in 1977 by **Carl Woese** and his collaborator **George Fox**. They compared the **small subunit ribosomal RNAs (SSU rRNAs)** from a variety of organisms to determine that all living organisms belong to one of **three domains**:

- Archaea
- Bacteria
- Eucarya

- **Close to the center is a line labeled "Root." This is where the data indicate the last common ancestor to all three domains should be placed.**



proposed by **Norman Pace**

Figure 17.4 Universal Phylogenetic Tree. These evolutionary relationships are based on rRNA sequence comparisons. Length of branches indicates evolutionary relationships between organisms but not time. Microbes are printed in black.

Table 17.1 Comparison of *Bacteria*, *Archaea*, and *Eucarya*

Property	*Bacteria*	*Archaea*	*Eucarya*
Membrane-Enclosed Nucleus with Nucleolus	Absent	Absent	Present
Complex Internal Membranous Organelles	Absent	Absent	Present
Cell Wall	Almost always have peptidoglycan containing muramic acid	Variety of types, no muramic acid; some have pseudomurein	No muramic acid
Membrane Lipid	Have ester-linked, straight-chained fatty acids	Have ether-linked, branched aliphatic chains	Have ester-linked, straight-chained fatty acids
Gas Vesicles	Present	Present	Absent
Transfer RNA	Thymine present in most tRNAs *N*-formylmethionine carried by initiator tRNA	No thymine in T or TΨC arm of tRNA Methionine carried by initiator tRNA	Thymine present Methionine carried by initiator tRNA
Polycistronic mRNA	Present	Present	Absent
mRNA Introns	Absent	Absent	Present
mRNA Splicing, Capping, and Poly A Tailing	Absent	Absent	Present

Ribosomes			
Size	70S	70S	80S (cytoplasmic ribosomes)
Elongation factor 2 reaction with diphtheria toxin	Does not react	Reacts	Reacts
Sensitivity to chloramphenicol and kanamycin	Sensitive	Insensitive	Insensitive
Sensitivity to anisomycin	Insensitive	Sensitive	Sensitive
DNA-Dependent RNA Polymerase			
Number of enzymes	One	One	Three
Structure	Simple subunit pattern (6 subunits)	Complex subunit pattern similar to eucaryotic enzymes (8–12 subunits)	Complex subunit pattern (12–14 subunits)
Rifampicin sensitivity	Sensitive	Insensitive	Insensitive
RNA Polymerase II Type Promoters	Absent	Present	Present
Metabolism			
Similar ATPase	No	Yes	Yes
Methanogenesis	Absent	Present	Absent
Nitrogen fixation	Present	Present	Absent
Chlorophyll-based photosynthesis	Present	Absent	Present[a]
Chemolithotrophy	Present	Present	Absent

Prescott's Principles of MICROBIOLOGY

Alternative hypotheses exist

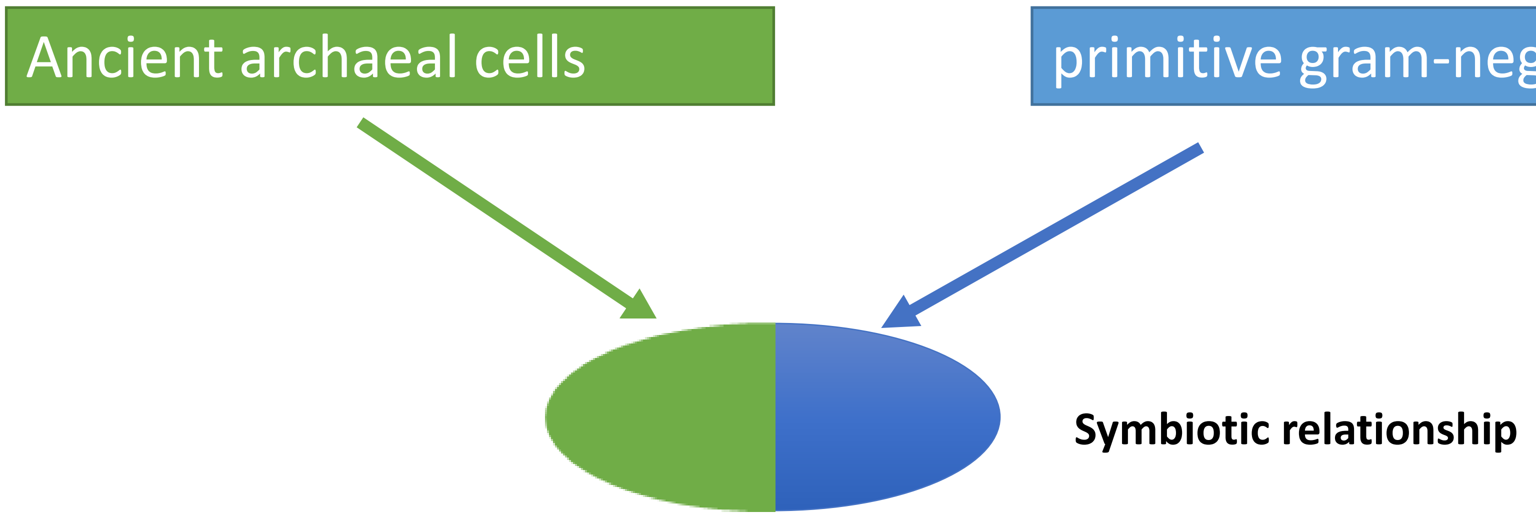
- Bacteria and the Eukarya arose independently and the Archaea are a mosaic, having combined traits of the other two.

- This view is based largely on the observation that while the Archaea share large numbers of genes with the Eukarya, they have an even larger number of genes in common with the Bacteria.

- Another interpretation suggests that the first eucaryotes arose from two ancient procaryotic ancestors: an archaeon and a bacterium.

As we have seen, genes from both the Archaea and the Bacteria can be found in eukaryotic chromosomes, but how did they get there?

Genome fusion hypothesis



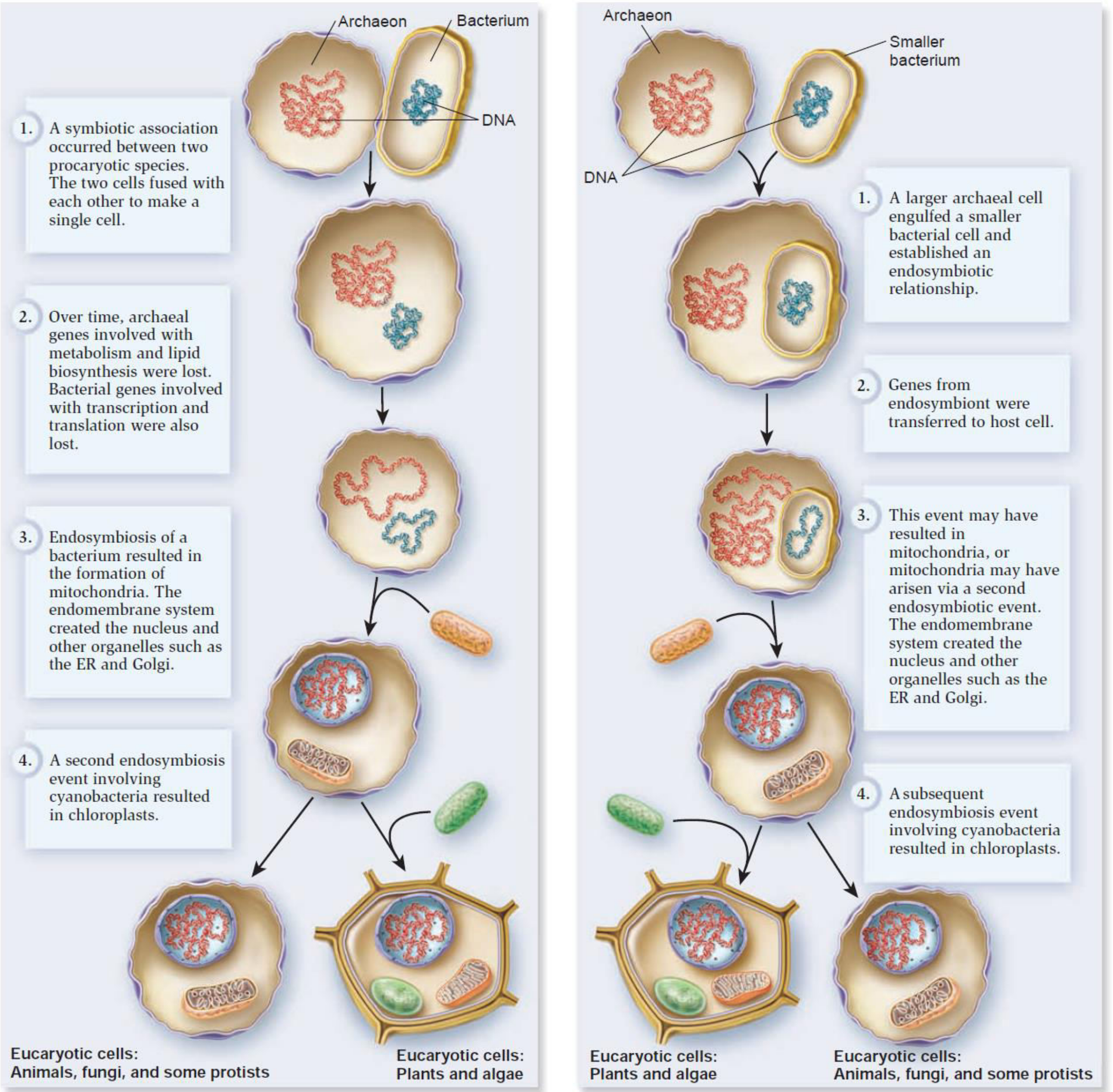
1. Symbiotic origin
2. Endosymbiotic origin

Bacterial genes for metabolism and archaeal genes for replication, transcription, and translation were retained or otherwise. Alternatively it has been also suggested that the bacterium was an endosymbiont of the archaeon.

The Endosymbiotic Origin of Mitochondria and Chloroplasts

- Nucleus origin is unresolved.
- Endosymbiotic hypothesis is generally accepted as the origin of mitochondria and chloroplasts.
- Both organelles have **bacterial-like ribosomes** and most have a **single circular chromosome**.
- α-proteobacterium, ***Rickettsia prowazekii***, an obligate intracellular parasite closely related to that of modern mitochondrial genomes.
- This hypothesis also accounts for the evolution of chloroplasts from an endosymbiotic **Cyanobacterium**.

Prescott's Principles of MICROBIOLOGY



(a) Origin from symbiotic relationship

(b) Origin from endosymbiotic relationship

Hydrogen hypothesis

- The hydrogen hypothesis asserts that the Endosymbiont was an **anaerobic α-proteobacterium** that produced H_2 and CO_2 as end products of fermentation. In the absence of an external H_2 source, the host became dependent on the bacterium, which made ATP by substrate-level phosphorylation.

- If the endosymbiont developed the capacity to perform aerobic respiration, it evolved into a mitochondrion.

- However, in those cases where the endosymbiont did not acquire the ability to respire, it evolved into a **hydrogenosome** an organelle **found in some extant protists** that produce ATP by fermentation.

Some believe that **hydrogenosomes** might be derived from mitochondria, but **three evidences** support the alternative idea that hydrogenosomes and mitochondria arose from the same ancestral organelle:

(1) The heat-shock proteins of α-proteobacteria, mitochondria, and hydrogenosomes are closely related.

(2) Subunits of the mitochondrial enzyme NADH dehydrogenase are active in the hydrogenosomes of the protist *Trichomonas vaginalis;* and

(3) The primitive genome found in the hydrogenosomes of the protist *Nyctotherus ovali* encodes components of a mitochondrial electron transport chain.

Taken together, these data suggest that mitochondria and hydrogenosomes are aerobic and anaerobic versions of the same ancestral organelle.

Serial endosymbiotic theory (SET)

- Put forth by **Lynn Margulis** and **her colleagues** combines elements of the endosymbiotic origin of mitochondria with the genome fusion hypothesis.
- The serial endosymbiotic theory (SET) calls for the development of eucaryotes in a **series of discrete endosymbiotic steps**.
- This theory suggests that motility evolved first through endosymbiosis between anaerobic spirochetes and another anaerobe.
- Next, **nuclei** are thought to have formed by the **development of internal membranes**. These early nucleated forms would have been similar to **modern protists with hydrogenosomes**.
- The **endosymbiotic events** needed for the evolution of mitochondria are thought to have occurred later, giving rise to early fungi and animal cells, with subsequent endosymbiotic events leading to the development of chloroplasts and plants.

Questions

Q1. What is RNA world hypothesis?

Q2. *Archaea* and the *Bacteria* share common genes interpreted in the universal tree of life. How can you explain using universal phylogenetic tree?

Q3. What is genome fusion hypotheses?

Q4. Explain the endosymbiotic hypothesis of the origin of mitochondria and chloroplasts with some evidences.

Q5. What is a hydrogen hypothesis? Why is it thought that mitochondria and hydrogenosomes arose from a single, common progenitor organelle?