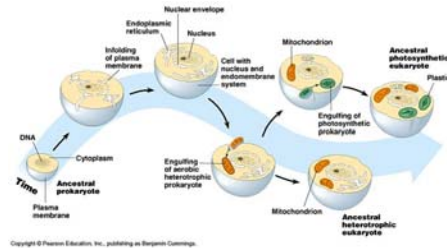


Prokaryotes, Protists, Photosynthesis, Endosymbiosis



Ch 28 & 29



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

1

Reconstructing the evolution of living things

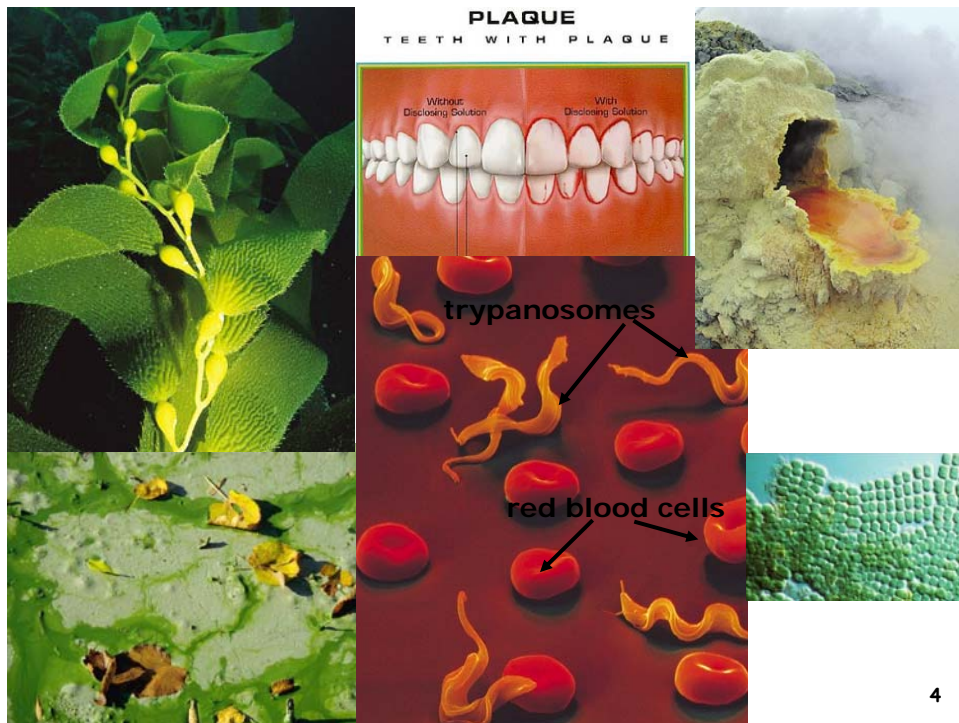
- *Systematists* study evolutionary relationships
- Look for *shared derived* (=different from ancestor) *traits* to group organisms
- Evidence used: morphology, development, and **molecular data** (especially DNA sequences)

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



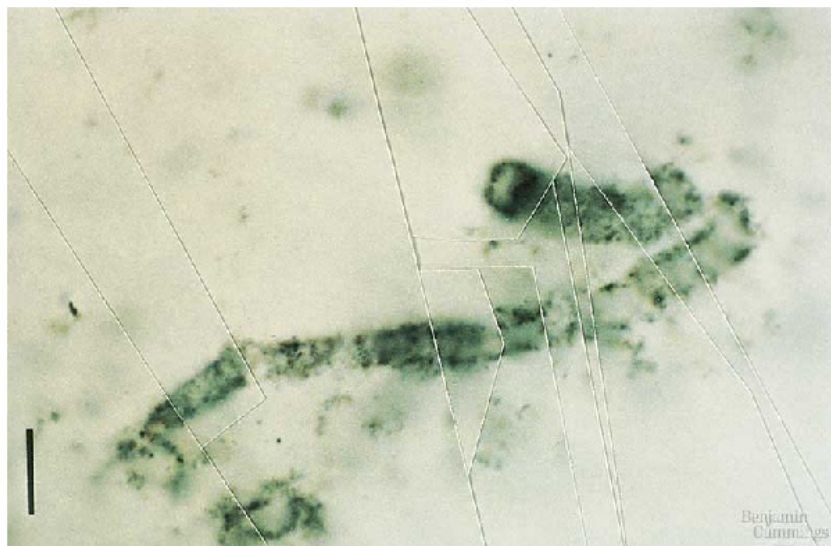
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Diversity of Prokaryotes

Bacteria & Archaea

5

Early prokaryote fossil



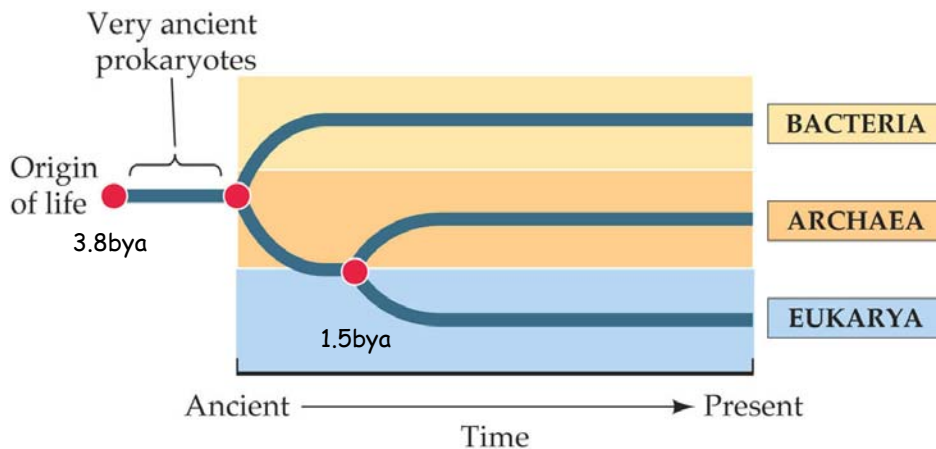
6

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

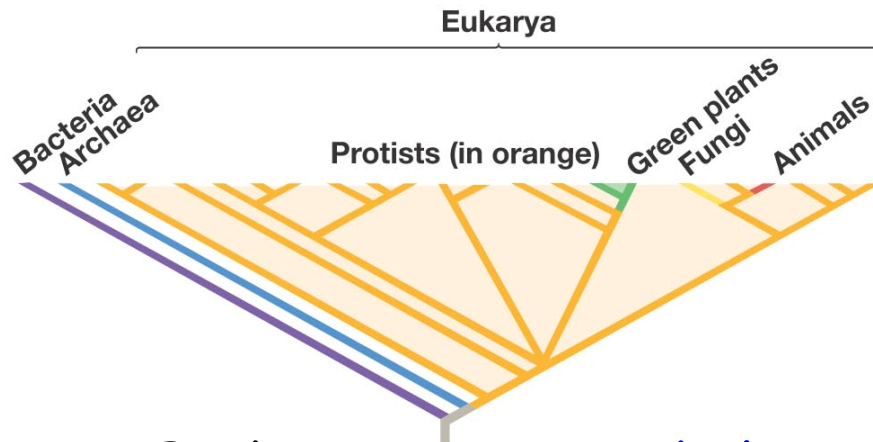
Life can be divided into 3 domains



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

8

Eukarya



are Prokaryotes **monophyletic**,
paraphyletic, **polyphyletic**?

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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
		Archaeobacteria	Archaea
Plantae	Fungi	Fungi	Eukarya
	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**

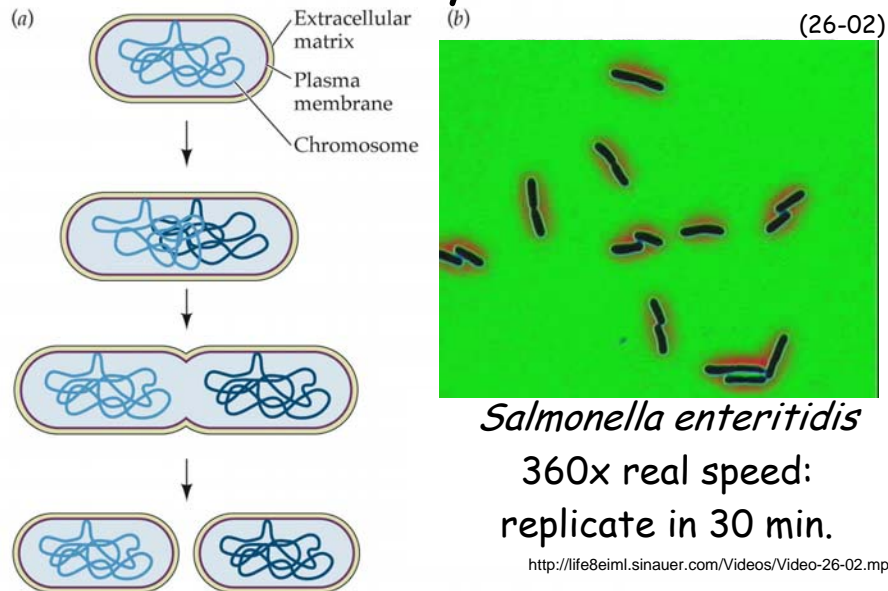
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Unique to Prokaryotes

- **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.]

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Divide by fission



LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 9.2 Prokaryotic Cell Division
© 2004 Sinauer Associates, Inc. and W. H. Freeman & Co.

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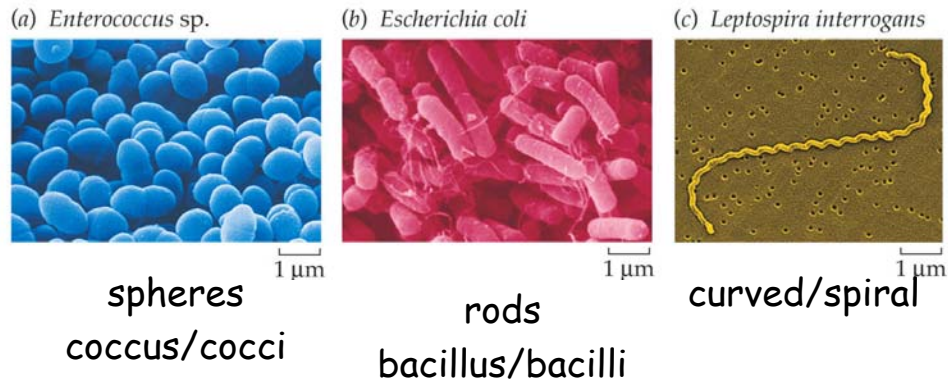
Prokaryotes are everywhere

- All around us and in us, too:
- Way more bacteria + archaea on your skin & in your intestinal tract than "you" cells
- WE ARE HABITAT
- $> 3 \times 10^{28}$ 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

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What do they look like?

Predominantly unicellular



may be found singly or in 2D/3D chains/plates/blocks
≠ multicellular: each cell is viable independently

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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

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Bioluminescence

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

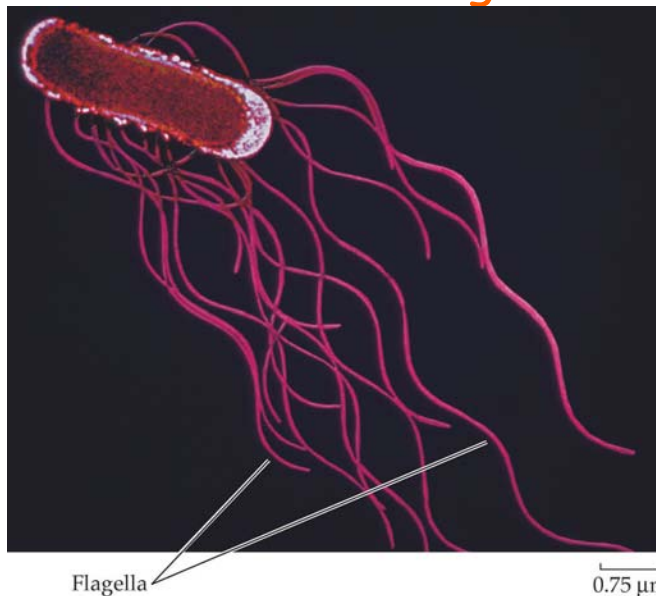


LIFE 8e, Figure 26.8

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Most common bacterial motion is via
flagella

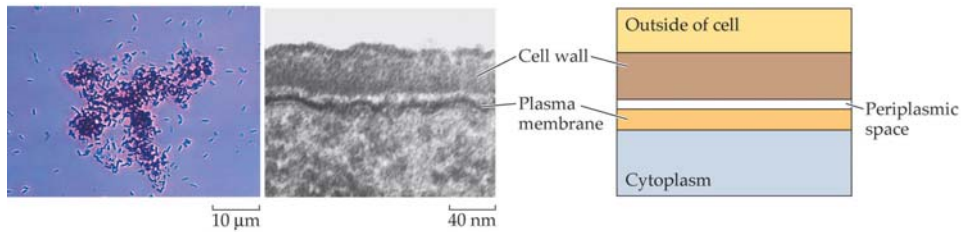


Fibril of
flagellin
protein, plus a
hook and basal
body

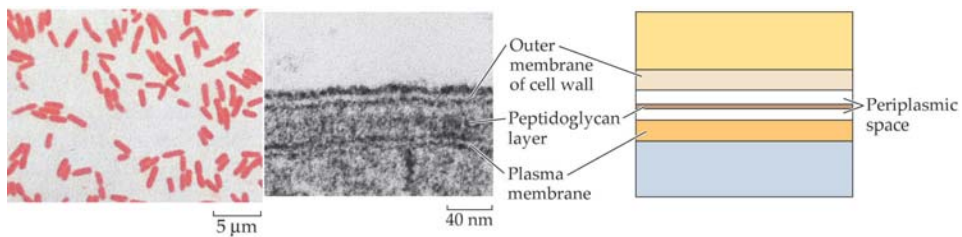
Rotates about
its base

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

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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

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Morphology gives only limited view of bacterial diversity

Huge diversity in **metabolic pathways**

- oxygen tolerance
- energy source
- carbon source
- nitrogen and sulfur metabolism

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Bioremediation? Hydrogen Production?

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

Enrichment Cultures

grow microbes under variable conditions and see which thrive

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6 nutritional categories (energy, carbon)

1. Photoautotrophs
energy from light, carbon from CO₂
2. Photoheterotrophs
energy from light, C from other organisms
3. Chemolithotrophs
energy from oxidizing inorganic substances
carbon from CO₂
some bacteria, many archaea
4. Chemolithotrophic heterotrophs
energy from oxidizing inorganic substances
carbon from other organisms

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6 nutritional categories (energy, carbon)

5. Chemoorganoautotrophs
energy from other organisms, carbon from CO₂
6. Chemoorganoheterotrophs
energy and carbon from other organisms
 - most known prokaryotes, all animals, fungi, many protists

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

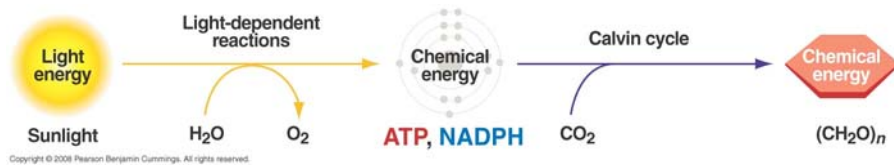
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Prokaryotic Metabolic Variety

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

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Evolution of Photosynthesis in Cyanobacteria



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Figure 27.11 Cyanobacteria (Part 2)



LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 27.11 Cyanobacteria (Part 2)
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OXYGEN

None in atmosphere for first 2.3 billion years

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

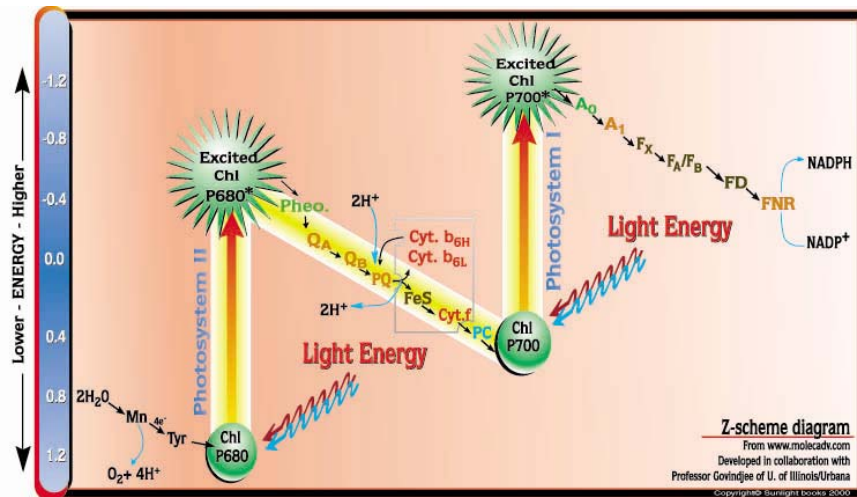
Aerobic more efficient than anaerobic

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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.

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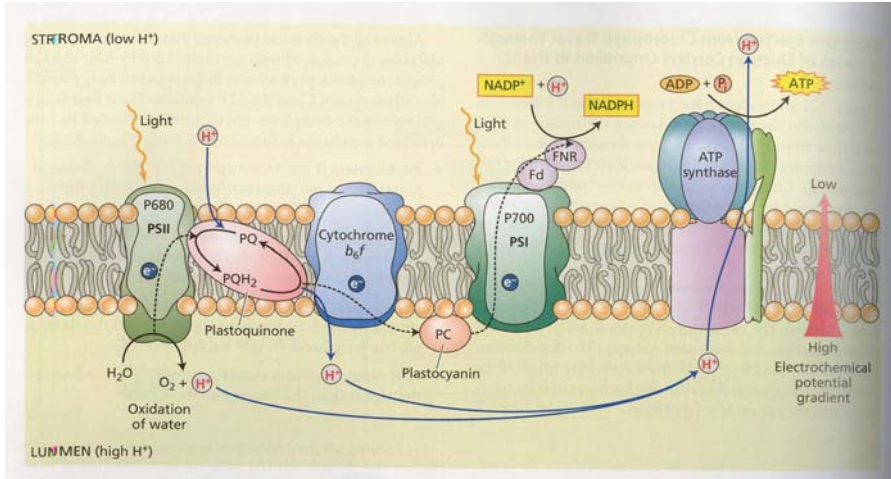


Stealing electrons

capturing light energy

producing high energy compounds

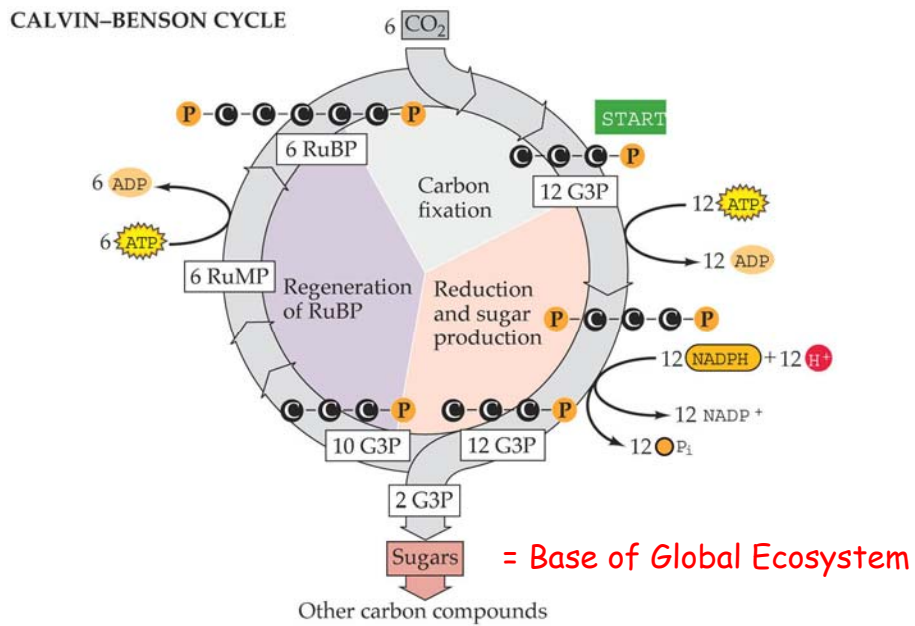
30



Then make glucose (and other sugars) ...

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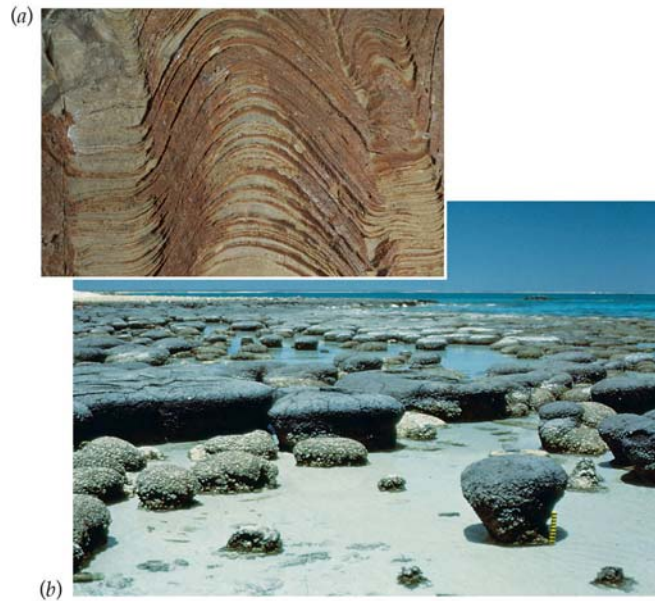
Figure 8.13 The Calvin-Benson Cycle



LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 8.13 The Calvin-Benson Cycle
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Oxygen-generating cyanobacteria form rocklike structures called stromatolites

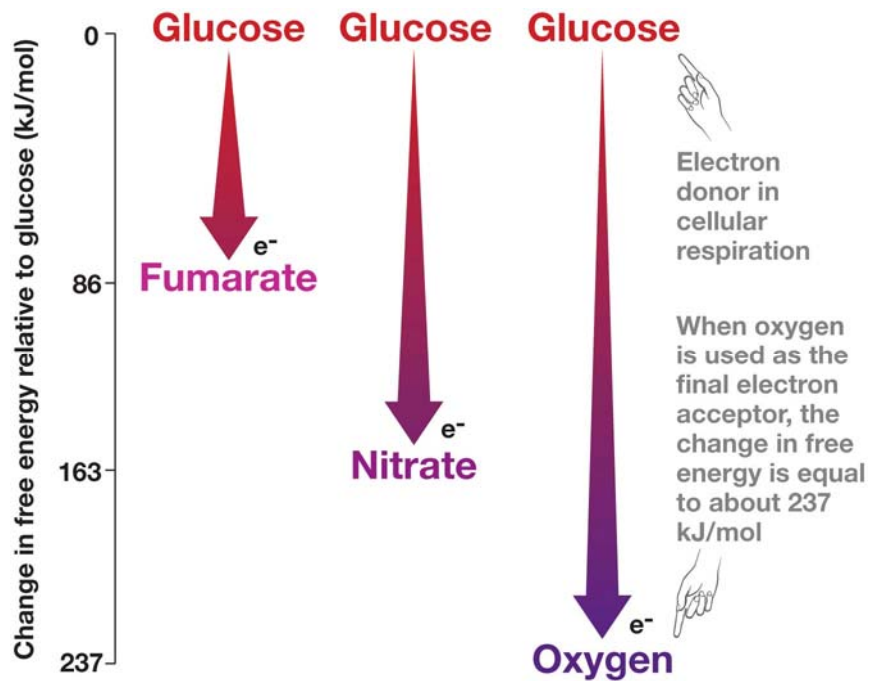


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Oxygen

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

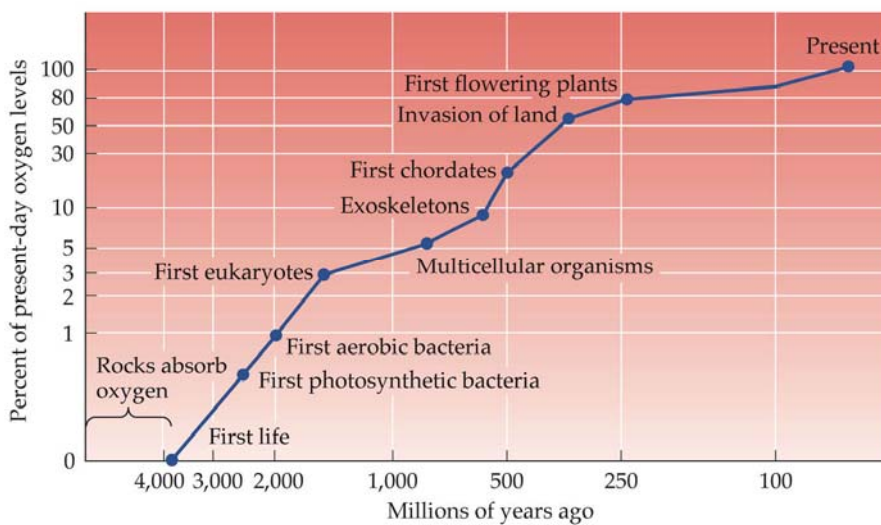
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Increasing oxygen in atmosphere



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

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Nitrogen and sulfur metabolism

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

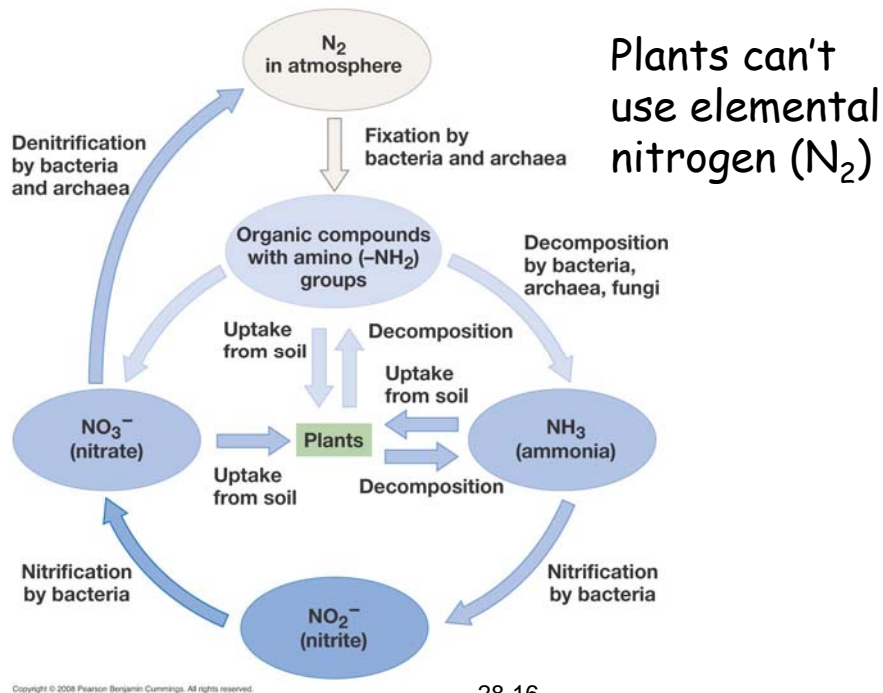
- **Denitrifiers**
- **Nitrogen fixers**
- **Nitrifiers**
- Sulfur-based metabolism

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Prokaryotes are important in element cycling

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

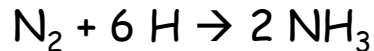
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Nitrogen fixers

- Convert atmospheric N₂ gas into ammonia by means of the following reaction:



- All organisms require fixed nitrogen (not N₂) for their proteins, nucleic acids, and other nitrogen-containing compounds
- Only archaea and bacteria, including some cyanobacteria, can fix nitrogen

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

Electron Donor	Electron Acceptor	By-Products		Category*
		From Electron Donor	From Electron Acceptor	
Sugars	O ₂	CO ₂	H ₂ O	Organotrophs
H ₂ or organic compounds	SO ₄ ²⁻	H ₂ O or CO	H ₂ S	Sulfate reducers
H ₂	CO ₂	H ₂ O	CH ₄	Methanogens
CH ₄	O ₂	CO ₂	H ₂ O	Methanotrophs
S ²⁻ or H ₂ S	O ₂	SO ₄ ²⁻	H ₂ O	Sulfur bacteria
Organic compounds	Fe ³⁺	CO ₂	Fe ²⁺	Iron reducers
NH ₃	O ₂	NO ₂ ⁻	H ₂ O	Nitrifiers
Organic compounds	NO ₃ ⁻	CO ₂	N ₂ O, NO, or N ₂	Denitrifiers (or nitrate reducers)
NO ₂ ⁻	O ₂	NO ₃ ⁻	H ₂ O	Nitrosifiers

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

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

Prokaryotes Variable!

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Sulfur-based metabolism

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

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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

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Prokaryotes live on and in other organisms

- Mitochondria and chloroplasts are descendants 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

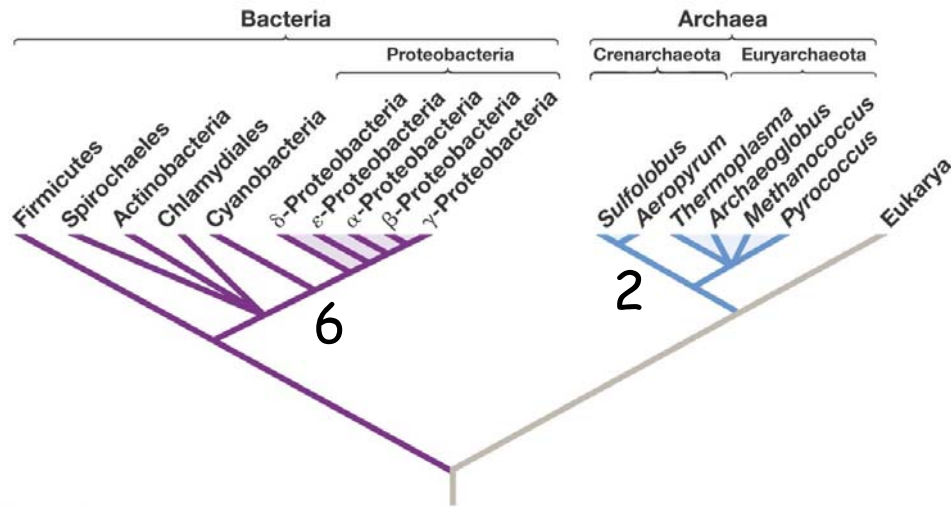
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A very few bacteria are pathogens

- **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

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Diversity of prokaryotes



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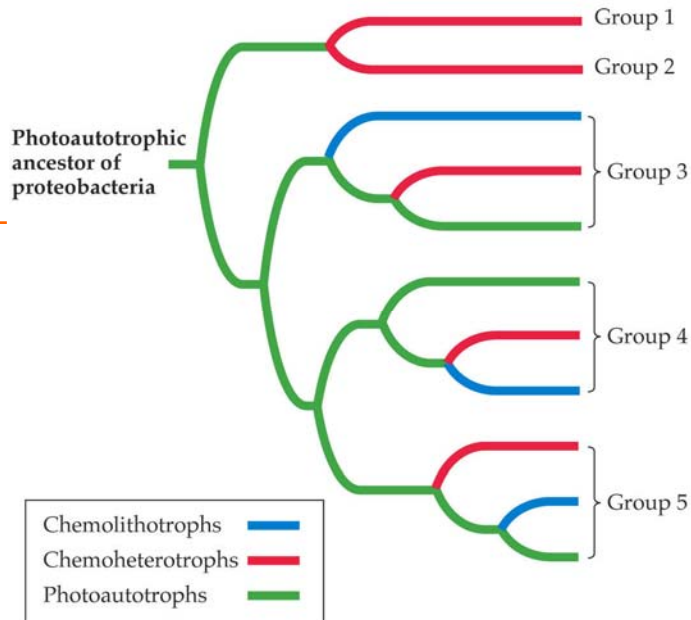
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Diversity of prokaryotes

- 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 ⁴⁸

1. Proteobacteria

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



2. Cyanobacteria

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

3. Spirochetes



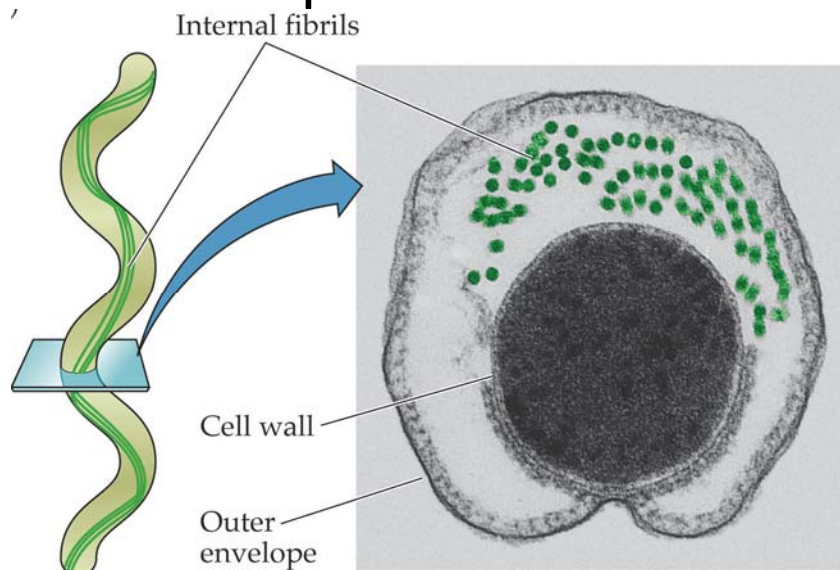
Treponema pallidum

200 nm

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

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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

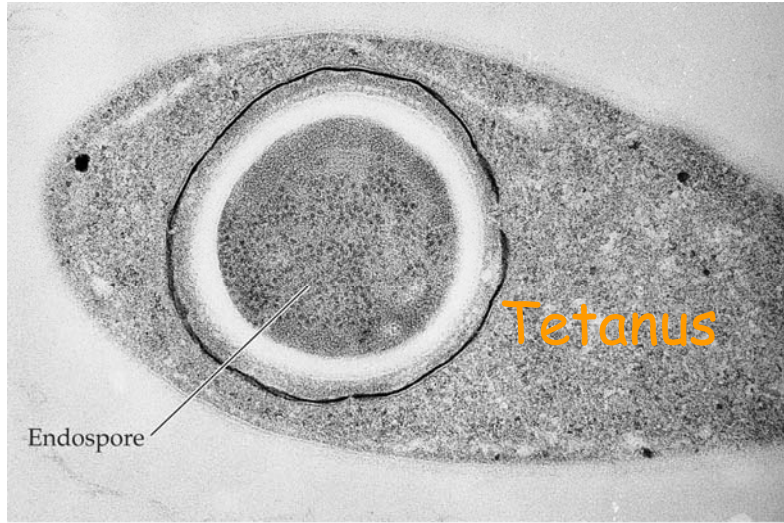
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5. Firmicutes

- 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**

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Firmicutes

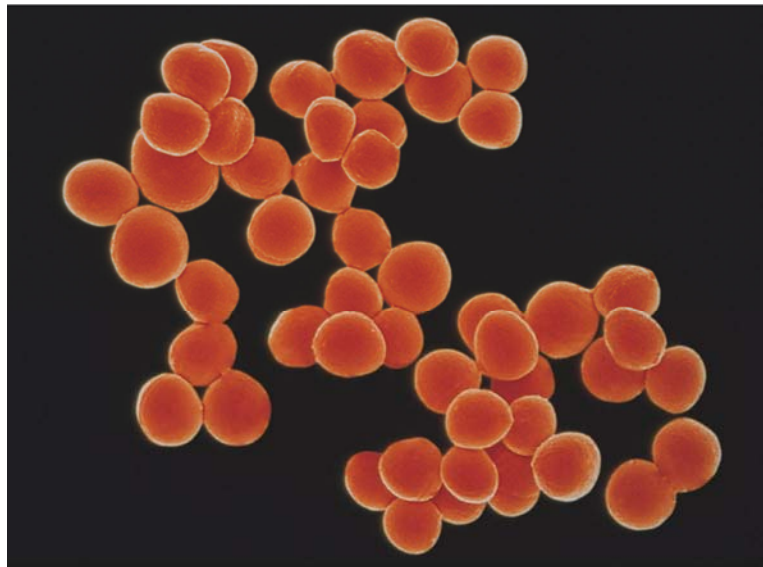


Clostridium tetani

1 μ m

55

Staphylococcus is a firmicute



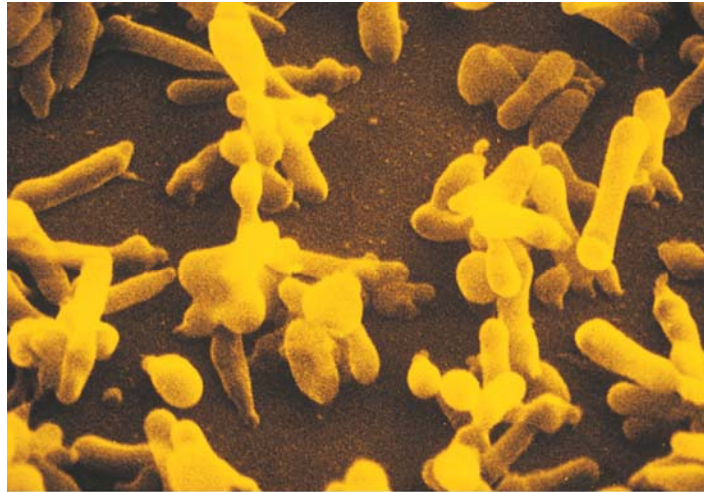
Staphylococcus aureus

1 μ m

56

Mycoplasmas are firmicutes

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



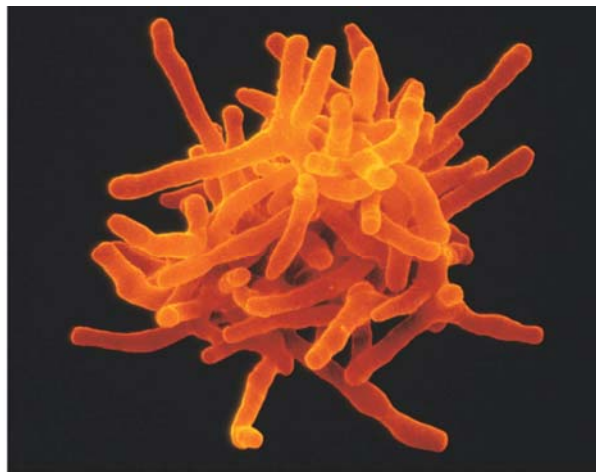
Mycoplasma gallisepticum

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

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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**

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Some Euryarchaeota are **halophiles**

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

