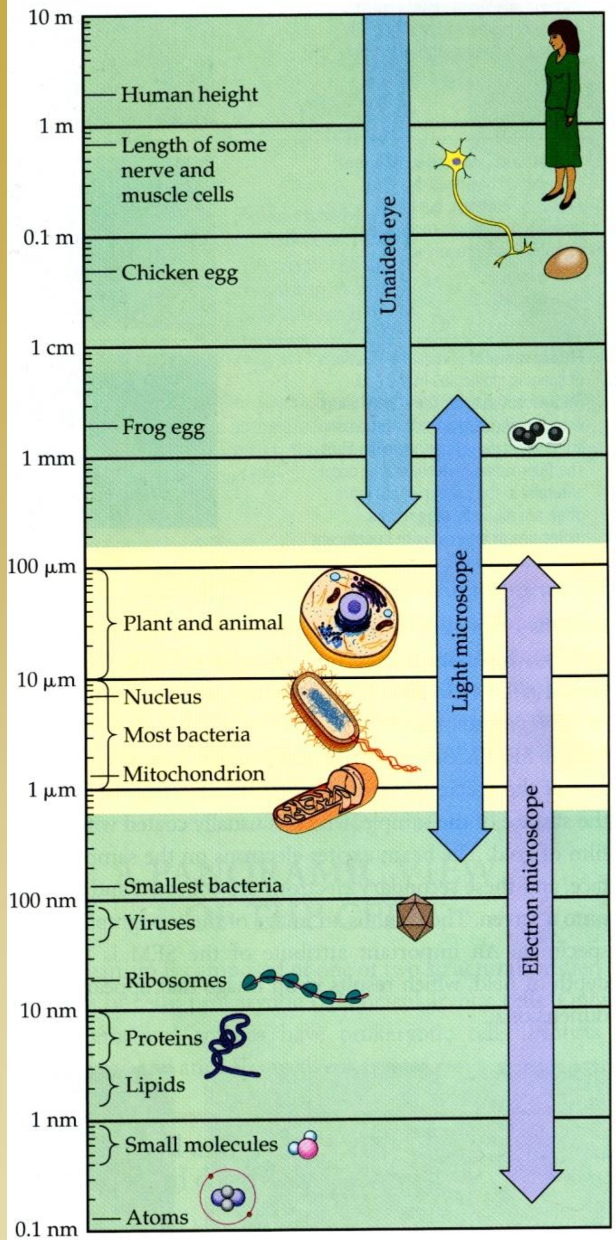
Bacteria and Archaea
Prokaryotic organisms

Premedical - Biology

Size of
the smallest is
100 nm to 10 µm



MEASUREMENTS
1 centimeter (cm) = 10^{-2} meter (m) = 0.4 inch
1 millimeter (mm) = 10^{-3} m
1 micrometer (µm) = 10^{-3} mm = 10^{-6} m
1 nanometer (nm) = 10^{-3} µm = 10^{-9} m

Prokaryotes are (almost) everywhere!

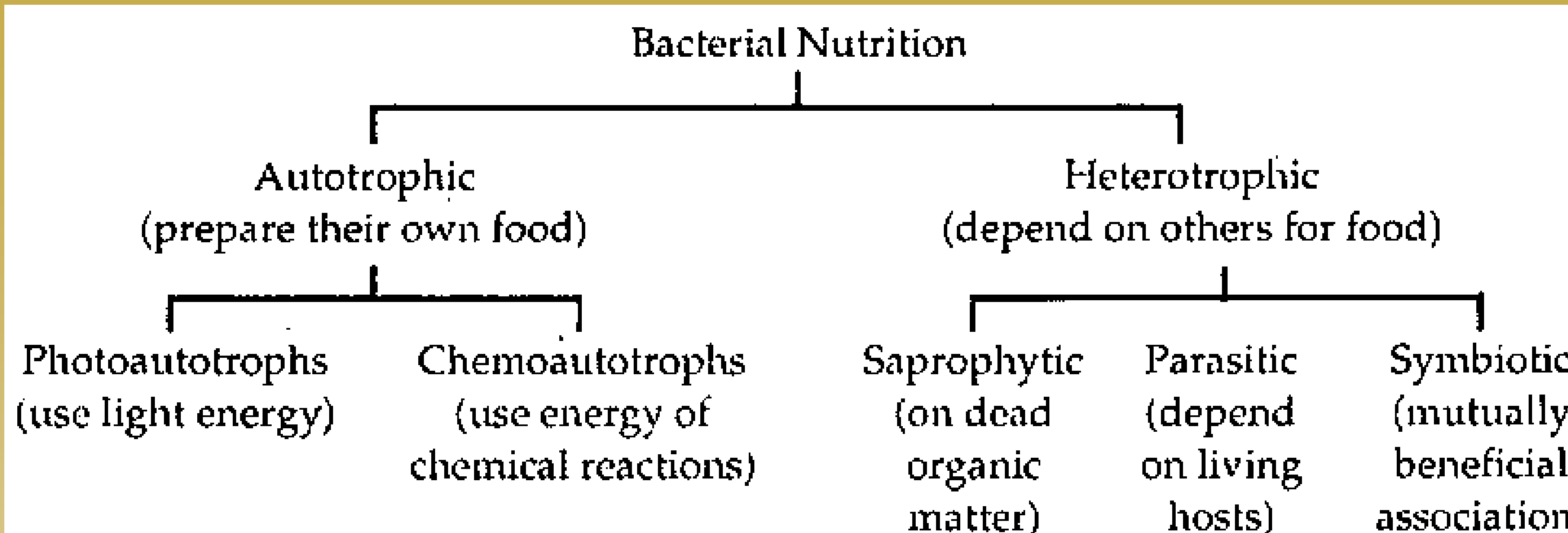
- Their history starts 3,5 billions years ago
- Dominate the biosphere
- Inhabit the human mouth, skin, digestive system – 500 – 1,000 species
- Only minority of them cause disease in humans or any other organism

Adaptation

Metabolic diversity of prokaryotes is broader than of all eukaryotes combined. **They are able to use various organic and inorganic molecules from the atmosphere (CO_2, N_2)**

Primary metabolism is anaerobic and heterotrophic.

Some anaerobic bacteria disappeared, some inhabited **anaerobic environments, became symbiotic or parasites.**



Bacteria have two strategies how to get **energy** and **carbon** (resources) for synthesis of organic compounds.

Autotrophic Bacteria

are organisms that makes organic compounds from inorganic sources. They synthesize organic compounds from carbon dioxide and other inorganic elements or molecules (H_2S).

They use either light energy or chemical energy.

green sulphur bacteria, purple sul-phur bacteria and the purple norisulphur bacteria

Photoautotrophs

use light-energy to drive synthesis of organic compounds from carbon dioxide. They have light-harvesting pigment systems.

Chemoautotrophs

need only CO_2 as a carbon source. They obtain energy by oxidizing inorganic substances: hydrogen sulfide (H_2S), ammonia (NH_3), ferrous ions (Fe^{2+})

Heterotrophic Bacteria

Majority of them are chemoheterotrophs.

They cannot make organic compounds from inorganic sources. They depend on small or large molecules, which they have to *absorb.*

There are three types of heterotrophic bacteria: saprophytic or saprobic, parasitic and symbiotic.

Pseudomonas, Staphylococus, Escherichia coli

Photoheterotrophs

use light-energy to generate ATP, but must obtain carbon in organic form.

Chemoheterotrophs

must consume organic molecules for both energy and carbon.

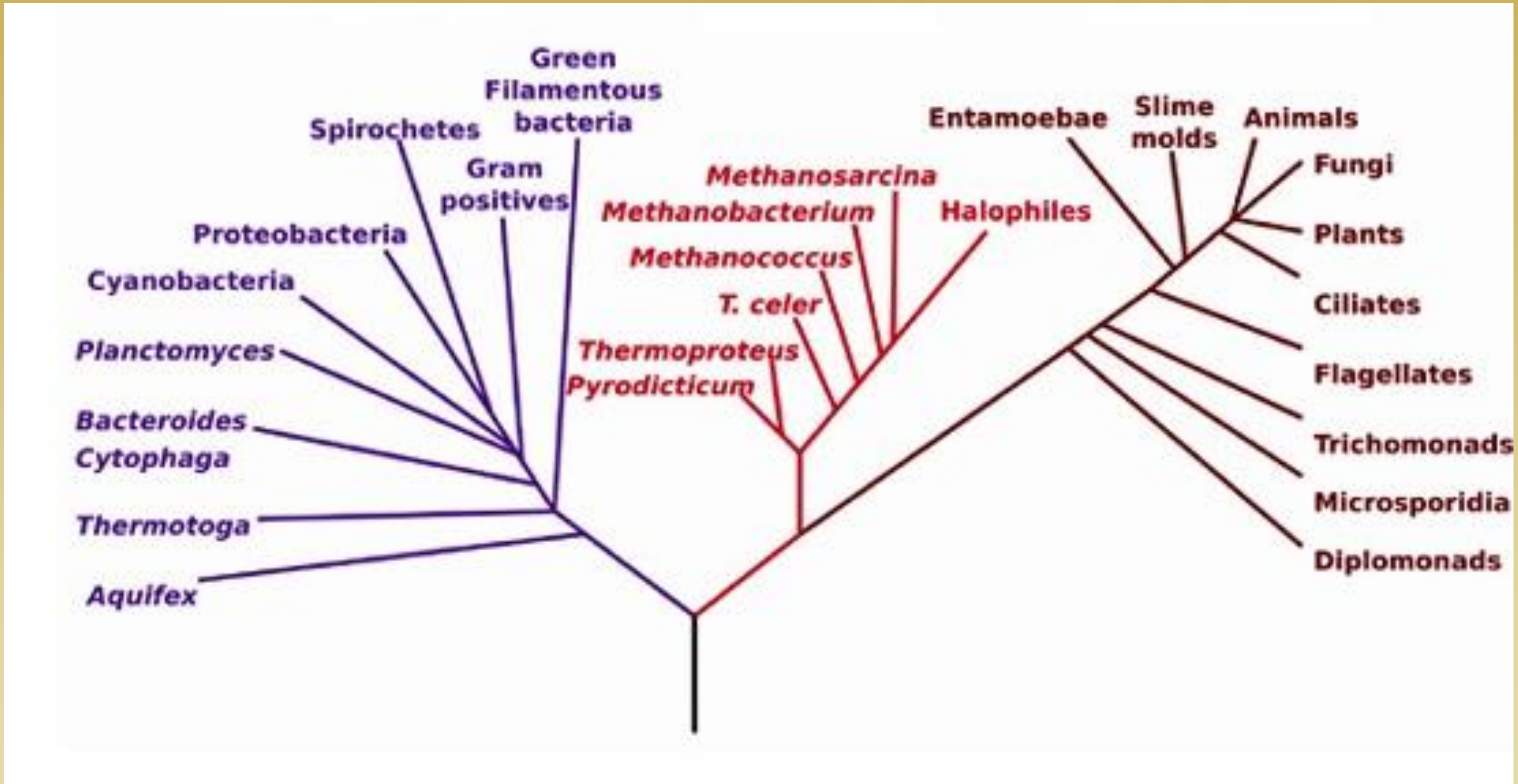
Metabolic relantioship to oxygen

Obligate aerobes use cellular respiration.

Facultative anaerobes use oxygen, if is present. They use fermentation in anaerobic environments.

Obligate anaerobes are poisoned by oxygen, they use fermentation or extract energy by **anaerobic respiration.**

Bacteria, Archae and Eukaryotes



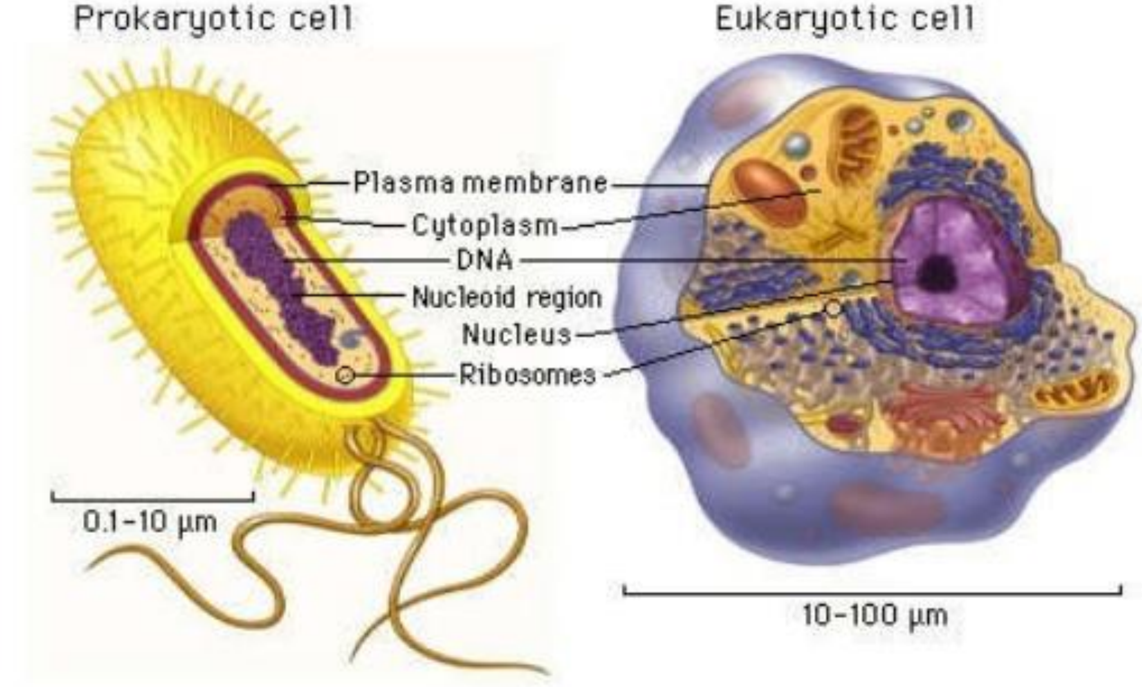
Common ancestor 3.5 bilion years ago

TABLE 10.1 Some Characteristics of Archaea, Bacteria, and Eukarya

	Archaea	Bacteria	Eukarya
	 *Methanosarcina*	 *E. coli*	 *Amoeba*
Cell Type	Prokaryotic	Prokaryotic	Eukaryotic
Cell Wall	Varies in composition; contains no peptidoglycan	Contains peptidoglycan	Varies in composition; contains carbohydrates
Membrane Lipids	Composed of branched carbon chains attached to glycerol by ether linkage	Composed of straight carbon chains attached to glycerol by ester linkage	Composed of straight carbon chains attached to glycerol by ester linkage
First Amino Acid in Protein Synthesis	Methionine	Formylmethionine	Methionine
Antibiotic Sensitivity	No	Yes	No
rRNA Loop*	Lacking	Present	Lacking
Common Arm of tRNA†	Lacking	Present	Present

*Binds to ribosomal protein; found in all bacteria.
†A sequence of bases in tRNA found in all eukaryotes and bacteria: guanine-thymine-pseudouridine-cytosine-guanine.

Comparing Prokaryotic and Eukaryotic Cells



a) Prokaryotes do not have a nucleus

b) Prokaryotes do not have membrane-bound organelles

Prokaryotes

- **unicellular**

sphere (cocci)

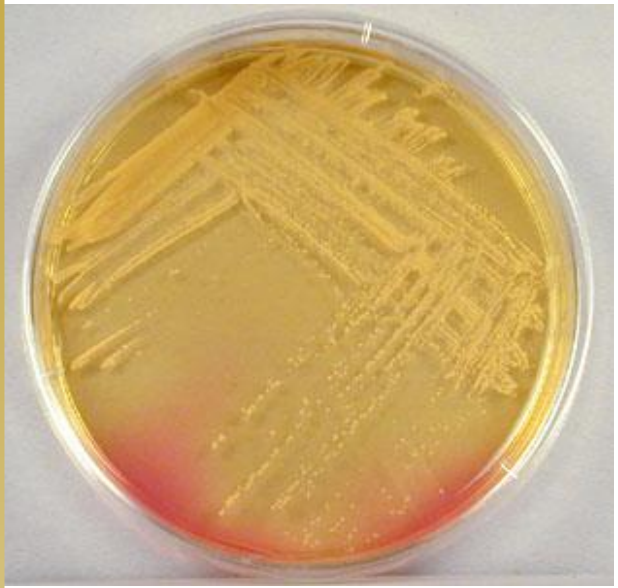
rods (bacilli),

helices (spirilla, spirochetes)

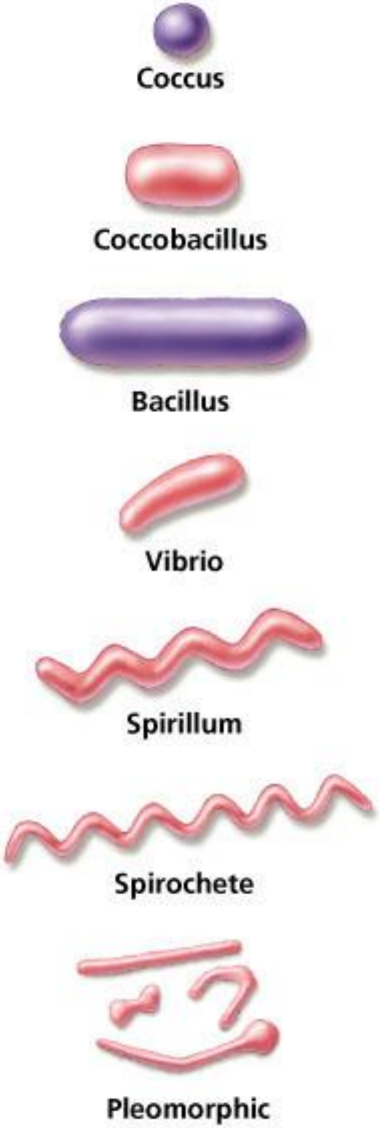
Can exist as groups of two or more cells, true colonies

- **0.5-5µm**

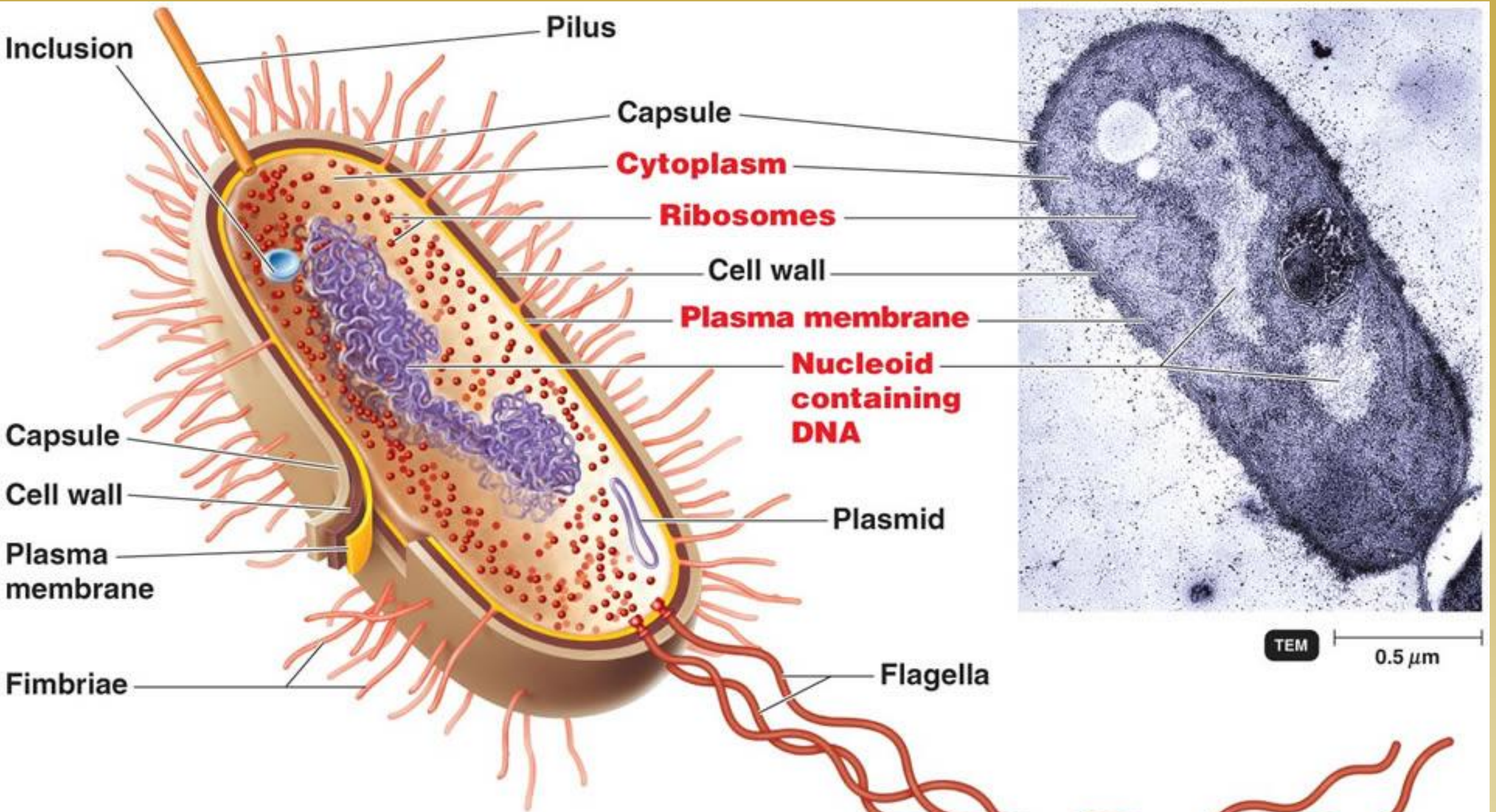
(10-100µm for eukaryotic cells)



Staphylococcus aureus



Bacterial structure



Note that not all bacteria have all the structures shown. Structures labeled in **red** are found in all bacteria. Both the drawing and the micrograph show a bacterium sectioned lengthwise to reveal the internal composition.

Key Concept

Prokaryotic cells lack membrane-enclosed organelles. All bacteria contain cytoplasm, ribosomes, a plasma membrane, and a nucleoid. Almost all bacteria have cell walls.

Haiti cholera outbreak 2010

after the disastrous earthquake earlier that year, cholera spread across the country and become endemic, causing high levels of both morbidity and mortality. Nearly 800,000 Haitians have been infected by cholera, and more than 9,000 have died, according to the United Nations. Cholera transmission in Haiti today is largely a function of eradication efforts including WASH (water, sanitation, and hygiene), education, oral vaccination and climate variability.

Cell wall

- function is protection (hypotonic environment) and patogenity

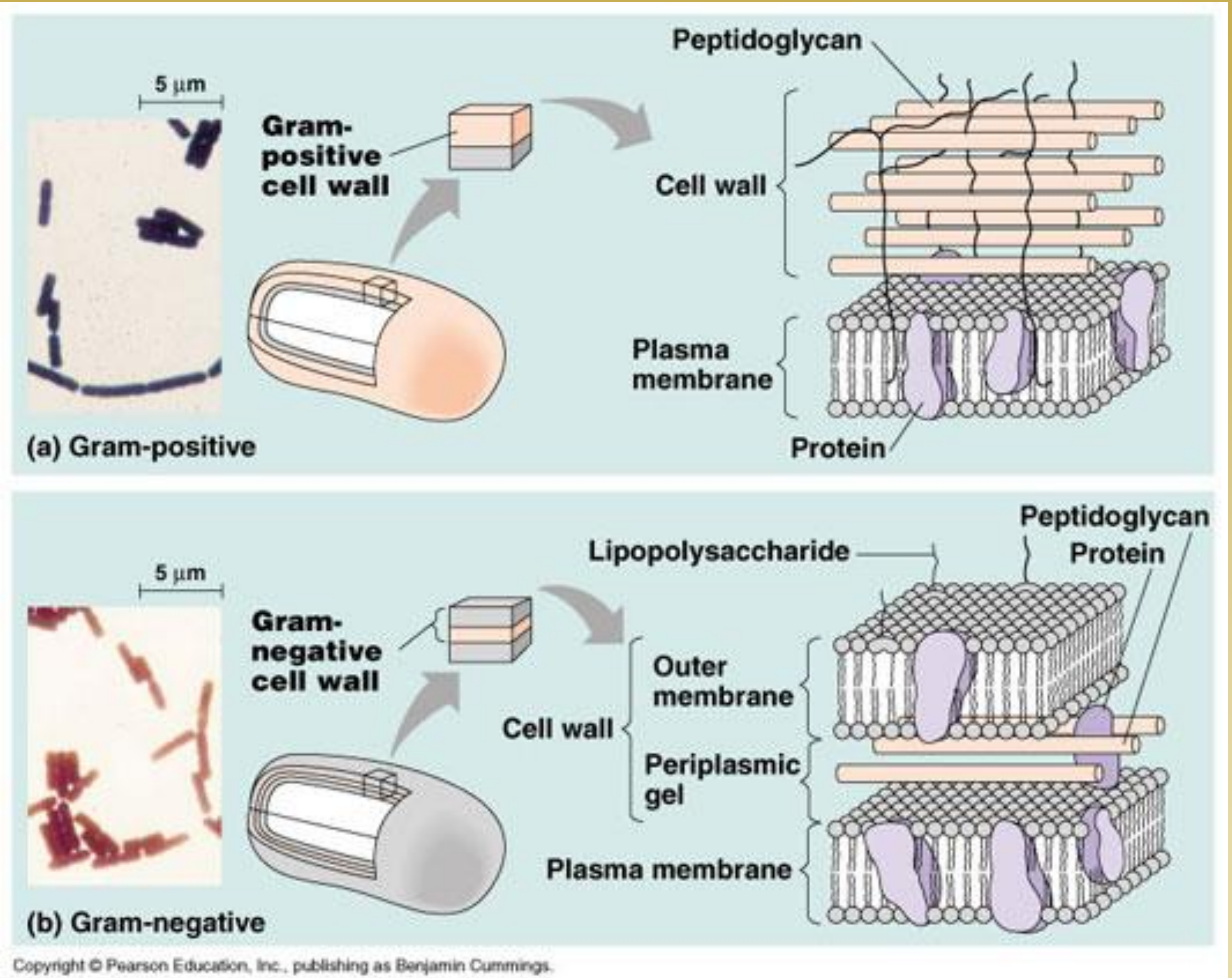
They **would die in hypertonic medium** (heavily salted meat).

- **peptidoglycan** is polymer of sugar cross-linked by short peptides

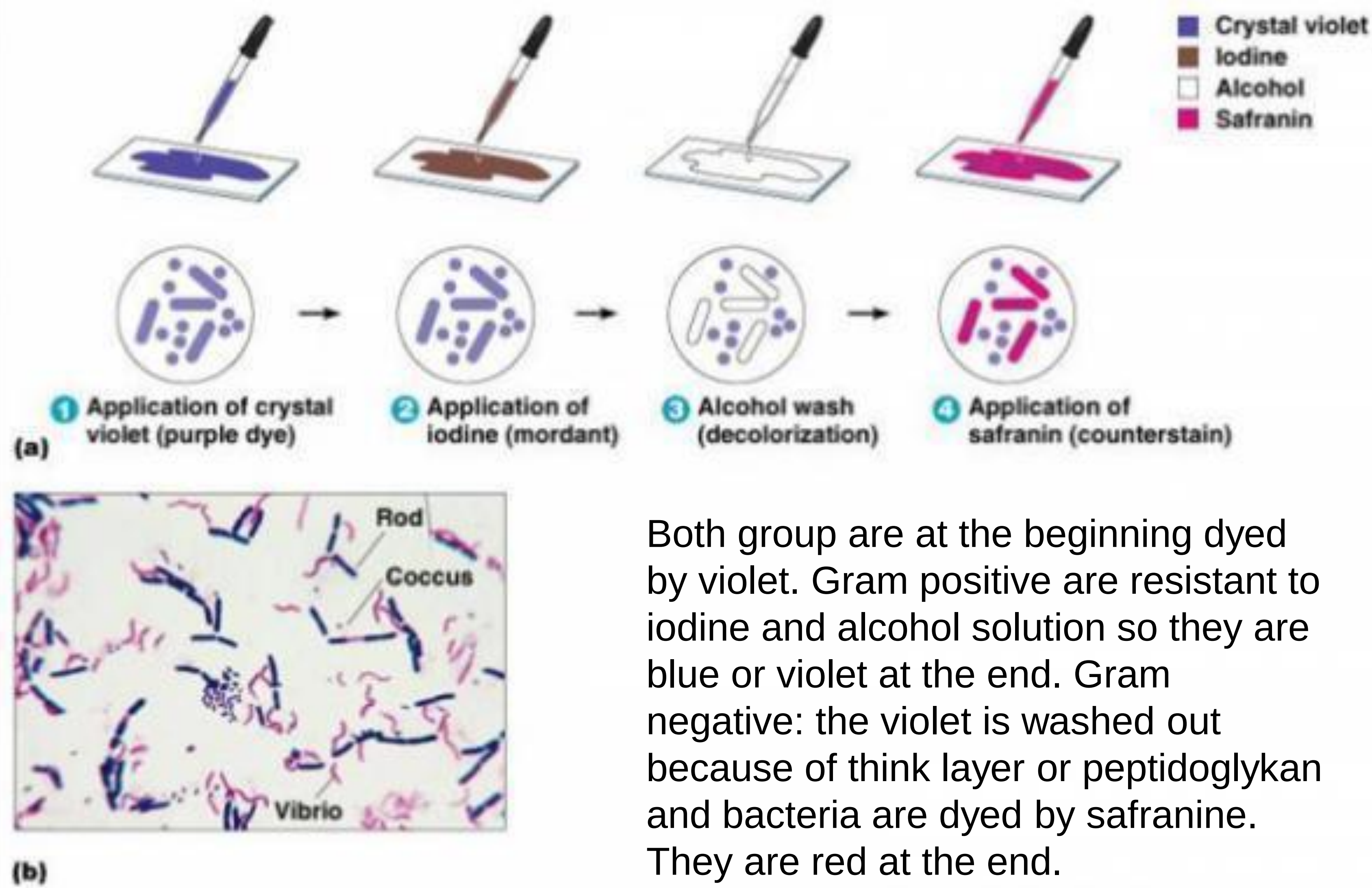
A tool in microbial taxonomy is **Gram staining**, which divide bact. into two groups based on differences in cell walls.

- **Gram positive** – thick layer of peptidoglycan
- **Gram negative** – thin layer of peptidoglycan, outer membrane with lipopolysaccharides (LPS) - carbohydrates bonded to lipids, Lipoteichoic acids (LTA)

Gram positive and Gram negative



Gram staining



Both group are at the beginning dyed by violet. Gram positive are resistant to iodine and alcohol solution so they are blue or violet at the end. Gram negative: the violet is washed out because of think layer or peptidoglykan and bacteria are dyed by safranine. They are red at the end.

Examples of G+ bacteria:

Actinomyces
Bacillus
Clostridium
Corynebacterium
Streptococcus
Staphylococcus

Examples of G- bacteria

Escherichia
Haemophilus
Helicobacteur
Neiserria
Pseudomonas
Salmonella
Shigela
Spirochaetaceae

Patogenity

Gram negative are **more pathogenic**

- LPS of Gram negative bact. are **toxic = Endotoxin:** thermostable
- **Exotoxin**: thermolabile (*Cl. botulinum, Co. diphthriae)*

Outer membrane protects against immune reaction of the host and **antibiotics**

Antibiotics, like penicillins, **inhibit** synthesis of cross-links in **peptidoglycan** and prevent formation of the cell wall

Capsule - adhered to substrate and of cells to colonies

Pili, pilus – Gram negative, adherence, conjugation

Some pathogen are **opportunistic** = normal residents of a host, but can cause illness, when the host‘s immune system is weak.

Genome

Bacteria do not have **true nuclei**, either **compartments separated** by internal membrane system.

DNA is concentrated in **nucleoid region, prokaryotic chromosome,** which is the double stranded circle molecule.

Genes of prokaryotic chromosome encode essential functions for cell.

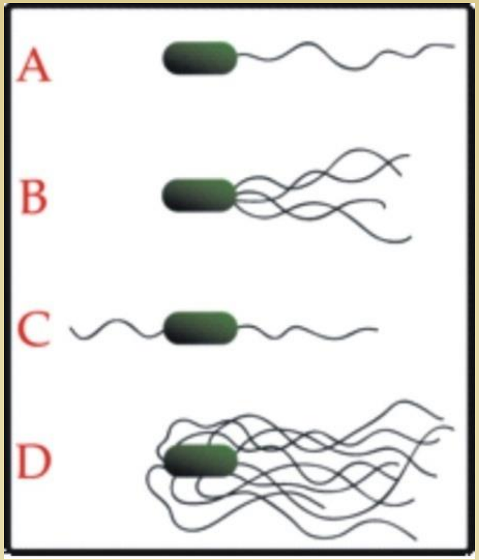
There are also **small rings of DNA – plasmids, which encode resistance** to antibiotics or **metabolism** of unusual nutrients.
They replicate independently of the main chromosome.

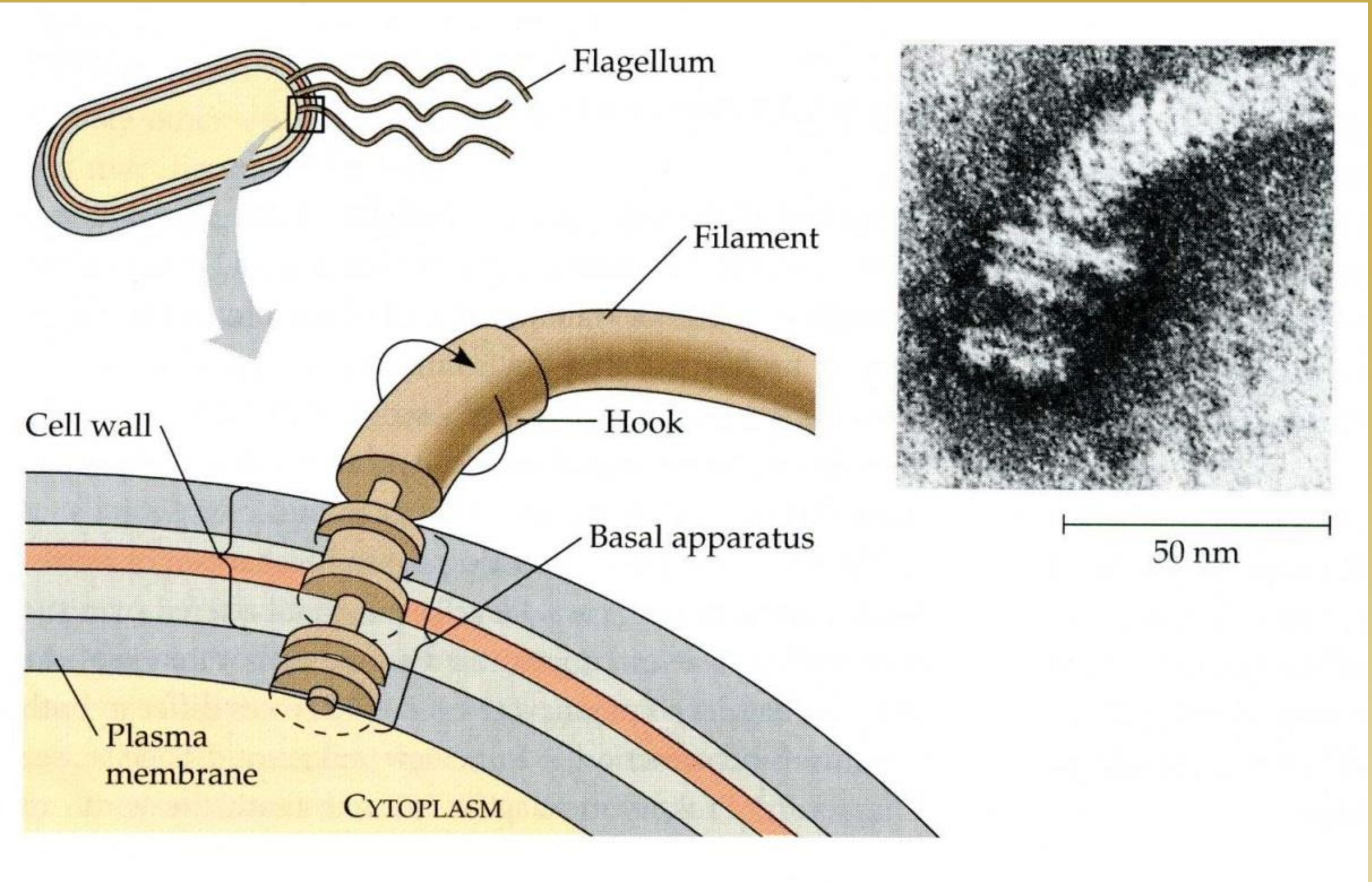
Movement

direct movement – in one second they are able to reach distance 100x their body length

Flagellar movement is the most common mechanism.

Flagella are distributed over the entire
cell surface or at one or both ends of the cell
Flagella of prokaryotes and eukaryotes differ in function and structure.

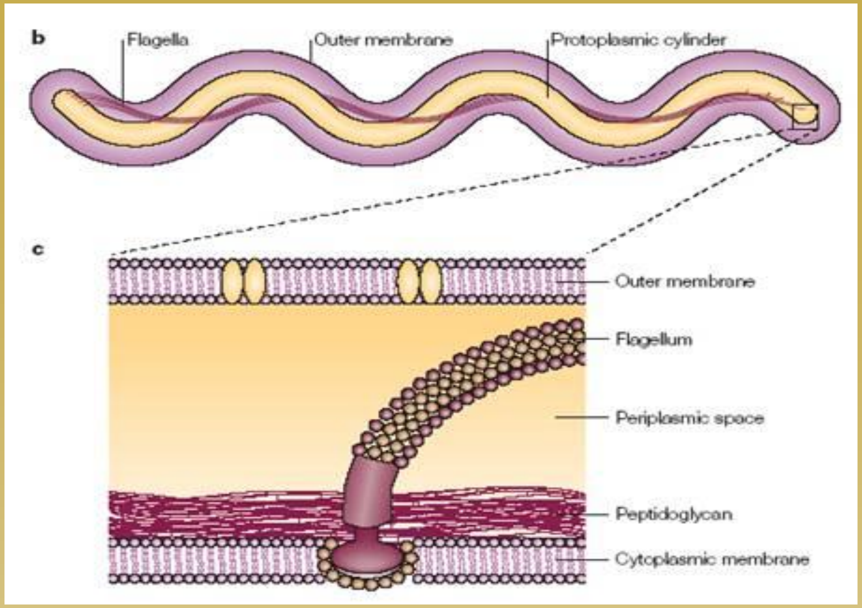




When filaments rotate, the cell moves like a corkscrew, disks rotate in the opposite direction.

• **Motility of spirochetes**

Managed by two or several helical filaments under the cell wall.



Rosa PA[1], Tilly K, Stewart PE. The burgeoning molecular genetics of the Lyme disease spirochaete. Nat Rev Microbiol. 2005, Feb;3(2):129-43.
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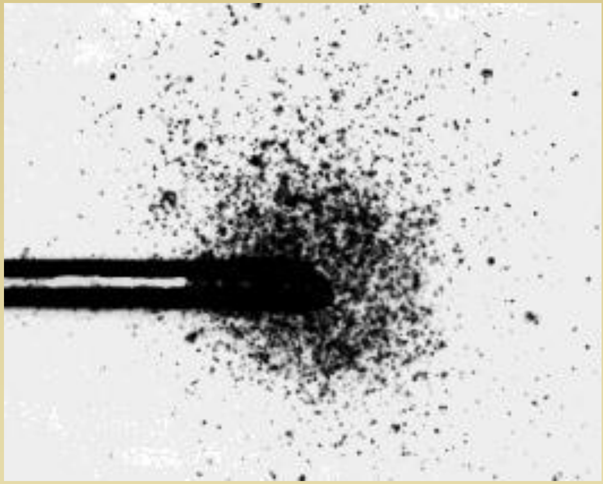
• **Taxis -** movement is toward to or away from stimulus.

chemotaxis

phototaxis

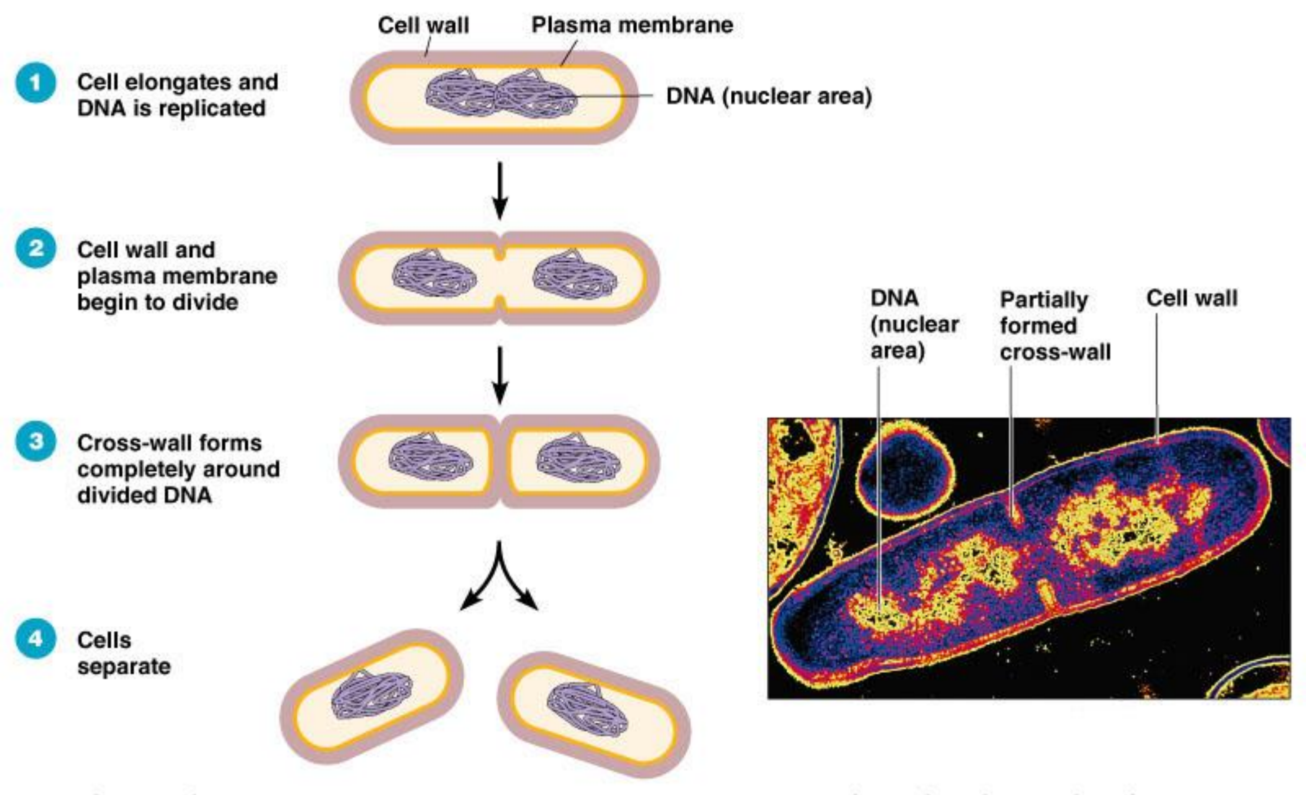


http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/T/Taxes.html

Division

is called **binary fission** – „division in the half".

Bacterial chromosome is attached to the plasma membrane.



(a) A diagram of the sequence of cell division.

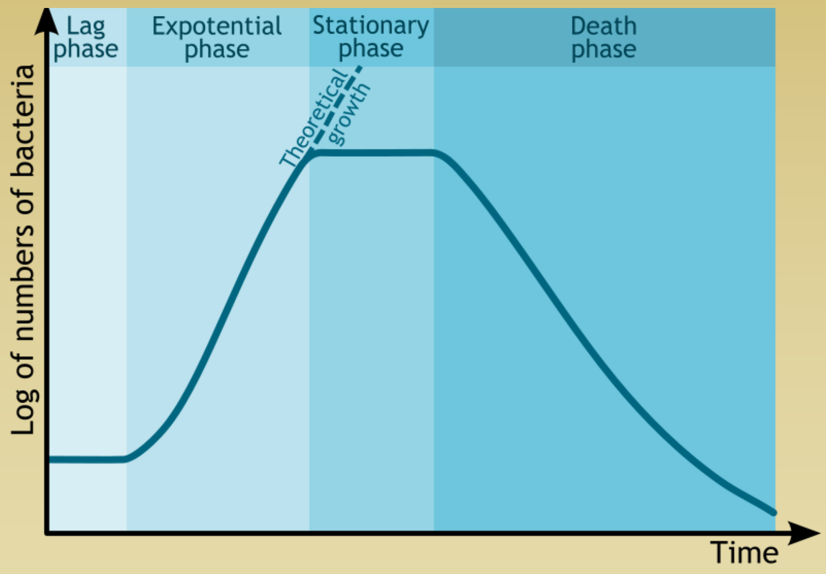
(b) A thin section of a cell of *Bacillus licheniformis* starting to divide.

Grow of populations

Important conditions are temperature, pH, salt concentrations and nutrient sources.

The growth means multiplication of cells, not their enlargement. Generation time is in the range of 1 to 3 hours.

During ***lag phase*** population adapt themselves to growth conditions. ***Exponential phase*** is a period characterized by cell doubling. At ***stationary phase*** is the nutrient depletion and accumulation of toxic products. At ***death phase*** bacteria run out of nutrients and die.



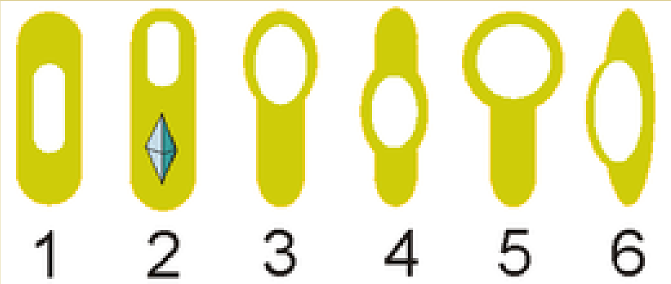
Endospores

- ability of some prokaryotes to **withstand harsh conditions**, as is **lack of water, nutrients, extreme heat or cold, poisons**.

Bacterial chromosome replicates. The copy is surrounded by thick, durable wall and the outer cell disintegrates.

Clostridium tetani

Bacillus cereus, *Bacillus subtilis*.



(1, 4) central endospore; 2, 3, 5) terminal endospore; (6) lateral endospore

Genetic variability of prokaryotes

Prokaryotes lack sexual cycle.

Recombination of genetic information (DNA molecule) is managed by three mechanisms:

Transformation – genes are picked up from surrounding environment

Conjugation – genes are relocated directly from one bacterial cell to another

Transduction – genes are relocated by viruses

Bacterial transformation

Bacterial genes, naked DNA, are picked up from surrounding environment into recipient cells.

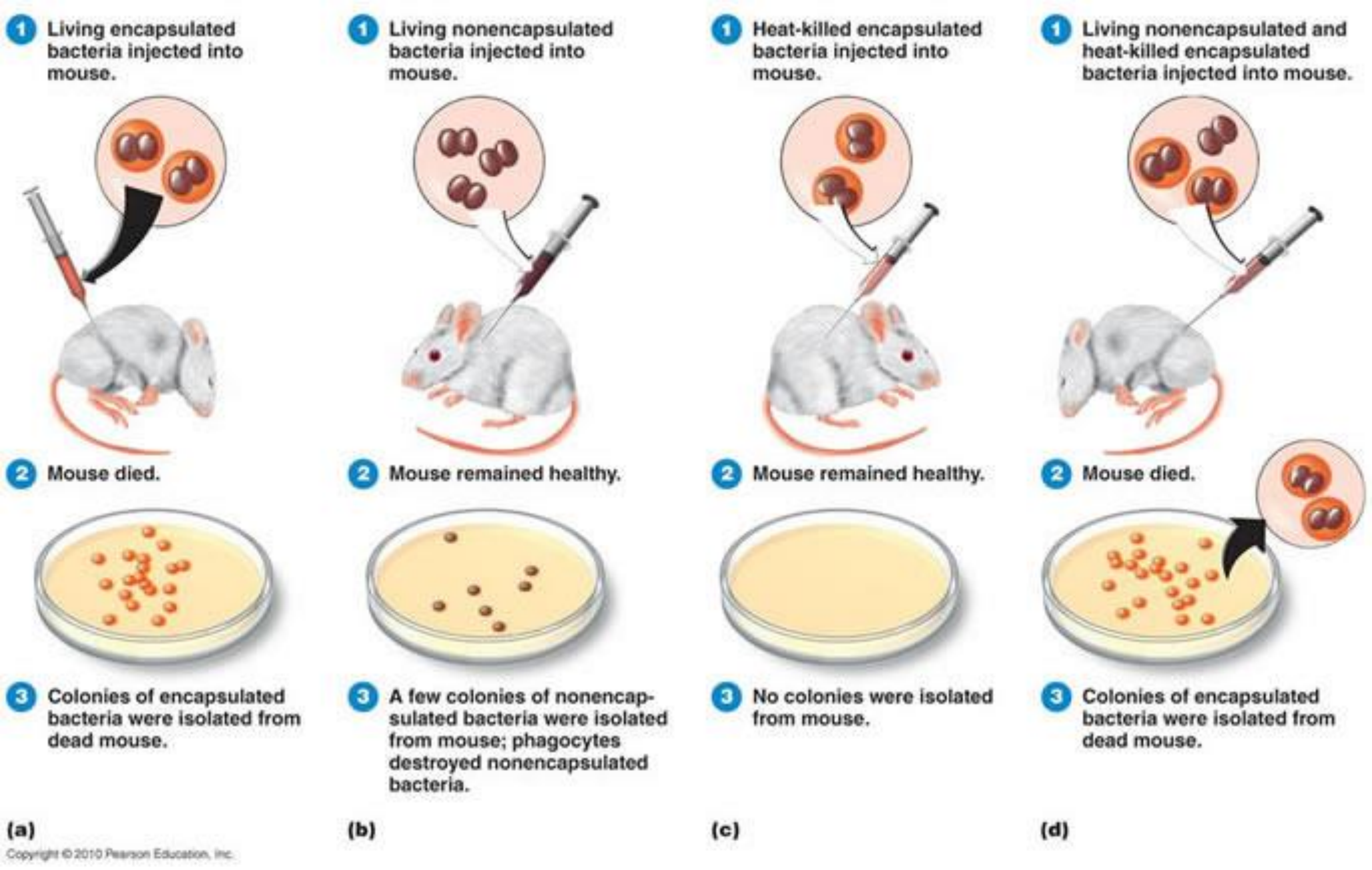
Homologous parts exchange, it is called homologous recombination.

First experiment of bacterial transformation was done by Griffith (1928).

It was proved that the carrier of genetic information is DNA.

Avery, McLeod, McCarthy (1944) proved the same effect with isolated DNA.

Griffith's experiment 1928



Transduction

Bacterial genes are transferred between prokaryotes by viruses.

Bacteriophages transmit bacterial genes spontaneously.

Special transduction is given by restriction mistakes during cutting of a prophage (bacteriophage) from bacterial genome.

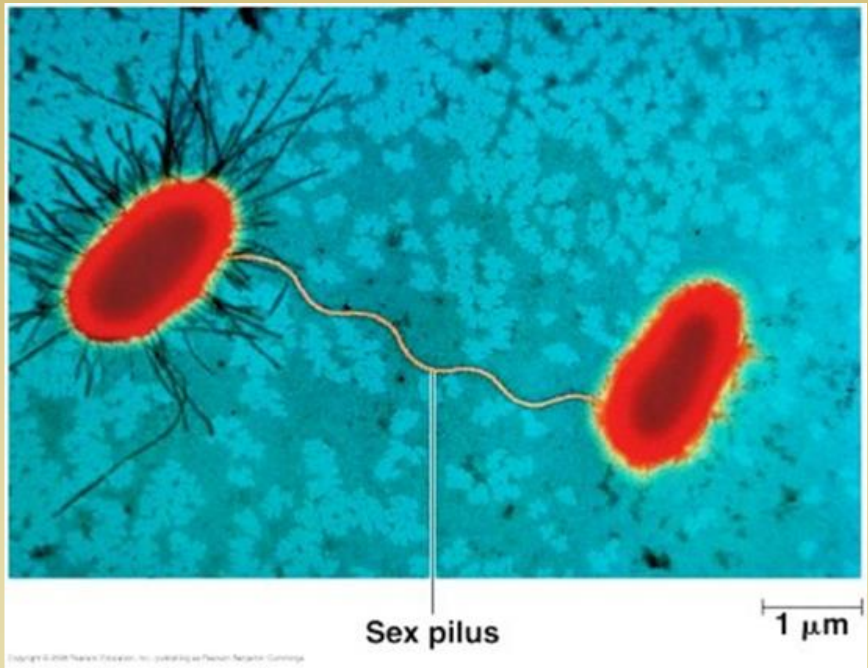
Generalised transd. happens, when random small parts of bacterial DNA are packed instead of phage‘s DNA.

Bacterial conjugation

Bacterial genes are relocated directly from one (F+) to another cell (F-).

F+ is the cell with special F plasmid encoding genetic information for conjugation, origin of cytoplasmic conjugative bridge and pilli.

Homologous parts are exchanged after transmission



Many prokaryotes are symbiotic

Symbiosis „living together“ is ecological relationship between organisms of different species that are in direct contact.

Symbionts: one is much larger than the other, the larger one is termed **host**

Mutualism is relationships, when both symbionts benefit.

Commensalism is relationships, when one symbiont receives benefits, while the other is not harmed or helped in any significant way.

Parasitism is relationships, when one symbiont, called a **parasite**, benefits at the expense of the host.

Bacteria in research and technology

Bacteria are simple model systems.

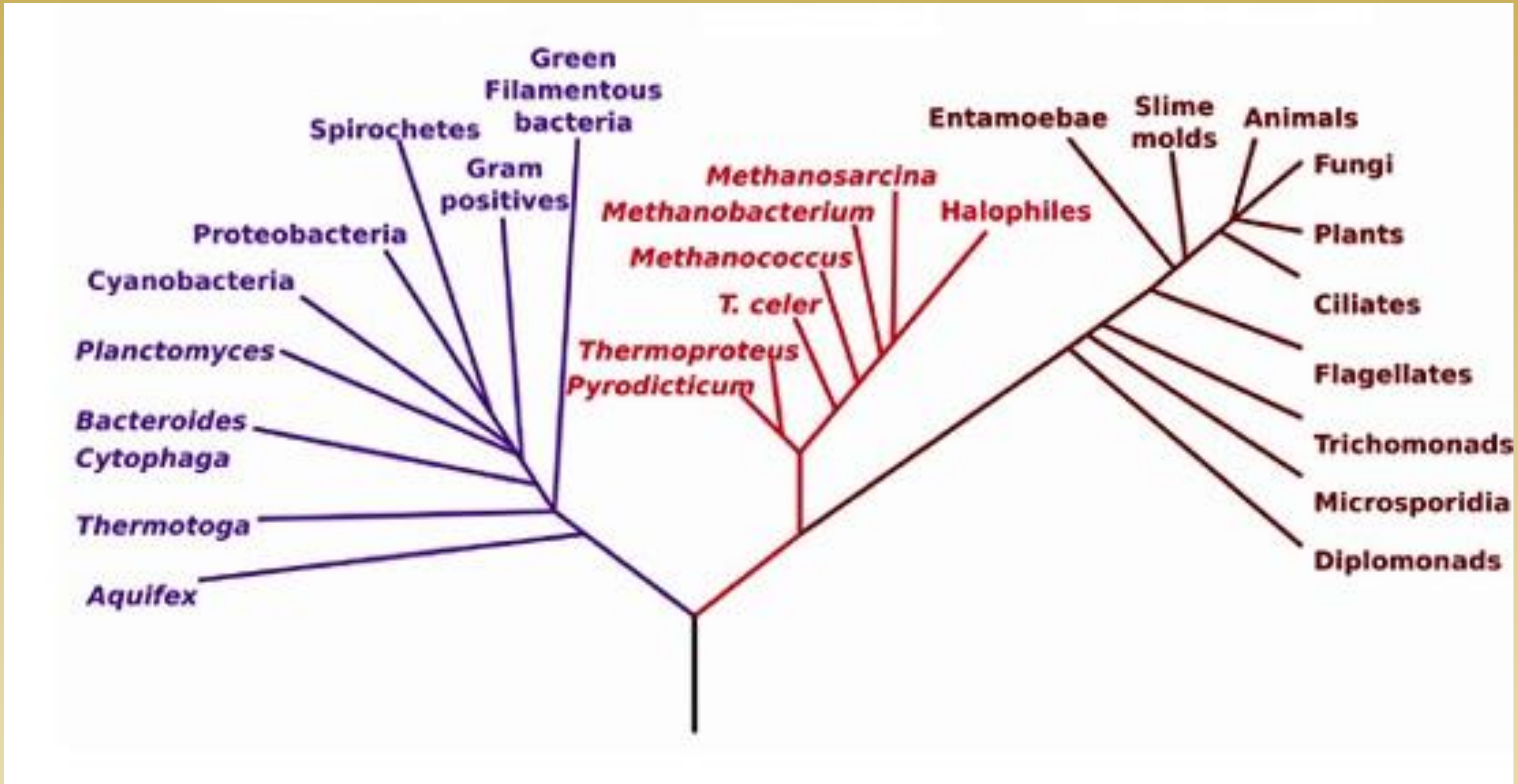
Escherichia coli is the prokaryotic „ white rat“

Soil bacteria called **pseudomonas decompose** pesticides, petroleum components and other.

The food industry uses bacteria to **convert milk to yogurt** and for origin of various kind of **cheese - bacteria of milky fermentation.**

Gram stain of yogurt, 1000x
with *Lactobacillus acidiphilus*

Bacteria, Archae and Eukaryotes



Common ancestor 3,5 bilion years ago

Archae

Two branches of prokaryotic evolution were identified by comparing ribosomal (16S-rRNA) RNA and complete sequences of genomes of several extant species.

Archaea inhabit extreme environments, hot springs and salt ponds.

Archea have at least as much in common with eukaryotes as they do with bacteria; have many unique traits.

Phylogeny of prokaryotes

domain ***Archea***

Methanogens

unique form of energy metabolism, H_2 is used to reduce CO_2 to methane CH_4. Oxygen is a poison. Live in swamps and marshes and other species inhabit the gut of animals.

Extreme halophiles

live in saline places as the Great Salt Lake and the Dead sea

Extreme thermophiles

thrive in hot environments, temperatures are of 60°C to 80°C, thermal springs

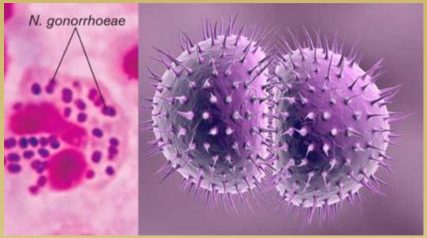
Most widely known pathogenic bacteria:

Borrelia burgdorferi – Lyme diseases - tick-borne d.

Treponema pallidum - syphilis

Neisseria gonorrhoeae – gonorrhoea

Neisseria meningitis – cerebro-spinal meningitis

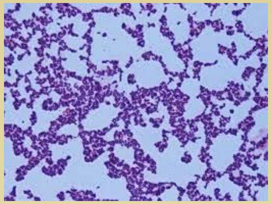


Salmonella typhi – typhus

Bordetella pertusis – whooping cough

Staphylococcus aureus – skin suppuration

Staphylococcus pneumonie – pneumonia

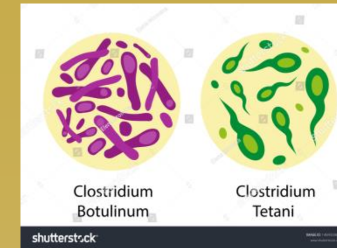


Streptococcus pyogenes – angina, sore throat

Streptococcus pneumonie – pneumonia

Clostridium tetani - tetanus

Clostridium botulinum- botulism



Bacillus anthracis – anthrax

Mycoplasma pneumonie – pneumoni

Shigella dysenterie - red pestilence, dysentery

Vibrio cholerae – cholera

Mycobacterium leprae - leprosy

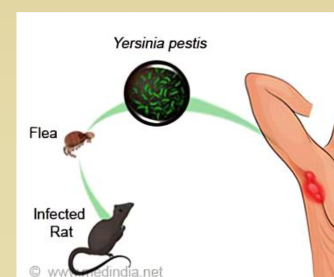
Mycobacterium tuberculosis - tuberculosis

Corynebacterium diphterie - diphtheria

Haemophilus influenzae – inflammation of airways

Rickettsia prowazeki - spotted fever

Pasteurella (Yersinia) pestis – plague



Francisella tularensis - tularaemia

Campbell, Neil A., Reece, Jane B., Cain Michael L., Jackson, Robert B., Minorsky, Peter V., **Biology**, Benjamin-Cummings Publishing Company, 1996 –2010.