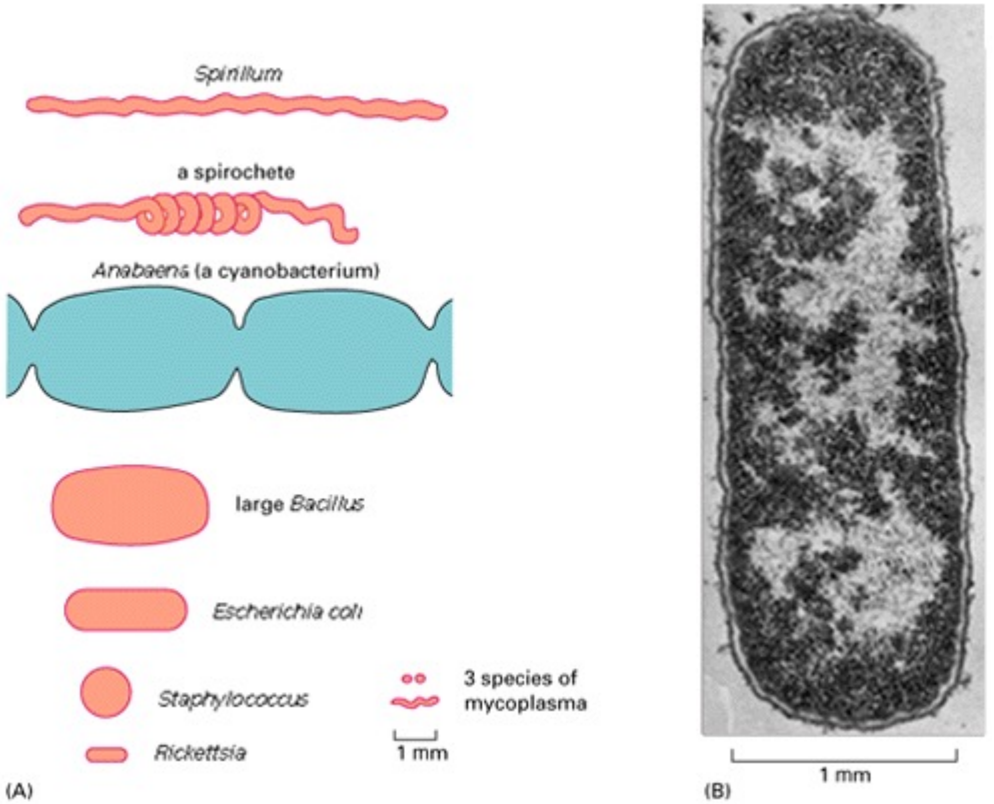
From Procaryotes to Eucaryotes

Lecture 4

Procaryotic Cells Are Structurally Simple but Biochemically Diverse

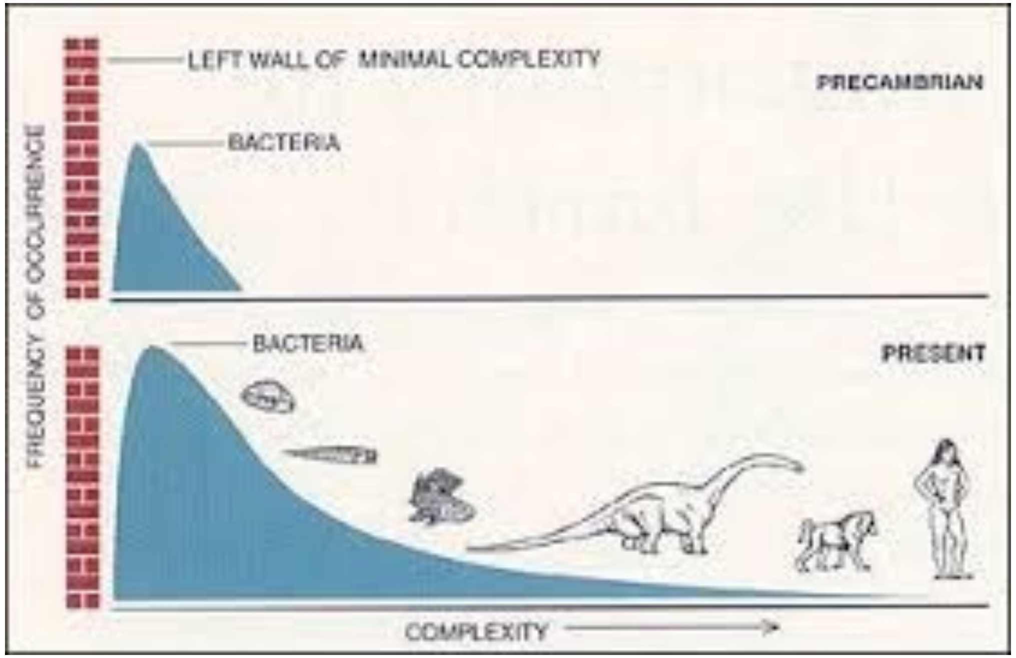
- Bacteria are the simplest organisms found in most natural environments.
- Spherical or rod-shaped cells, commonly several micrometers in linear dimension Possess a tough protective coat, cell wall, beneath which a plasma membrane encloses a single cytoplasmic compartment containing DNA, RNA, proteins, and small molecules.



Procaryote sizes and structures. (A) Some procaryotic cells drawn to scale. (B) Electron micrograph of a longitudinal section through a bacterium (Escherichia coli); the cell's DNA is concentrated in the palely stained region. (Courtesy of E. Kellenberger.)

The power of the lowly bacteria

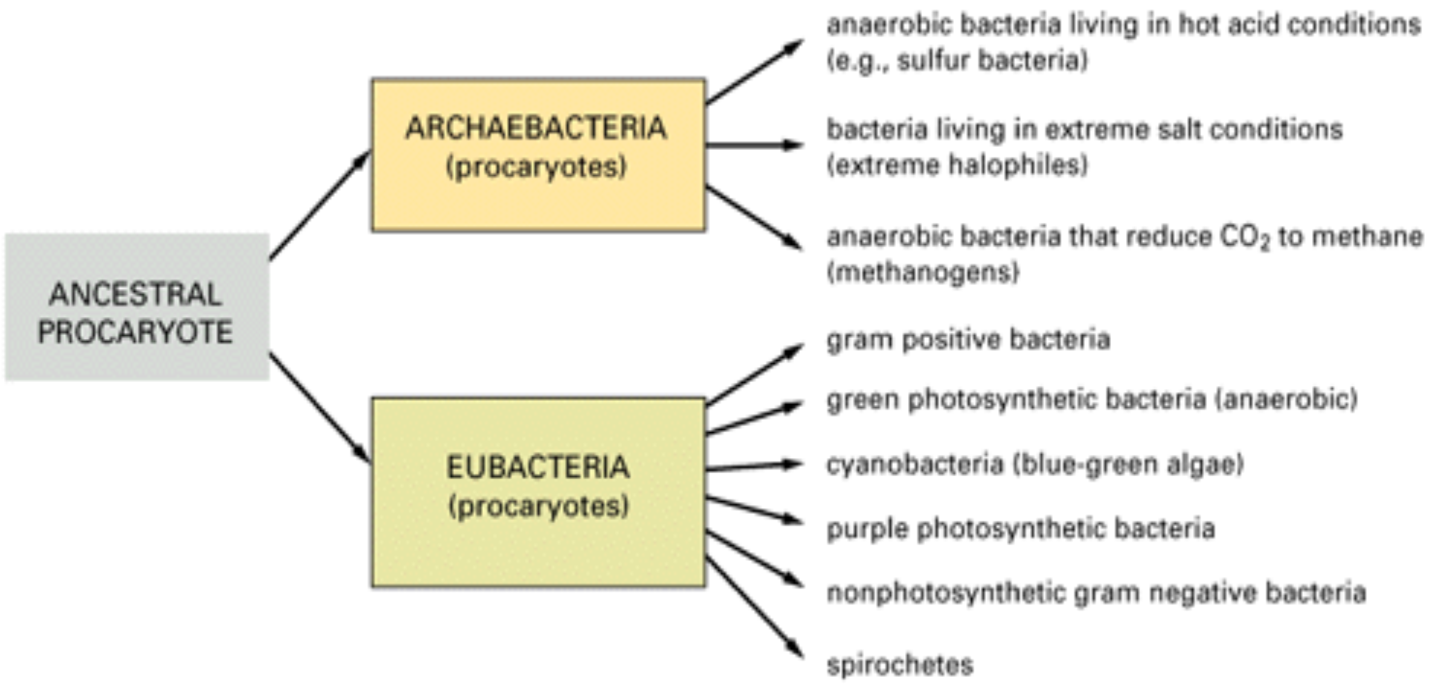
- Bacteria replicate quickly, dividing in two by binary fission.
- When food is plentiful, "survival of the fittest" means survival of those that can divide the fastest.
- Under optimal conditions a single procaryotic cell can divide every 20 minutes and thereby give rise to 5 billion cells (approximately equal to the present human population on earth) in less than 11 hours.
- Ability to divide quickly enables bacteria to adapt rapidly to changes in their environment.



Family relationships between present-day bacteria

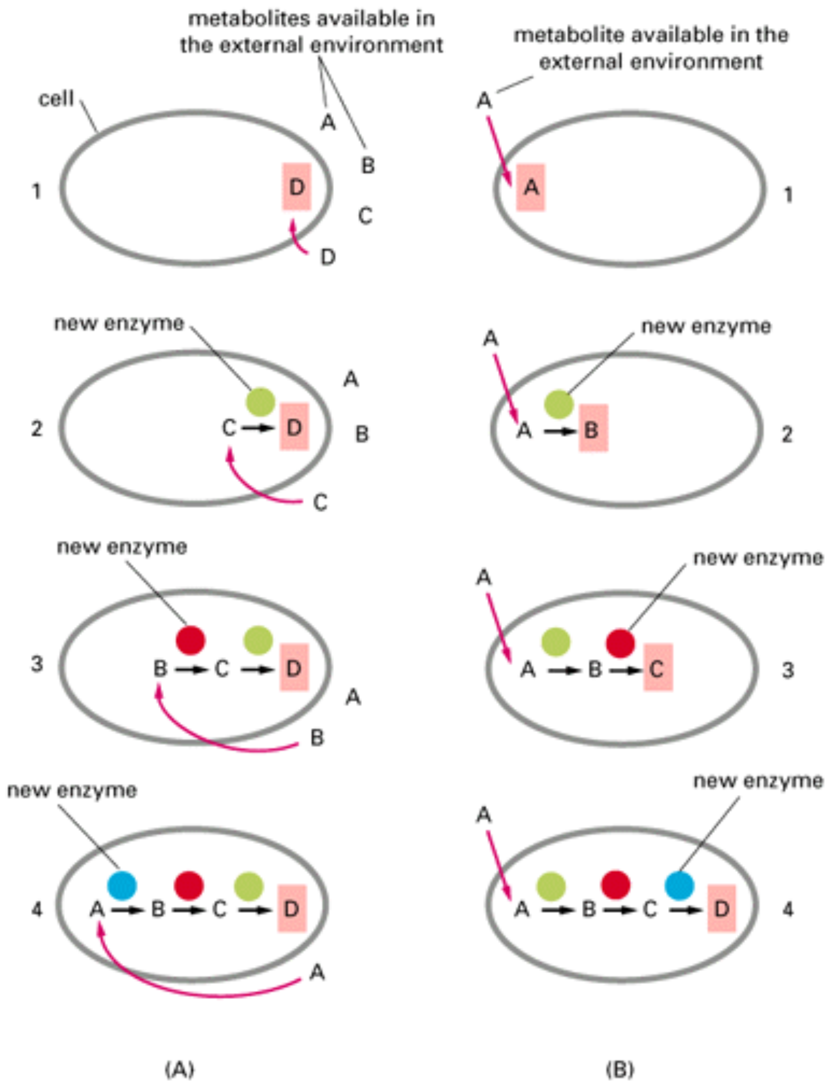
- Bacteria live in an enormous variety of ecological niches, and show a corresponding richness in their underlying biochemical composition.

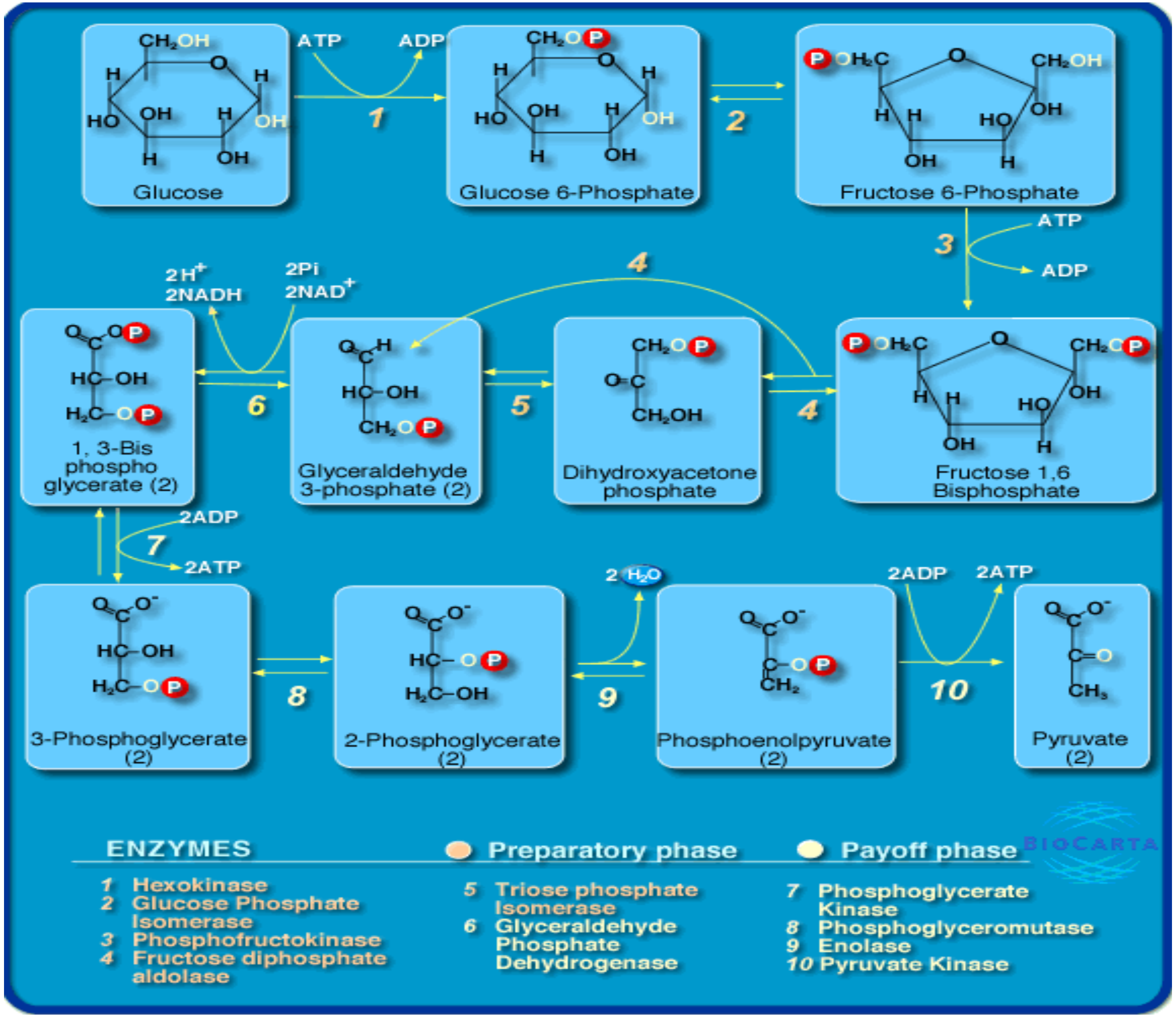
- Two distantly related groups can be recognized: eubacteria, inhabit soil, water, and larger living organisms; and archaebacteria, found in ocean depths, salt brines, and hot acid springs.



More about metabolic reactions

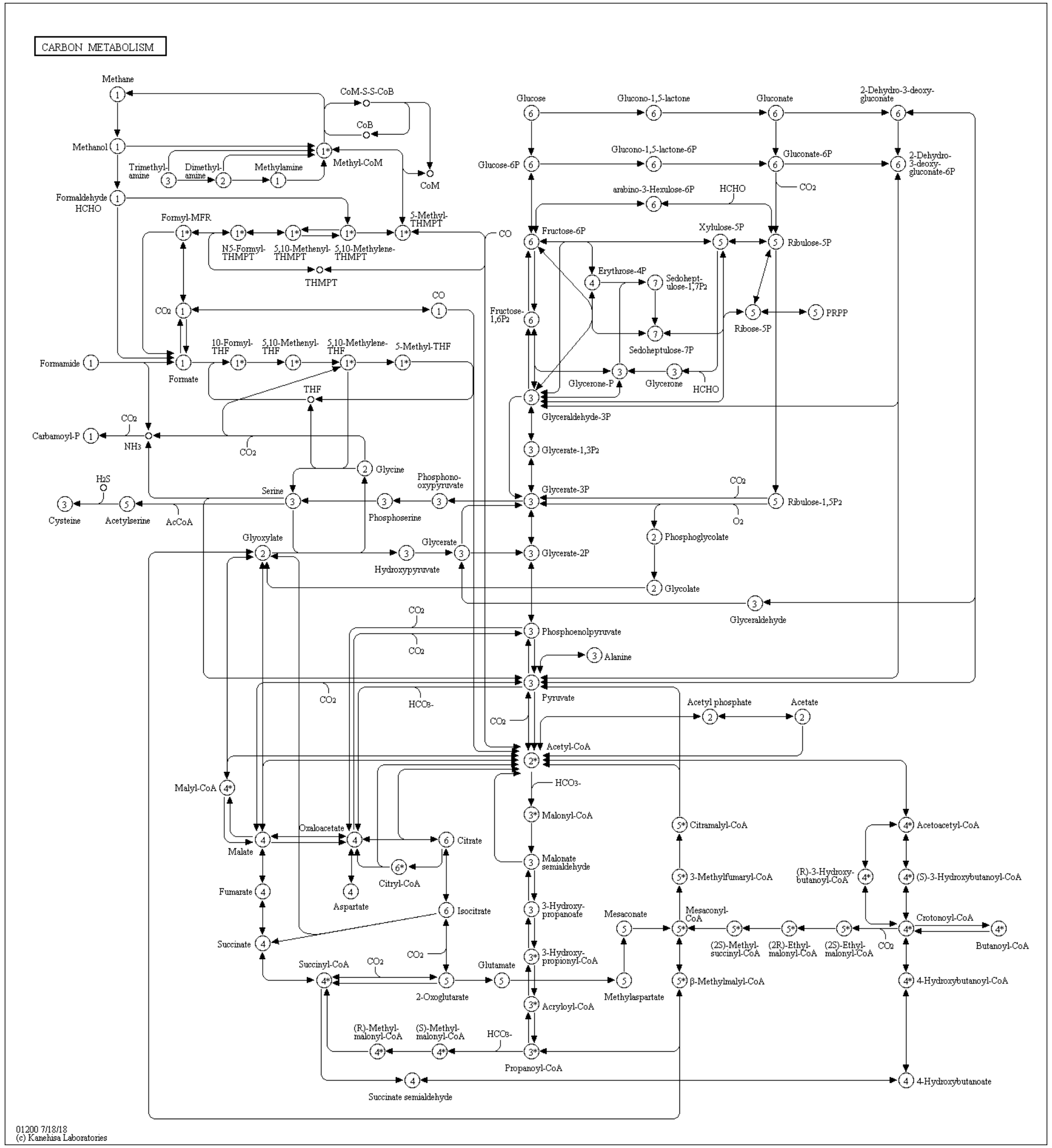
- [KEGG]





Glucose
ATP
ADP
1
Glucose 6-Phosphate
2
Fructose 6-Phosphate
3
ATP
ADP
Fructose 1,6 Bisphosphate
4
Dihydroxyacetone phosphate
5
Glyceraldehyde 3-phosphate (2)
2Pi
2NAD+
2 H+
2NADH
6
1, 3-Bis phospho glycerate (2)
2ADP
7
2ATP
3-Phosphoglycerate (2)
8
2-Phosphoglycerate (2)
9
2 H2O
Phosphoenolpyruvate (2)
2ADP
2ATP
10
Pyruvate (2)
ENZYMES
Preparatory phase
Payoff phase
BIOCARTA
1 Hexokinase
2 Glucose Phosphate Isomerase
3 Phosphofructokinase
4 Fructose diphosphate aldolase
5 Triose phosphate Isomerase
6 Glyceraldehyde Phosphate Dehydrogenase
7 Phosphoglycerate Kinase
8 Phosphoglyceromutase
9 Enolase
10 Pyruvate Kinase

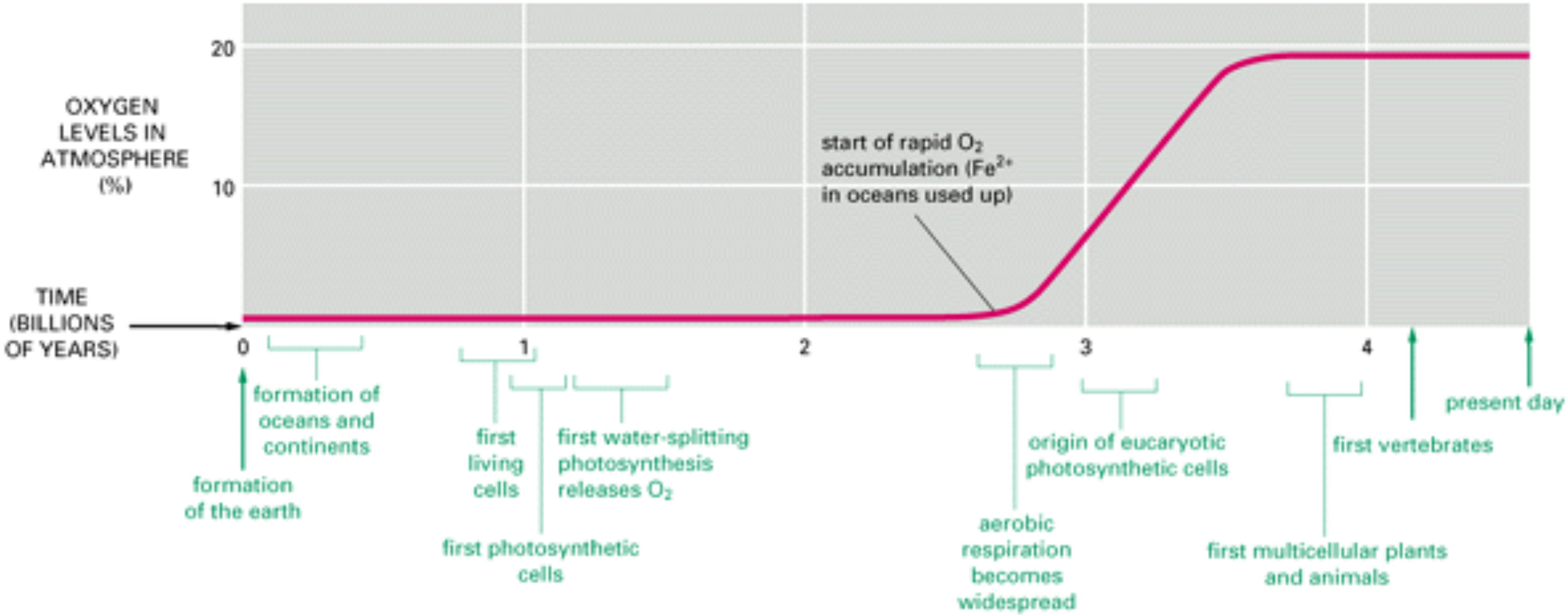
Carbon Metabolism



Metabolic reactions are similar in all organisms

- Similarity in all kinds of organisms, suggesting an extremely ancient origin
- Linked to core reactions of glycolysis are hundreds of other chemical processes
    - Generation of energy in ATP-ADP currency
    - Synthesis of small molecules
    - Make large polymers specific to the organism
    - Degrade complex molecules, taken in as food, into simpler chemical units

The synthesis and release of oxygen into the atmosphere



Cyanobacteria were the first organisms to synthesize oxygen

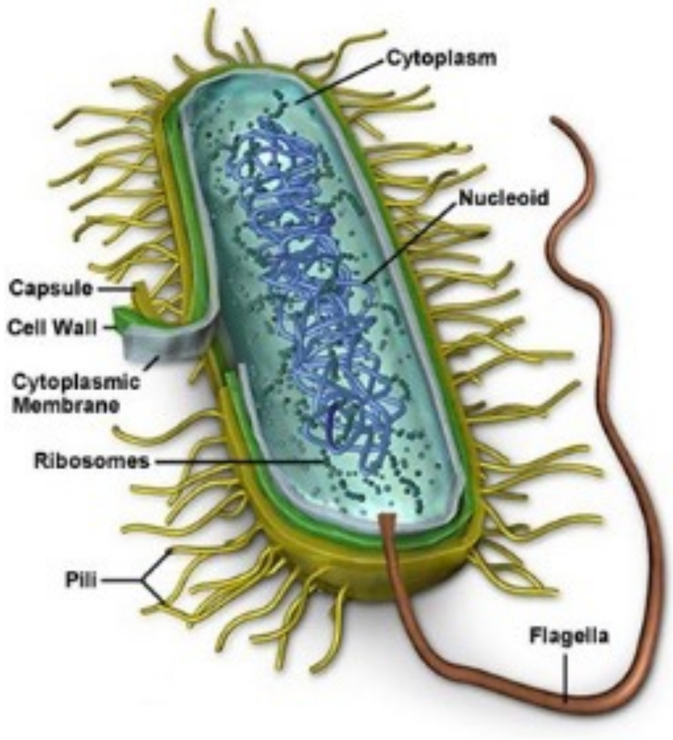
- As competition for raw materials for organic syntheses intensified, a selective advantage gained by organisms able to utilize carbon and nitrogen atoms (in the form of CO_2 and N_2) directly from the atmosphere
- While they are abundantly available, it required a large amount of energy to convert CO_2 and N_2 to a usable organic form like simple sugars
- The major mechanism that evolved to achieve this was photosynthesis: radiant energy captured from the sun converted CO_2 into organic compounds
- Interaction of sunlight with chlorophyll, excites an electron to a more highly energized state. As the electron drops back to a lower energy level, the energy it gives up drives chemical reactions that are facilitated and directed by protein molecules

The utilization of oxygen by organisms

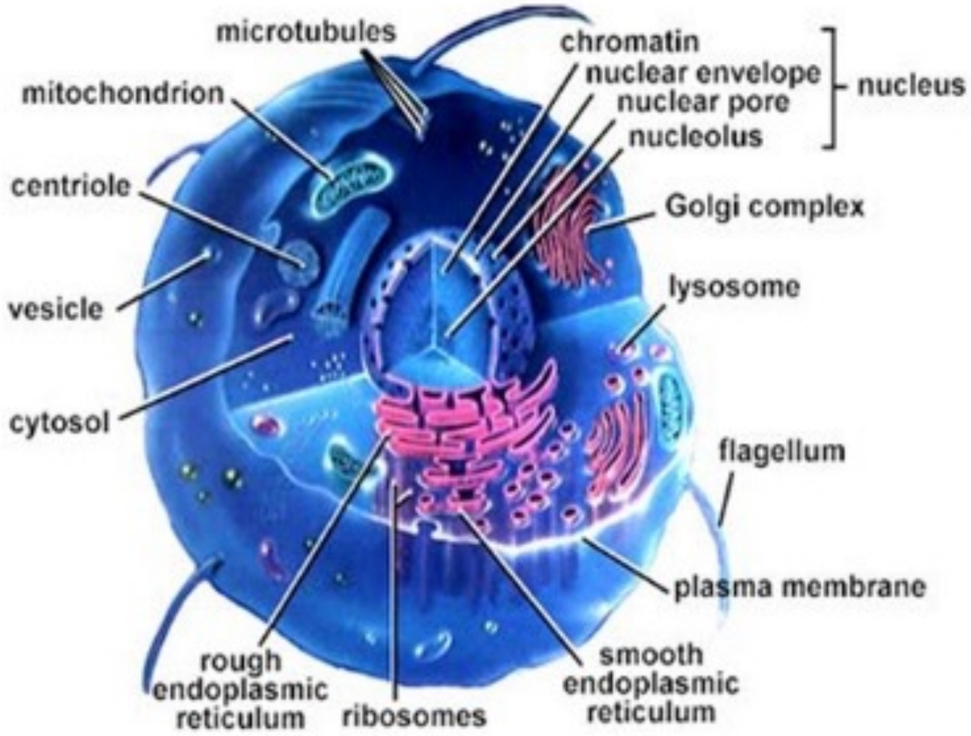
- Extremely reactive chemical that can interact with most cytoplasmic constituents; must have been toxic to many early organisms

- The simplest of carbon molecules used by organisms is glucose
- In the absence of oxygen glucose broken down only to lactic acid or ethanol, the end products of anaerobic glycolysis.
- In the presence of oxygen glucose completely degraded to CO2 and H2O; much more energy can be derived from each gram of glucose

Procaryotes and Eucaryotes

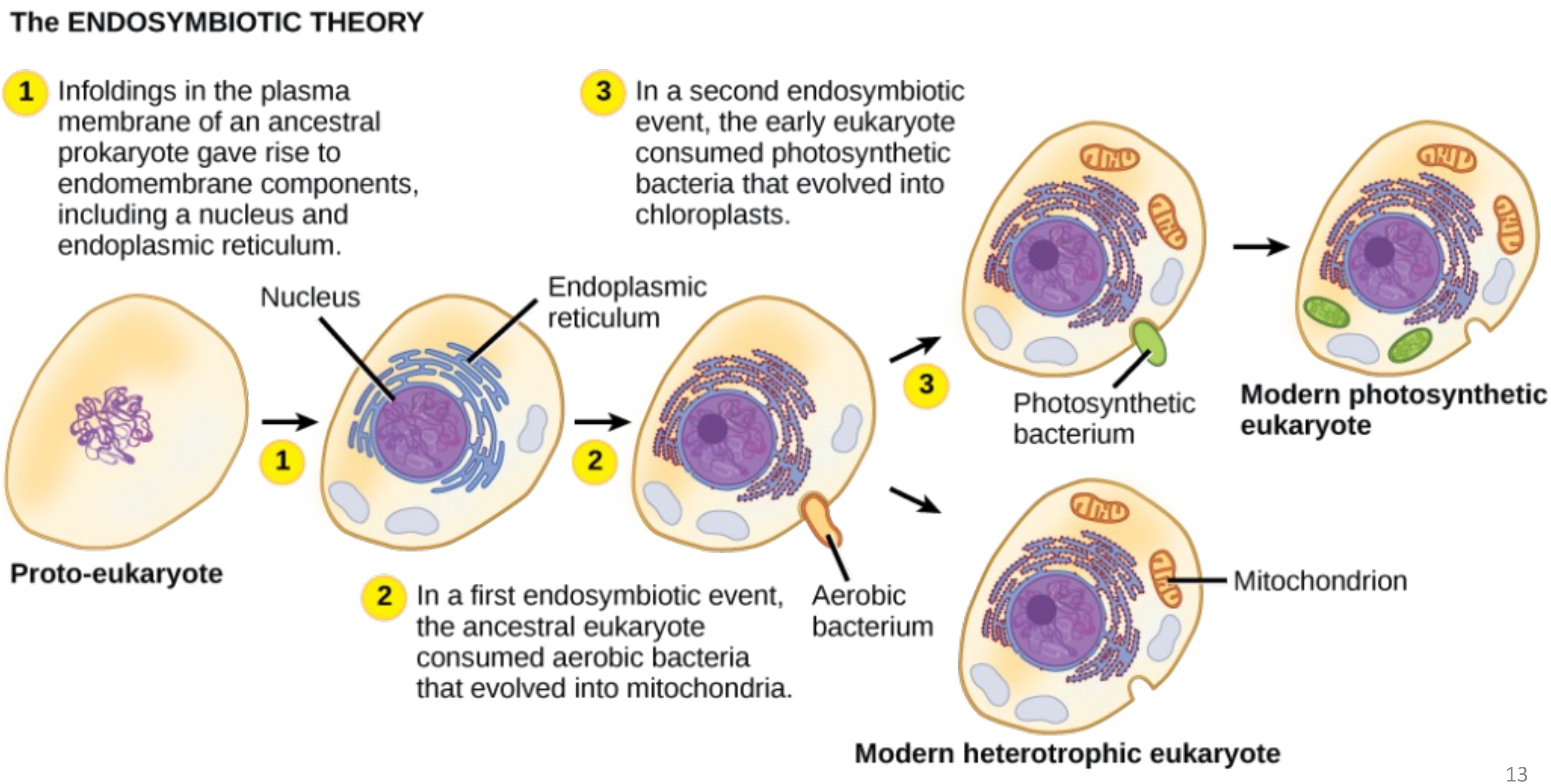


prokaryotic cell
(bacteria)



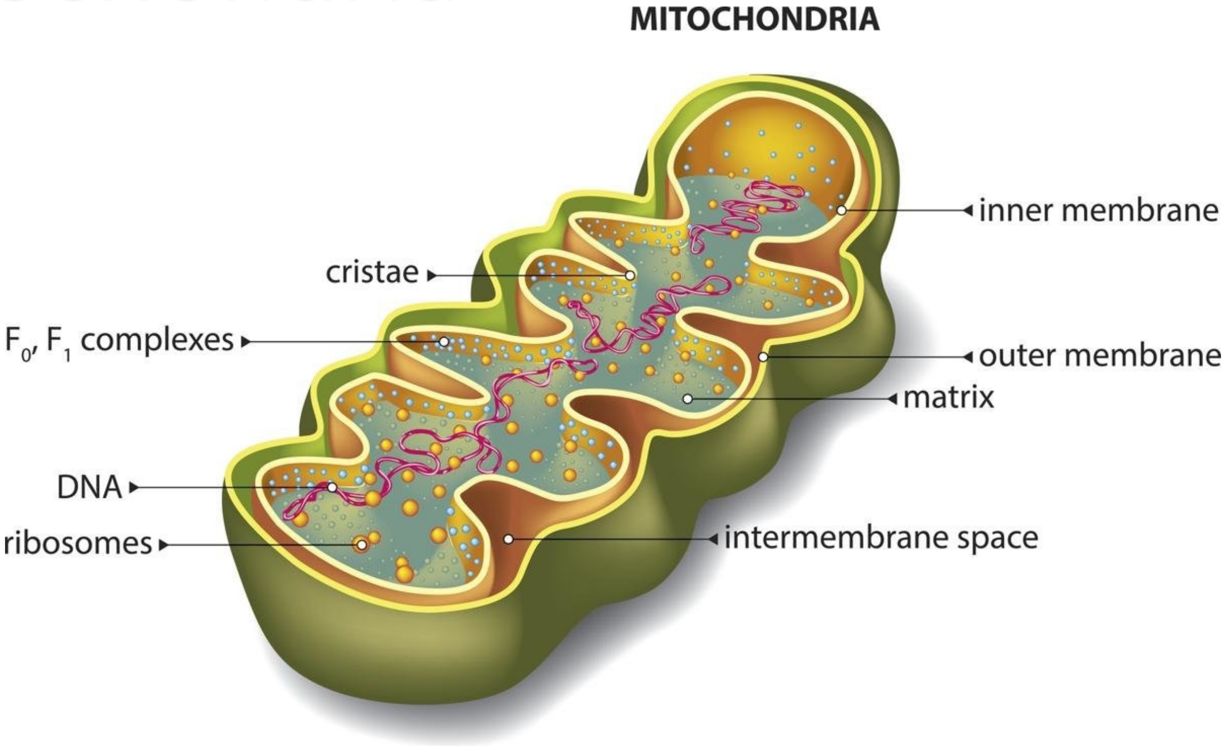
eukaryotic cell
(protists, fungi, animals, plants)

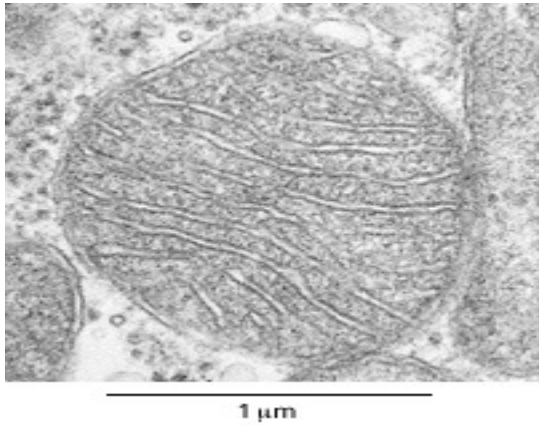
The creation of the eukaryote cell



The mitochondria

- Often resemble bacteria in size and shape,
- Contain DNA, make protein, reproduce by dividing in two and is responsible for respiration.
- Many present-day bacteria respire like mitochondria
- The amoeba *Pelomyxa palustris,* while lacking mitochondria, nevertheless carries out *oxidative* metabolism by harboring aerobic bacteria in its cytoplasm in a permanent symbiotic relationship

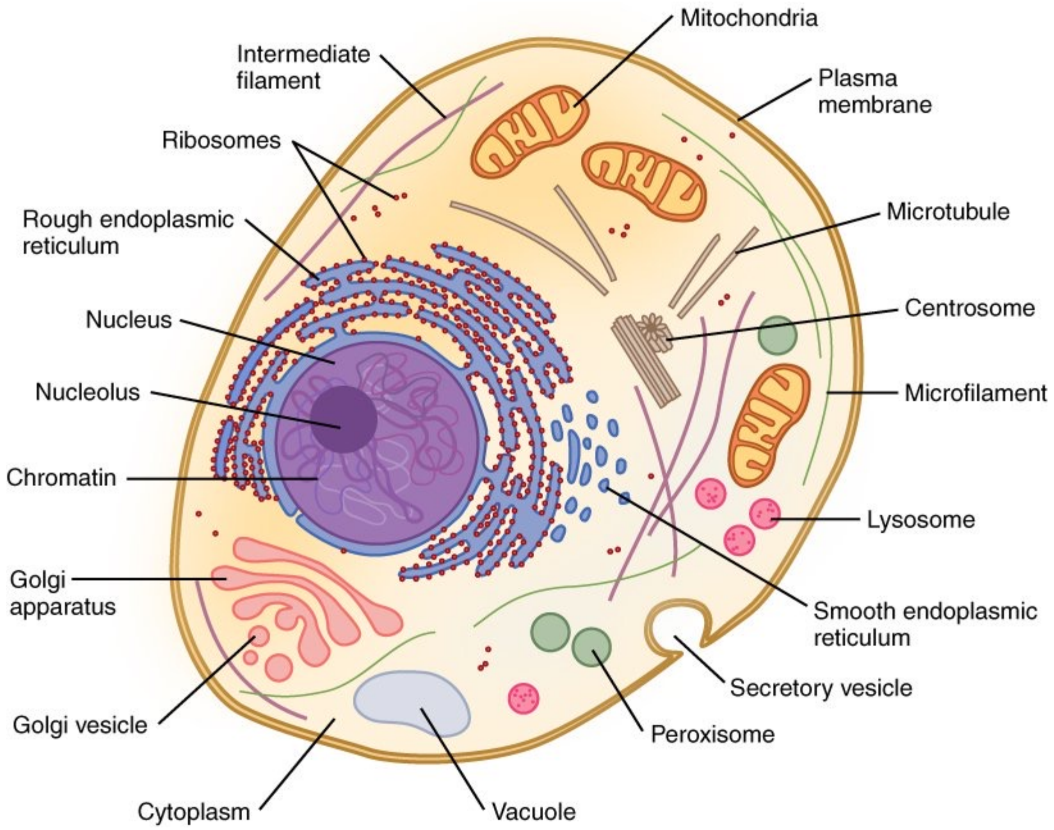




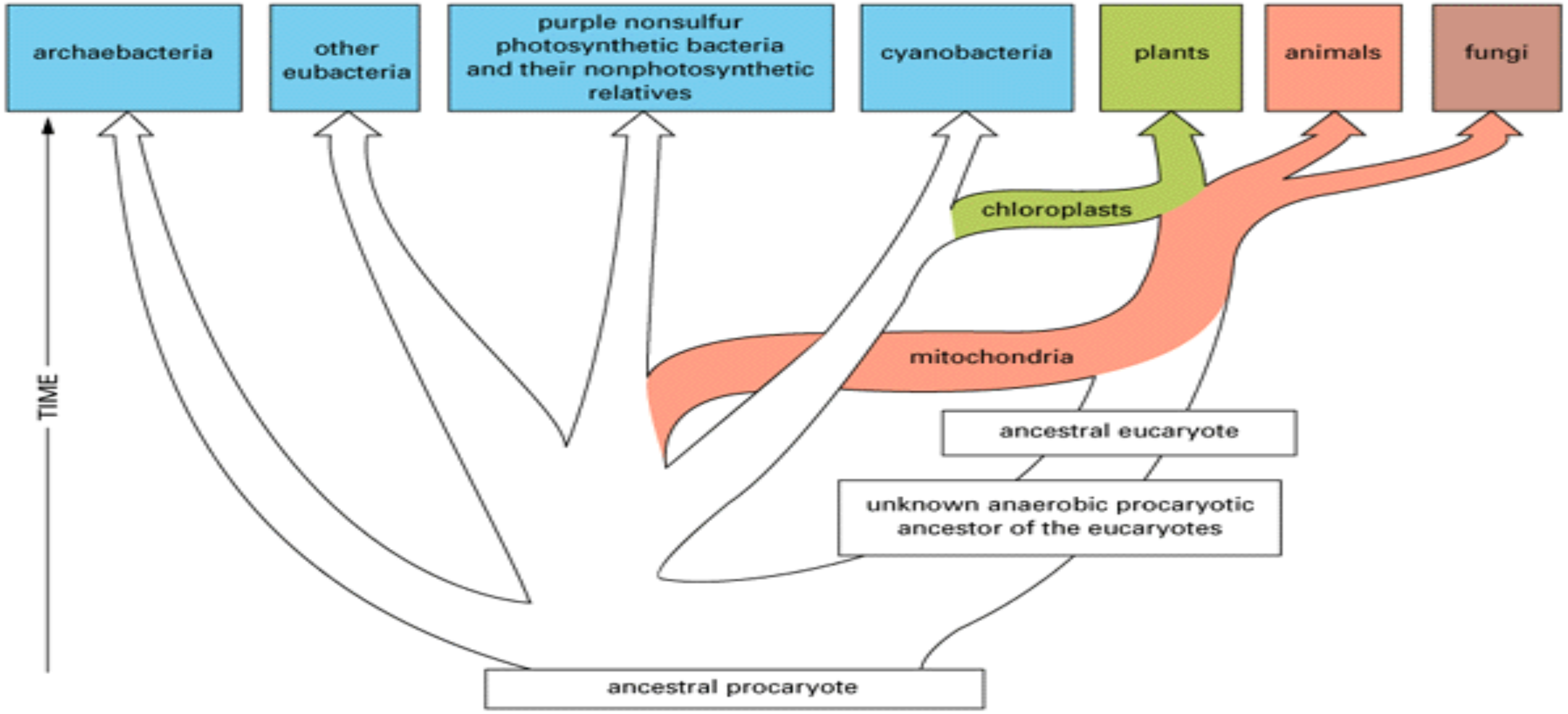
Implications of the creation of the mitochondria

- Acquisition of mitochondria must have had many repercussions!
- Plasma membrane is heavily committed to energy metabolism in procaryotic cells but not in eucaryotic cells, where this crucial function has been relegated to the mitochondria
  - Separation of functions left the eucaryotic plasma membrane free to evolve important new features.
- Because eucaryotic cells need not maintain a large H+ gradient across their plasma membrane, as required for ATP production in procaryotes, it became possible to control changes in ion permeability of the plasma membrane for cell-signaling.
  - A variety of ion channels appeared in the eucaryotic plasma membrane.
  - Today, these channels mediate elaborate electrical signaling processes in higher organisms - notably in the nervous system -and they control much of the behavior of single-celled free-living eucaryotes such as protozoa.

More organelles of the eukaryote cell

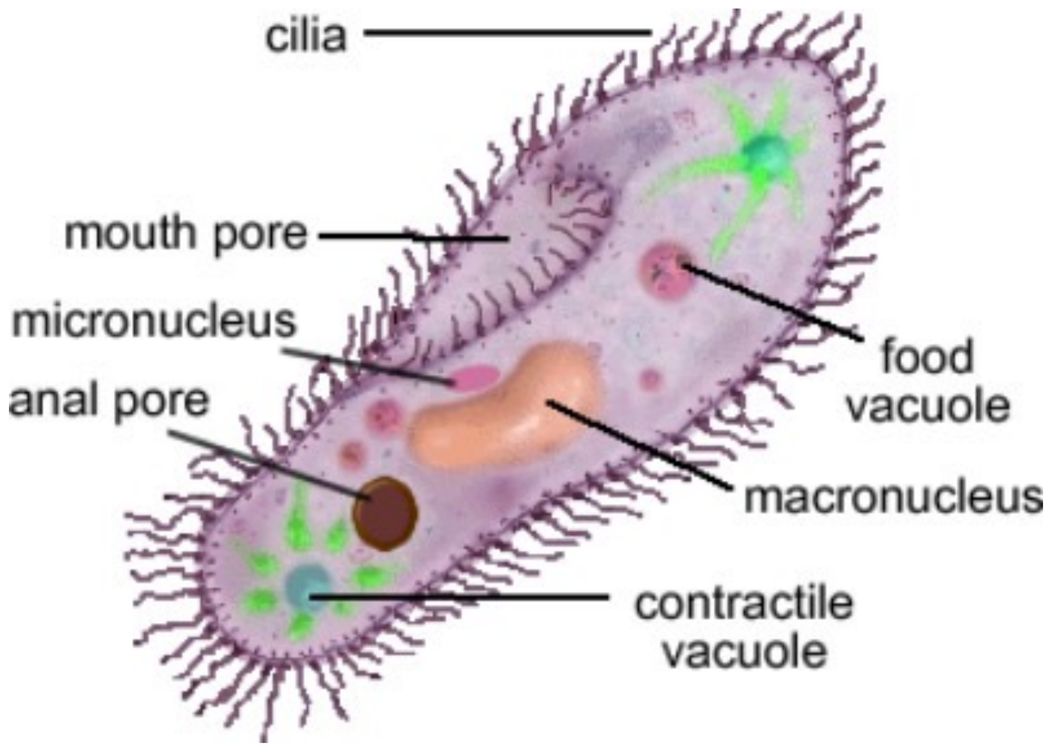


Postulated origin of the eukaryotic cell



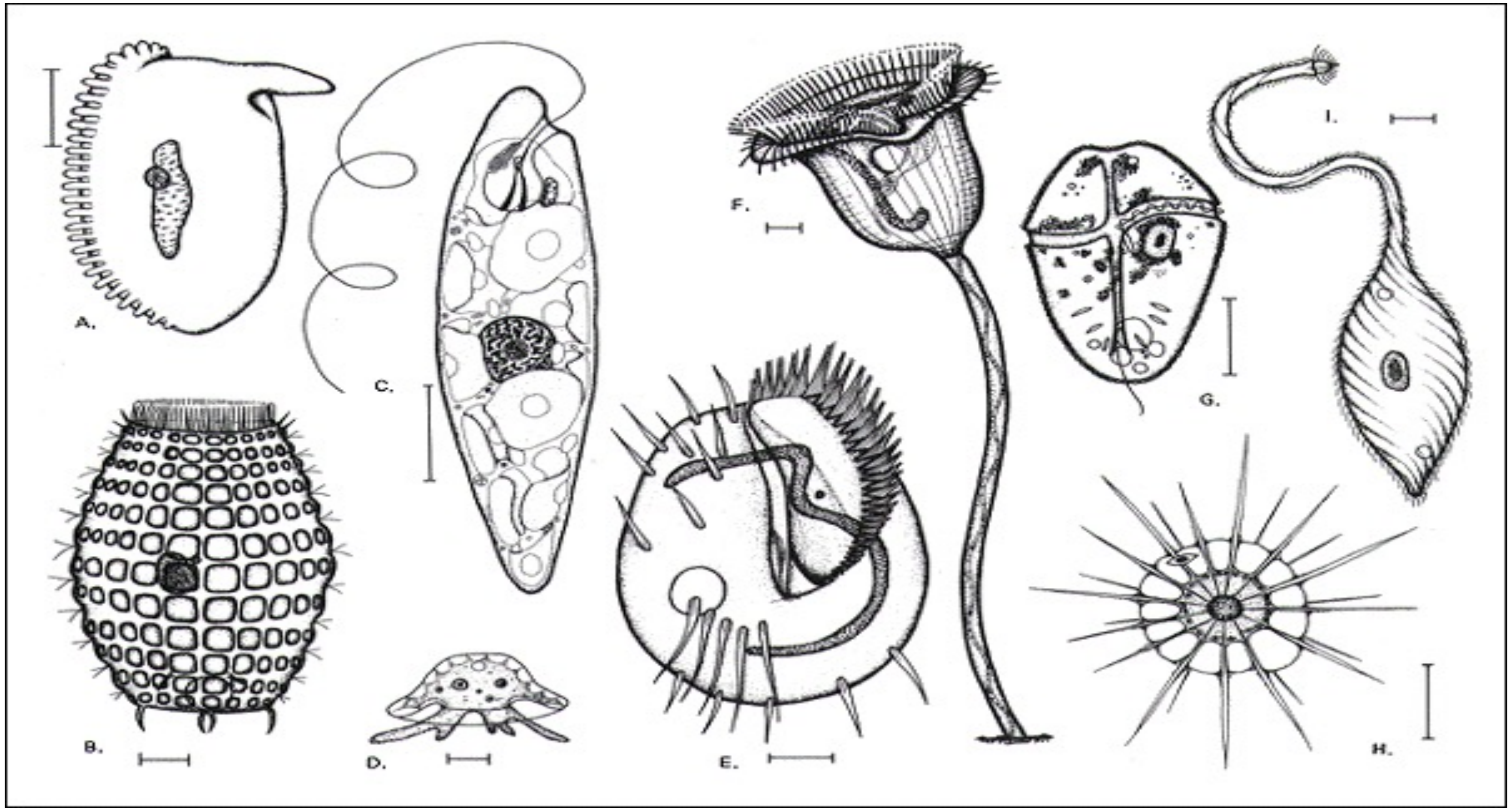
Complexity of the protest – a single-celled creature

- The complexity that can be achieved by a single eucaryotic cell is nowhere better illustrated than in the free-living, single-celled eucaryotes known as protists
    - Evolutionarily diverse
    - Exhibit a bewildering variety of different forms and
    - Behaviors: photosynthetic, carnivorous, motile, sedentary
    - Anatomy: complex and includes structures as: sensory bristles
        - photoreceptors, flagella, leg-like appendages, mouth parts, stinging darts, muscle like contractile bundles



https://www.youtube.com/watch?v=0-6dzU4gOJo

The length-scale of protists



These drawings are done to different scales, but in each case the bar denotes 10 mm. The organisms in (A), (B), (E), (F), and (I) are ciliates; (C) is an euglenoid; (D) is an amoeba; (G) is a dinoflagellate; (H) is a heliozoan.

From M.A. Sleigh, The Biology of Protozoa. London: Edward Arnold, 1973.

Summary

1. Order and self-organization
   a) Physical, chemical, small molecules with structural information
2. Association certain molecules according
   a) RNA and proteins, later DNA
3. Isolation of these specialized molecules from the environment
   a) LUCA
   b) The central dogma DNA→ RNA→ Proteins
4. Development of metabolic reactions to utilize specific nutrient molecules
5. Oxygen synthesizing cells to oxygen utilizing cells
6. Procaryotes to eucaryotes
7. Unicellular organisms

Acknowledgements:
Molecular Biology of the Cell. Fifth Edition. 2007. Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, Peter Walter