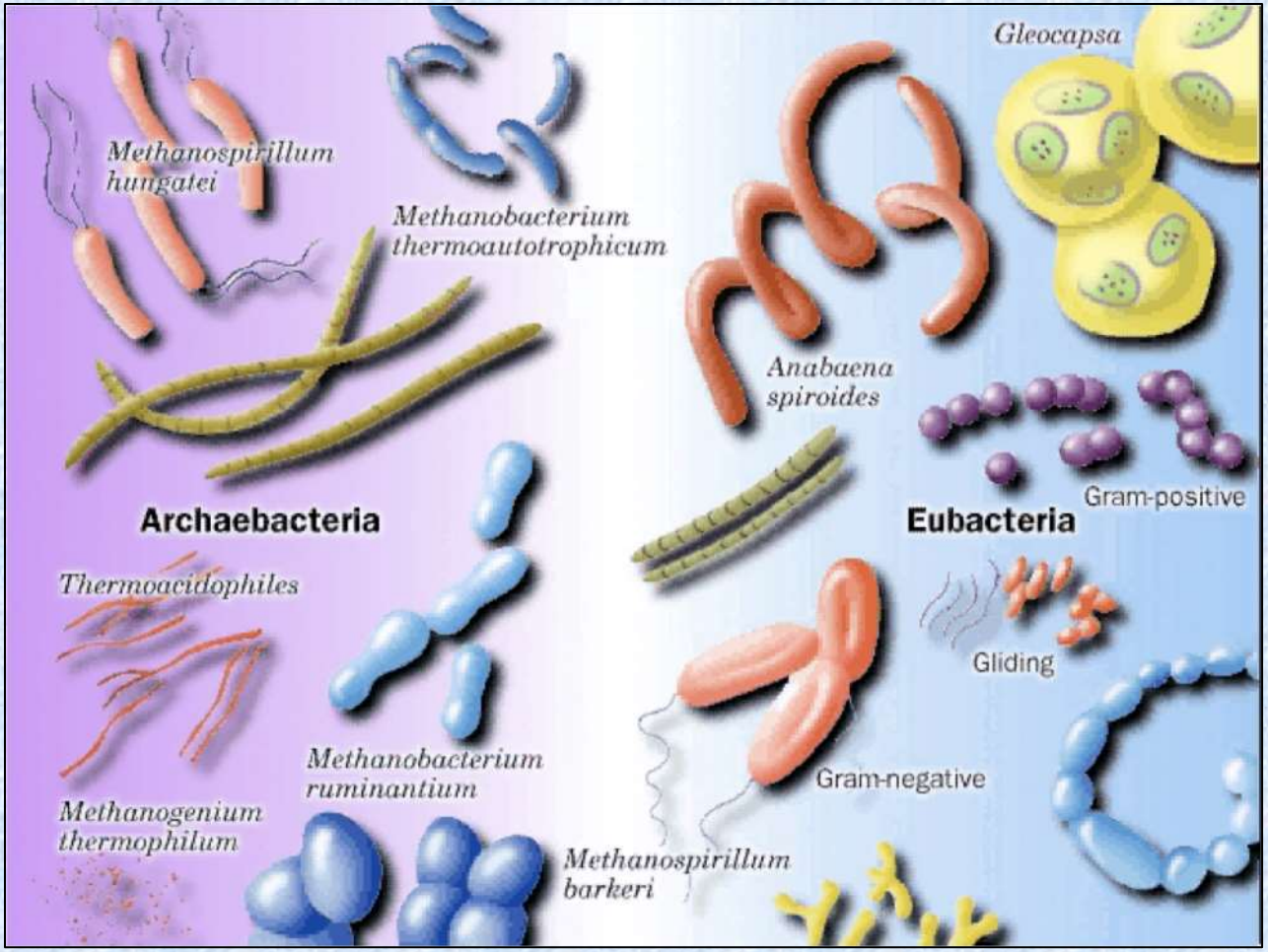
Prokaryotes - Bacteria and Archaea



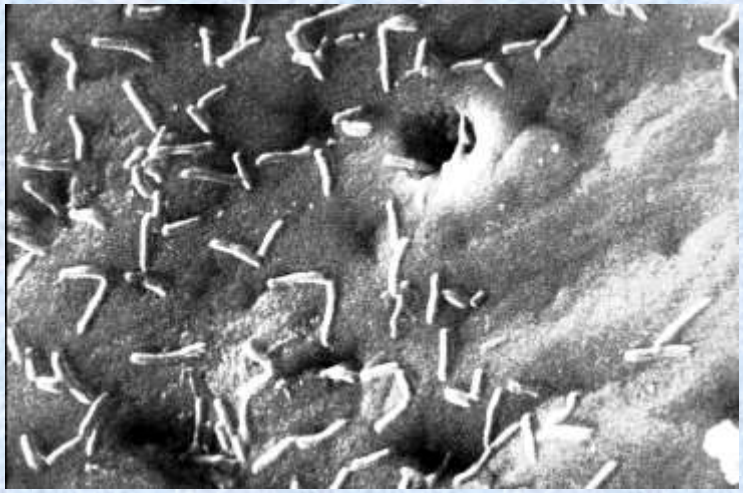
The Prokaryotes

- Include bacteria and archaea, which are fully functioning cells
- Means “before a nucleus”
- Microscopic
  - Range in size from 1–10 μm in length and 0.7–1.5 μm in width
- Abundant in air, water, and soil and on most objects
- Louis Pasteur showed that a previously sterilized broth cannot become cloudy with growth unless it is exposed directly to the air.

Bacteria - abundance

Head of a pin

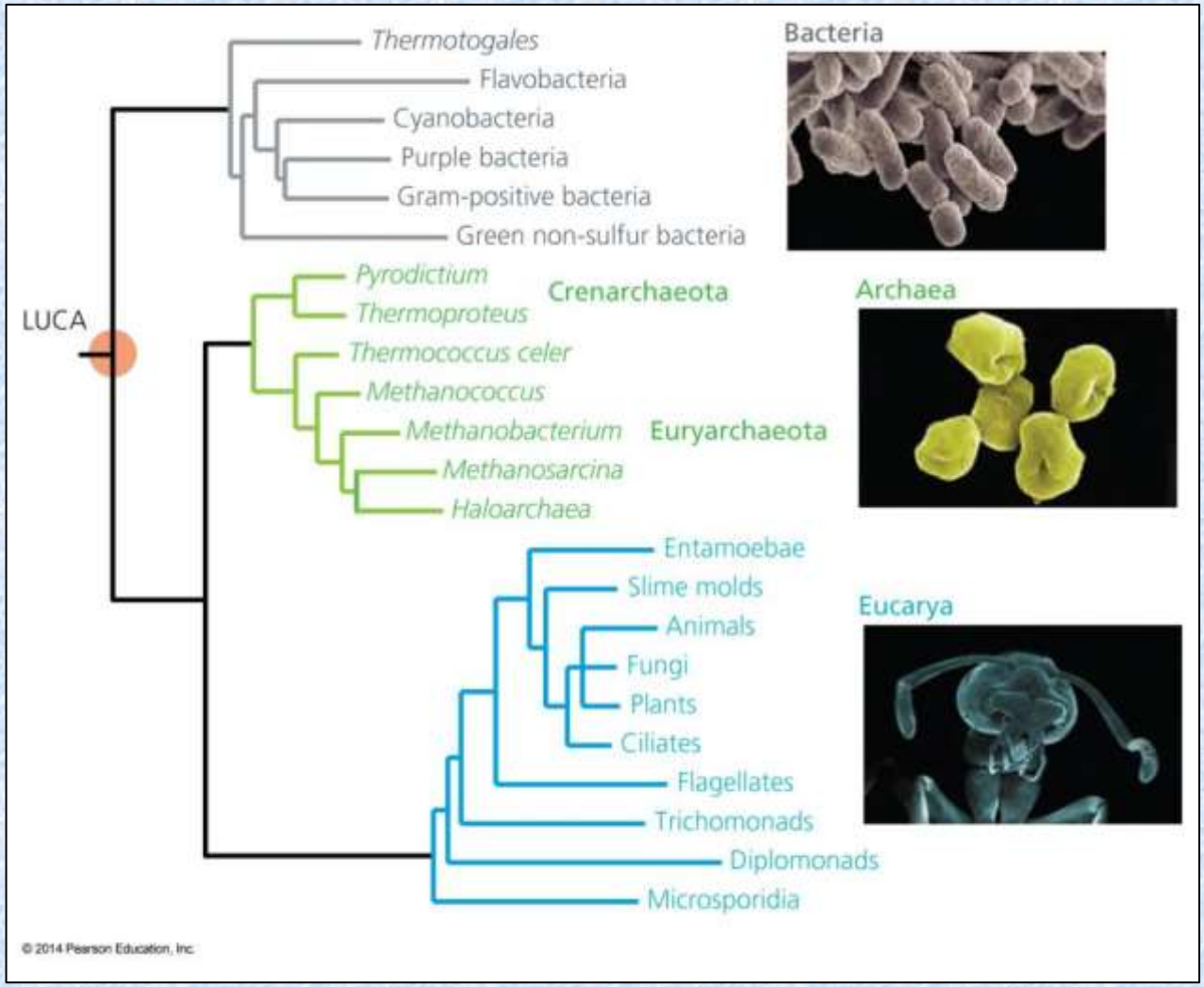
Bacteria in mouth



Freshly brushed teeth

Phylogeny of All Living Organisms

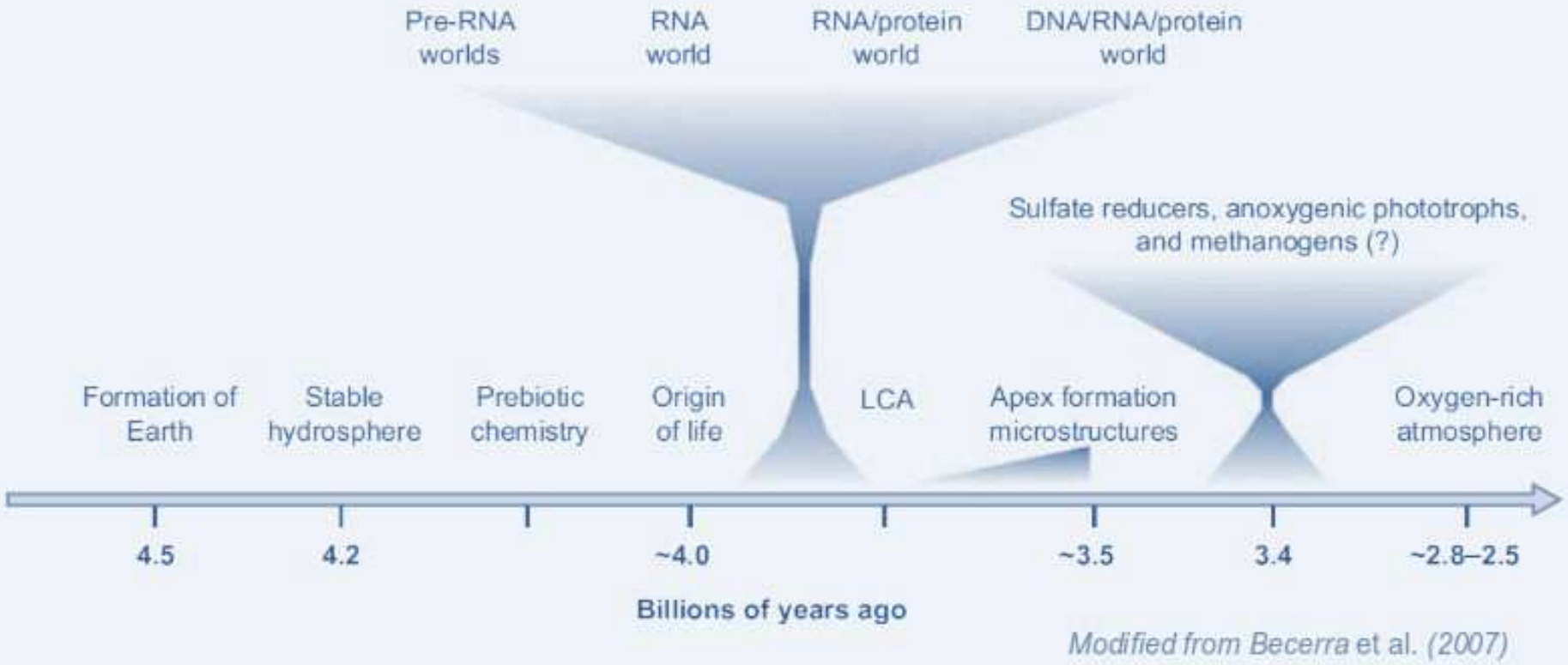
LUCA – Last Universal Common Ancestor



Eukarya is more closely related to domain Archaea than to domain Bacteria. Analysis of rRNAs and other highly conserved genes and proteins provide the strongest evidence

Archean Eon: 4-2 BYA

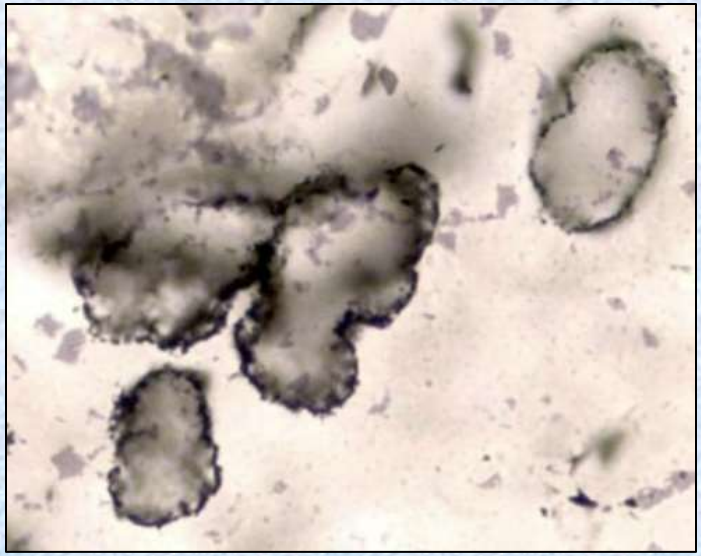
Timeline

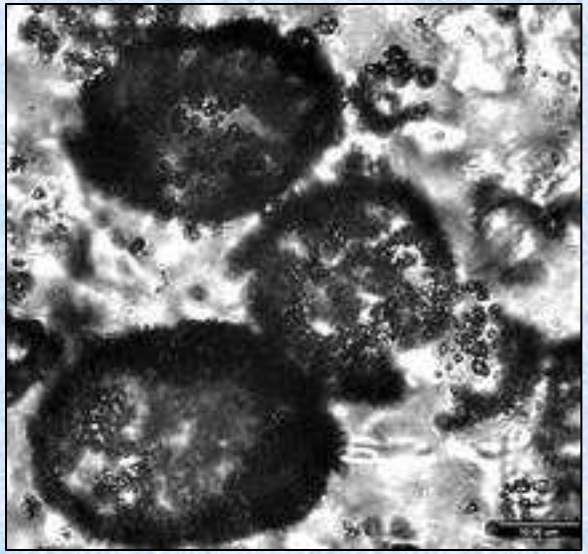


Modified from Becerra et al. *(2007)*

Oldest definite fossils ~3.5 BY

Older fossil evidence questionable

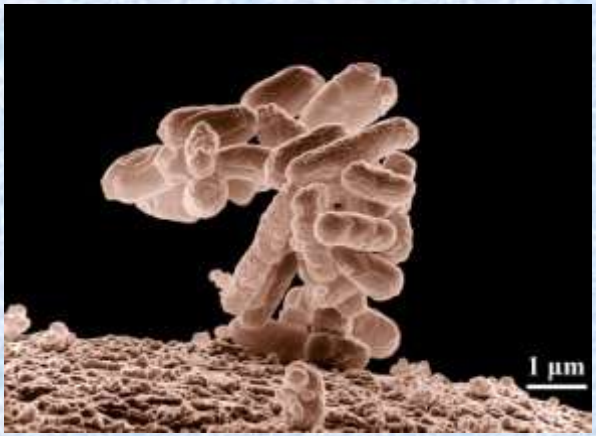


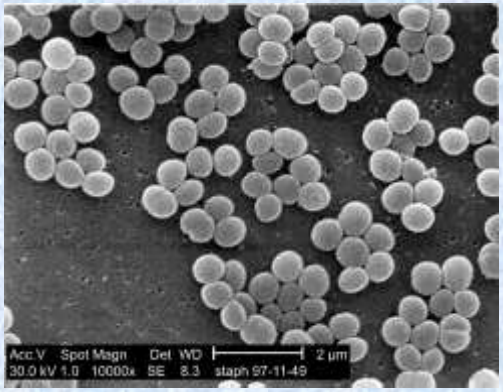


- Found in a remote part of Western Australia
- In some of the oldest sedimentary rocks that can be found anywhere.

Bacteria (Eubacteria)

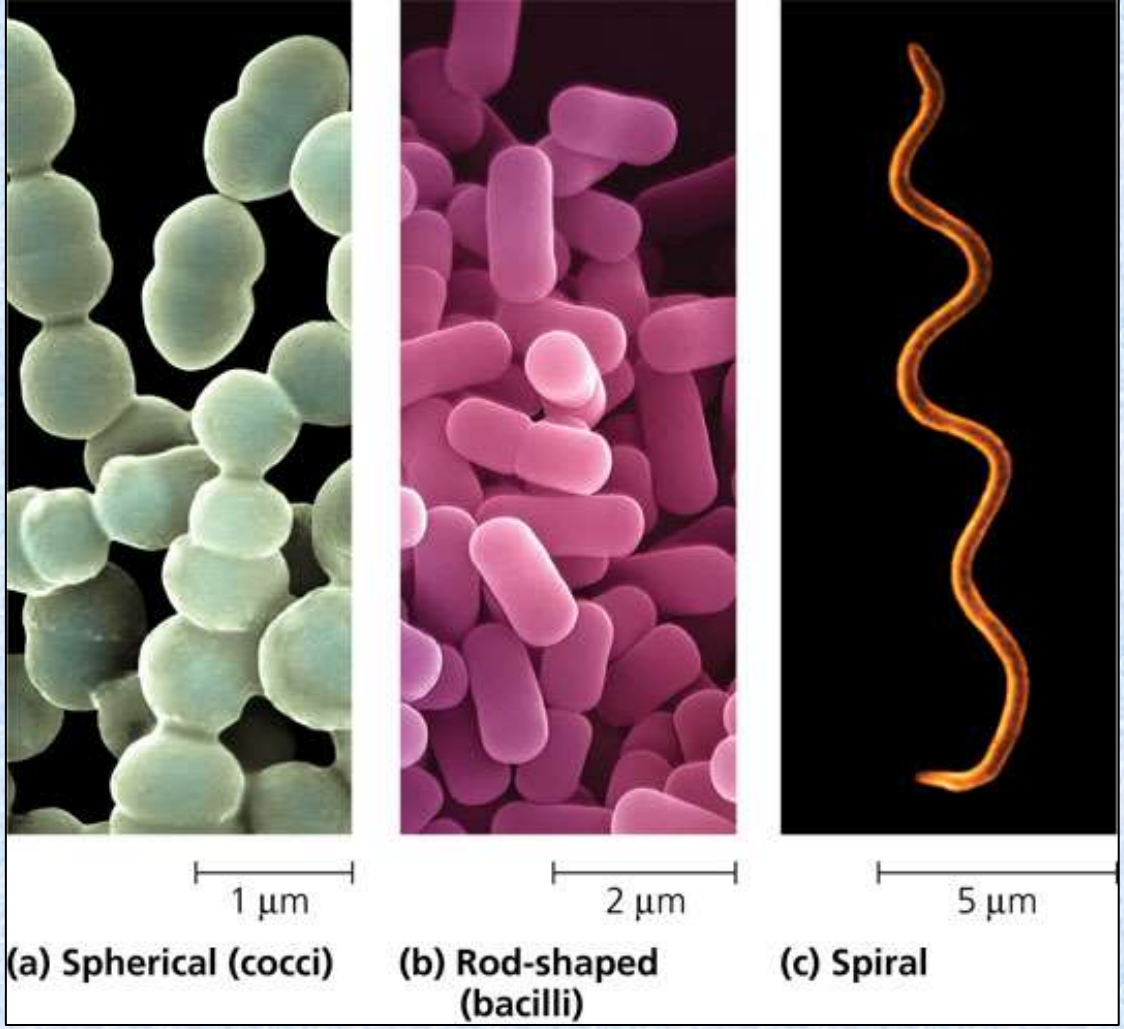
- Major group of prokaryotes
- Strong cell walls (peptidoglycan)
- Simple gene structure
- Contains most modern prokaryotes
- Includes photosynthetic bacteria (cyanobacteria)



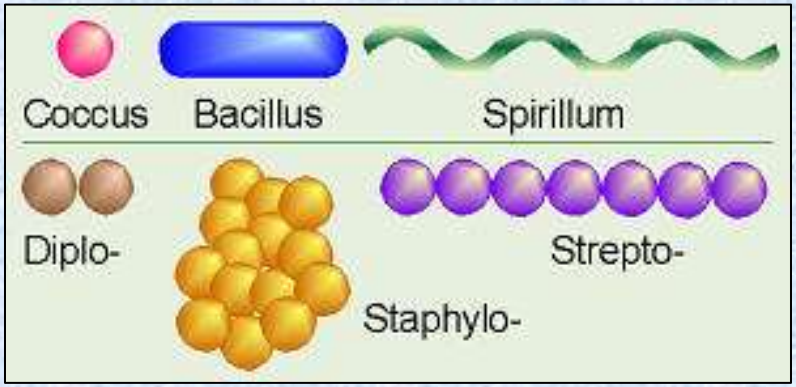


Bacteria
Basic shapes

Cocci – round
Bacilli – rod
Spirilli - spiral

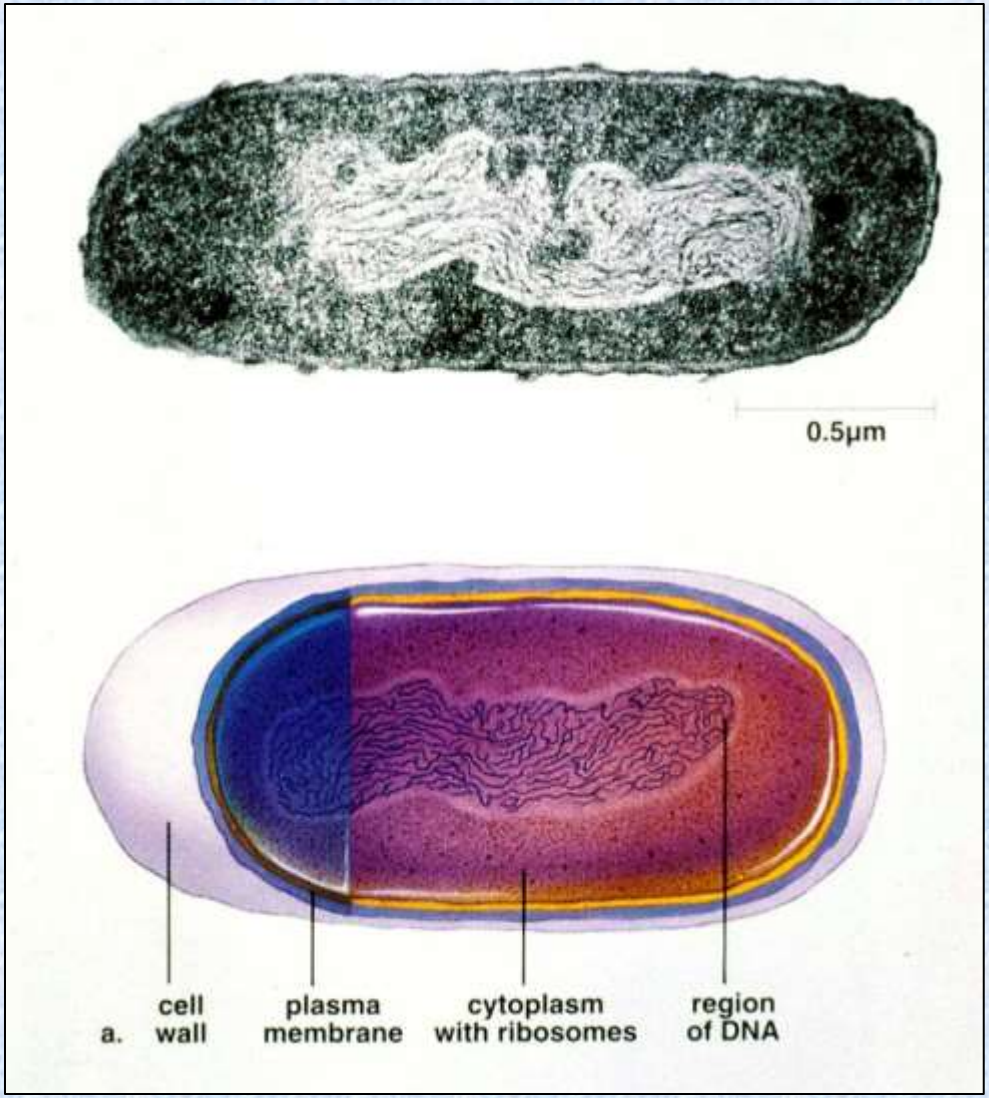


Diplo – paired
Staphylo – clustered
Strepto - chains



Basic Bacteria Morphology

- Prokaryotic, **lacking a nucleus and complex organelles**.
- Have a cell membrane
- Circular DNA
- Cell wall made up of **peptidoglycan** which is a combo of protein and carbohydrate, different from Archaea and Eukaryotes such as plants or fungi.

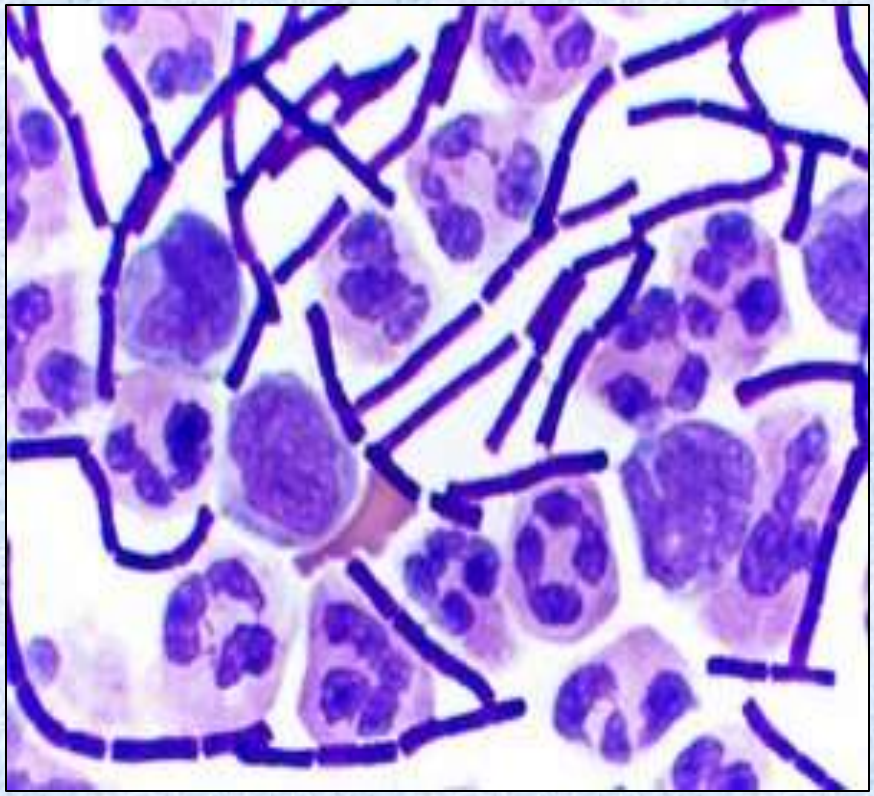


Two Types of Bacterial Cell Walls

Gram Positive

Thick Cell Wall

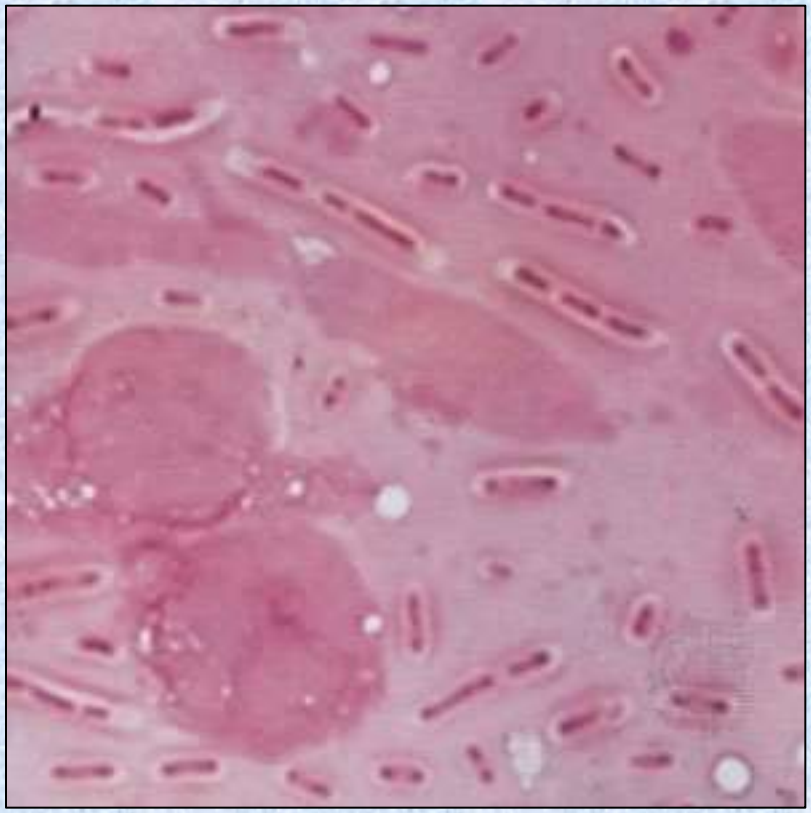
(Less Common)



Gram Negative

Thin Cell Wall with lipoproteins

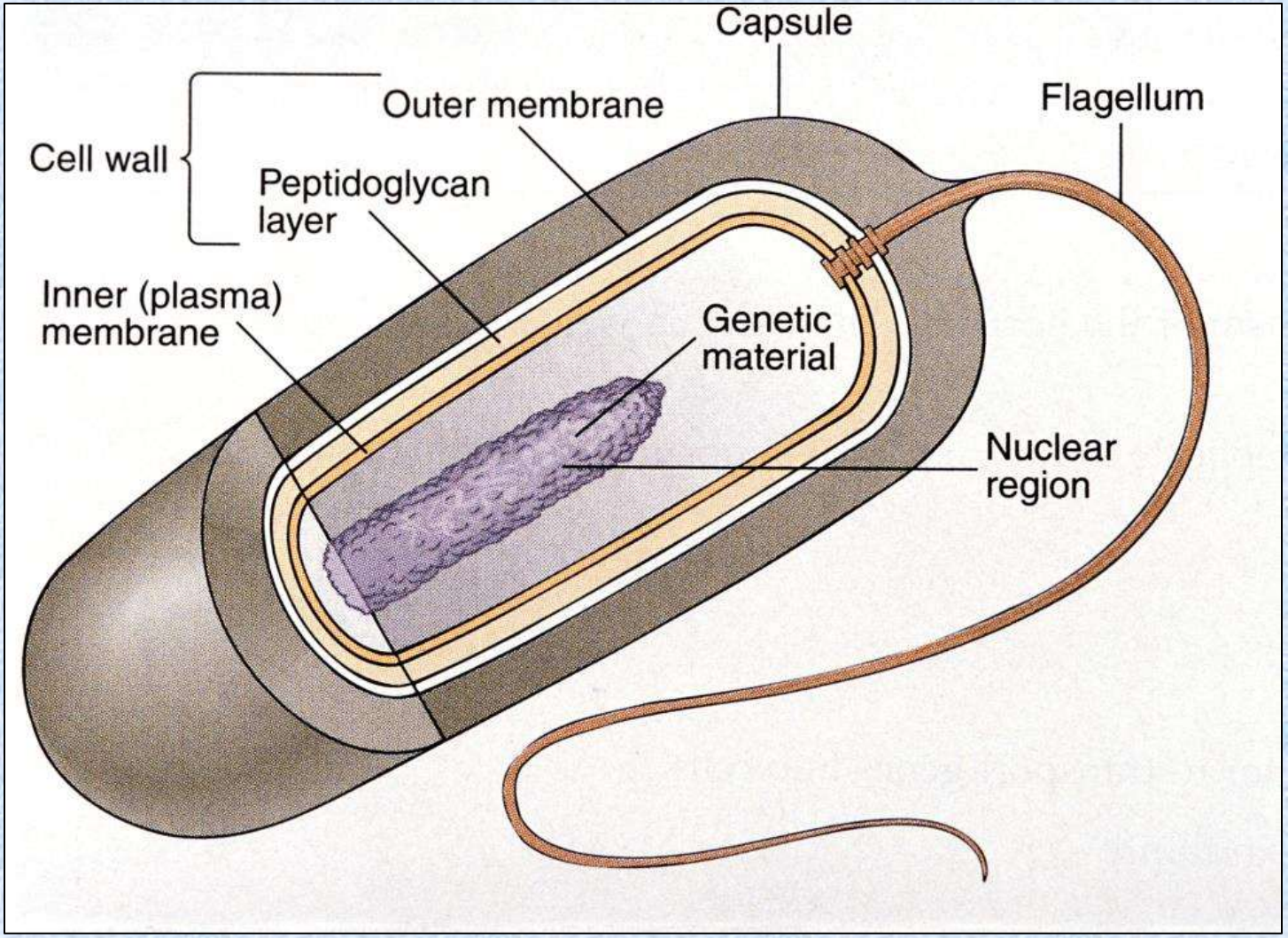
(More Common)



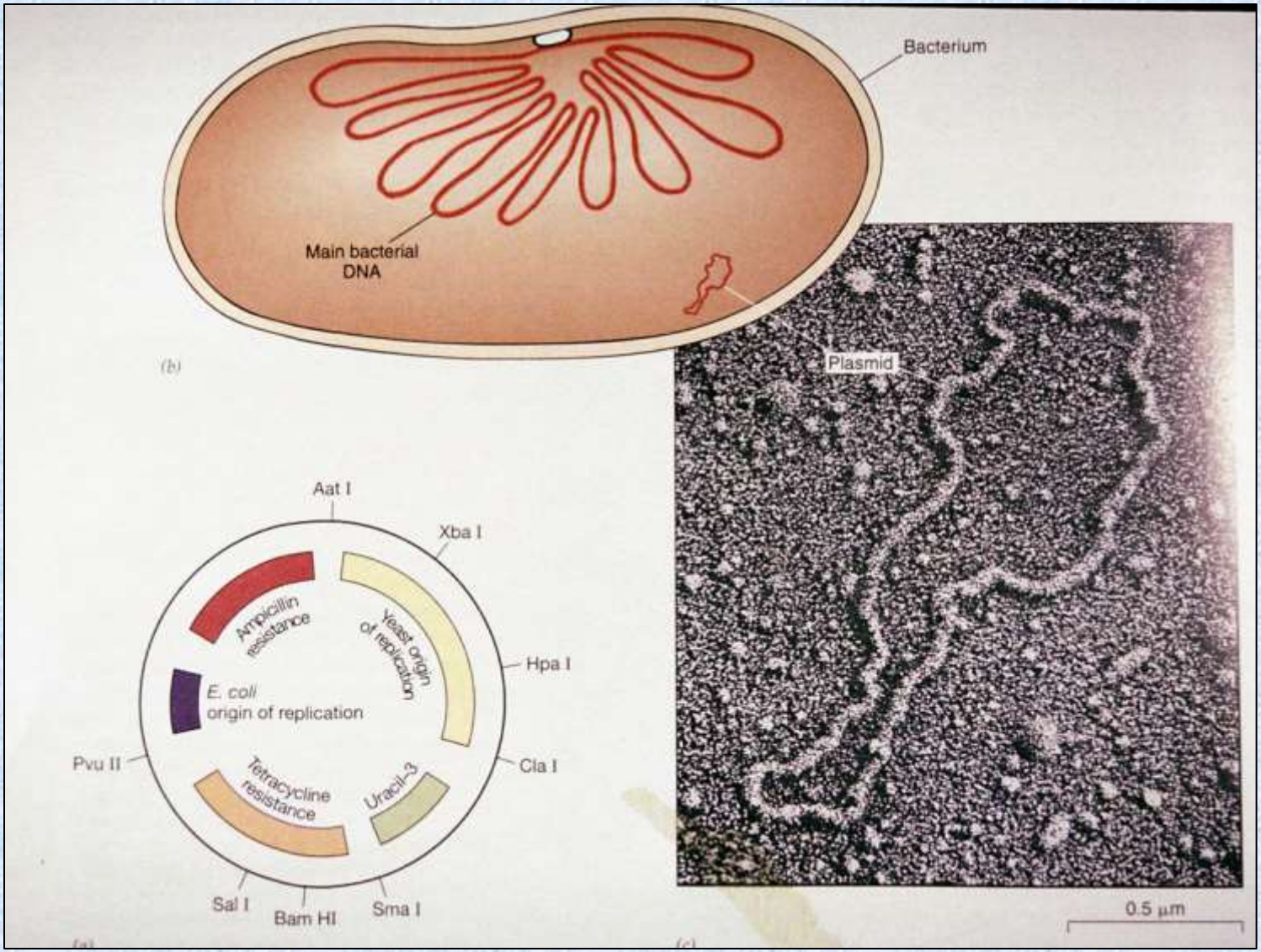
Structures Present in some bacteria:

Capsule – gel-like coating outside cell wall, polysaccharide called glycocalyx

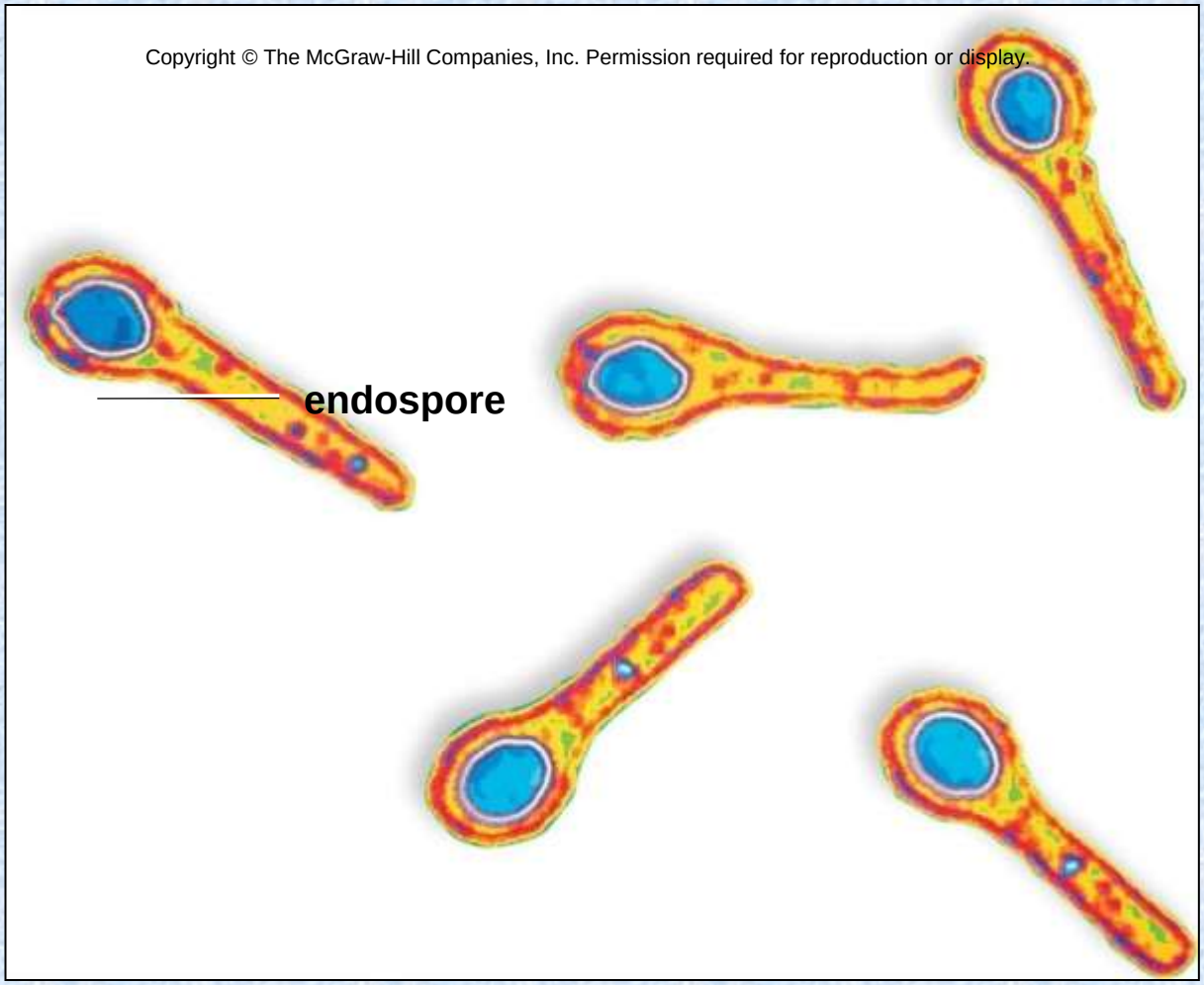
Flagellum – turns 360 degrees like propeller, anchored by basal body



Bacteria DNA – circular chromosome and plasmids



Endospore of *Clostridium tetani*



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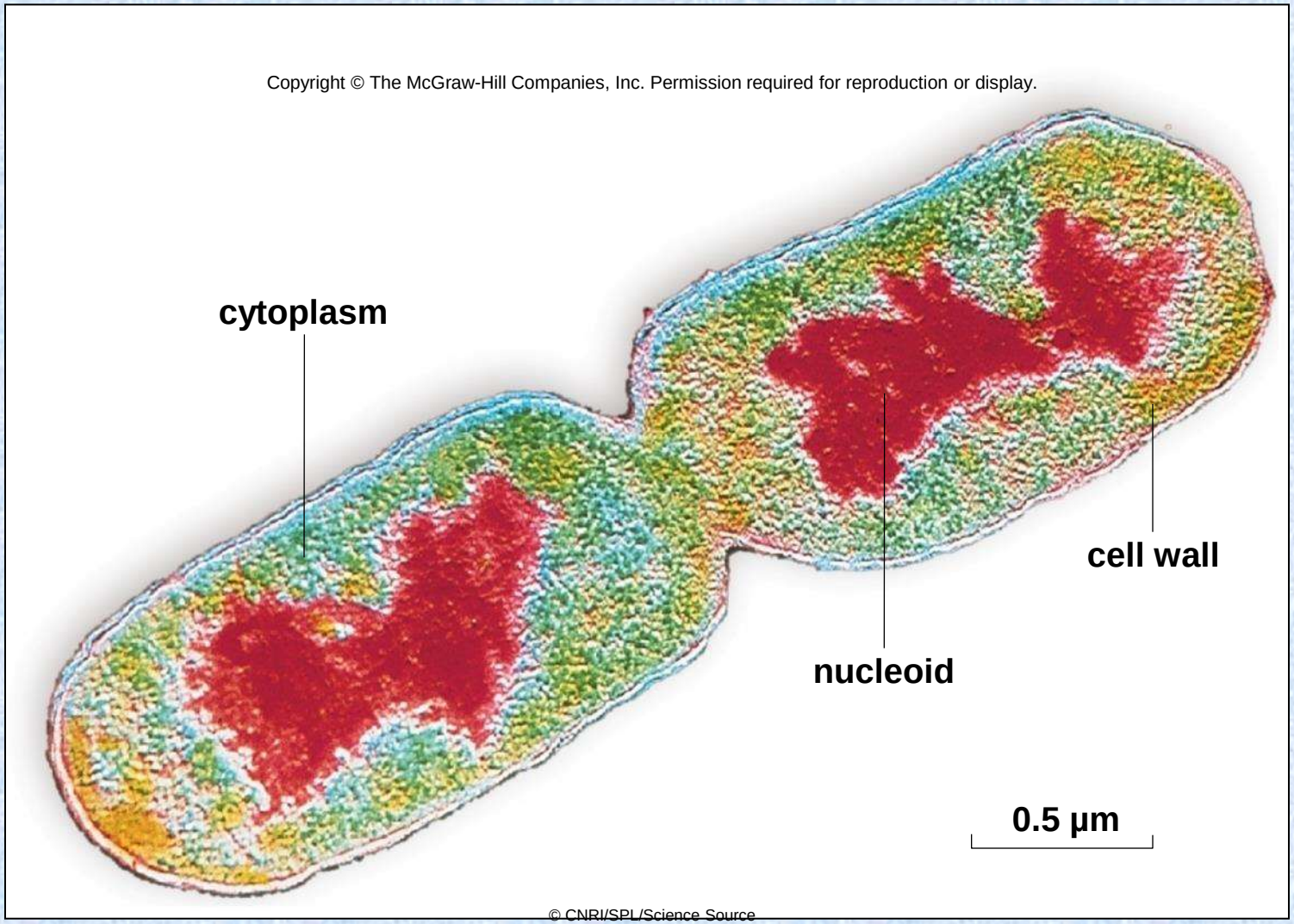
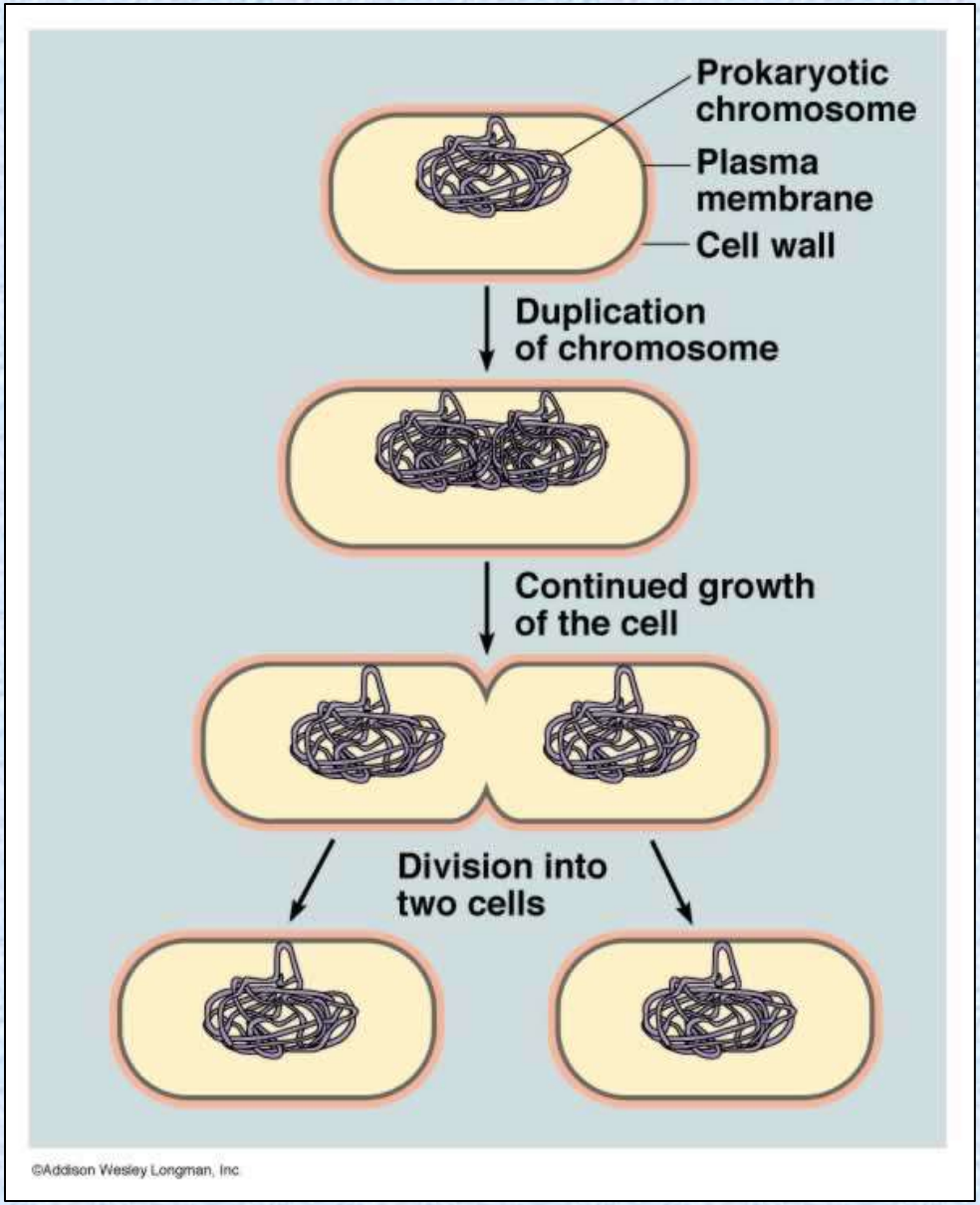
Asexual Reproduction - Binary Fission



Bacterial Reproduction

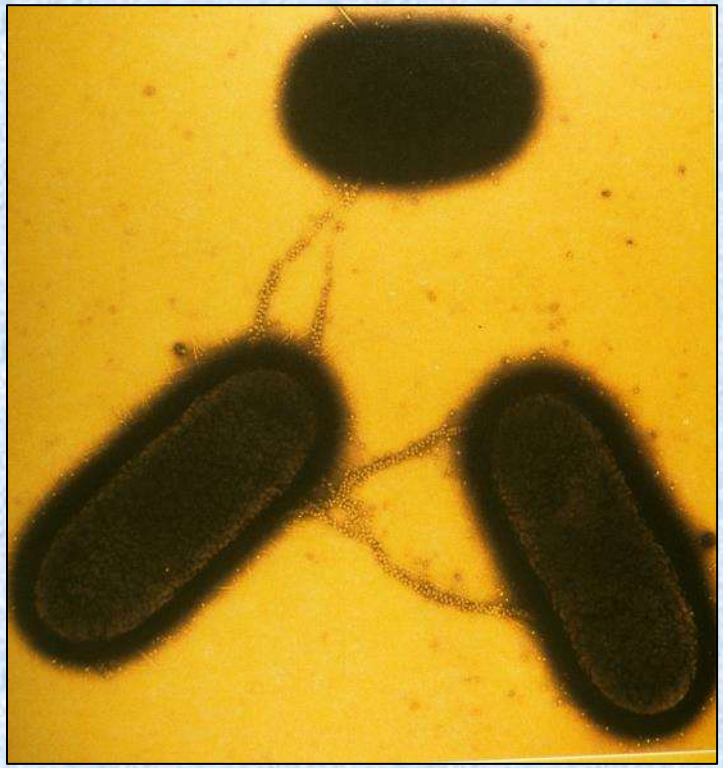
- Bacteria usually reproduce asexually using the process of binary fission

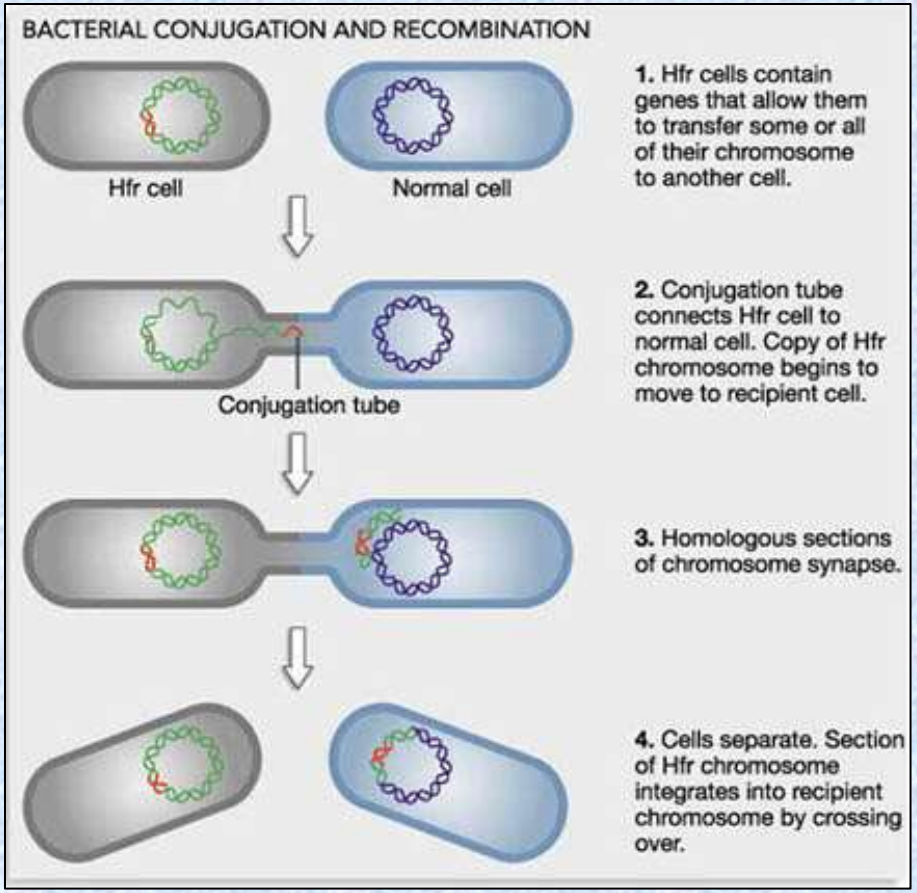


Sexual Reproduction -Recombination

- **Conjugation**
  - **Conjugation pilus** forms between two cells
  - Donor cell passes DNA to recipient cell through the pilus
- **Transformation**
  - Occurs when bacterium picks up free pieces of DNA from other prokaryotes
  - Becomes incorporated into genome
- **Transduction**
  - Occurs when bacteriophages carry portions of bacterial DNA from one cell to another
  - Serve as vectors

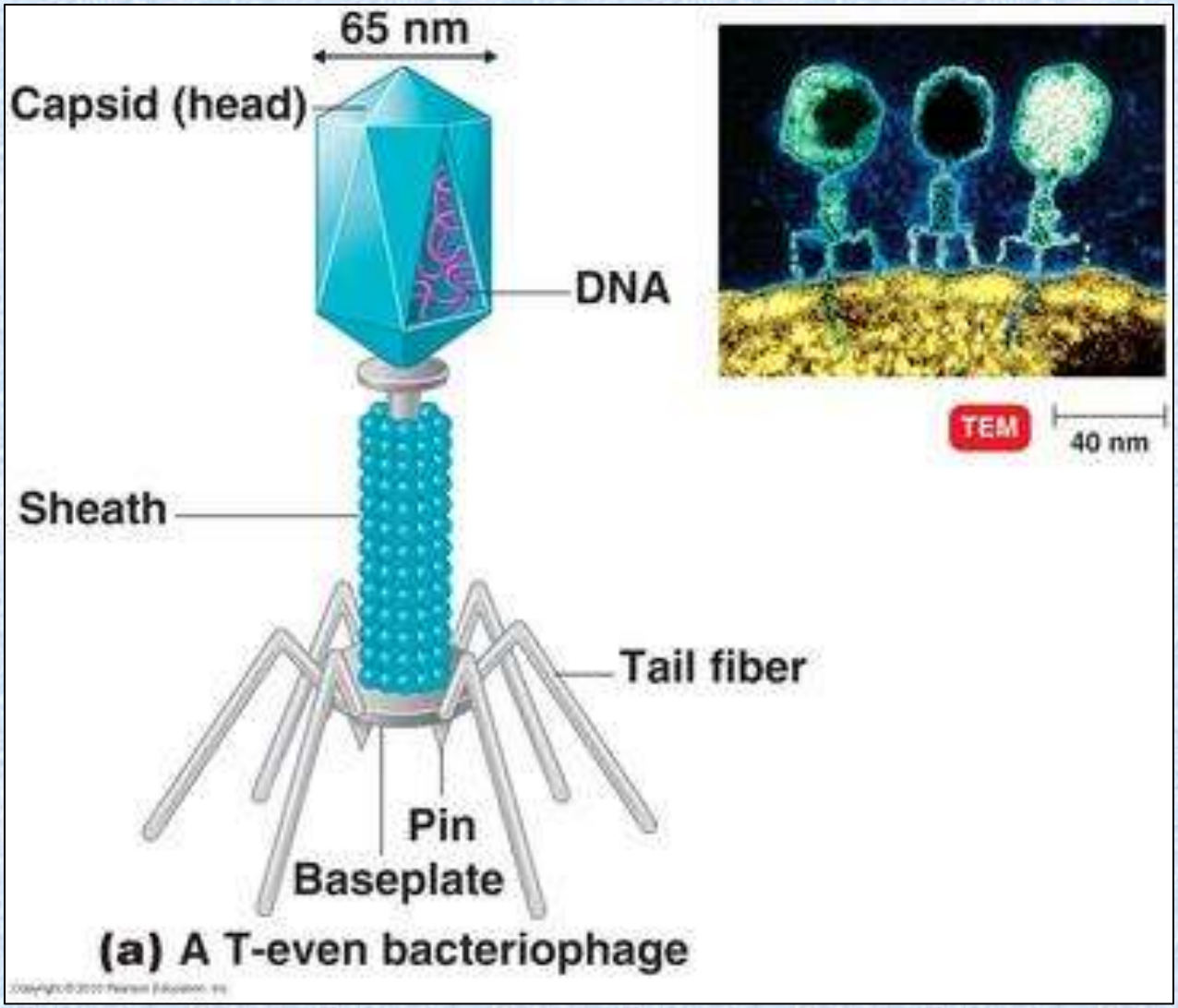
Bacteria Conjugation



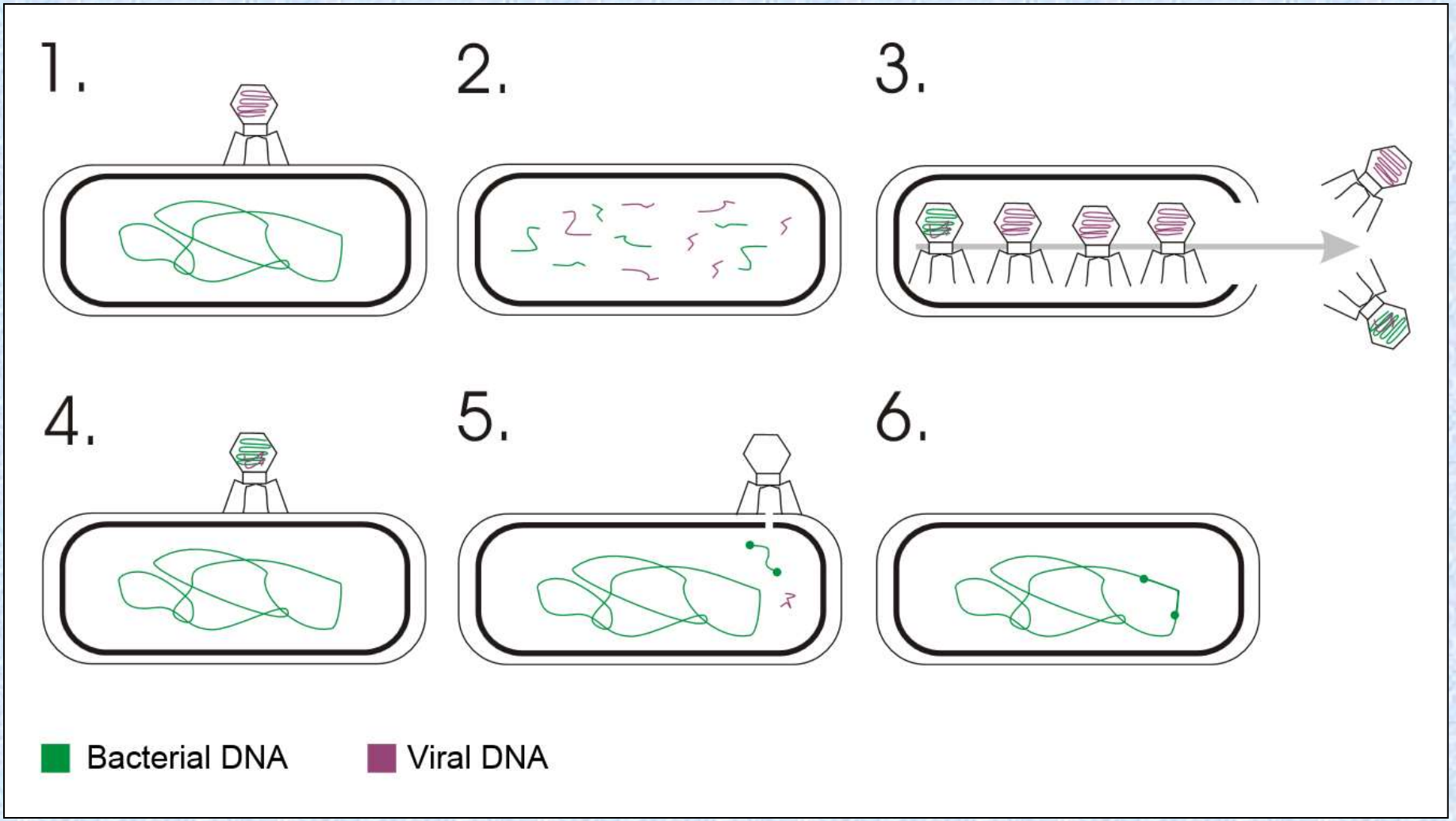


- Some bacteria exchanging some of their DNA through a conjugation tube to another bacterium.
- Usually plasmid DNA, not genomic DNA.

Bacteriophage - Transduction



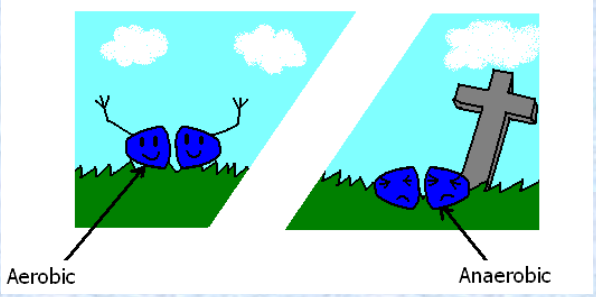
Transduction



Bacterial Metabolism

Oxygen requirements:

- **Obligate aerobes** – unable to grow in the absence of free oxygen
- **Obligate anaerobes** – unable to grow in the presence of free oxygen
  - Examples: Botulism, gas gangrene, and tetanus
- **Facultative anaerobes** – able to grow in either the presence or absence of free oxygen



Bacteria Metabolism

Autotrophs ("self-feeders")

- Make their own organic compounds from inorganic sources.
- Obtain carbon from CO2. They get their energy from the sun (photosynthesis) or from inorganic chemicals.

Heterotrophs ("other feeders")

- Derive organic compounds from other organisms (like animals).
- Most bacteria are heterotrophs.
- Saprobes or feed on living organisms.

Bacteria Metabolism

Autotrophic Bacteria:

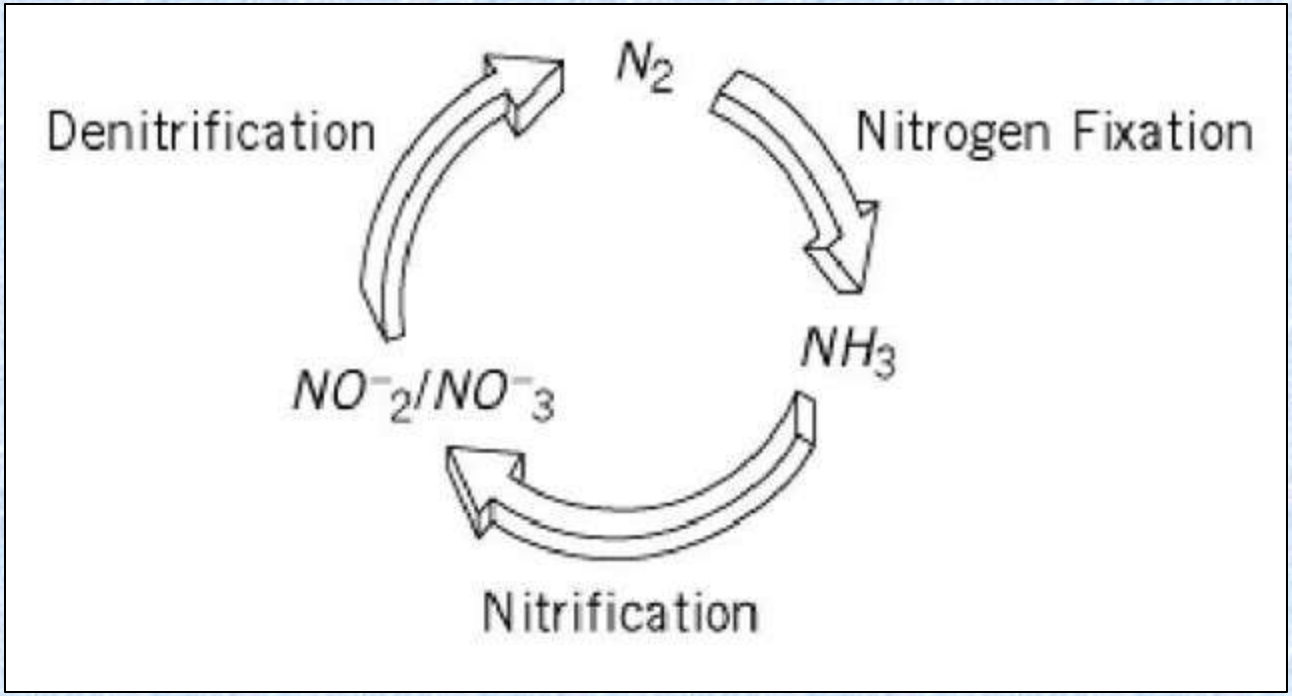
- **Photoautotrophs**
  - Use solar energy to reduce CO_2 to organic compounds
  - Photosynthetic (about like land plants)
    - Anoxygenic – Green sulfur and some purple bacteria living in oxygen-poor conditions
    - Oxygenic
- **Chemoautotrophs**
  - Oxidize inorganic compounds (HS, NH3, Fe2) to obtain energy
  - Energy is used to reduce CO_2 to an organic compound
  - Chemosynthetic
    - Live in environments such as deep sea vents 2.5 km below sea level

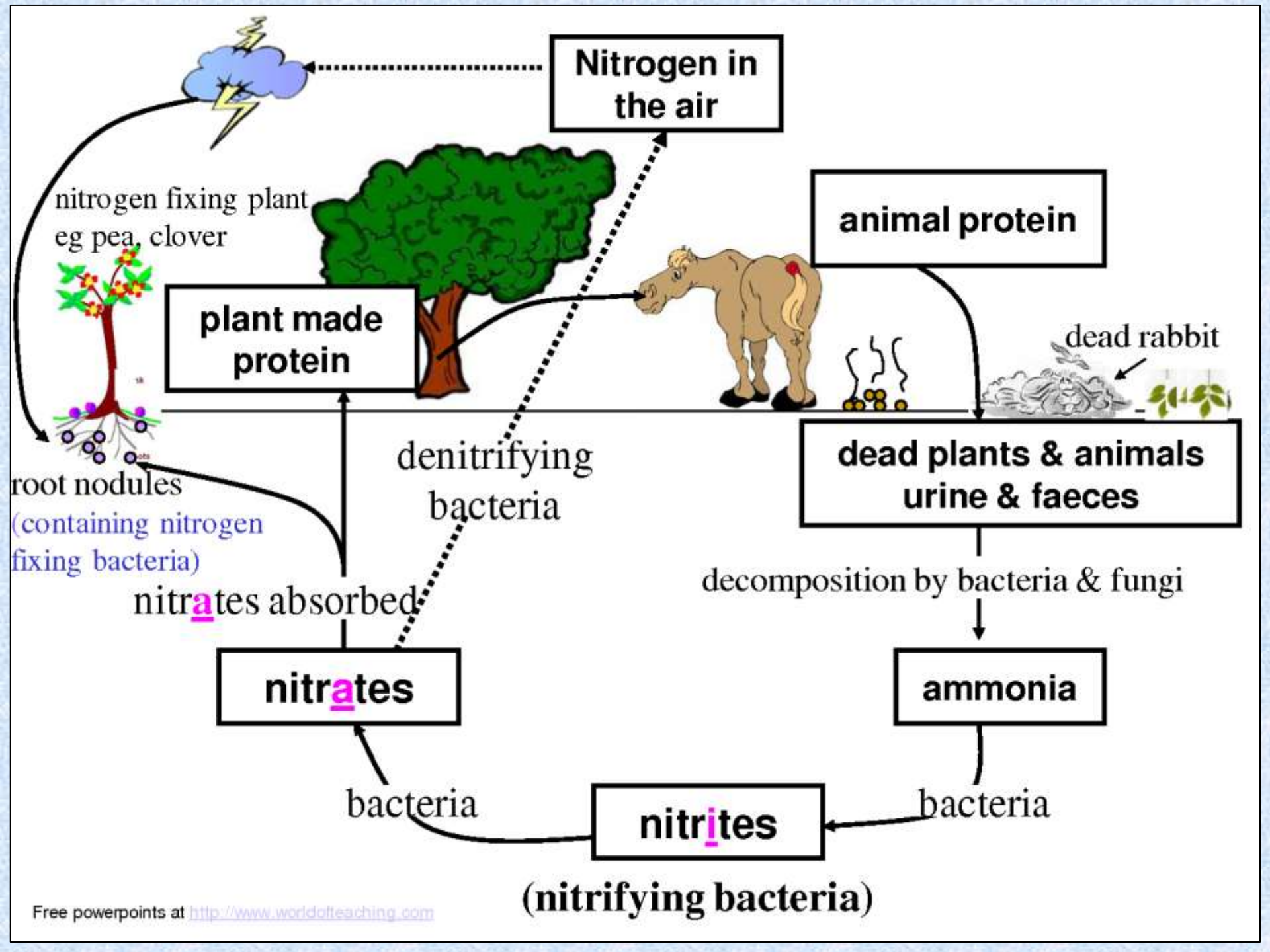
Heterotrophic Bacteria

- Most prokaryotes are **chemoheterotrophs** that take in organic nutrients.
  - Aerobic **saprotrophs** decompose most large organic molecules to smaller molecules.
- May be free-living or symbiotic (two different species live together in an intimate way)
  - **Commensalism**
    - One population modifies the environment in such a way that a second population benefits.
    - Obligate anaerobes live in our intestine because bacterium *E. coli* uses up oxygen.
  - **Mutualism**
    - Both species benefit from association.
    - Mutualistic bacteria live in human intestines and release vitamins K and B_{12} which help produce blood components.
  - **Parasitism**
    - Parasite benefits at host expense; disease-causing bacteria are called pathogens
    - Many form **endospores**

Nitrogen Metabolism

- Many prokaryotes can metabolize various forms of nitrogen (animals are quite limited).
- These include nitrification, denitrification, N-fixation



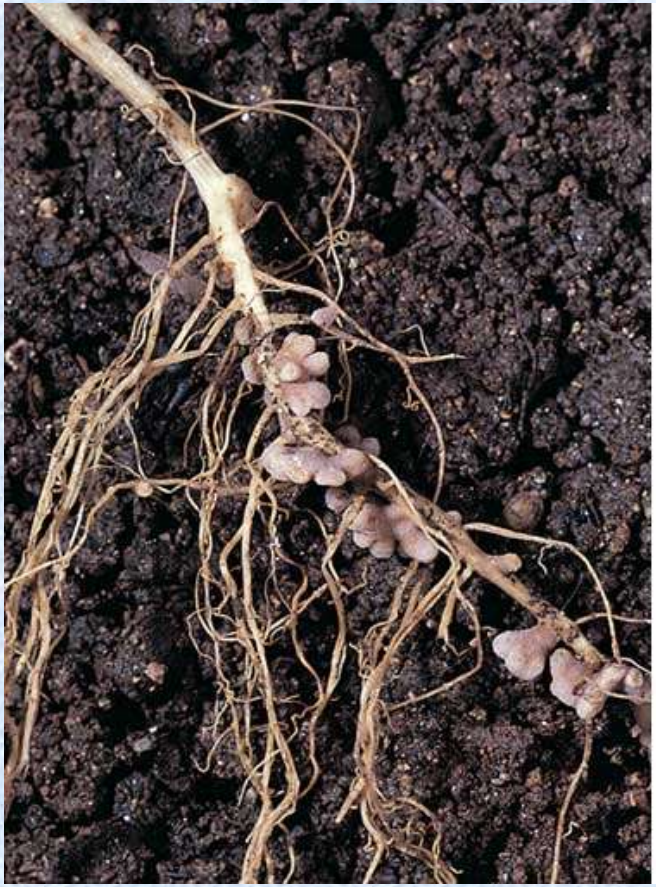


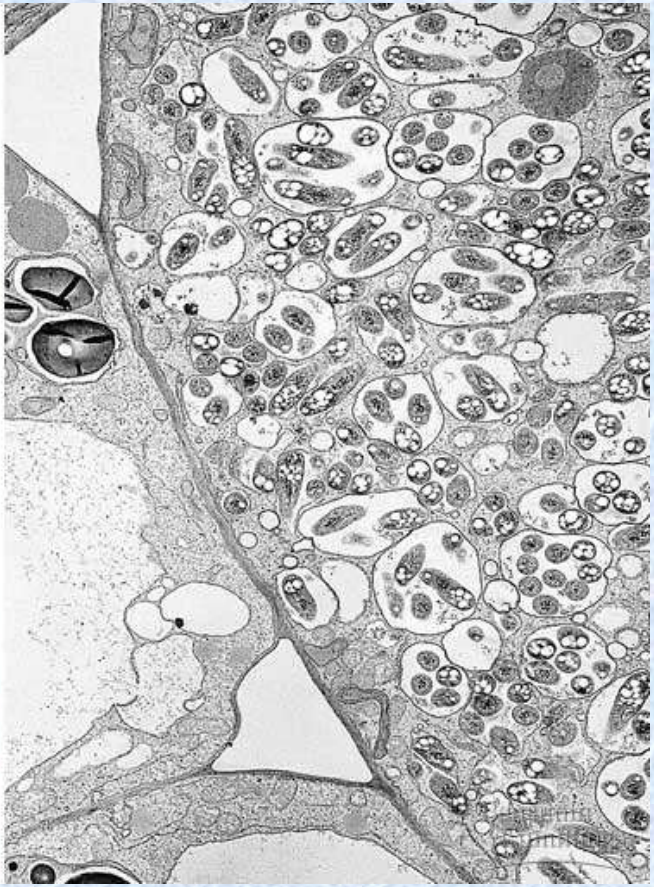
Nitrogen-fixing bacteria

- Certain bacteria and cyanobacteria have ability to reduce nitrogen (N_2) gas to ammonium NH_4^+
  - cells can convert NH_4^+ to compounds
  - called **Nitrogen-fixation**
  - organisms are called nitrogen-fixing
  - have special enzyme Nitrogenase that can break the triple bond of N2

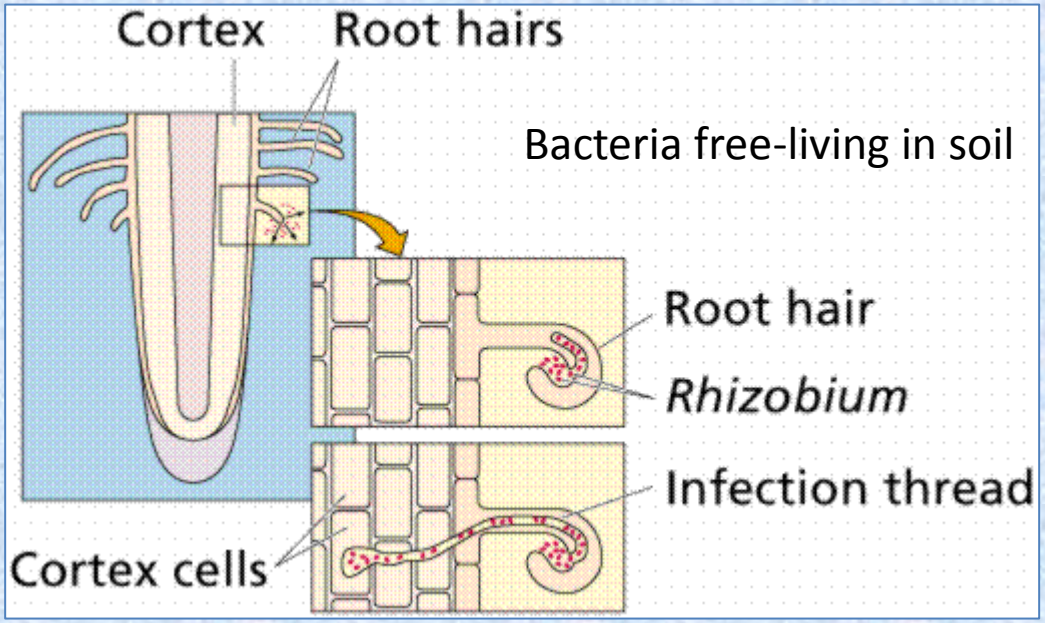
Root Nodules

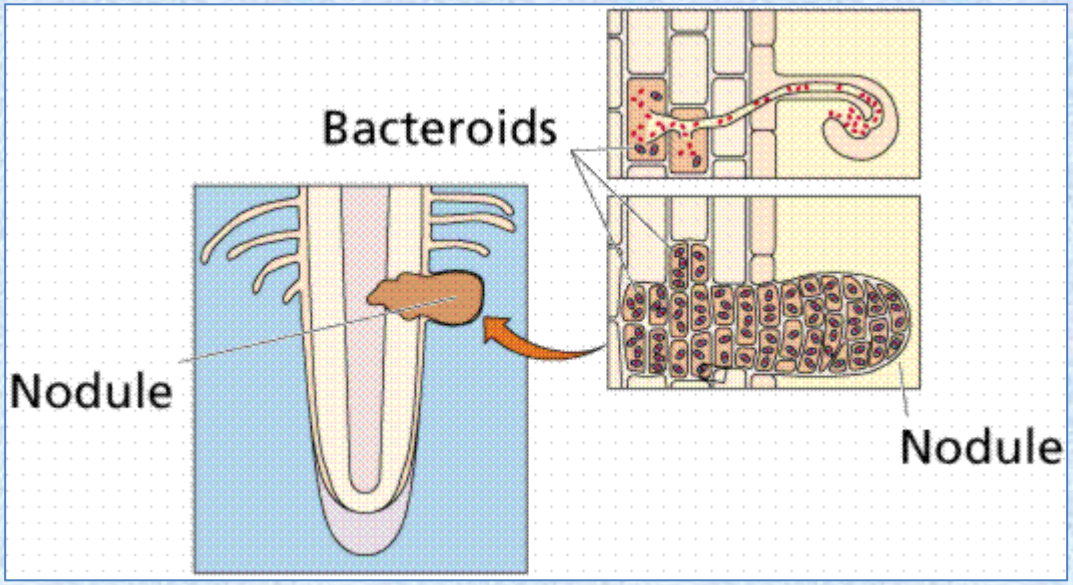
- *Rhizobium* bacteria form symbiotic relationships with roots
- Legume produce nodules with *Rhizobium* inside, site of nitrogen fixation



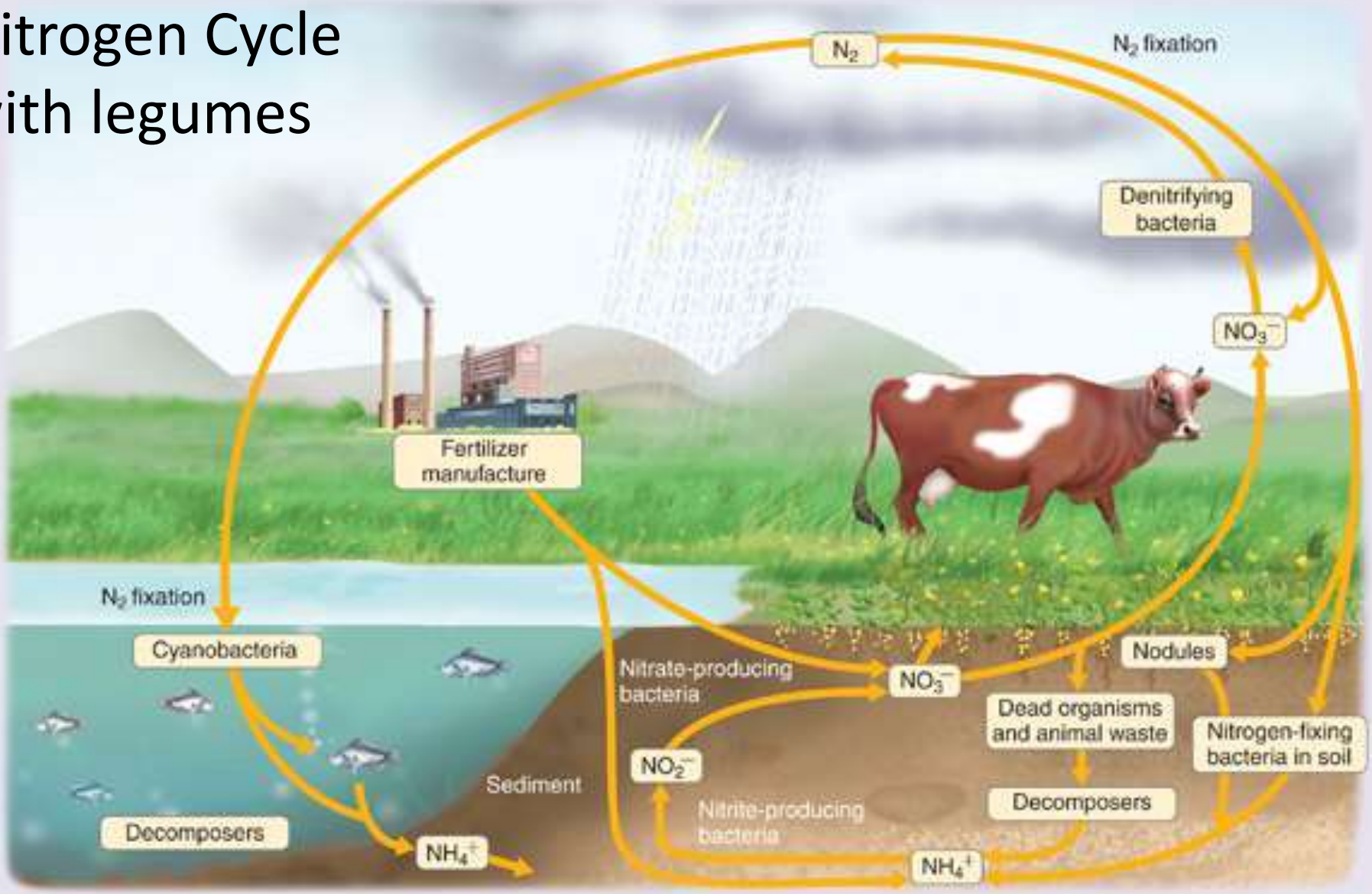


Formation of Root Nodule

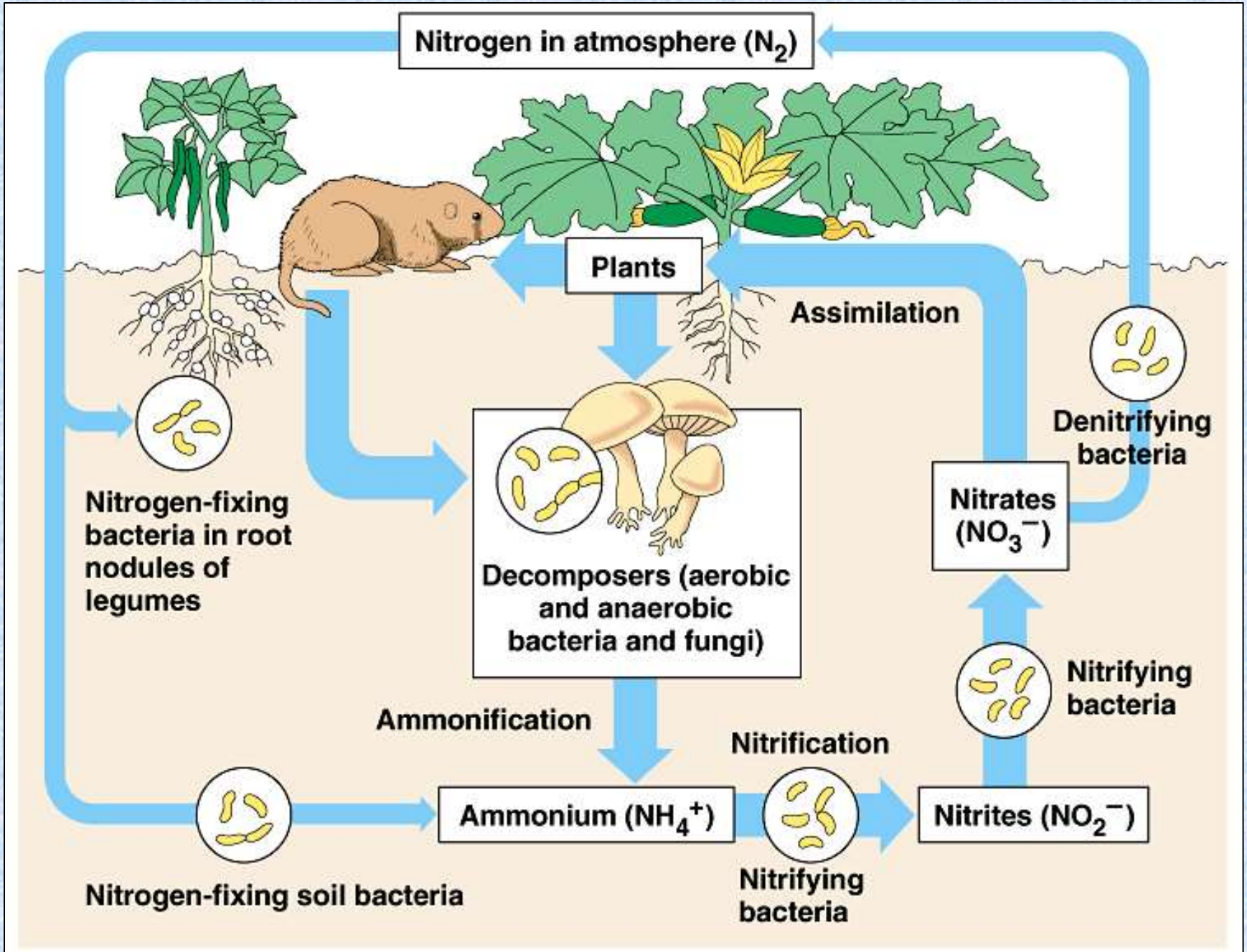




Nitrogen Cycle with legumes



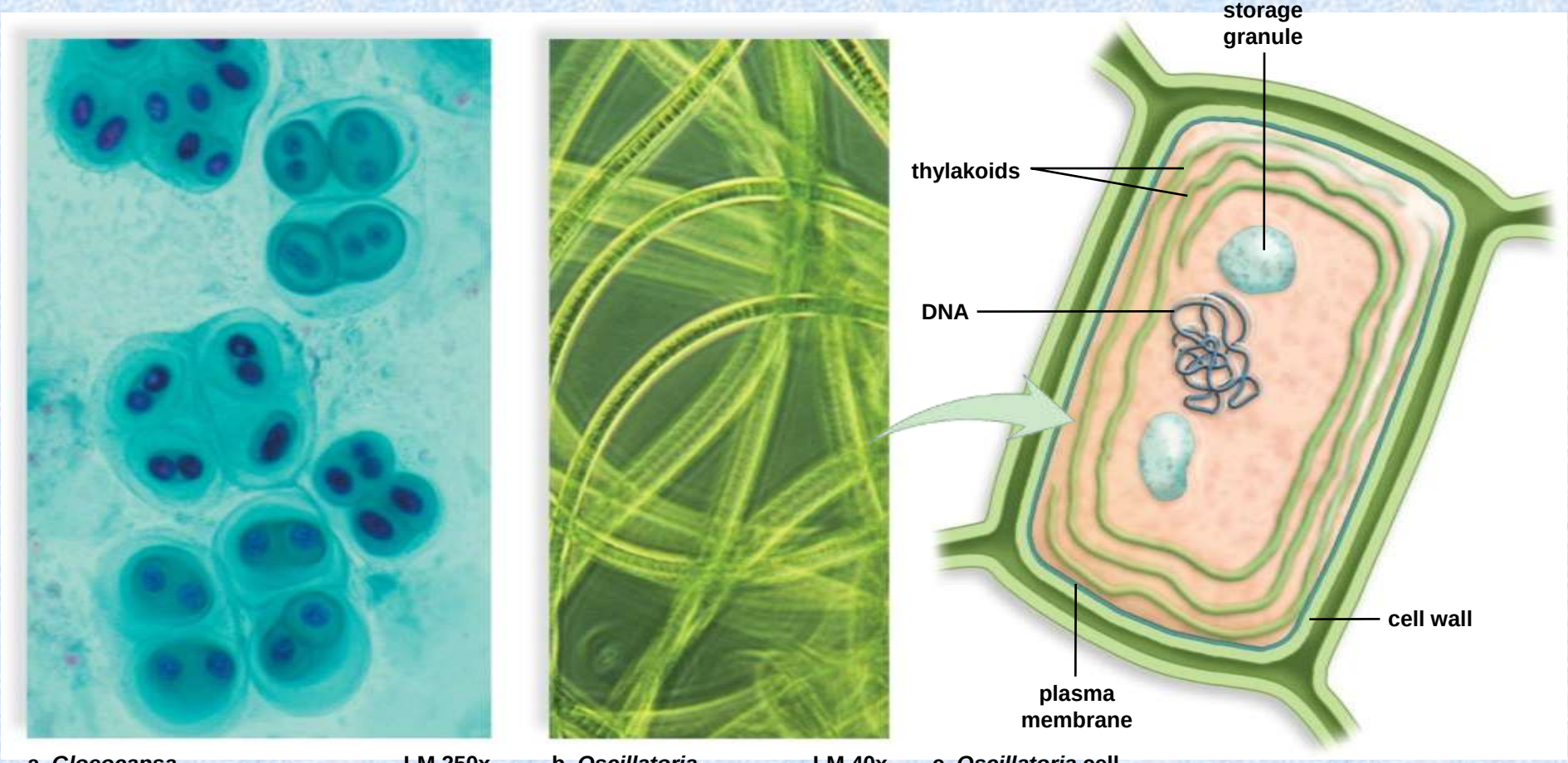
Box Figure 13.1 The nitrogen cycle. Nitrogen is cycled through the environment via the actions of microorganisms. Nitrogen-fixing cyanobacteria and bacteria, free-living or associated with legumes, convert nitrogen gas into ammonium (NH_4^+). Bacteria and other microorganisms decompose dead organisms and animal wastes, releasing ammonium. Other bacteria convert ammonium into nitrite (NO_2^-) and nitrate (NO_3^-).



Cyanobacteria – “Blue-Green Algae”

- Single cells, colonial, or filaments
- Photosynthesis like higher plants
- Have variety of pigments
- Introduced oxygen into atmosphere
- Fix nitrogen
- Symbiosis - lichens

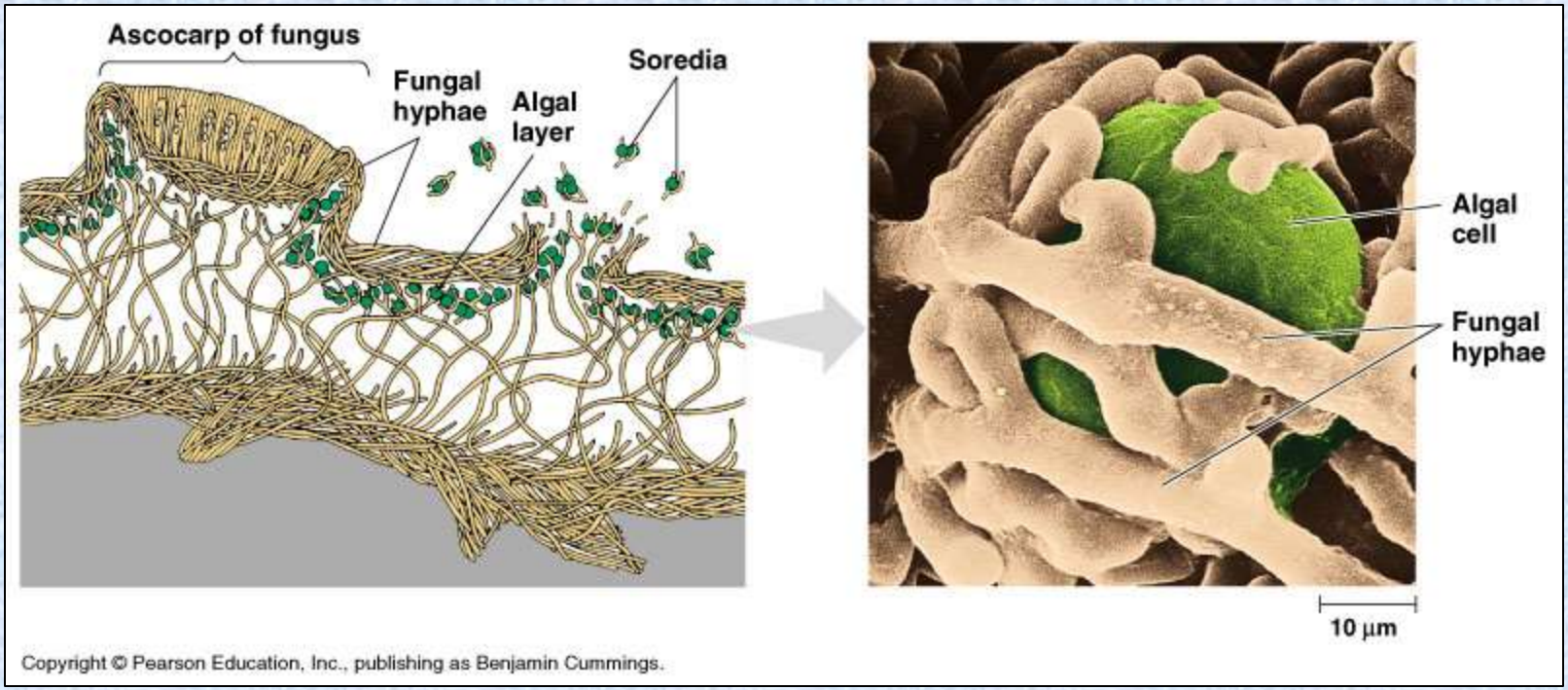
Cyanobacteria – “Blue-Green Algae”



a. *Gloeocapsa* LM 250x b. *Oscillatoria* LM 40x c. *Oscillatoria* cell

Lichens

- Part fungus,
- Part cyanobacteria

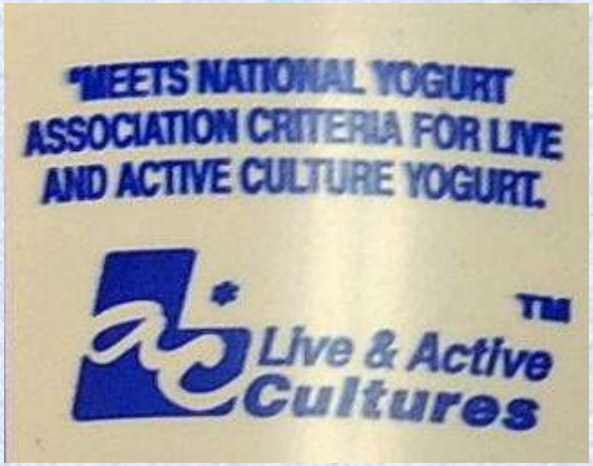


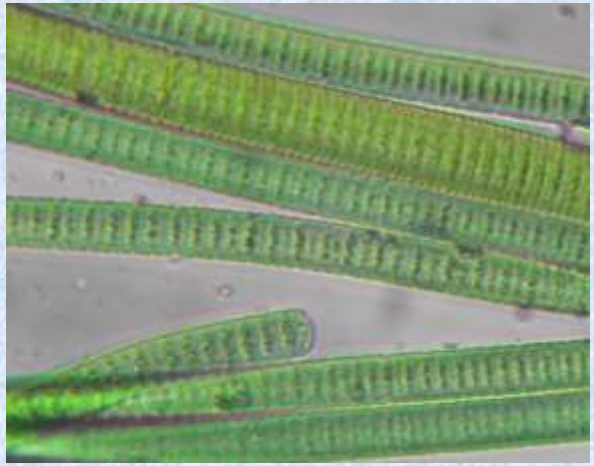
Cyanobacteria – algal bloom, toxic

Toxic bloom in Baltic Sea, satellite image

Useful bacteria...

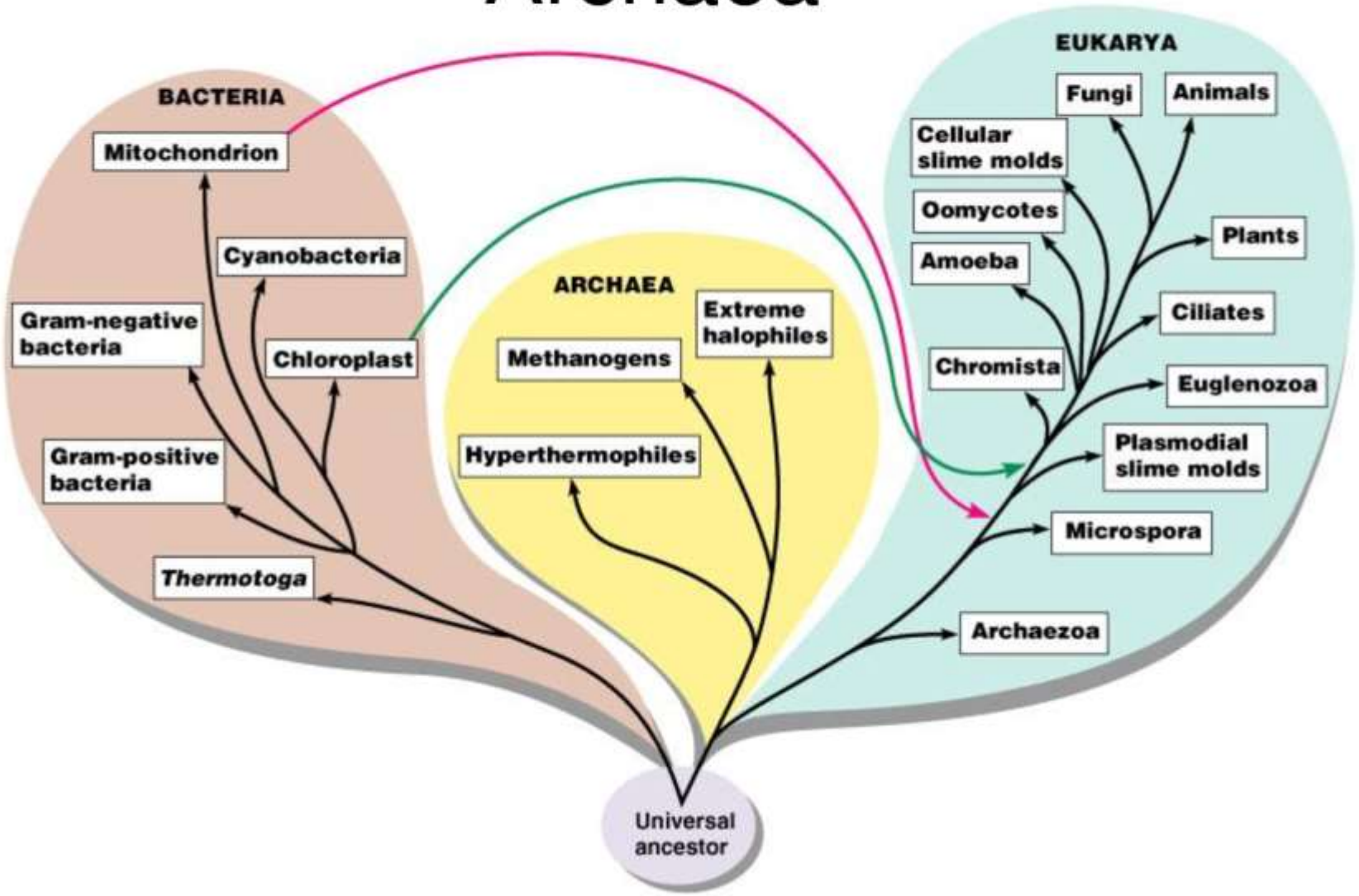
- Help make yogurt, cheese, sauerkraut
- Environmental recycling and clean-up; decomposers; compost
- Pharmaceuticals





Archaea

Archaea


BACTERIA
Mitochondrion
Cyanobacteria
Gram-negative bacteria
Chloroplast
Gram-positive bacteria
Thermotoga
ARCHAEA
Extreme halophiles
Methanogens
Hyperthermophiles
EUKARYA
Fungi
Animals
Cellular slime molds
Oomycotes
Plants
Amoeba
Ciliates
Chromista
Euglenozoa
Plasmodial slime molds
Microspora
Archaezoa
Universal ancestor

Domain Archaea (Archaebacteria)

- Cell walls lack peptidoglycan
- Ribosomal RNA different
- Membrane lipids with branched hydrocarbons
- Archaea has more in common with Eukarya than with Bacteria

Some live in <u>extreme conditions</u>

- methanogens
- halophiles
- thermoacidophiles

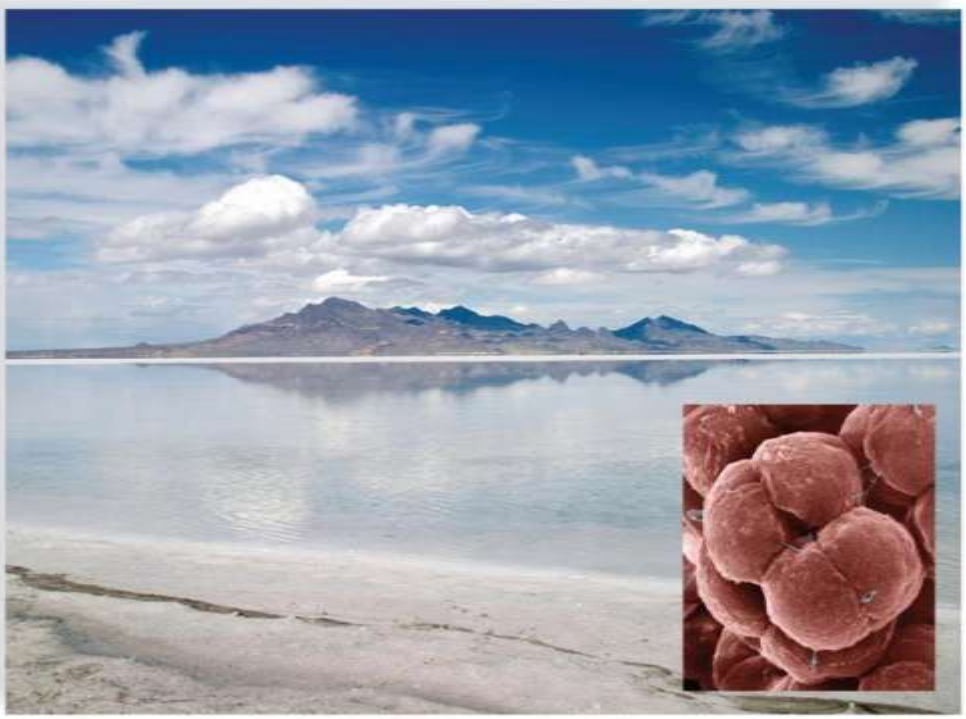
Methanogens: Swamps

c.

c(main): © Susan Rosenthal/Corbis; (inset):
© Dr. M. Rohde, GBF/Science Source.

Use Hydrogen to reduce CO_2 to methane (CH_4), a greenhouse gas

Halophiles: Salt Lakes



a.

a(main): © Marco Regalia Sell/Alamy RF; a(inset): © Eye of Science/Science Source

Survive high salt concentration, increase concentration of chloride ions, potassium etc. (perish in normal water)

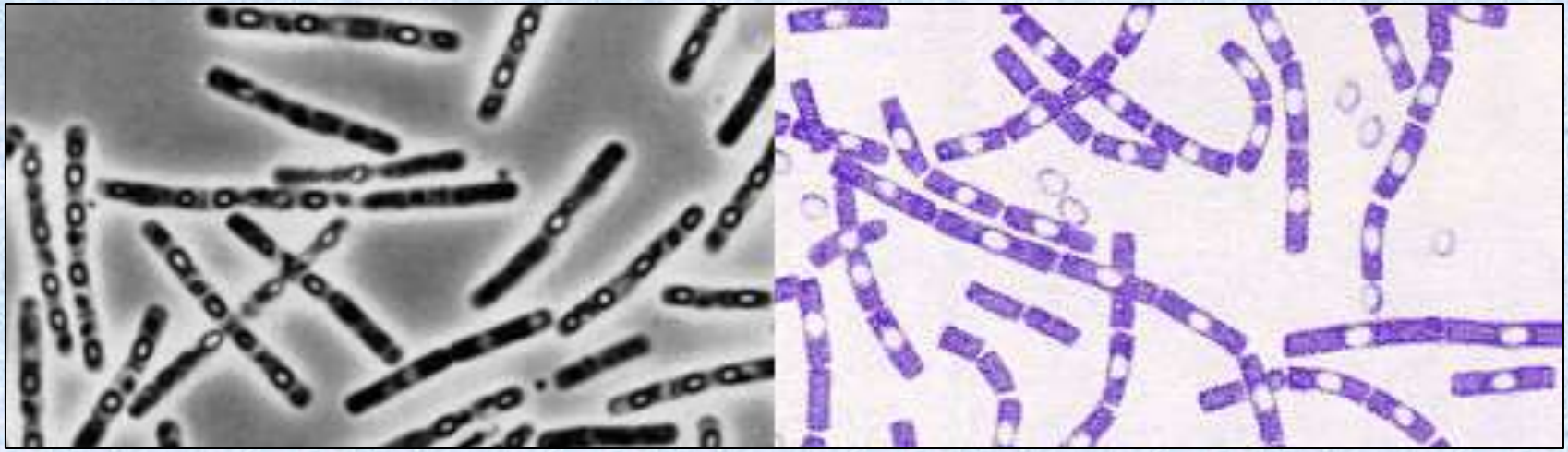
Thermoacidophiles: Hot Springs

b.

b(main): © Jeff Lepore/Science
Source; (inset): © Eye of Science/Science Source;

Thrive in hot, acidic environments; Hot springs, geysers, deep-sea vents, volcanos
Grow best at pH between 1 and 2.
Chemoautotrophic, use H2 gas and Sulfur, produce H2S

Bacteria and Human Health



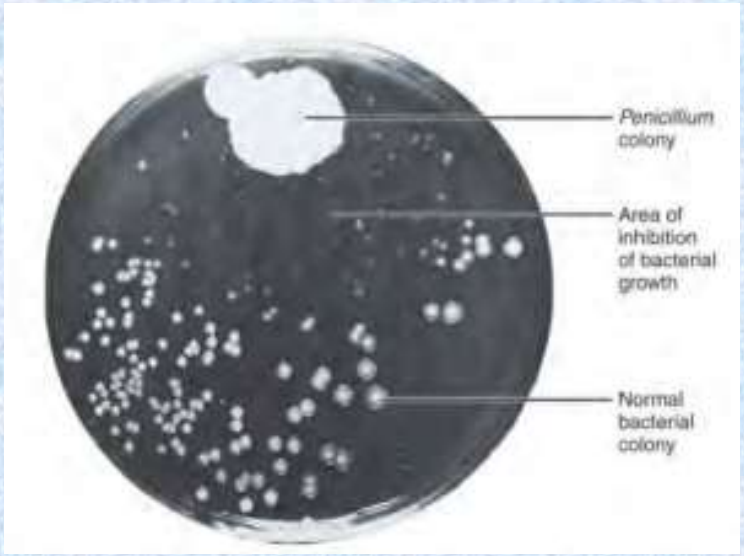
Bacteria and Human Health

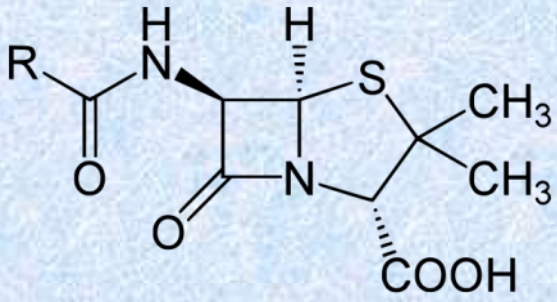
Category	Disease
Sexually transmitted diseases	Syphilis, gonorrhea, chlamydia
Respiratory diseases	Strep throat, scarlet fever, tuberculosis, pneumonia, Legionnaires disease, whooping cough, inhalation anthrax
Skin diseases	Erysipelas, boils, carbuncles, impetigo, acne, infections of surgical or accidental wounds and burns, leprosy (Hansen disease)
Digestive tract diseases	Gastroenteritis, food poisoning, dysentery, cholera, peptic ulcers, dental caries
Nervous system diseases	Botulism, tetanus, leprosy, spinal meningitis
Systemic diseases	Plague, typhoid fever, diphtheria
Other diseases	Tularemia, Lyme disease

Antibiotic Resistant Bacteria

What are antibiotics?

- Powerful medicines that treat *bacterial* infections
- They work by either killing bacteria or preventing growth and reproduction of bacteria, cell walls
- The first antibiotic was penicillin isolated from the mold *Penicillium* by Alexander Fleming in 1929.





Antibiotic resistance

- Unfortunately, pathogens have evolved in response to the selection pressures imposed by overuse of antibiotics.
- Overuse and misuse in medicine, livestock productions, cosmetics, in waste, etc
- Long term exposure to antibiotics allows for the selection of those bacteria that contain genes or mutations for resistance to antibacterial chemicals.

Antibiotic resistance

- Penicillin saved thousands of lives in World War II and subsequently.
- Today, however, penicillin is ineffective against bacteria that previously were highly vulnerable, and many bacteria have evolved resistance to multiple antibiotics.
- As a result, infectious diseases have reemerged as a significant threat.

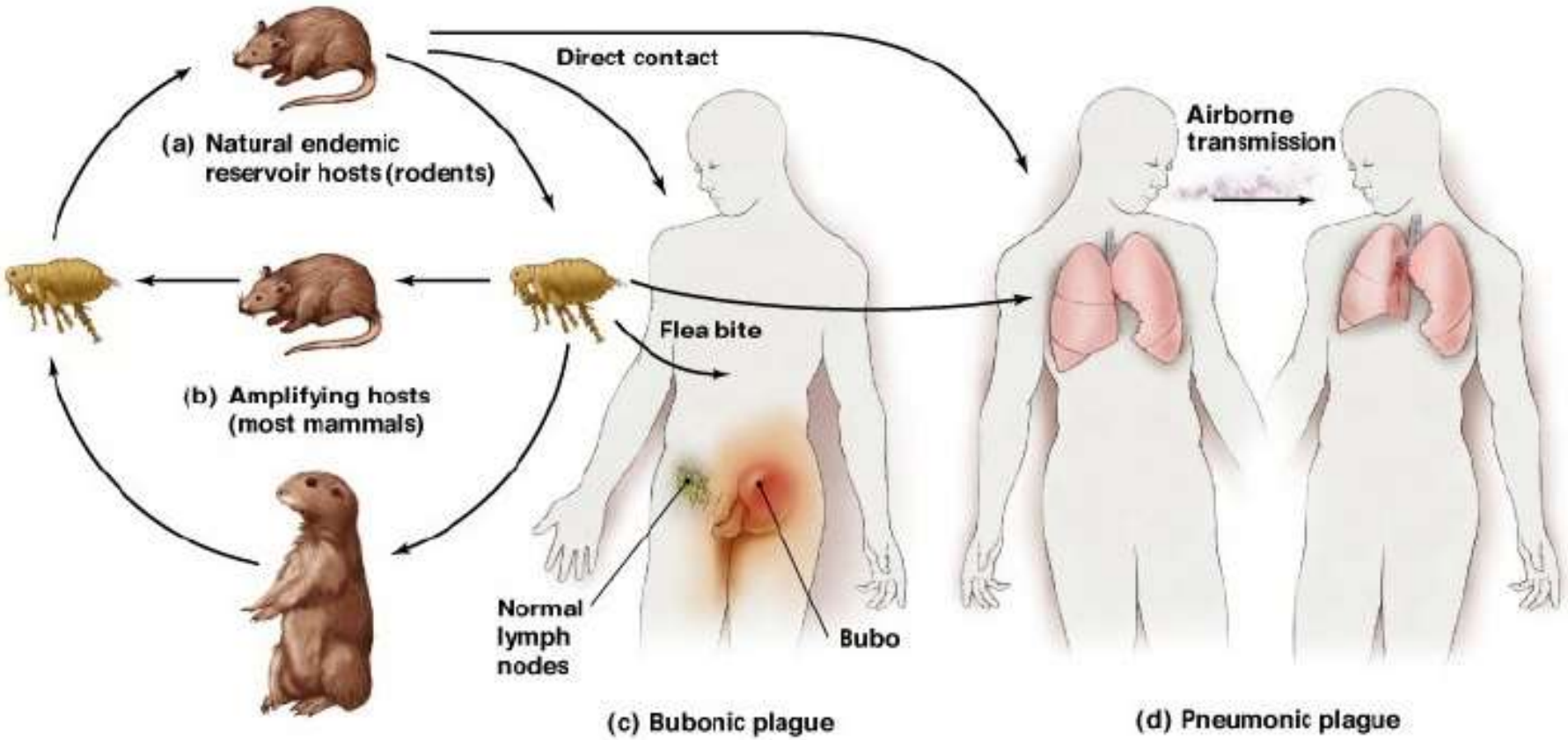
Staphylococcus aureus(staph) is a common cause of hospital infections that can spread to the heart, bones, lungs, and bloodstream with fatal results.

57.1 percent (an estimated 102,000 cases) of the staph bacteria found in U.S. hospitals were methicillin-resistant (MRSA), according to CDC.

Bubonic Plague - *Yersinia pestis*

- Black Death, Plague
- Transmitted by bite of flea that has fed on infected animals (rats)
- Death occurs in 3-10 days, 30-90% death rate
- One of the worst in history, killed many millions of people
- Characteristic bubos in groin, gangrene of limbs
- Approximately 1000/3000 cases per year, 20 in U.S.

Transmission of *Yersinia pestis*



Black Death - Plague

- In 1300s, the “Black Death,” killed about one-third (20 to 30 million) of Europe’s population.
- In the mid-1800s, it killed 12 million people in China.
- Recent outbreaks in China, Ukraine, Madagascar

Cholera - Vibrio cholera

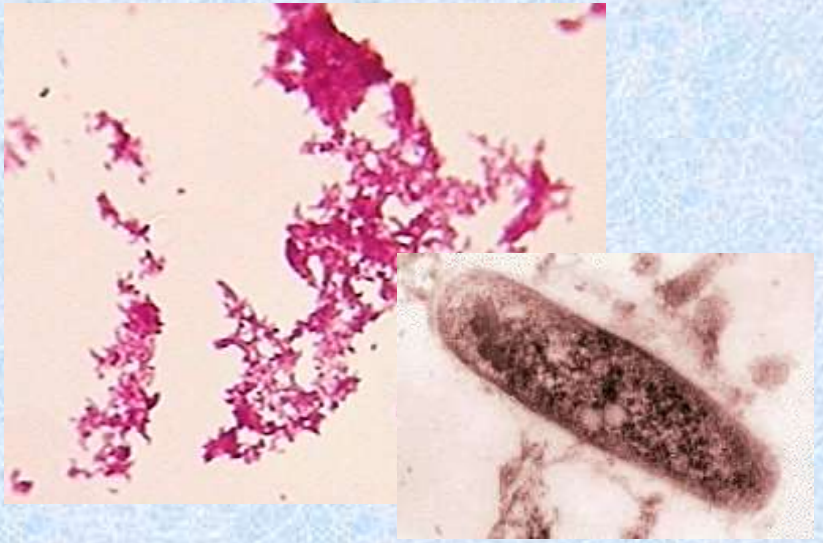
- Marine and freshwater bacterium
- Severe and often deadly illness
- Contaminated water, raw seafood
- 6 hr to 5 day incubation, produces toxin
- Severe diarrhea and vomiting.
- Large pandemics occur

Cholera - Vibrio cholera

- About 3-5 million cases and over 100,000 deaths occur each year around the world.
- Profuse watery diarrhea, vomiting, and leg cramps.
- Rapid loss of body fluids leads to dehydration and shock.
- Without treatment, death can occur within hours.
- Treated by immediate replacement of the fluid and salts lost through diarrhea.

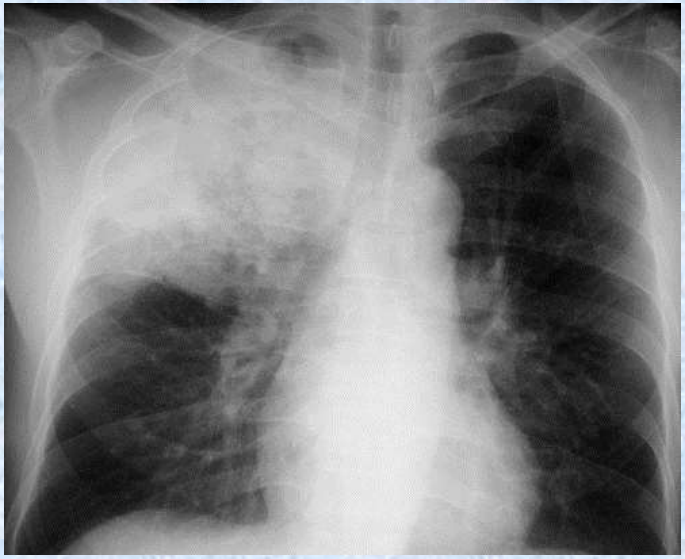
Tuberculosis - *Mycobacterium tuberculosis*

- TB is a re-emerging bacterial lung infection
- Kills 2-3 million/year
- Rates of tuberculosis resistant to multiple drugs (MDR-TB) are now at their highest level ever.



Warrant Issued for Man With Drug-Resistant Tuberculosis Deemed Public Health Threat

Posted 3:10 PM, August 22, 2014,



TB lung infection

Leprosy - *Mycobacterium leprae*

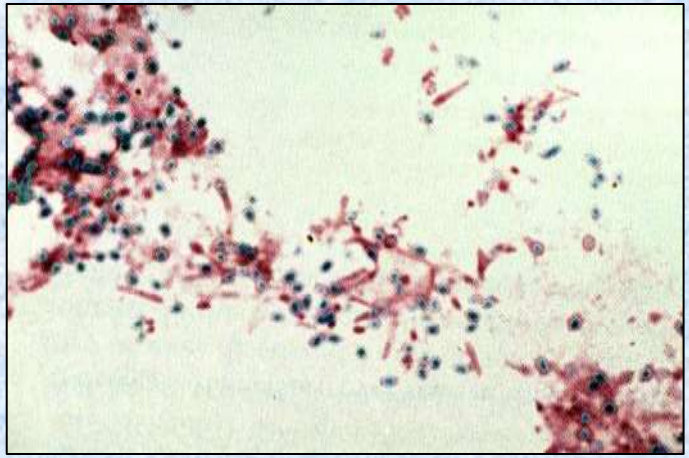
- Hansen's Disease
- Rampant in Europe in 1200s, leper colonies
- Not very common anymore, 200,000 cases
- Requires close contact to spread, nasal droplets
- Natural reservoir is the armadillo

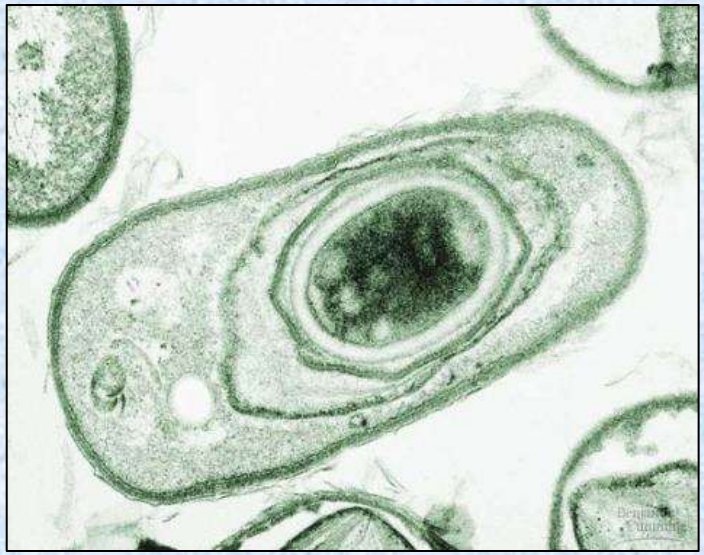
Clostridium spp.

- Obligate anaerobes
- Gram+ Rods
- Endospore forming
- Produce toxins

  -Botulinum

Botulism, Tetanus

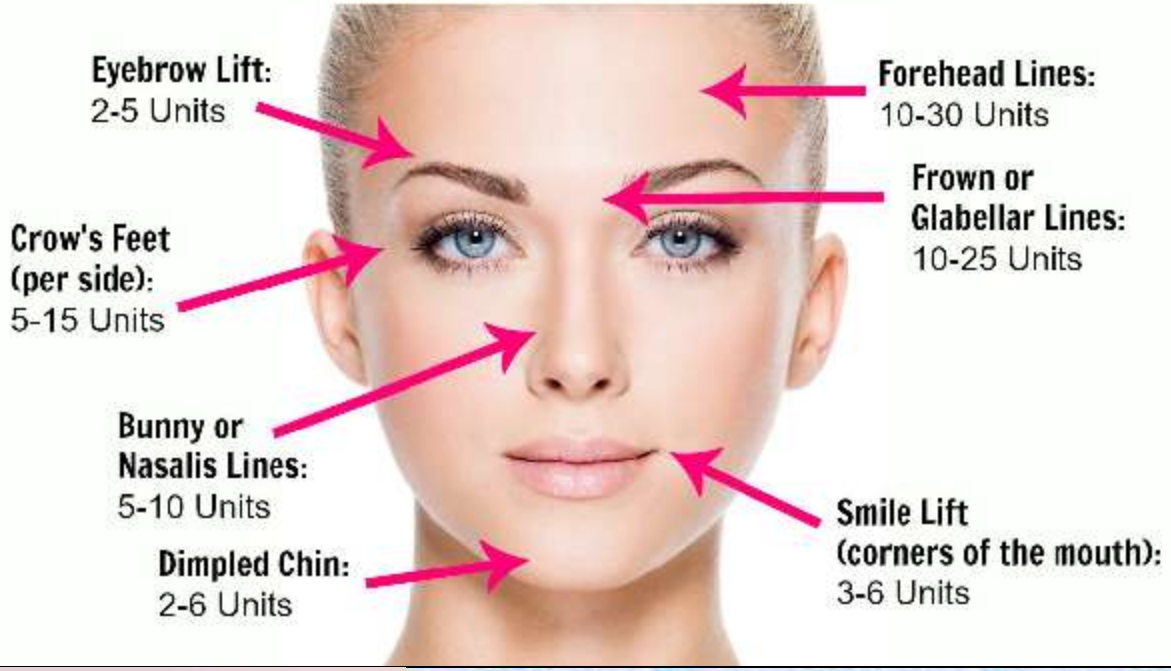




Botulism - *Clostridium botulinum*

- Soil bacterium that requires an oxygen free environment.
- Canned fruits and veggies, honey?
- Disease due to a toxin
  - Botulinum toxin
  - Botox – used cosmetically
- 4 – 36 hr incubation
- Causes paralysis
- Most common in low-acid home-canned foods, meats
- Nitrite added to meats to inhibit *Clostridium*

How much Botox will I need?

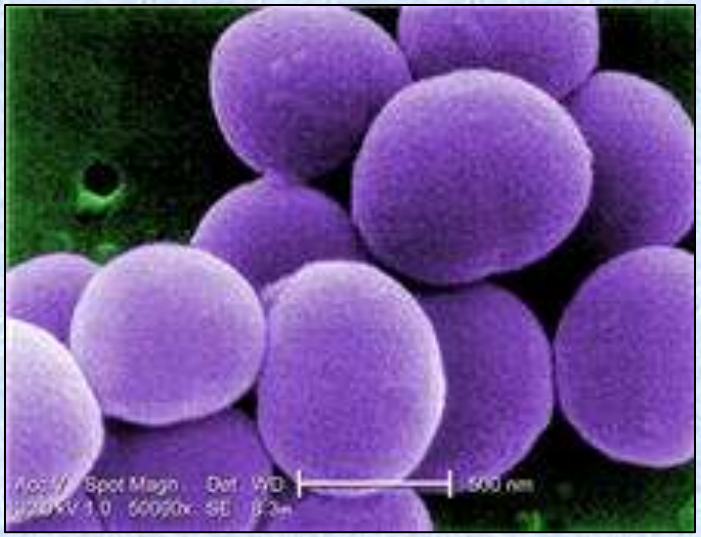


Tetanus - *Clostridium tetani*

- Endospores in soil enter through a wound
- Dangerous exotoxin produced
- Enters spinal chord, block neurotransmitters, spasms, lockjaw
- Once common, now rare
- Immunization now available

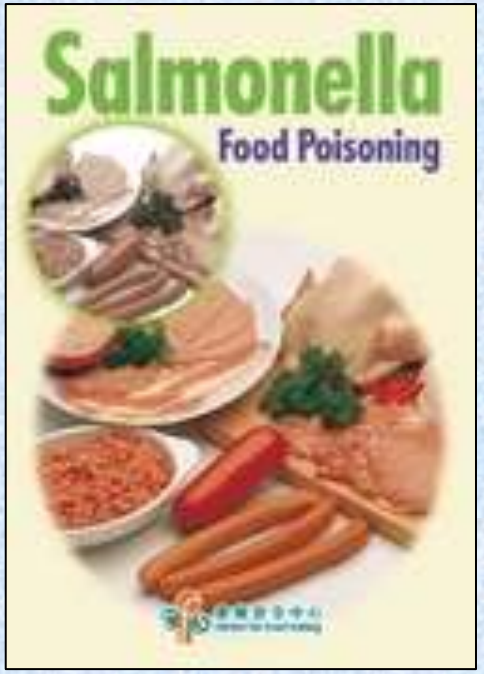
Staphylococcus aureus

- Common skin bacterium, causes pimples; common in hospitals
- Produces a fast acting toxin
- Dairy products, salads, cream filled pastries and deserts
- Incubation in as little as 30 minutes (meat, mayonnaise)
- Nausea, cramps, vomiting, diarrhea
- Dangerous if enters bloodstream
- Antibiotic resistant strains



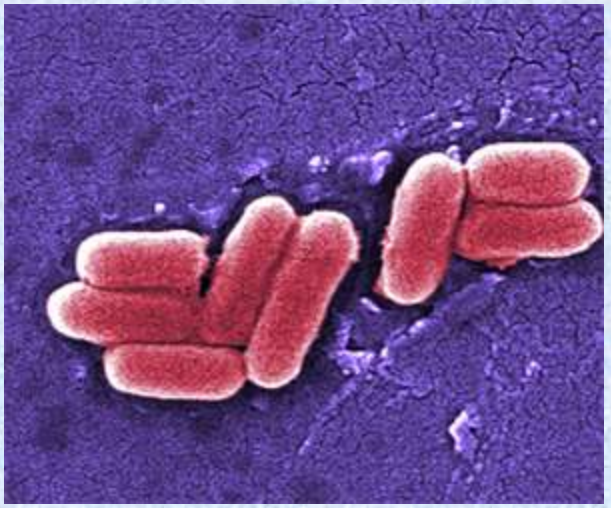
Salmonella

- Leading cause of food poisoning
- 2-4 million cases/year
- Raw or undercooked food, especially eggs and milk products, chicken
- Contact with turtles, frogs (kids)
- Cramps, fever, diarhea
- Multiple antibiotic resistance now a problem
- Related to *S. typhi* – Typhus, deadly disease, appears when sanitation breaks down



Escherichia coli O157:H7

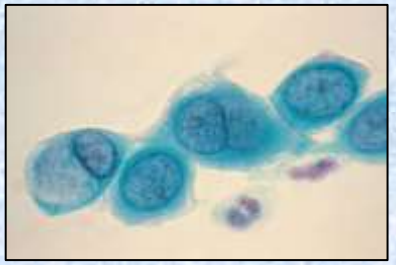
- Hundreds of strains of *E. coli*, most harmless
- Deadly Shiga toxin causes severe cramps and bloody diarrhea.
- Meat (i.e raw hamburger), uncooked produce, raw milk, unpasteurized juice, contaminated water.
- Estimated 73,000 cases of infection and 61 deaths in the U.S. each year



Sexually Transmitted Diseases (STDs)

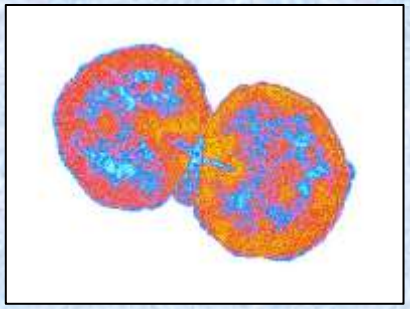
Chlamydia - *Chlamydia* spp.,

- Infects eyes, urinary tract, genital area
- Most common STD, 5-10 million Americans contract it each year, 10-15% of student population
- Inflammation, or often no symptoms, affects fertility



Gonorrhea - *Neisseria gonorrhoeae*

- Sores, white discharge, painful urination in men
- Cramps, painful burning, inflammation in women
- Resistant to many antibiotics



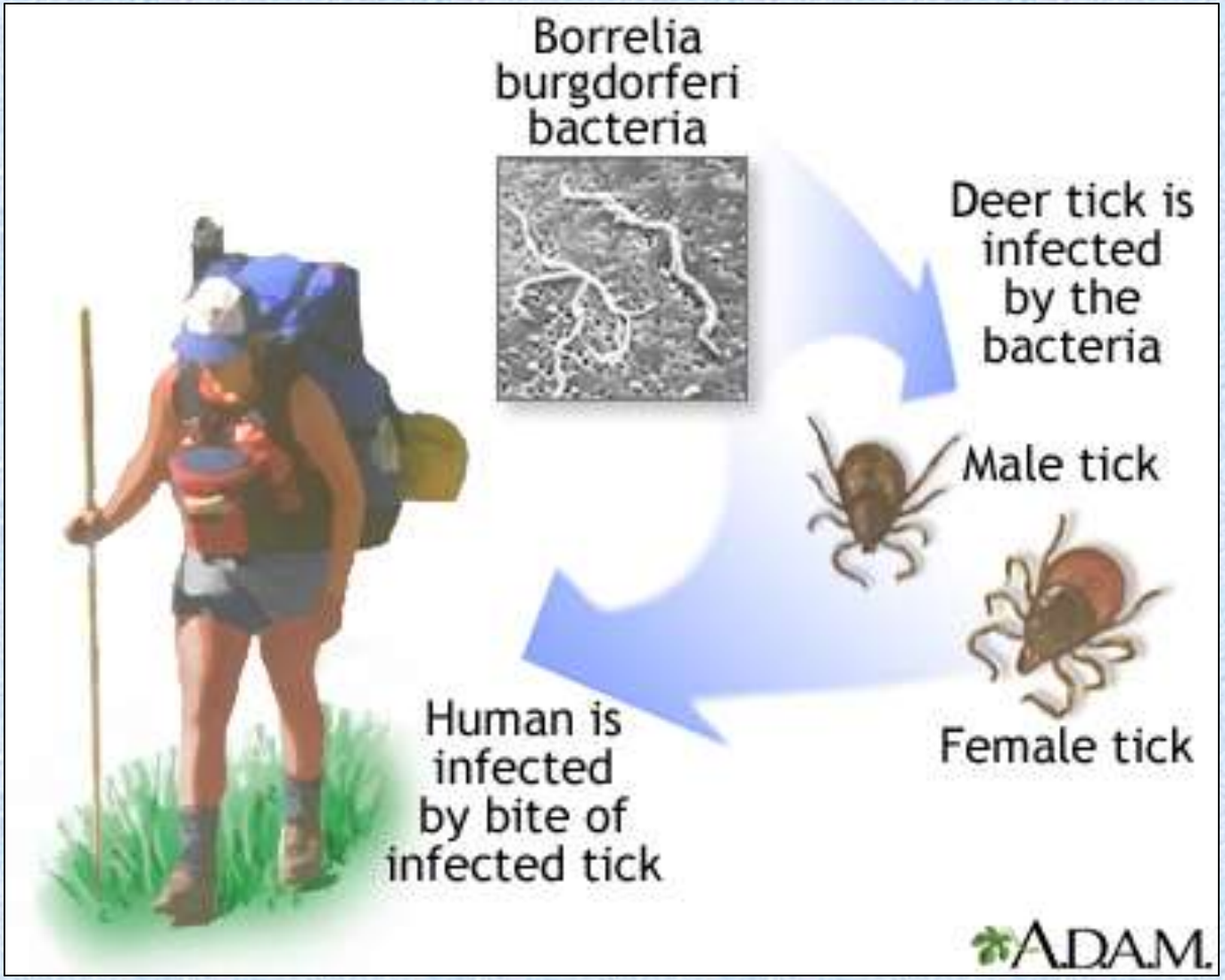
Syphilis - *Treponema pallidum* , a Spirochaete,

- Spreads to nervous system
- Tertiary stage with mental deterioration, blindness
- Treated with antibiotics

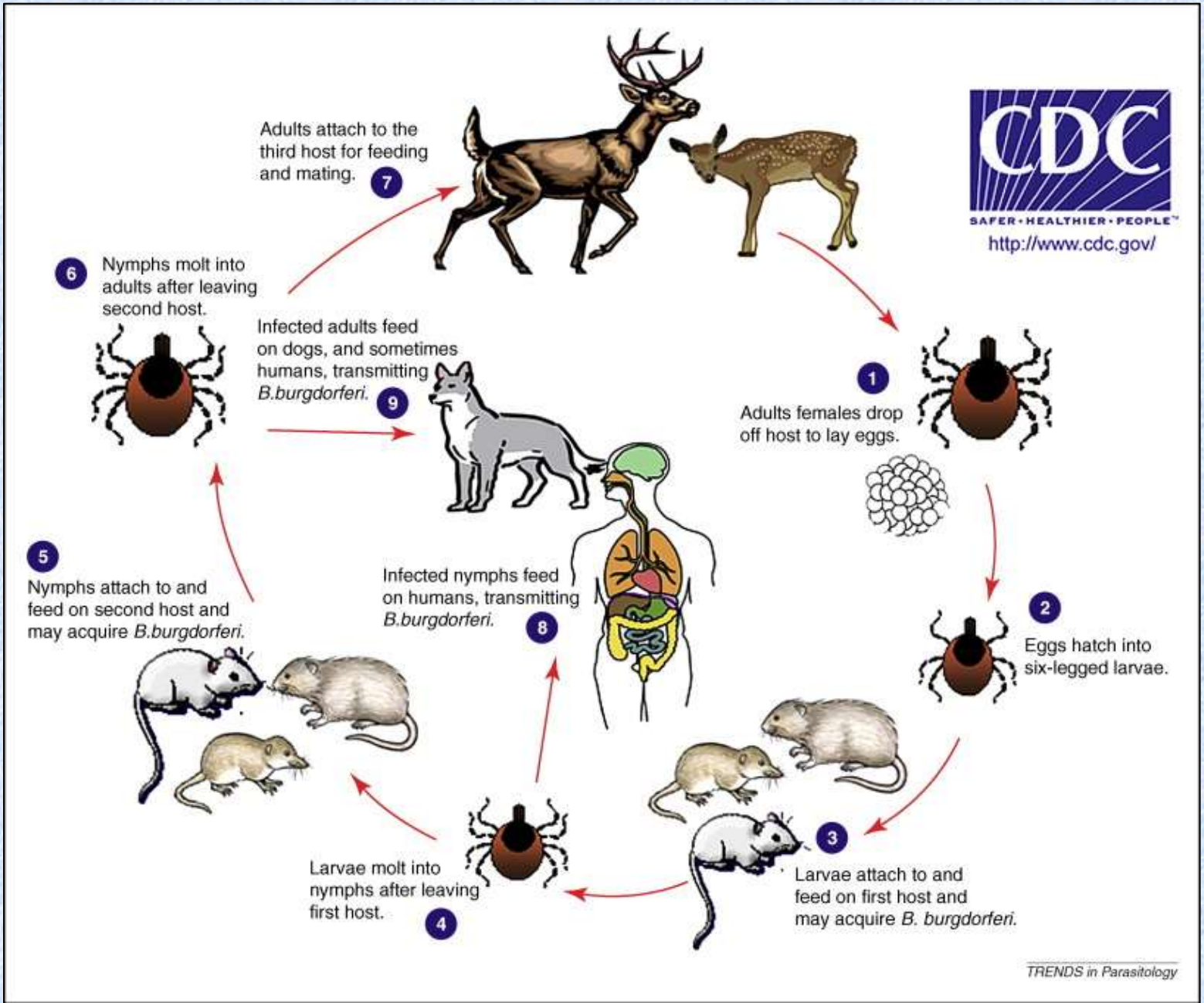
Lyme disease – *Borrelia burgdorferi*

- Rodents are reservoir for *B. burgdorferi;*
- Transmitted by ticks
- First cases reported in Lyme, Connecticut in 1975
- Has spread westward through the U.S.
- Hard to diagnose, half cases develop a Bull's Eye Rash
- Nervous disorders, heart problems, malaise
- Can be treated with antibiotics

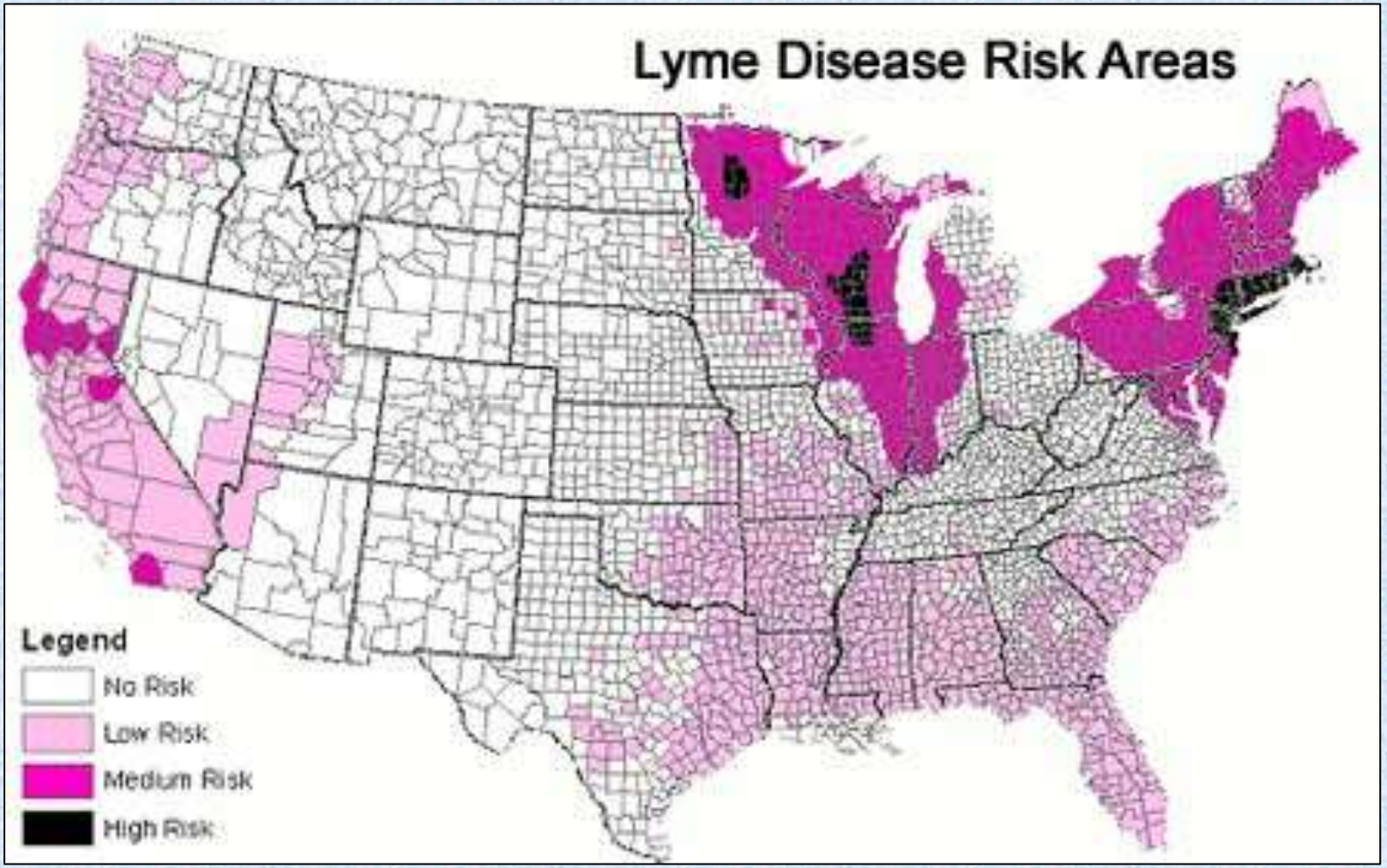
Lyme disease – *Borrelia burgdorferi*



Lyme disease – *Borrelia burgdorferi*

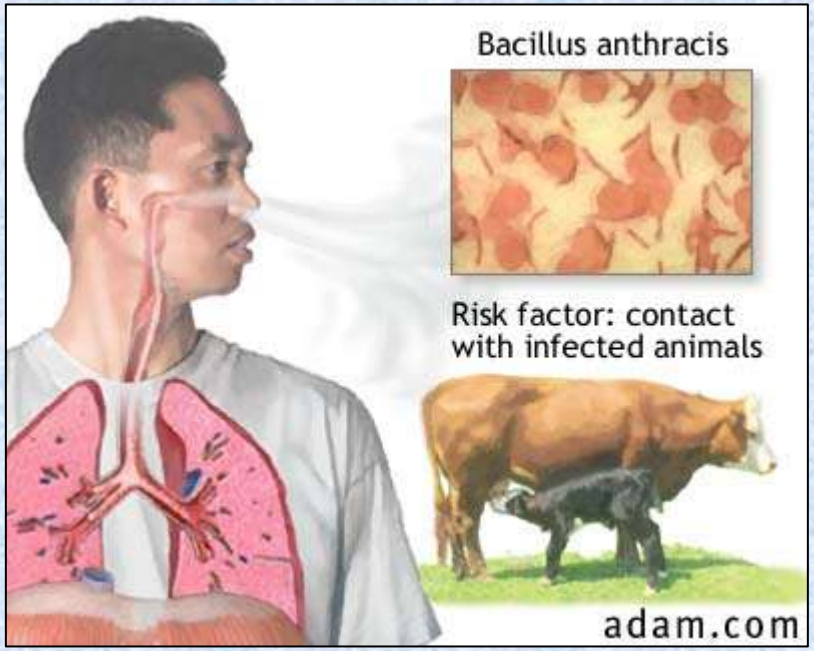


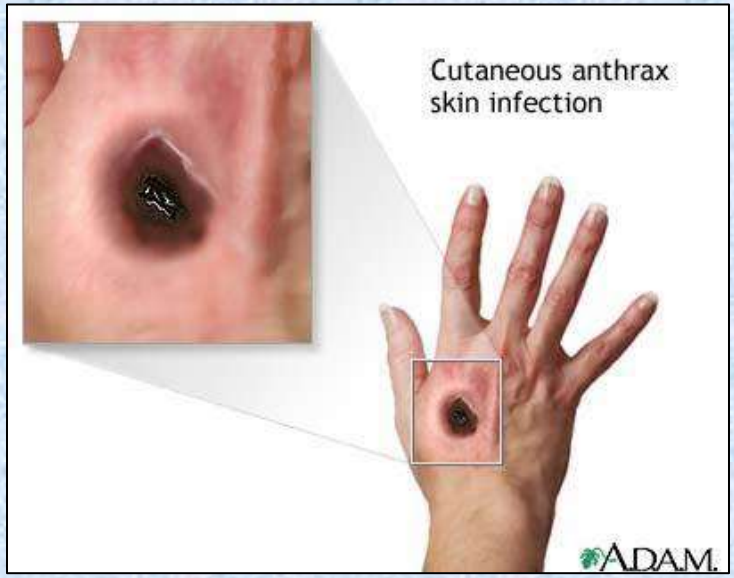
Lyme disease – *Borrelia burgdorferi*



Anthrax - *Bacillus anthracis*

- People catch it from animals, handling dead animals, tanning hides, wool
- Spores enter body through cuts, breathing, or bad meat.
- Black lesions on skin
- Produces toxin, causes spasms and convulsions
- Inhaling spores will cause death
- Developed as a Bioweapon





Anthrax as a Bioweapon

- Anthrax spores are a leading bioweapon due to their stability and ease of dispersal.
- Non-specific symptoms, like more common respiratory diseases.
- Mortality rates approach 100% if untreated.

October 2001, fear of anthrax gripped the nation. Five people died.

End