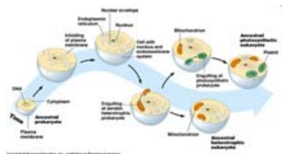
Prokaryotes, Protists, Photosynthesis, Endosymbiosis

Ch 28 & 29



26 February 2009
ECOL 182R UofA
K. E. Bonine

1

Reconstructing the evolution of living things

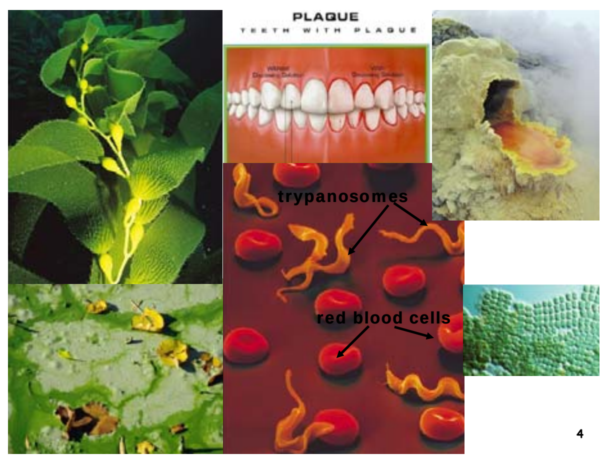
- *Systematists* study evolutionary relationships
- Look for *shared derived* (=different from ancestor) *traits* to group organisms
- Evidence used: morphology, development, and molecular data (especially DNA sequences)

2

Why can't we figure it out perfectly?

- More distant history is obscured by more changes
- Among oldest lineages of Bacteria and Archaea in particular, lots of "lateral gene transfer." Makes it difficult to infer relationships from phylogeny of single genes.

3

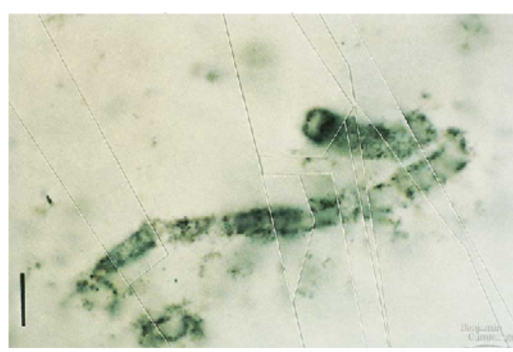


4

Diversity of Prokaryotes
Bacteria & Archaea

5

Early prokaryote fossil



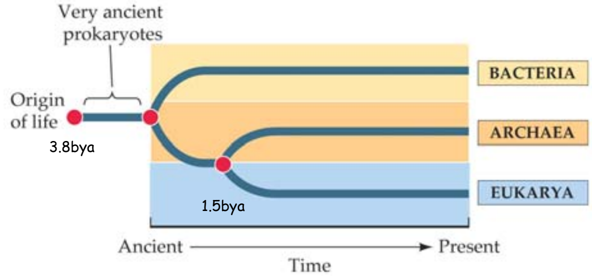
6

What are microbes?

- Only a minority make us sick
- Robert Koch, Germ Theory of Disease
- In ordinary English, might be anything small
  - bacteria
  - yeast
  - protists
  - viruses
- In science, classify by evolutionary relationships…

7

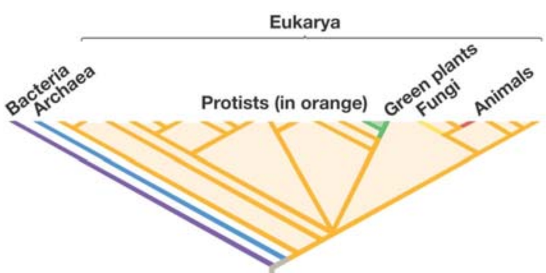
Life can be divided into 3 domains



- Prokaryotes = bacteria + archaea
- Prokaryote was ancestral and only form for billions of years

8

Eukarya



are Prokaryotes monophyletic, paraphyletic, polyphyletic?

9

Scheme has been revised before:

Haeckel (1894) Three kingdoms	Whittaker (1959) Five kingdoms	Woese (1977) Six kingdoms	Woese (1990) Three domains
Protista	Monera (prokaryotes)	Eubacteria	**Bacteria**
		Archaebacteria	**Archaea**
	Protista	Protista	**Eukarya**
Plantae	Fungi	Fungi	
	Plantae	Plantae	
Animalia	Animalia	Animalia	

modified from Wikipedia

10

Shared by all 3 domains

- Glycolysis (use glucose to get ATP)
- Semiconservative DNA replication: (2 strands in double helix, during replication each daughter cell gets one strand from parent, other is new)
- DNA encodes polypeptides
- Polypeptides produced by transcription and translation according to genetic code
- Plasma membranes and ribosomes

11

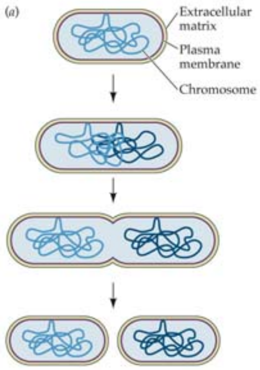
Unique to Prokaryotes

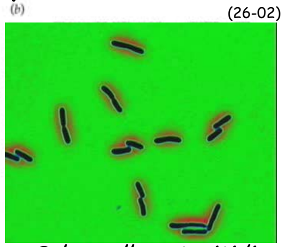
- Circular chromosome
- Genes organized into operons
- NO
  - nucleus: translation of mRNA into protein begins before transcription of DNA into mRNA is complete
  - organelles
  - cytoskeleton
  - meiosis [Genes can still get moved around in other ways, both within and between species. The latter is horizontal gene transfer. Antibiotic resistance can spread in this way.]

12

Divide by fission

(26-02)





Salmonella enteritidis

360x real speed:

replicate in 30 min.

http://life8eiml.sinauer.com/Videos/Video-26-02.mpg

13

Prokaryotes are everywhere

- All around us and in us, too:
- Way more bacteria + archaea on your skin & in your intestinal tract than "you" cells
  - WE ARE HABITAT
- > 3×10^{28} in ocean (vs. visible stars in universe)
- Some survive extreme heat, alkalinity, saltiness
- Bottom of the sea
- Rocks more than 2km into Earth's solid crust

14

What do they look like?

Predominantly unicellular

spheres
coccus/cocci

rods
bacillus/bacilli

curved/spiral

may be found singly or in 2D/3D chains/plates/blocks

≠ multicellular: each cell is viable independently

15

Biofilms

- Many prokaryotes (and some other microbes) lay down a gel-like substance on a surface. This matrix traps others, forming a biofilm.
- Biofilms can make bacteria difficult to kill. Pathogenic bacteria may form a film that is impermeable to antibiotics, for example.
- Dental plaque is a biofilm

16

Bioluminescence

- Some bacteria make light
- Useful for getting into a new fish gut!

LIFE 8e, Figure 26.8

17

Most common bacterial motion is via flagella

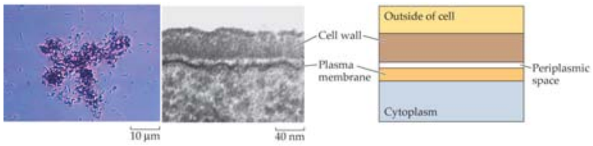
Fibril of flagellin protein, plus a hook and basal body

Rotates about its base

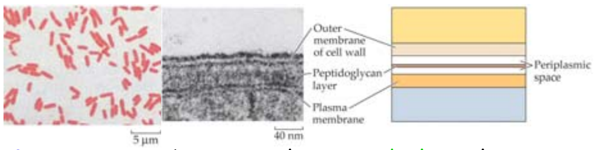
Different from eukaryotic flagellum, which beats

18

Cell wall differences seen by Gram stain



Gram-positive bacteria: dense peptidoglycan cell wall



Gram-negative bacteria: thin peptidoglycan layer, behind outer membrane

19

Exploiting unique bacterial features

- Peptidoglycan cell walls unique to bacteria: not found in eukaryotes or archaea
- Many antibiotics disrupt cell-wall synthesis
- This affects only bacteria, and has little or no effect on eukaryotic cells

20

Morphology gives only limited view of bacterial diversity

Huge diversity in metabolic pathways
- oxygen tolerance
- **energy source**
- **carbon source**
- nitrogen and sulfur metabolism

21

Bioremediation? Hydrogen Production?

-Clean up oil spills, toxins
-Produce chemicals we find useful

Enrichment Cultures

grow microbes under variable conditions and see which thrive

22

6 nutritional categories (energy, carbon)

1. Photoautotrophs
   energy from **light**, carbon from CO_2
2. Photoheterotrophs
   energy from **light**, C from other organisms
3. Chemolithotrophs
   energy from oxidizing **inorganic** substances
   carbon from CO_2
   some bacteria, many archaea
4. Chemolithotrophic heterotrophs
   energy from oxidizing **inorganic** substances
   carbon from other organisms

23

6 nutritional categories (energy, carbon)

5. Chemoorganoautotrophs
   energy from other organisms, carbon from CO_2
6. Chemoorganoheterotrophs
   energy and carbon from other organisms
   - most known prokaryotes, all animals, fungi, many protists

3 ways to get energy x 2 ways to get carbon = 6 nutritional (metabolic) categories

24

Prokaryotic Metabolic Variety

6 Metabolic Categories	Energy Source	Carbon Source
Photoautotrophs	light	CO_2
Photoheterotrophs	light	other organisms
Chemolithotrophs	oxidizing inorganic substances	CO_2
Chemolithotrophic heterotrophs	oxidizing inorganic substances	other organisms
Chemoorganoautotrophs	other organisms	CO_2
Chemoorganoheterotrophs	other organisms	other organisms

Evolution of Photosynthesis in Cyanobacteria

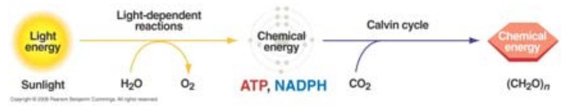


Figure 27.11 *Cyanobacteria (Part 2)*

OXYGEN

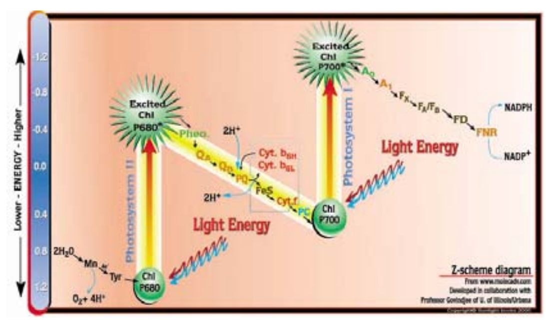
None in atmosphere for first 2.3 billion years

Cyanobacteria evolved photosynthesis (oxygenic): (ATP + water + oxygen)

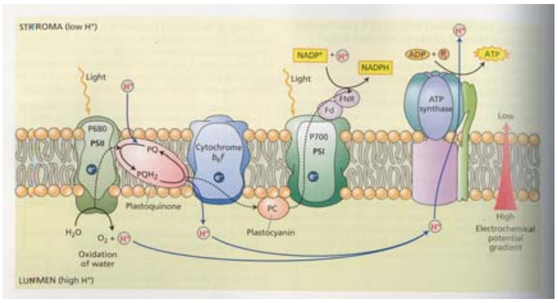
Aerobic more efficient than anaerobic

Oxygen

- Early earth had little free oxygen (O_2)
- 2.5 bya prokaryotes evolved ability to split $2H_2O \rightarrow 4H^+ + O_2 + 4e^-$
- Electrons used to reduce CO_2 and make organic compounds.
- O_2 was a waste product.



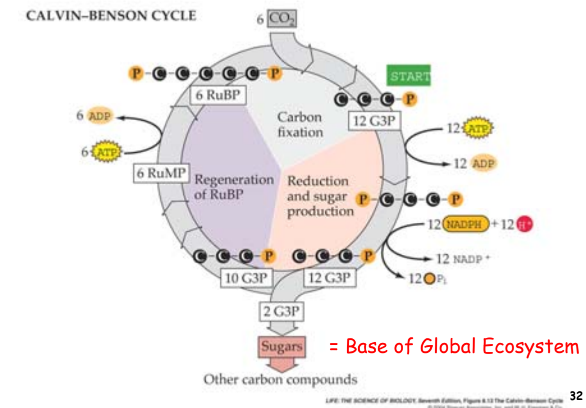
Stealing electrons	capturing light energy	producing high energy compounds



Then make glucose (and other sugars) …

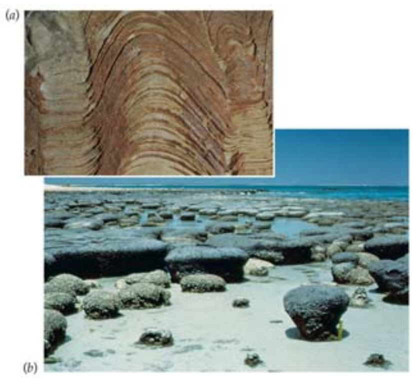
31

Figure 8.13 *The Calvin-Benson Cycle*



32

Oxygen-generating cyanobacteria form rocklike structures called stromatolites

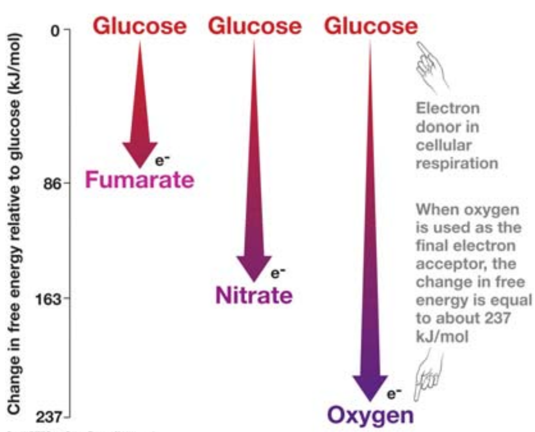


33

Oxygen

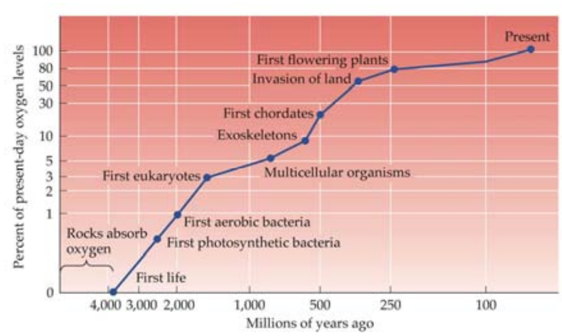
- Oxygen was poison when it first appeared
- Organisms evolved not just to tolerate oxygen, but to thrive
- Aerobic metabolism faster and more efficient

34



35

Increasing oxygen in atmosphere



Aerobic vs anaerobic metabolism

1. Oxygen is toxic to obligate anaerobes
2. Facultative anaerobes can shift between anaerobic metabolism (such as fermentation) and the aerobic mode (cellular respiration).
3. Aerotolerant anaerobes don't use oxygen, but aren't damaged by it
4. Obligate aerobes cannot survive without oxygen

37

Nitrogen and sulfur metabolism

Some bacteria use oxidized inorganic ions, such as nitrate, nitrite or sulfate

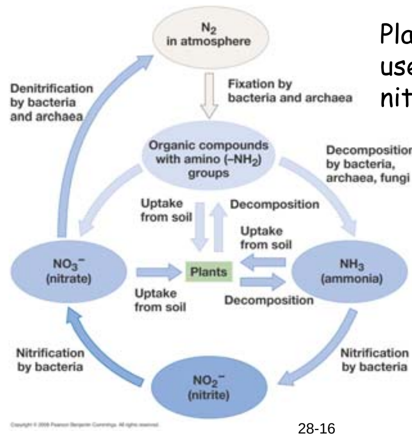
- Denitrifiers
- Nitrogen fixers
- Nitrifiers
- Sulfur-based metabolism

38

Prokaryotes are important in element cycling

- Plants depend on prokaryotic nitrogen-fixers
- Denitrifiers prevent accumulation of toxic levels of nitrogen in lakes and oceans

39



28-16

Plants can't use elemental nitrogen (N_2)

40

Nitrogen fixers

- Convert atmospheric N_2 gas into ammonia by means of the following reaction:

$$N_2 + 6\ H \rightarrow 2\ NH_3$$

- All organisms require fixed nitrogen (not N_2) for their proteins, nucleic acids, and other nitrogen-containing compounds
- Only archaea and bacteria, including some cyanobacteria, can fix nitrogen

41

TABLE 28.5 Some Electron Donors and Acceptors Used by Bacteria and Archaea

		By-Products		
Electron Donor	Electron Acceptor	From Electron Donor	From Electron Acceptor	Category*
Sugars	O_2	CO_2	H_2O	Organotrophs
H_2 or organic compounds	SO_4^{2-}	H_2O or CO	H_2S	Sulfate reducers
H_2	CO_2	H_2O	CH_4	Methanogens
CH_4	O_2	CO_2	H_2O	Methanotrophs
S^{2-} or H_2S	O_2	SO_4^{2-}	H_2O	Sulfur bacteria
Organic compounds	Fe^{3+}	CO_2	Fe^{2+}	Iron reducers
NH_3	O_2	NO_2^-	H_2O	Nitrifiers
Organic compounds	NO_3^-	CO_2	N_2O, NO, or N_2	Denitrifiers (or nitrate reducers)
NO_2^-	O_2	NO_3^-	H_2O	Nitrosifiers

*The name biologists use to identify species that use a particular metabolic strategy.

We use sugars as electron donor and oxygen as electron acceptor when making energy (=Cellular Respiration)

Prokaryotes Variable!

42

Sulfur-based metabolism

Some photoautotrophic bacteria and chemolithotrophic archaea use H_2S as an electron donor instead of H_2O

Archaea stave off global warming

- 10 trillion tons of methane lying deep under the ocean floor
- Archaea at the bottom of the seas metabolize this methane as it rises
- Otherwise global warming would be extreme

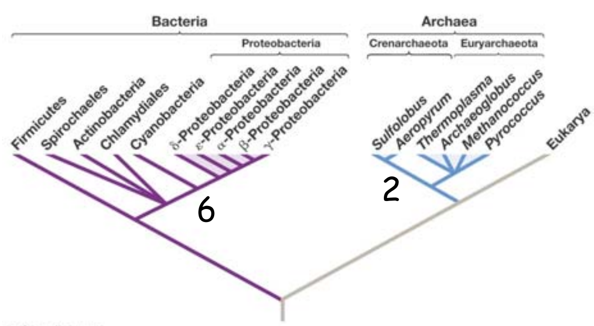
Prokaryotes live on and in other organisms

- **Mitochondria and chloroplasts are descendents of free-living bacteria**
- Plants and bacteria form cooperative nitrogen-fixing nodules on plant roots
- Ruminants depend on prokaryotes to digest cellulose
- Humans use vitamins produced by our intestinal bacteria

A very few bacteria are pathogens

- Endotoxins
  - e.g. *Salmonella* and *Escherichia*
  - released when bacteria die or lyse (burst)
  - lipopolysaccharides from the outer membrane of Gram-negative bacteria
  - usually cause fever, vomiting, diarrhea
- Exotoxins
  - e.g. tetanus, botulism, cholera, plague, anthrax
  - released by living, multiplying bacteria
  - can be highly toxic, even fatal without fever

Diversity of prokaryotes

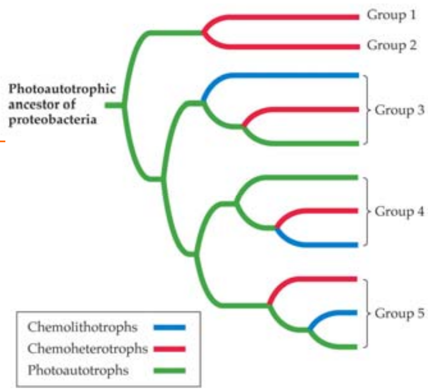


Diversity of prokaryotes

- We will discuss 6 clades of bacteria and 2 of archaea
- More are known
- More still are uncharacterized: can be hard to culture in lab
- PCR allows sequencing of unculturable organisms
- Phylogeny based primarily on DNA sequence: other traits can evolve rapidly

1. Proteobacteria

- "purple bacteria"
- ancestor of mitochondria
- Some fix nitrogen (*Rhizobium*)
- *E. coli*
- Some cycle nitrogen and sulfur



50

2. Cyanobacteria

- "blue-green" bacteria
- photoautotrophs
- transformed Earth with O_2
- many fix nitrogen
- ancestor of chloroplasts

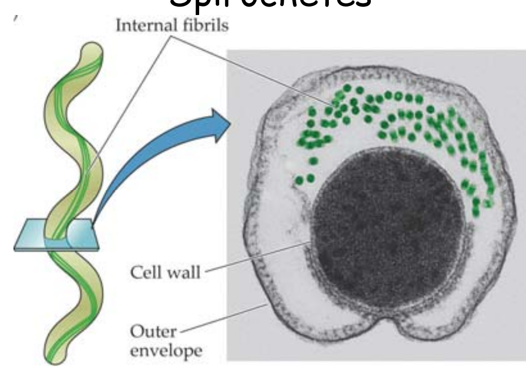
3. Spirochetes

Treponema pallidum 200 nm

- Gram-negative
- motile
- chemoheterotrophic
- some are human parasites
- cause syphilis and Lyme disease

51

Spirochetes



Axial filaments produce corkscrew-like motion

4. Chlamydias

- extremely small: 0.2-1.5 μm diameter
- Gram-negative cocci
- can only live as parasites
- cause
  - sexually transmitted disease
  - eye infections (especially trachoma)
  - some forms pneumonia

53

5. Firmicutes

- mostly Gram-positive
- some produce dormant endospores to wait out bad times e.g heat, cold, drought
  - replicate DNA and encapsulate one copy in a tough cell wall
  - parent cell breaks down, releasing endospore
  - some endospores can be reactivated after more than a thousand years of dormancy

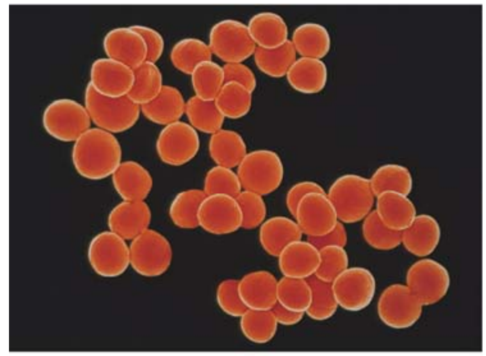
54

Firmicutes

Clostridium tetani 1 µm

55

Staphylococcus is a firmicute

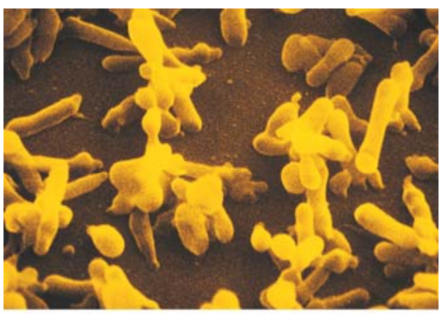


Staphylococcus aureus 1 µm

56

Mycoplasmas are firmicutes

- no cell walls
- smallest known cellular organisms
- very little DNA



Mycoplasma gallisepticum 0.2 µm

6. Actinobacteria
often w/ branching filaments

Mycobacterium tuberculosis is an actinomycete

Most of our antibiotics come from actinomycetes e.g. *Streptomyces*

Actinomyces sp. 2 µm

Archaea

- We don't know much
- None are human pathogens
- Most live in extreme environments: temperature, salinity, oxygen concentration, or pH
- Have distinctive lipids in their membranes
- Look at 2 groups
  - Crenarchaeota
  - Euryarchaeota

59

1. Crenarchaeota

- Most are thermophilic and acidophilic
- *Sulfolobus* live in hot sulfur springs, die of cold at 131°F

2. Euryarchaeota

- Some are methanogens, producing CH_4 from CO_2
- Responsible for 80-90% atmospheric methane, often from belching cows
- CH_4 is potent greenhouse gas

61

Some Euryarchaeota are halophiles

- very salty environments
- most organisms “dry” to death
- contain pink carotenoids
- live in commercial evaporating ponds