Building a microbe
1. Bacteria

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Learning objectives

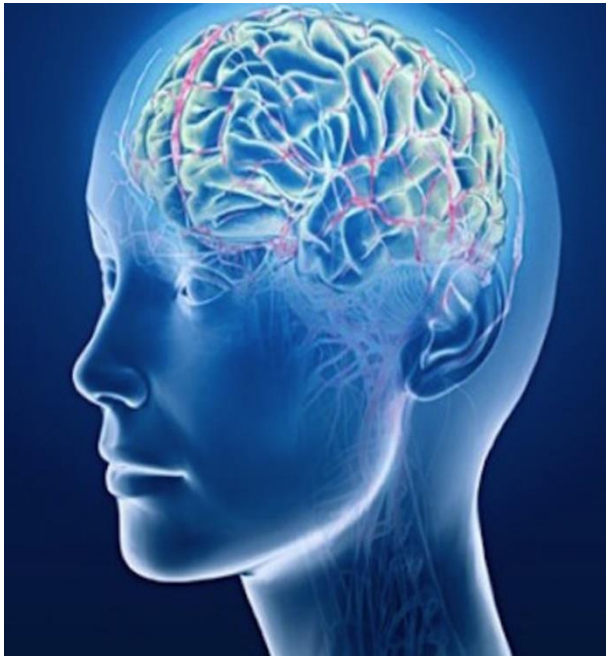
'Prescott's Microbiology' 10th ed, 2017, chapter 3.

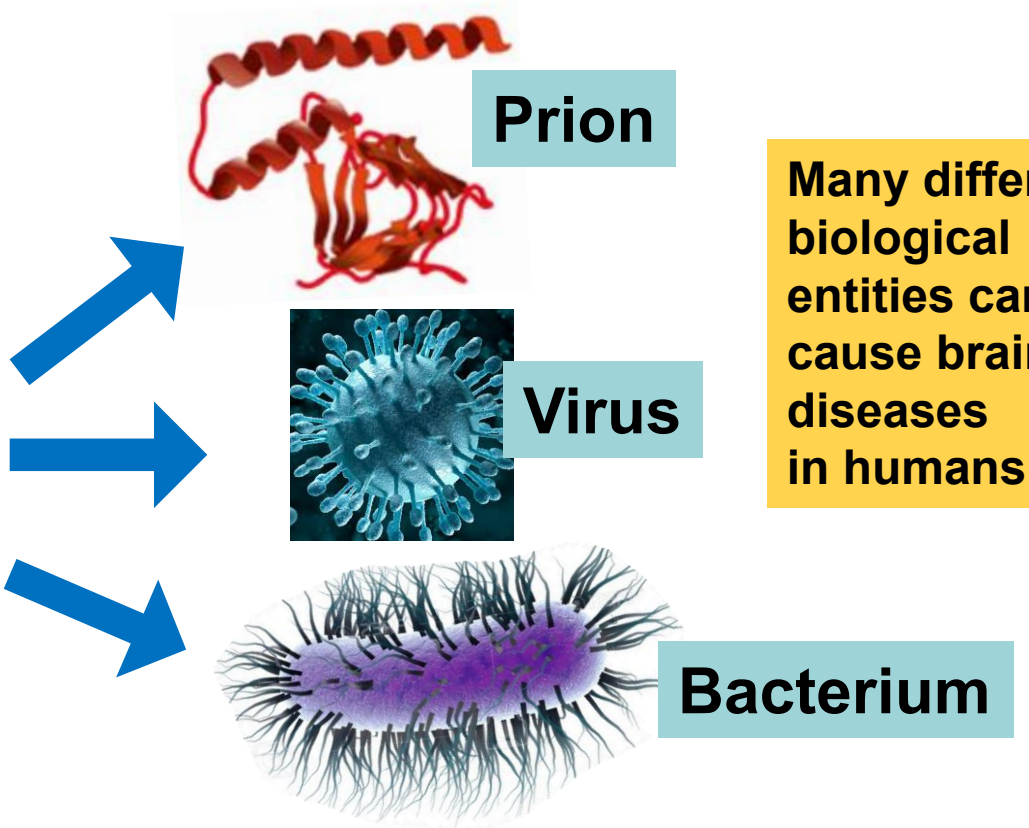
Students should be able to :

- Define: prions, plasmids, viruses, Bacteria, Archaea, Eukarya
- Explain six differences between cells of Bacteria and Eukarya
- Explain the role of different cell structures in bacterial life, and in the diagnosis and treatment of disease
- Specifically, explain the structure, functions, significance of:
  - nucleoid
  - ribosomes
  - plasma membrane
  - peptidoglycan
  - outer membrane

Microorganisms vs. other biological entities

- **What do both groups share?**
  - **Both contain information (nucleic acid and/or protein)**
  - **… therefore both have the <u>ability to evolve</u>**
  - **Both interact with 'higher' organisms**

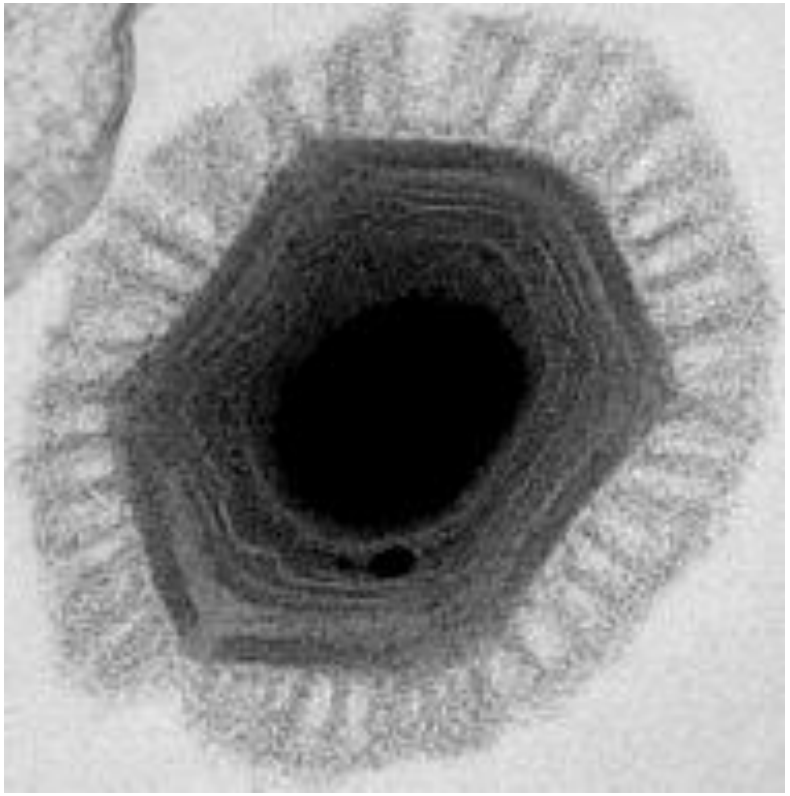




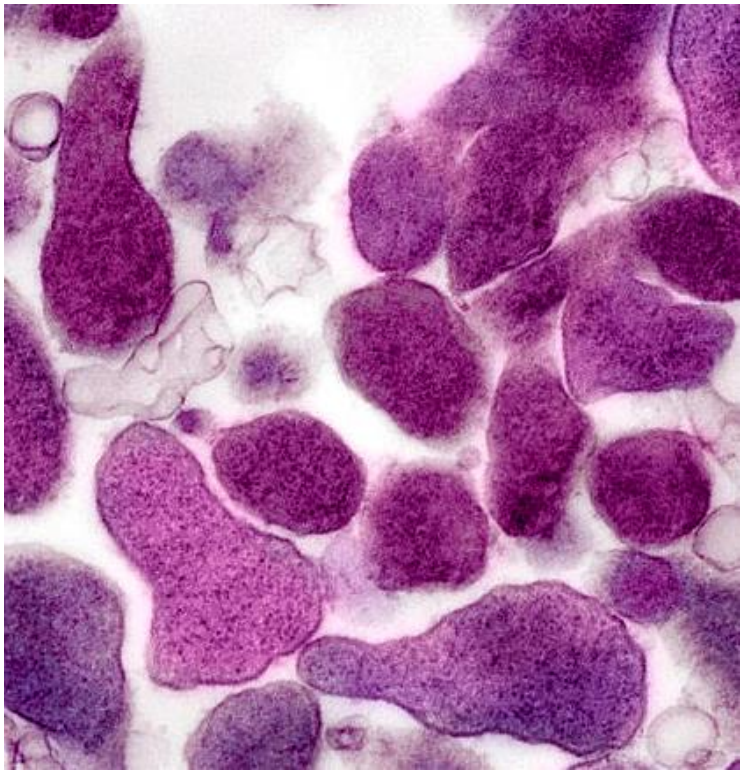
Many different biological entities can cause brain diseases in humans

Microorganisms vs. other biological entities

- **Beware of over-simplifications and ‘rules’ in biology !**



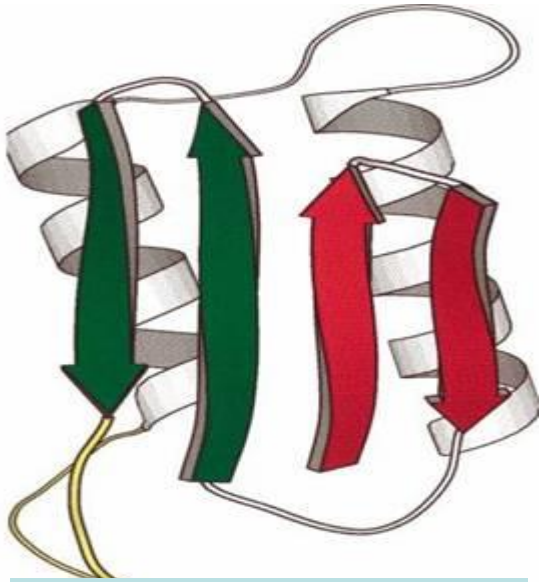
Mimivirus (virus)
~1000 genes



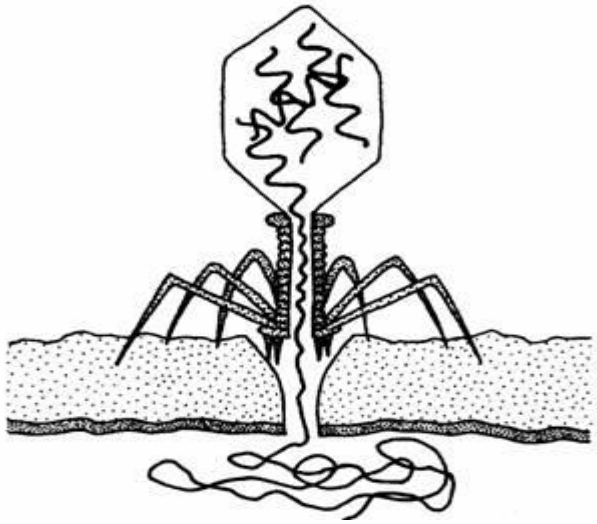
***Mycoplasma* (bacterium)**
~500 genes

Major microbial groups: Acellular entities

- Depend on a host cell for replication and metabolism, therefore not truly 'alive' (?debatable?)
  - Prion: self-replicating protein, no nucleic acids
  - Virus: nucleic acids (RNA or DNA) with protein coat
  - Plasmid: made of DNA, like virus but no protein coat



Prion protein from 'mad cow' brain

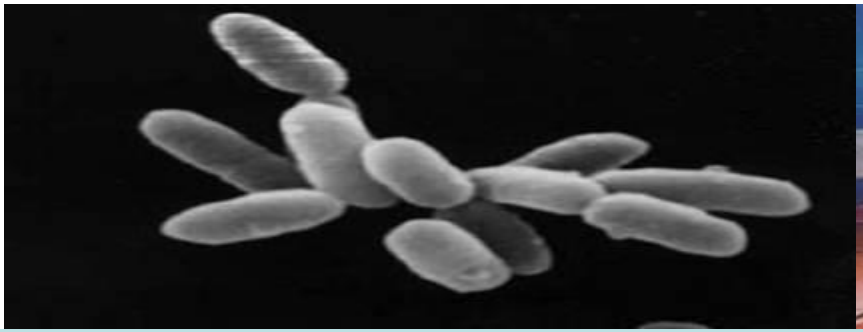


T4 virus infecting the bacterium *E.coli*

Double-strand DNA of a circular plasmid

Major microbial groups: Bacteria

- Sometimes called ‘prokaryotes’. Simplest free-living organisms, independent replication and metabolism.
- Mostly unicellular, but can show differentiation (eg. spores) and morphological complexity (eg. filaments)
- Two bacterial Domains exist:
  - Eubacteria: peptidoglycan wall, ester-lipid membrane
  - Archaea: glycoprotein wall, ether-linked membrane

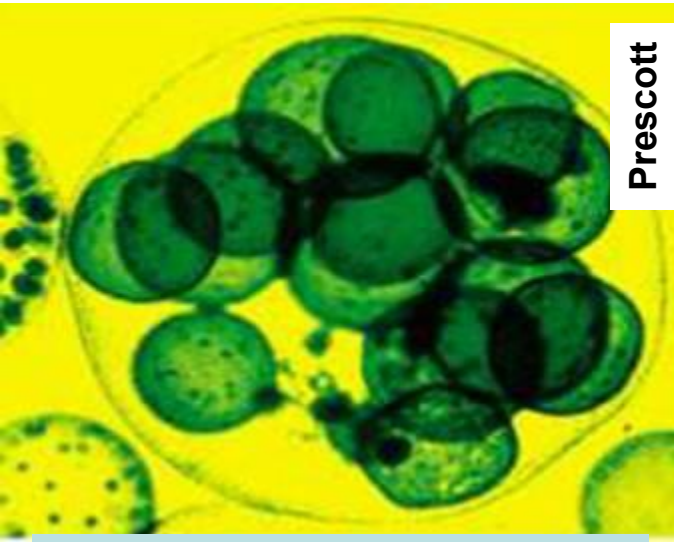


Some Archaea are halophiles (salt-loving), eg. *Halobacterium* gives red colour to salt lakes

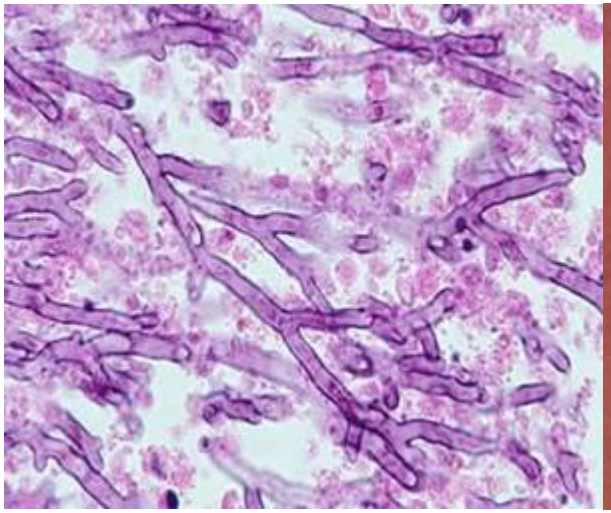
Major microbial groups: Eukaryotes

- More complex and larger than bacteria, contain membrane-bound nucleus and organelles, often multicellular

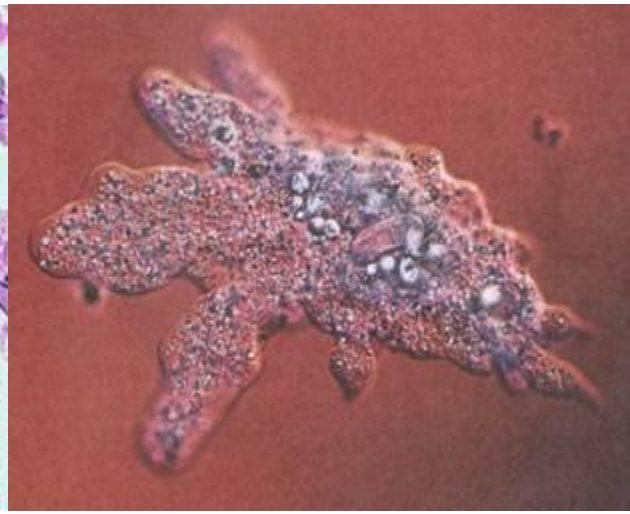
- Domain Eukarya = animals + plants + eukaryotic microbes:
  - Algae: chlorophyll, photosynthesis
  - Fungi: heterotrophic, non-motile, extracellular digestion
  - Protozoa: heterotrophic, motile, intracellular digestion



Algae: *Volvox* – simplest multicellular eukaryote?



Fungi: *Aspergillus* infecting lung tissue



Protozoa: *Amoeba* is motile by pseudopodia

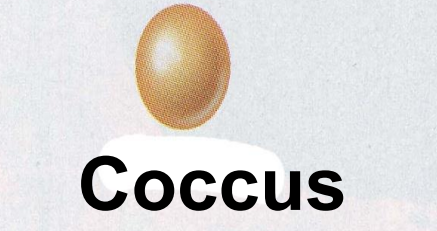
Distinction of bacteria and eukaryotes

Cell property	Bacteria	Eukaryotes
Nucleus	Absent	Membrane-bound
Complex organelles*	Absent	Membrane-bound
Cell size	Small (<10 μm)	Large (>10 μm)
Cell wall	Peptidoglycan**	Cellulose / chitin
Chromosome state	Haploid only	Haploid / Diploid
Reproduction	Asexual (binary fission)	Asexual (mitosis) + sexual (meiosis)

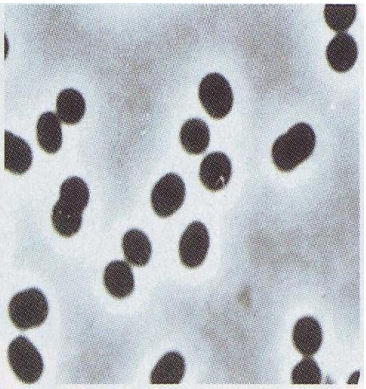
*mitochondria, chloroplasts, endoplasmic reticulum, Golgi apparatus, vacuoles

**except Archaea – glycoprotein cell wall

Bacterial cell morphology: a diversity of shapes

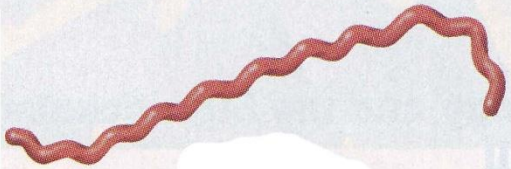


Coccus

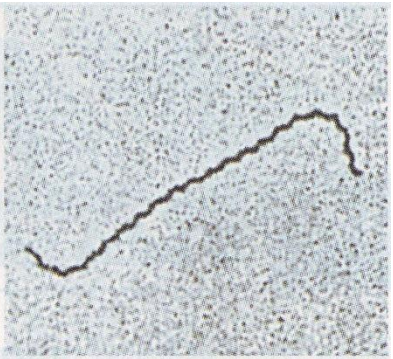


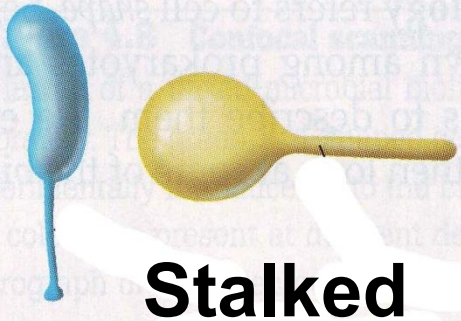
Rod

Spirillum

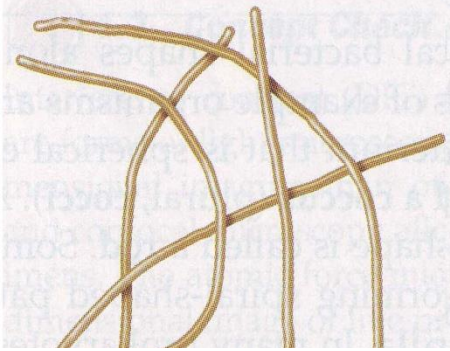


Spirochaete





Stalked



Filamentous

Bacterial morphology: clinical relevance

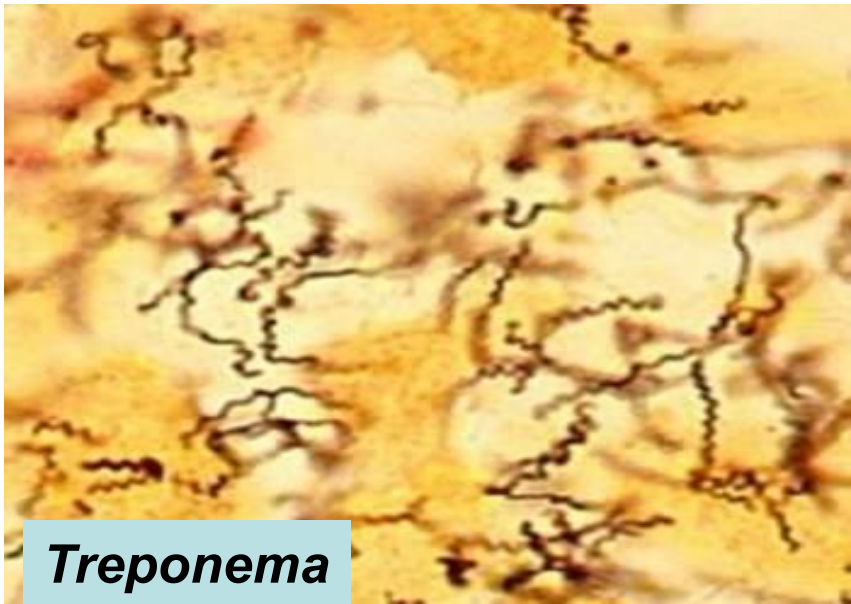
- Morphology is useful for identification and classification

Staphylococcus & *Streptococcus*

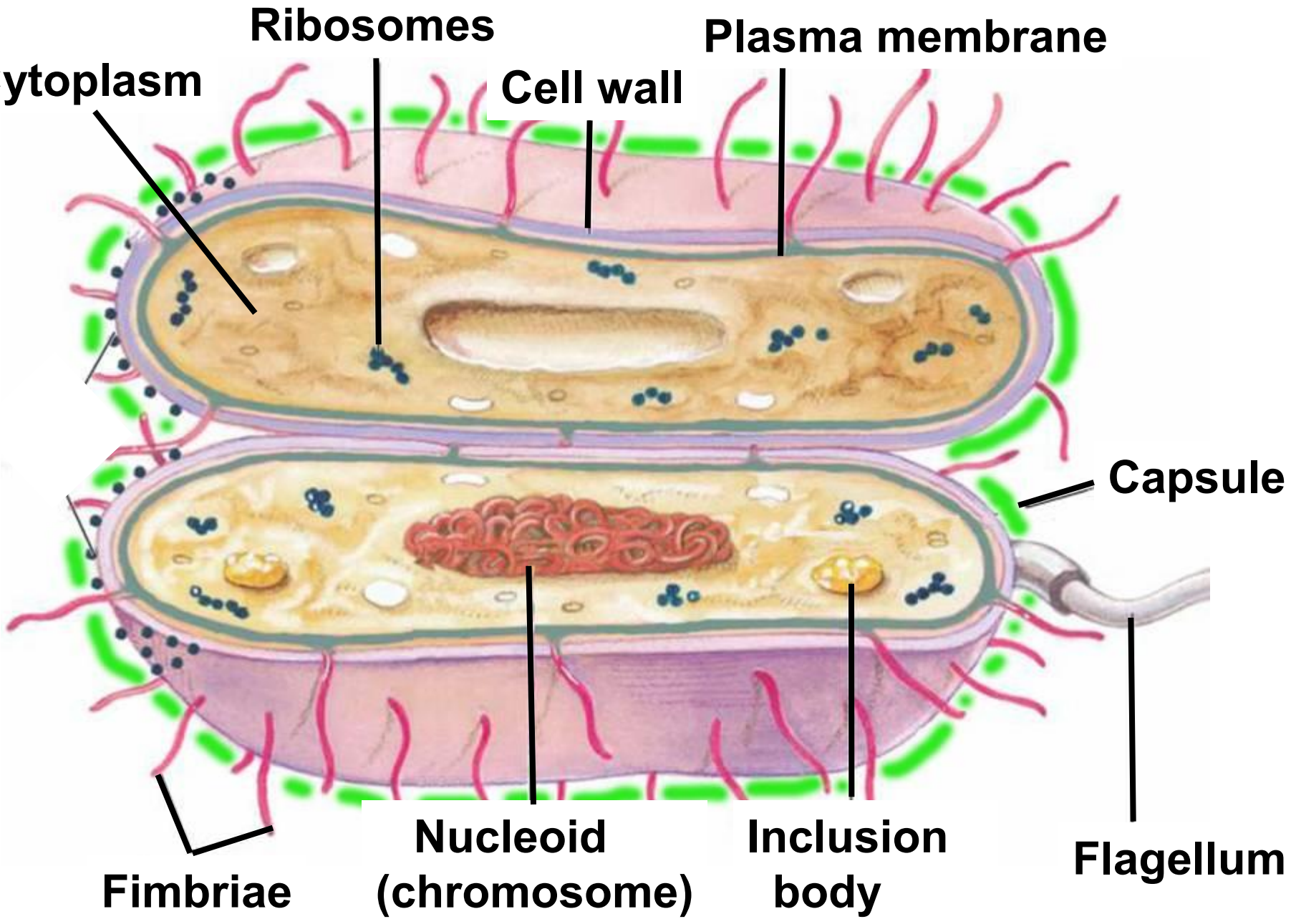
differ in arrangement: clusters vs. chains

Spirochaetes are rare pathogens.
Cell shape v.useful for diagnosis

eg. spirochaetes observed in genital sores = syphilis



Overview of bacterial cell structure



The nucleoid: where the chromosome is

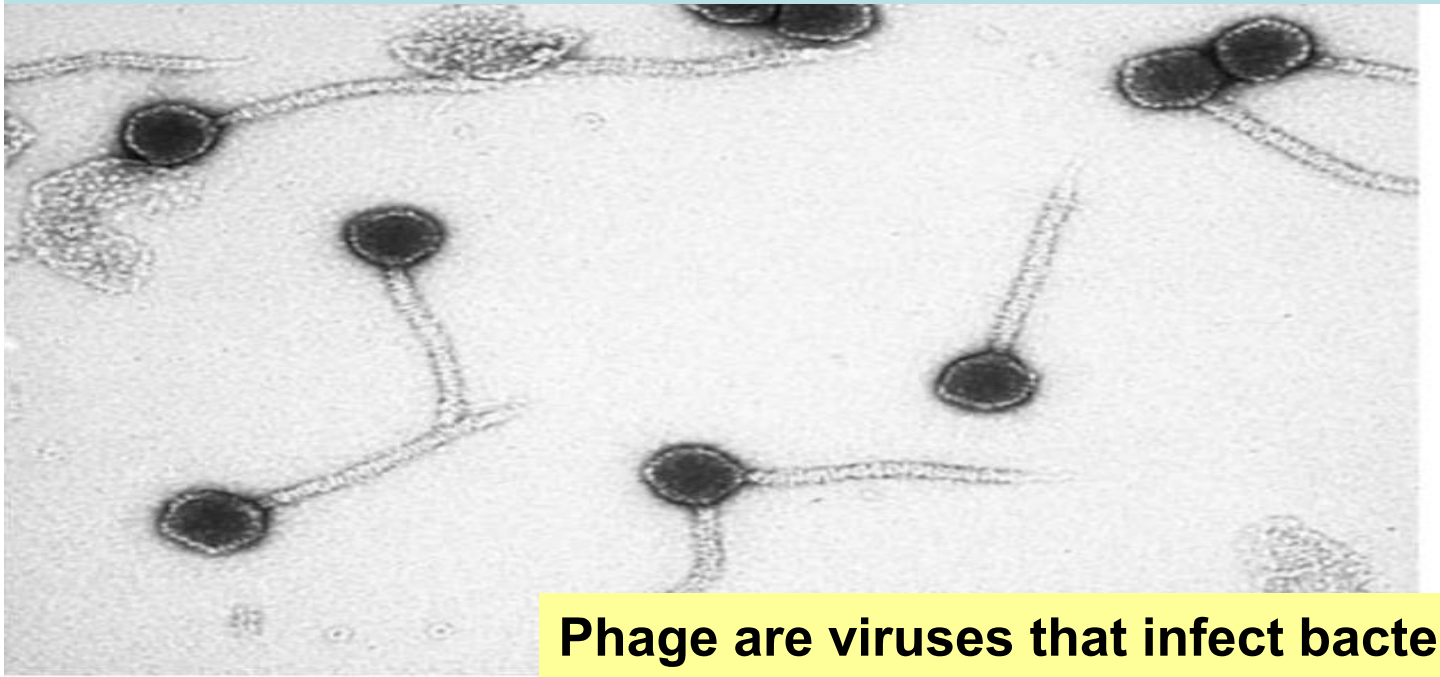
- Bacteria usually have a single circular chromosome
- Chromosome + structural proteins = nucleoid
- Bacterial nucleoid is NOT membrane bound

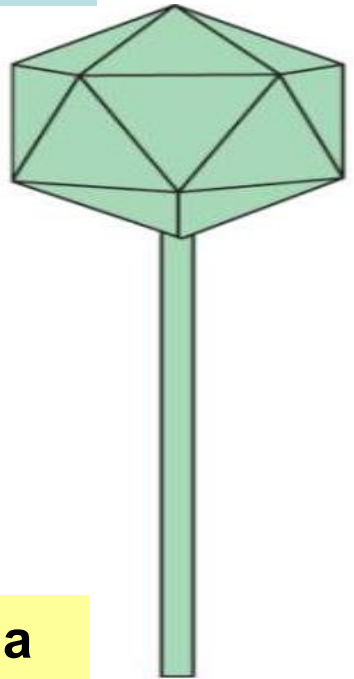
Electron micrograph (left) and plasticine model (right) of nucleoid. Actively transcribed regions extend into cytoplasm

The nucleoid: not the only DNA in bacteria

- Bacteria often contain accessory DNA elements that can replicate independently of the chromosome
- **Plasmids:** - naked DNA
- **Bacteriophage:** - DNA or RNA plus protein coat

Electron micrograph and structural model of lambda phage

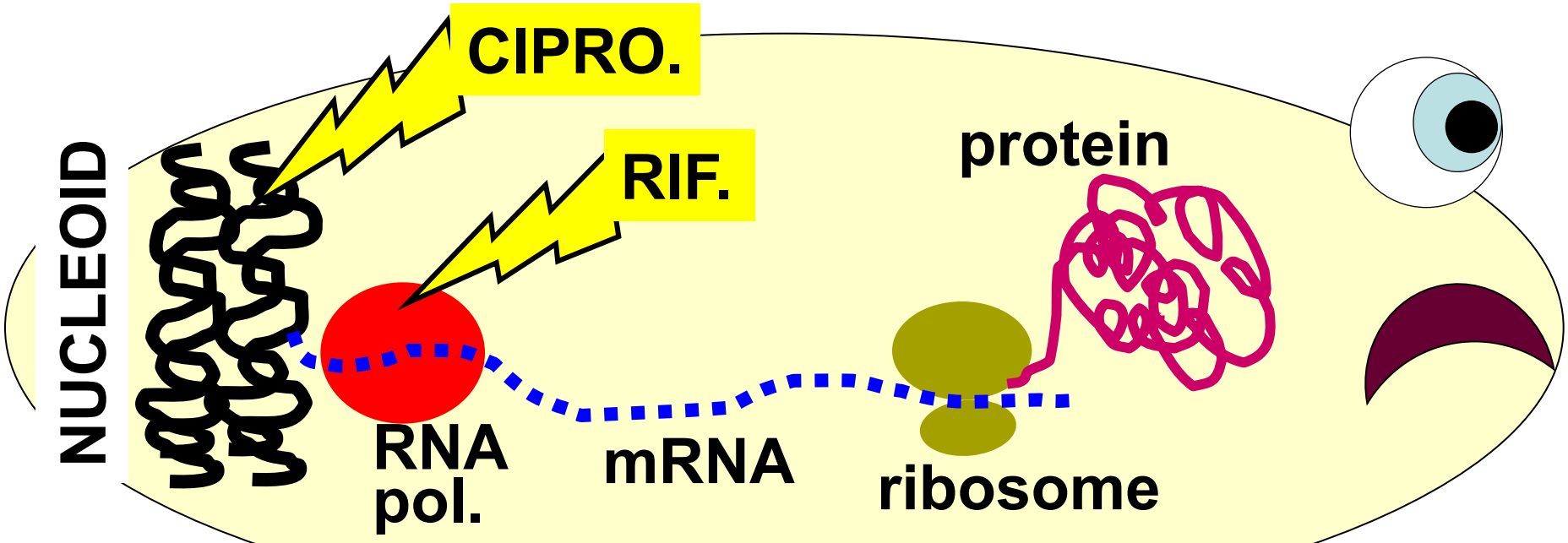




Phage are viruses that infect bacteria

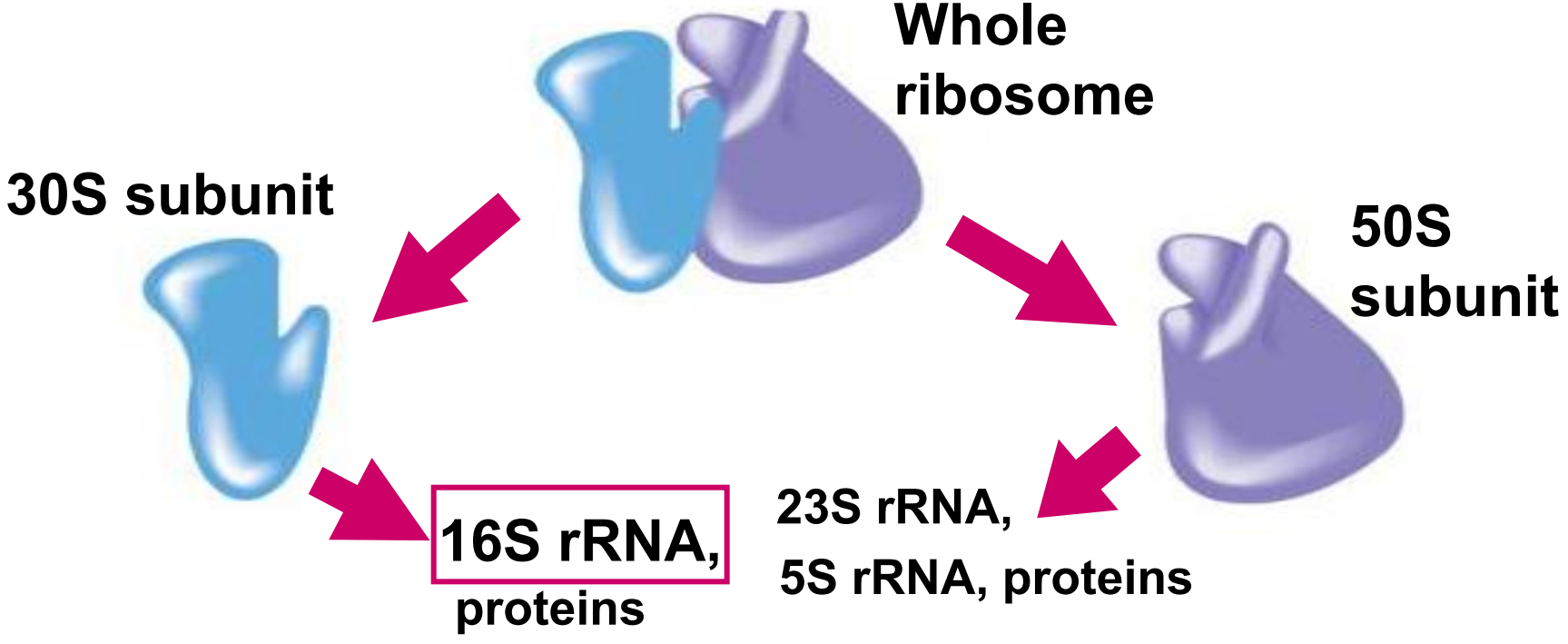
The nucleoid: functions and significance

- Nucleoid is the core genome of the cell (Plasmids & phage: accessory functions or parasites)
- Information flows from nucleoid to messenger RNA (via RNA polymerase) to protein (via ribosomes)
- Antibiotics can target the nucleoid: ciprofloxacin inhibits DNA synthesis, while rifampin inhibits RNA synthesis



Ribosomes: protein synthesis factories

- Small (~20 nm) and very numerous (~20,000/cell)
- Complex structure, made of many different subunits: both ribosomal RNA (rRNA) and ribosomal proteins
- The 16S rRNA sequence is strongly conserved in all bacteria → can use PCR to diagnose disease

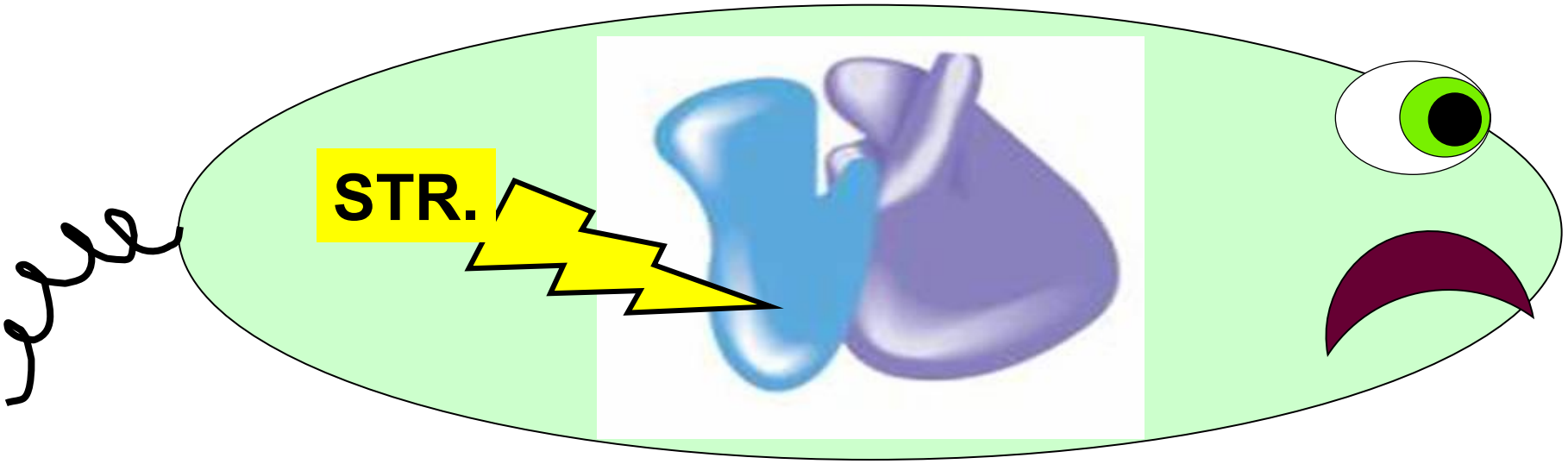


Ribosome function and significance

- Function: Translation of mRNA into protein

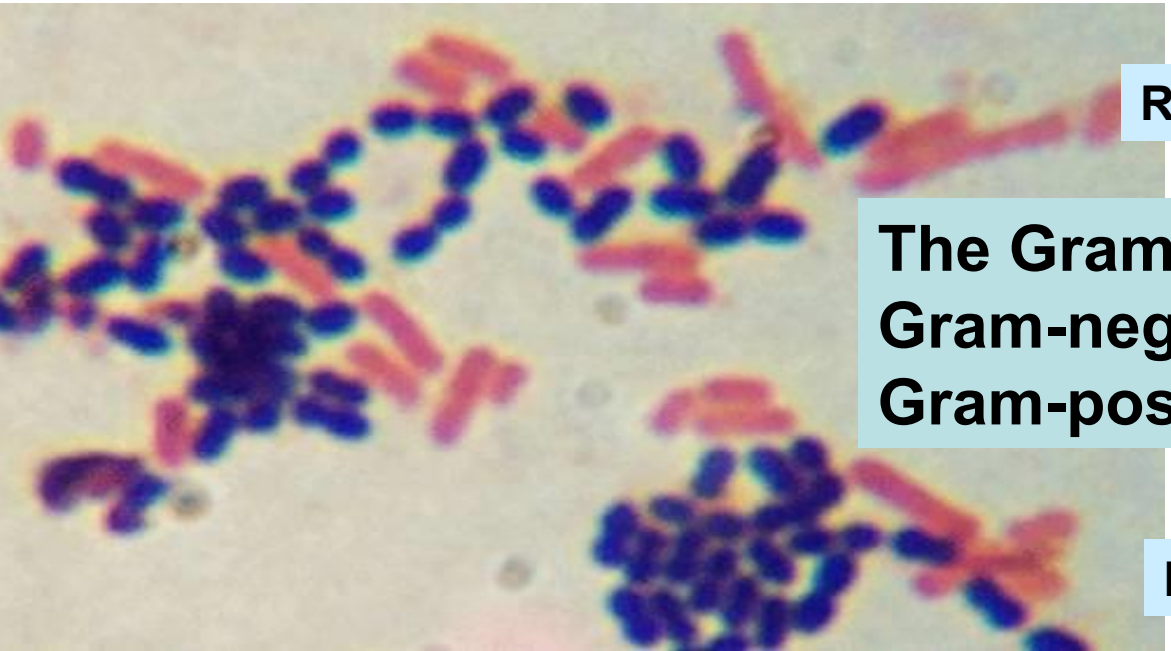
- Proteins (enyzmes) are central to all aspects of life
  → translation is a critical cellular function

- Many different antibiotics inhibit ribosome function
  eg. streptomycin, chloramphenicol, tetracycline



Intro to the cell envelope

- Cell envelope surrounds cell. Primary components are the cell wall and cell membrane(s)
- Overall function: protective barrier against environment, separates ordered cytoplasm from chaotic exterior
- Differences in cell envelope provide basis for dividing bacteria into Gram-negative and Gram-positive

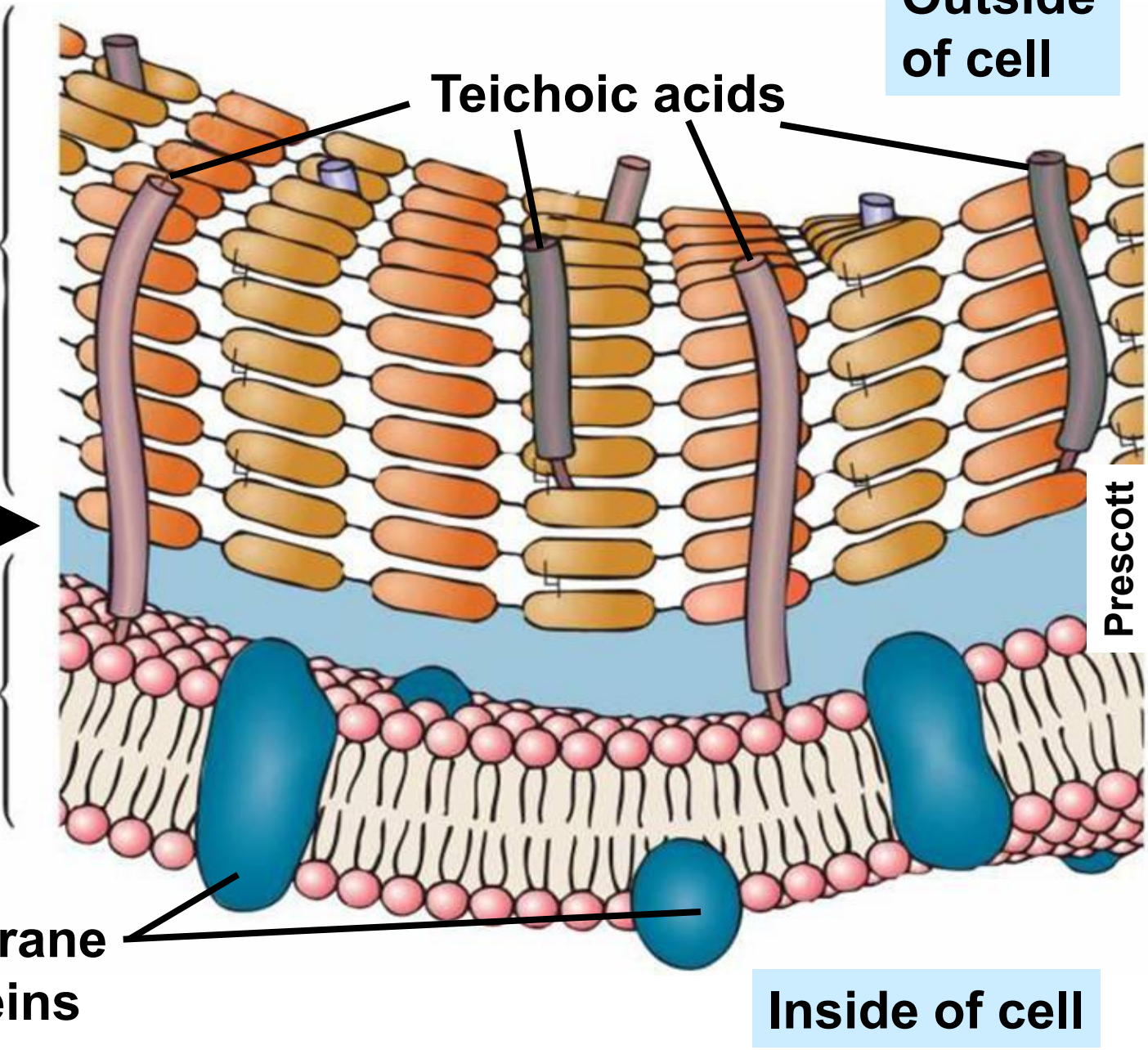


Red = *Escherichia* (*E.coli*)

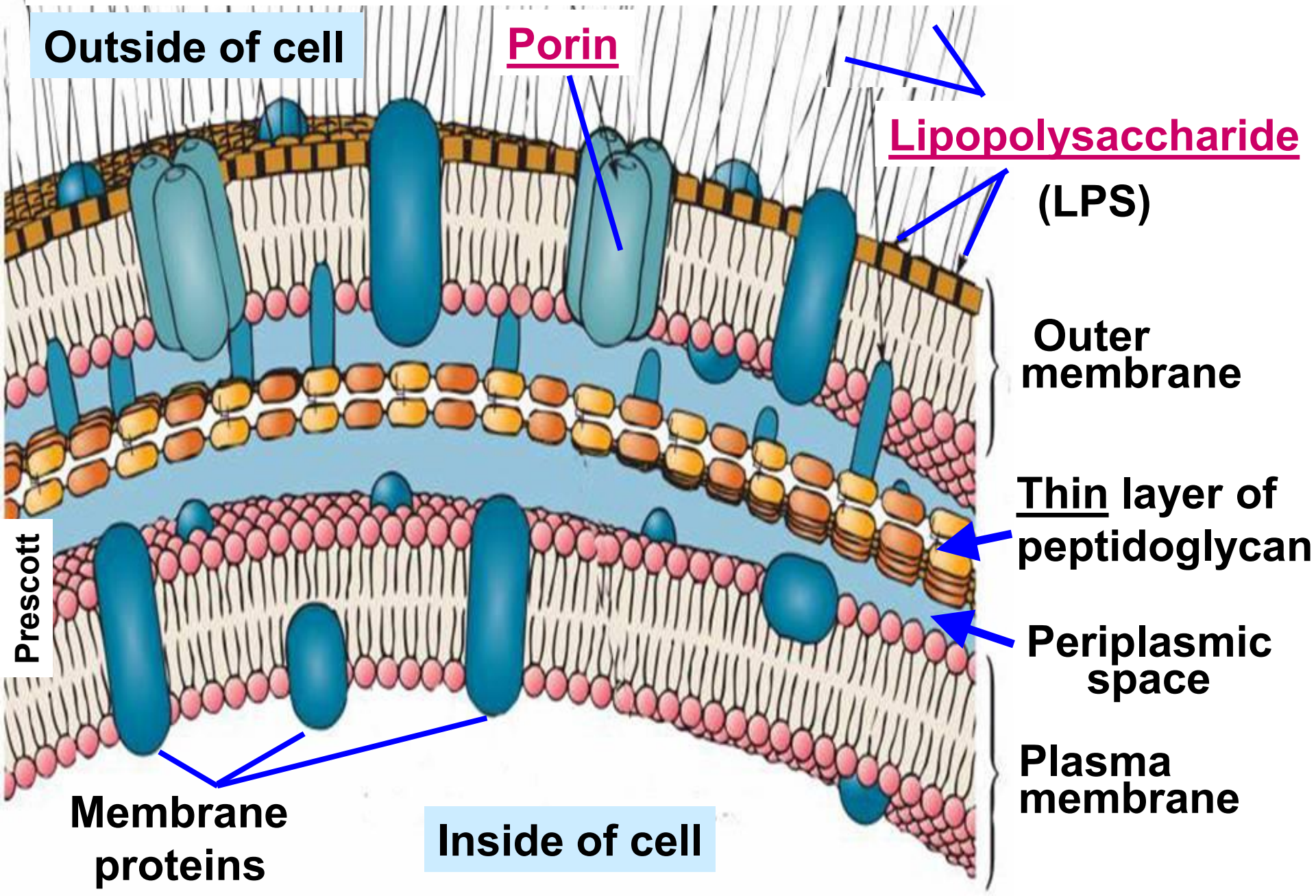
The Gram stain differentiates Gram-negative bacteria (red) from Gram-positive bacteria (purple)

Purple = *Streptococcus*

Cell envelope: Gram-positive bacteria



Cell envelope: Gram-negative bacteria



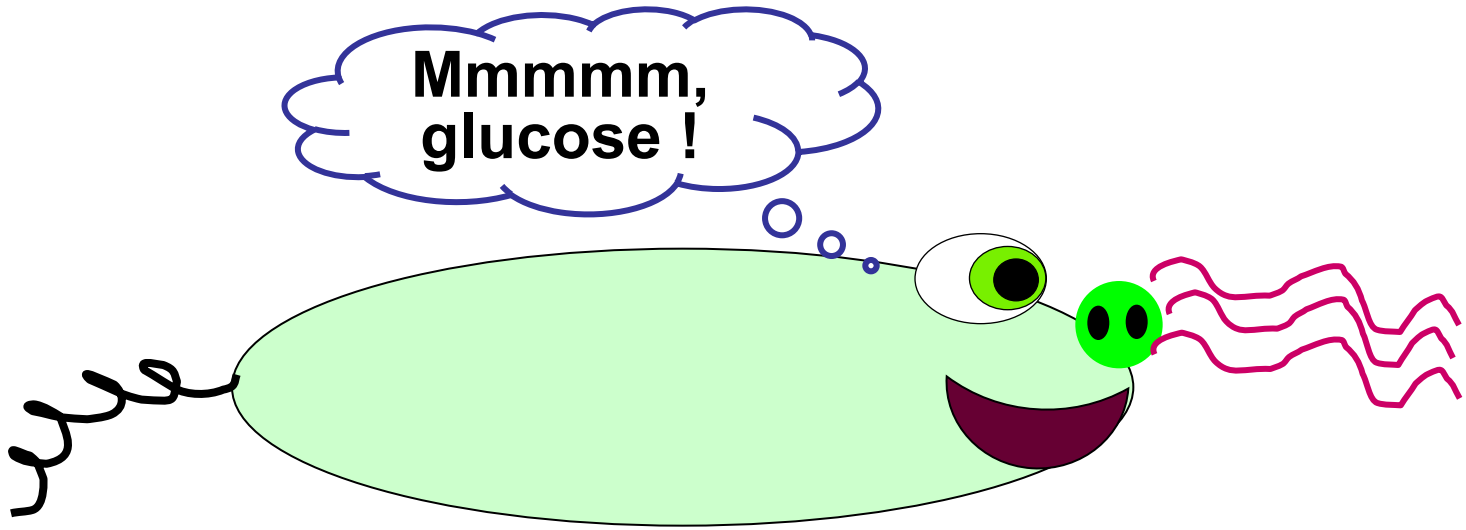
Plasma membrane: functions

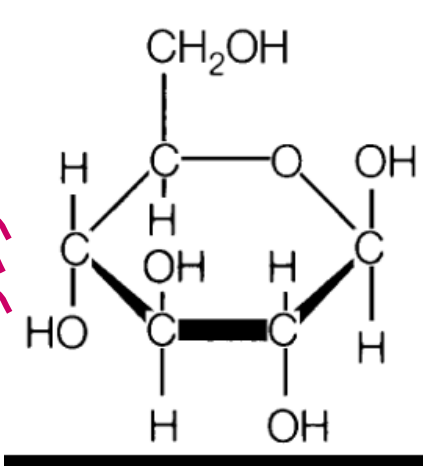
- **Selective permeability:** influx of nutrients, efflux of waste;

  → Selectivity critical: can't let cytoplasm out or toxins in

- **Metabolic processes** eg. electron transport, respiration, and lipid biosynthesis all occur in the membrane

- **Detection of environmental signals**: membrane receptors switch on regulatory proteins → activate transcription

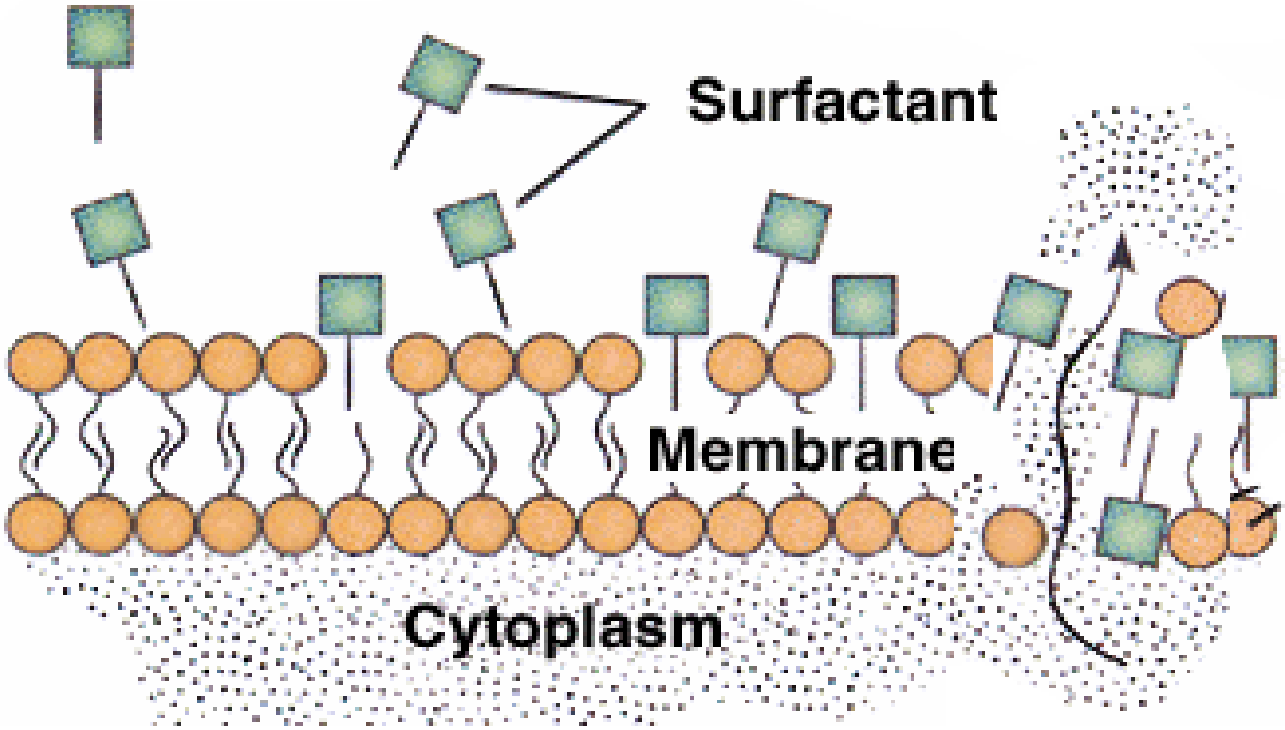




Plasma membrane: clinical significance

- Many antimicrobials disrupt membrane structure → leakage of cytoplasm → cell death

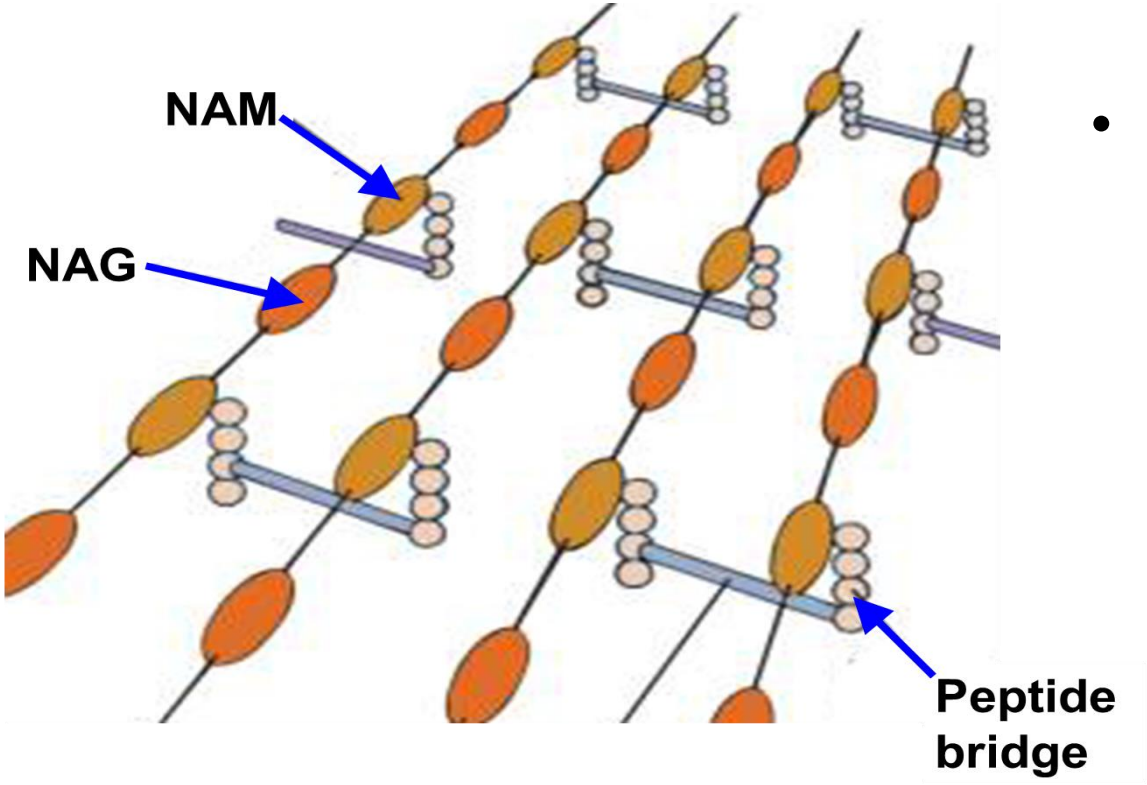
- eg. detergents (eg. SDS), antiseptics (eg. benzalkonium), and antibiotics (eg. polymyxin)



Cell wall contains peptidoglycan

- **Peptidoglycan (PG): structural polymer made of sugars and amino acids that is unique to bacteria**

- **PG backbone made of a repeating di-saccharide unit; N-acetylglucosamine(NAG) + N-acetylmuramic acid (NAM)**



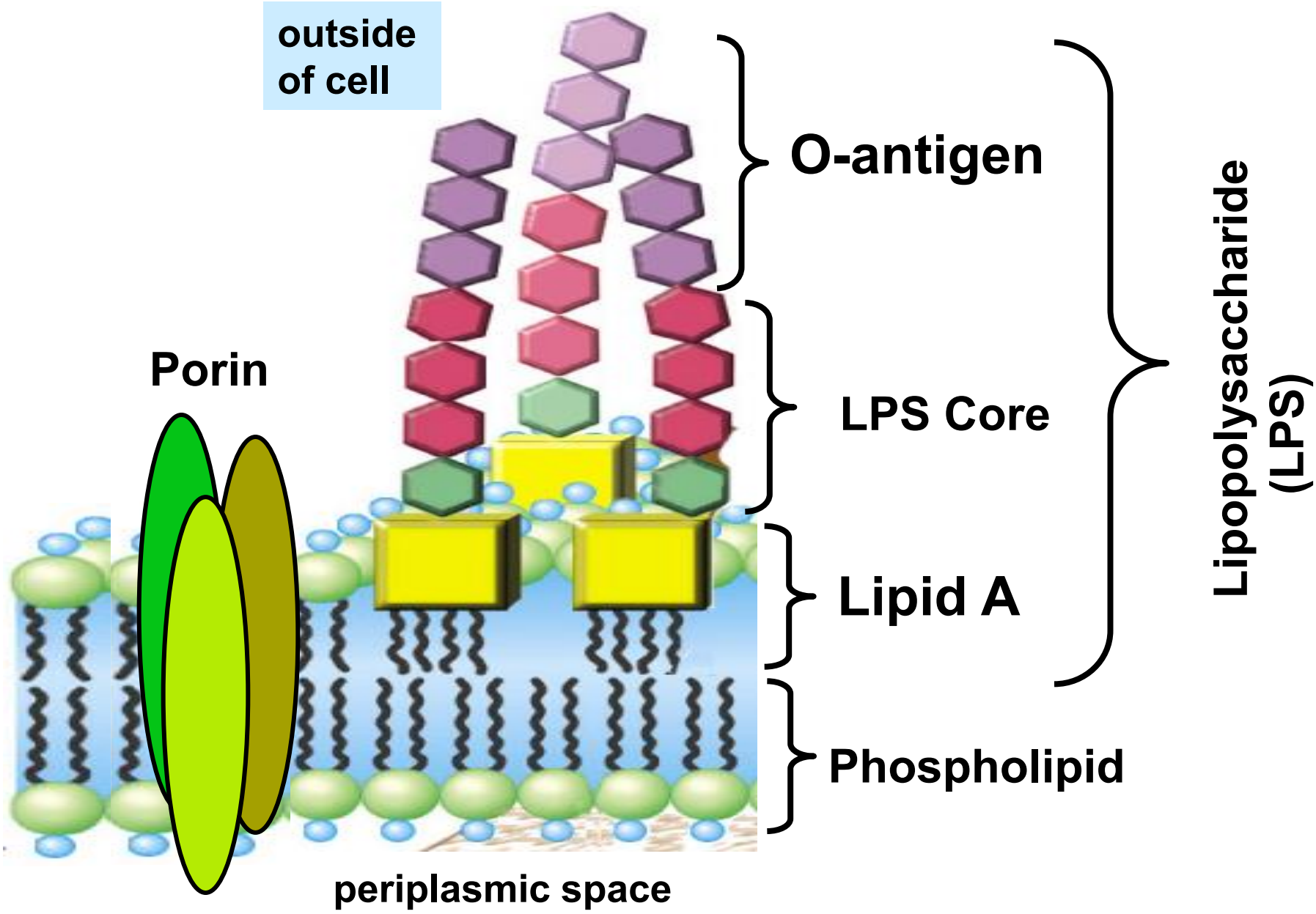
- **PG is cross-linked by peptide bridges**

Peptidoglycan: function + significance

- Function is osmotic protection. Cytoplasm very salty → high pressure; membrane alone can't resist this
- Destruction of PG (eg. lysozyme) → cell lysis and death
- Many antibiotics target PG biosynthesis eg. penicillin
- Thickness of PG determines Gram stain reaction

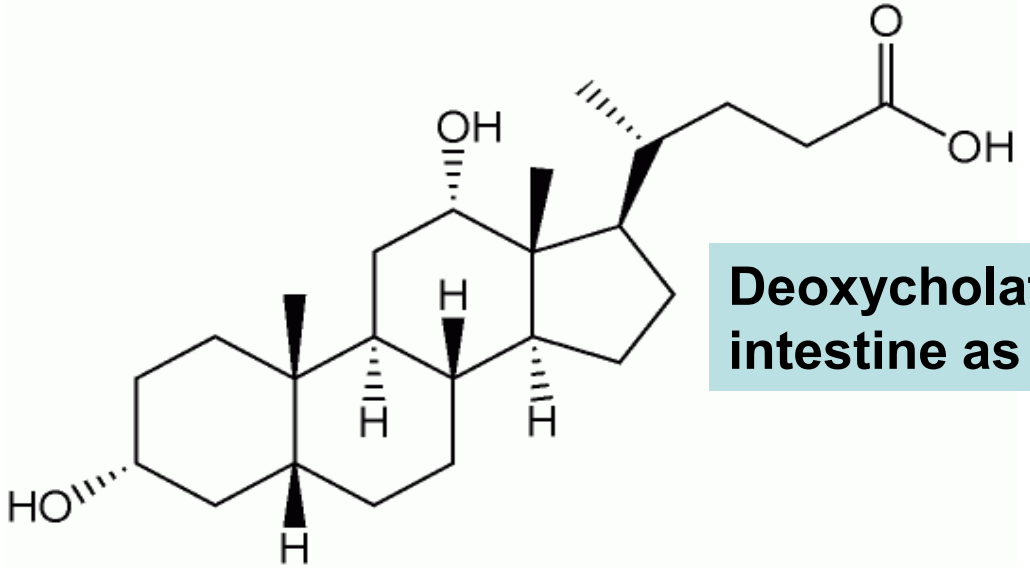
Killing of *E.coli* cells by lysozyme. Penicillin has a similar lytic effect

Outer membrane structure (Gram negatives only)



Outer membrane (OM): function & significance

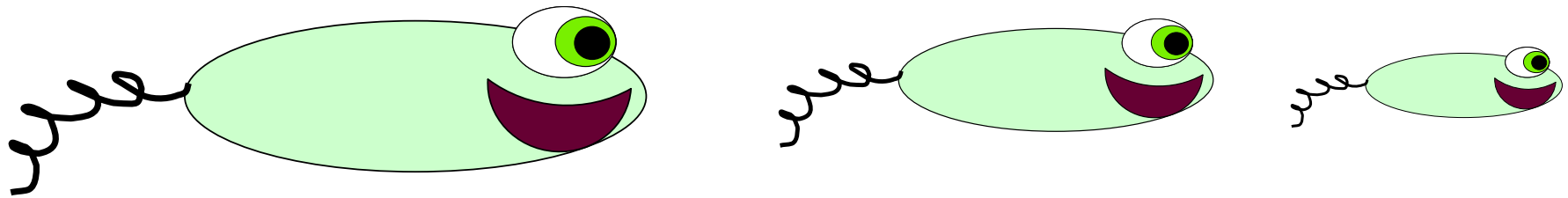
- **Protective barrier against toxins eg. antibiotics, bile salts**



Deoxycholate is a bile salt: functions in intestine as emulsifier and antimicrobial

- **O-antigen is highly variable, allows Gram neg. bacteria to rapidly change surface → evade immune system**

- **Lipid A component is also known as endotoxin → systemic toxic effects in Gram neg. infections**

Summary: Bacteria structures / functions / significance

- **Cell morphology**: diagnosis via microscopy
- **Nucleoid**: information archive / cipro. / rif.
- **Ribosomes**: protein factories / streptomycin
- **Plasma membrane**: selective barrier / detergents
- **Peptidoglycan**: osmotic protection / penicillin
- **Outer membrane**: protection- toxins, immune system