The Prokaryotic World

A. An overview of prokaryotic life

There is no doubt that **prokaryotes are everywhere**. By everywhere, I mean living in every geographic region, in extremes of environmental conditions, in habitats, and in various associations with other organisms.

[Give examples of these]

Numbers of species of prokaryotes are not comparable to eukaryotes is partly due to scientists' definitions of species (usually defined in terms of reproduction and inheritance of the sexual variety). If we count every newly evolved strain, then there are currently millions of species.

B. Phylogeny of Prokaryotes

Molecular, biochemical, structural and functional studies give evidence for **2 major lineages of prokaryotes** – **Bacteria** and **Archaea**.

[FIGURES 27.1 and earlier 26.10]

Comparison of 3 domains – Bacteria, Archaea, and **Eukarya –** reveals some of the features that lead evolutionary biologists to distinguish prokaryotes from eukaryotes (similar features for B and A vs. E), and others that support a common ancestor for Archaea and Eukarya.

[TABLE 27.2]

Biology of Archaea is dominated by their living in extreme environments. Consider the biology of **methanogens**, **extreme halophiles**, and **extreme thermophils**.

[Will be treated in detail in LAB / RECITATION]

Biology of Bacteria reflects wide diversity in form, function, metabolism, and life history. Consider photosynthetic **cyanobacteria**, pathogenic **spirochetes** and **chlamydias**, and the highly diverse **gram-positive** and **proteobacteria**.

[Will be treated in detail in LAB / RECITATION]

The Form, Function, and Reproduction of Prokaryotes

A. Overview of Prokaryotic cell structure (review Chapter 7, pp. 102-110)

Prokaryotes are fully functionally unicellular organisms that differ from eukaryotes (unicellular and multicellular) by fundamental features of cell form and function.

[REVIEW FIGURES from CHAPTER 7]

Prokaryotic cell walls (external to plasma membrane) are integral to their organismal function. The nature of that wall effects their ability to contact and infect other organisms, adhere to each other or materials in their environment, or resist defenses of host organisms they infect.

Peptidoglycans found in the cell walls of gram-positive bacteria are critical components facilitating many organismal functions. Their nature and presence/absence explain a great deal about the effectiveness of antibiotic strategies employed against them.

Capsules, **pili**, and other **cell surface structures** are important to some forms.

[FIGURES from CAMPBELL and Others]

B. Many prokaryotes are motile – THEY CAN MOVE

Directional movement, the ability to move in a directed way, is common in about 50% of prokaryotes. Although we don't think of them moving about like we do animals, the flagella they beat can move them at rates up to 100 times their length per second !

Prokaryotic flagella are fundamentally different in form and function compared with those found in eukaryotes. Compare their features.

[FIGURE 27.5 to that in FIGURE 7.24]
Note esp. the figure legend to 27.5

c. Prokaryotic cellular and genomic organization

The **extensive cellular compartmentalization found in eukaryotes** is absent in prokaryotes. Compare the form and function of a typical prokaryotic and eukaryotic cell. However, note that some prokaryotes (e.g., cyanobacteria) have plasma membrane specializations associated with photosynthesis or other specialized functions.

[FIGURES from CHAPTER 7]

The **prokaryotic genome** is not only smaller, but is structured and functions differently from that of eukaryotes. Recall differences in gene regulation between prokaryotes and eukaryotes.

d. Population growth and adaptation is rapid in Prokaryotes

Prokaryotes reproduce asexually. That is, they have no sexual cycle and undergo a binary fission mode of cell (and organismal) division.

Binary fission (see pp. 213-216 in Chapter 12) involves replication of the prokaryotic circular DNA, and growth of the plasma membrane septum across the cell. Little opportunity for genetic recombination compared to eukaryotic systems.

The **genetics of prokaryotes** was described in Chapter 18. For our purposes, it is sufficient to know that –

1. **Mutation** is the major source of genetic variation
2. **Transformation**, **conjugation**, and **transduction** are means of genetic recombination (transfer of genes)

When scientists speak of **growth in prokaryotes** they are referring to **population growth** – the increase in numbers of individual cells in a growing colony – rather than growth in size of a cell.

Population growth is usually **geometric** – doubling per unit time – under favorable growth conditions until those conditions change. A single cell can rapidly give rise to a **colony**.

Factors influencing population growth include temperature, pH, solute concentration (e.g., osmotic concentration, salinity), and nutrient source. Availability of appropriate ranges of these conditions for a given "species" or strain may prohibit or limit growth.

[EXAMPLES of applications of these factors in our experiences]

Mutations or genetic recombinations introduce **new genetic variation** to the genome of a prokaryote. Given the high rate of population growth, any new variation can be quickly **propagated.** Thus, **evolutionary adaptation** can be rapid with great impact on diversity. Examples include **evolution of resistance to antibiotics.**

Nutritional and Metabolic Diversity of Prokaryotes

A. Prokaryotic modes of nutrition – energy and carbon sources

Nutrition refers to how organisms obtain **energy** and **carbon sources** to synthesize organic compounds to carry-out organismal functions. These functions include building and maintaining macromolecules and cellular structures, as well as cellular processes – i.e., **metabolism**.

Prokaryotic nutritional or metabolic modes are the most diverse of any other group of organisms. Organismal nutritional / metabolic modes have been grouped into four functional categories –

1. Photoautotrophs
2. Chemoautotrophs
3. Photoheterotrophs
4. Chemoheterotrophs

[REVIEW TABLE 27.1 and note features of these modes]

MODE of NUTRITION	ENERGY SOURCE	CARBON SOURCE	TYPES of ORGANISMS
Autotroph			
Photoautotroph	Light	CO_2	Photosynthetic prokary, plants, some protists
Chemoautotroph	Inorganic comp.	CO_2	Some prokaryotes
Heterotroph			
Photoheterotroph	Light	Organic comp.	Some prokaryotes
Chemoheterotroph	Organic comp.	Organic comp.	Most prok. & protists, fungi, animals, few plants

B. Nutritional Diversity among Chemoheterotrophs is tremendous

Most prokaryotes are chemoheterotrophs of one kind or another, meaning that various specific forms specialize on metabolizing nearly every kind of organic compound as a nutritional base for energy and carbon source. This includes many of the forms which are **saprobes** – decomposers who absorb nutrients from other dead organisms – as well as **parasites** – who absorb their nutrients from living host cells.

C. Prokaryotic Metabolism of Nitrogen

Nitrogen is an important element involved in various cellular and organismal processes (think of proteins, nucleic acids). Whereas most eukaryotic organisms can only use one or a couple forms of nitrogen and are therefore **nitrogen-limited**, prokaryotes are able to metabolize most nitrogenous compounds.

Nitrogen fixation is the process whereby atmospheric nitrogen gas is converted to ammonia ($N_2 \rightarrow NH_3$). This is the only process by which atmospheric nitrogen is made available to other organisms.

Some chemoautotrophs can convert ammonia (NH_3) to NO_2, whereas others take the process the other way starting with $NO_2 \rightarrow NH_3 \rightarrow N_2$. **Some cyanobacteria can directly use N_2**, toxic to many other organisms. The bottom line is that it is prokaryotes who not only have tremendous flexibility in nitrogen metabolism, but which also provide all other organisms with critical forms of nitrogen for their own use.

D. Prokaryotic Metabolism of Oxygen

Oxygen is another important element involved in various cellular and organismal functions. Many prokaryotes are **anaerobic**, meaning that they live without O_2, which is toxic to them. **Obligate anaerobes** live by extracting chemical energy directly by using anaerobic respiration or through **fermentation**. **Facultative anaerobes** can use O_2, but utilize fermentation in anaerobic environments. **Obligate aerobes** use O_2 for cellular respiration and must have it to live.

E. The Origin of Metabolism

Because prokaryotes were the first organisms (and only ones for nearly 2 billion years) and they possess the entire diversity of metabolic modes, it is reasonable to predict that the diversity of metabolic modes found in eukaryotes **evolved first in prokaryotes.**

ATP is the universal chemical energy "currency" in all living organisms, as is the use of **glycolysis.**

It is likely the **earliest prokaryotes** were **chemoautotrophic anaerobes,** making or using ATP as energy intermediary through a combination of photosynthesis and/or absorption. Alternate views on whether early earth environments could have supported organic compounds continued to be argued, leading some to study the possibility of the use of **sulfides or iron as catalysts.**

F. The Origin of Photosynthesis

Photosynthetic prokaryotes use a very broad spectrum of light energy and are included amongst the earliest organisms. Several independent evolutionary events apparently lead to the use of different pigments by various prokaryotic lineages.

Association of photosynthetic pigments with cell (plasma) membranes occurs in some (but not all) prokaryotic phototrophs, a condition found in photosynthetic eukaryotes.

G. The Origin of Cellular Respiration – the Oxygen revolution

Although photosynthesis serves to fix CO_2 (reducing it in the presence of water to form O_2), some photosynthetic prokaryotes use sulfides and do not produce O_2. Others, including the cyanobacteria, generated abundant O_2.

For many millions of years, O_2 released via prokaryotic photosynthesis was **bound in mud sediments** (often with iron and other metals) or in **ocean waters**. Eventually, O_2 began to **accumulate in the atmosphere**, requiring a major adaptation by anaerobic organisms (especially obligate anaerobes). The led to evolution of aerobic organisms and systems.

Ecological Roles and Impacts of Prokaryotes

A. Prokaryotes are central to global ecosystem nutrient cycling

As noted earlier, **prokaryotes not only utilize** carbon, nitrogen, oxygen, phosphorus, and other elements in nearly any form, they **transform them** to useable forms **for use by most other organisms** on the planet. In some cases they do this directly from atmospheric gases or soils and in others via decomposition of dead organisms.

The **role of prokaryotes in decomposition** is very large and important to the planet's current biodiversity systems.

[EXAMINE FIGURES from CHAPTER 54 on C, N, P Cycles]

B. Prokaryotes roles in symbiosis have been central to evolution

Prokaryotes have entered into **symbiotic relationships** with other organisms that have shaped the evolution of all eukaryotic organisms.

Symbiosis is a significant, direct contact relationship between organisms, and have been characterized as one of the following categories –

1. Mutualism
2. Commensalism
3. Parasitism

The nutrient cycling contributions of prokaryotes to other organisms, especially in decomposition, are often **mutualistic**.

Pathogenic prokaryotics – those causing disease in other organisms – are examples of **parasitic symbiosis**. Effects of pathogens may be slight, minor, chronic, or lethal.

The biology of specific pathogenic prokaryotes cannot be easily characterized, especially in light of their ability to evolve rapidly. The responses of multicellular hosts (be they plants or animals) are also complex, so that the **host response effects** to infection (parasitism) might be more severe than the direct actions of the pathogen.