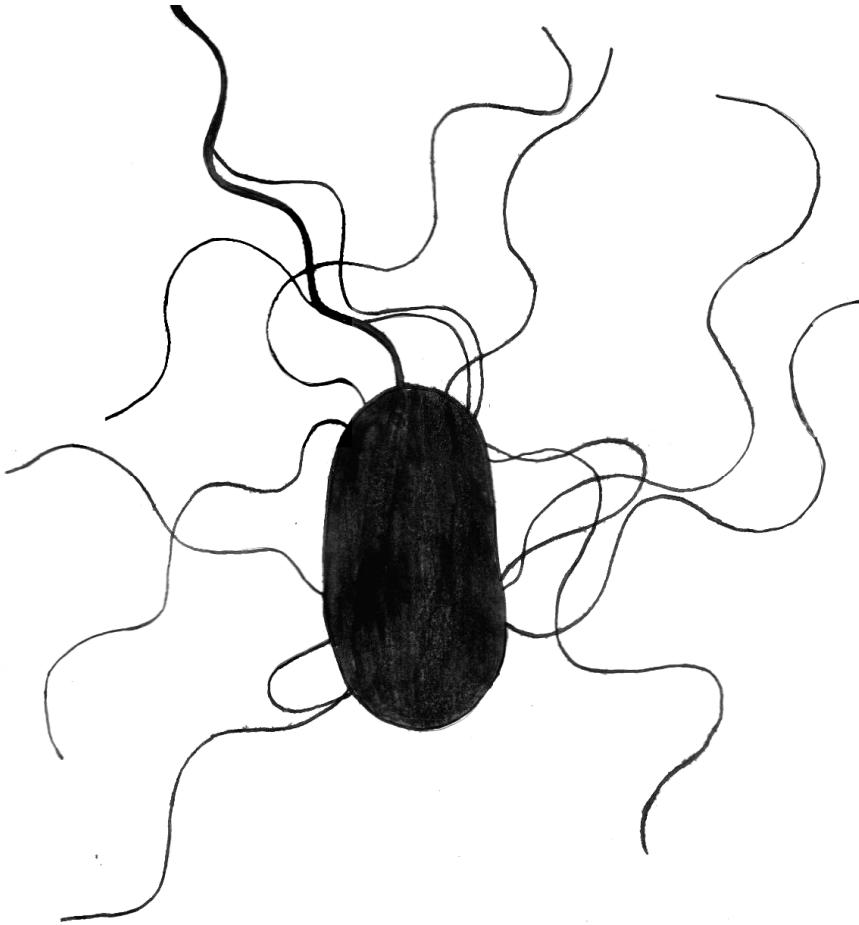


# Bacteria

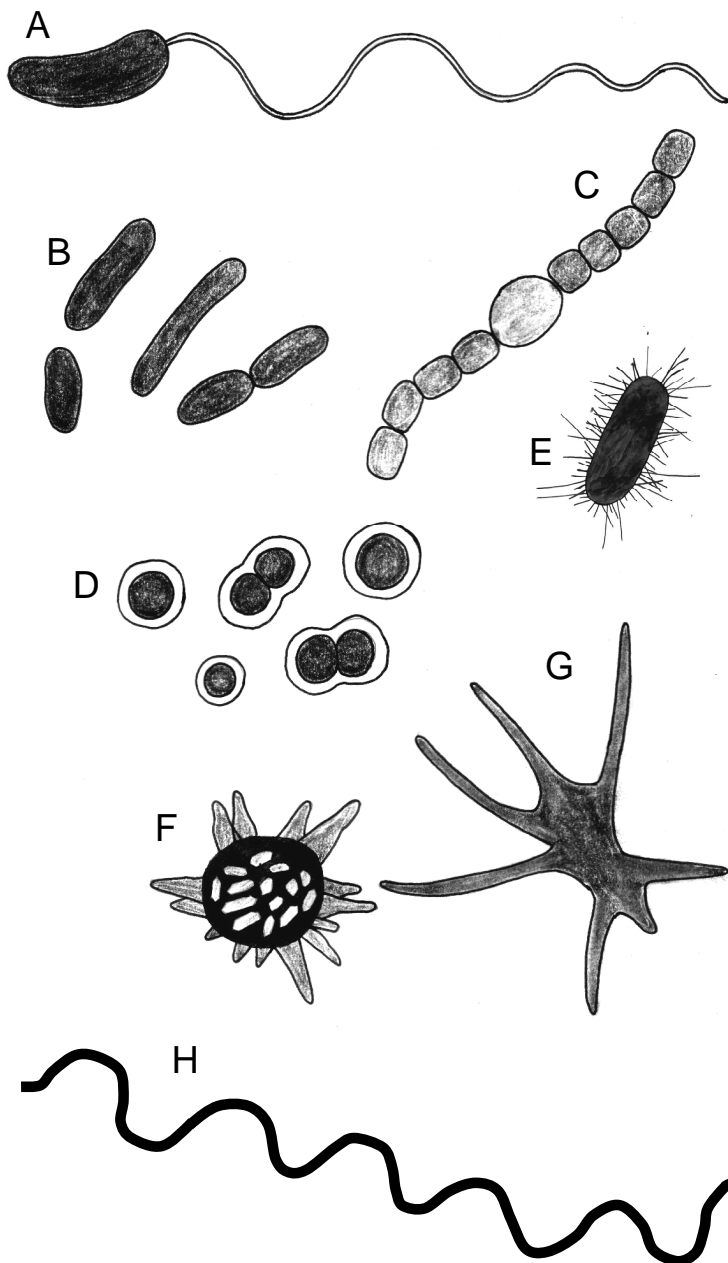


Above: The bacterium *Vibrio*, a single cell with numerous flagella with which it swims or crawls over moist surfaces. The flagella are helical propellers that rotate – they are driven by tiny rotating electric motors in the cell wall. Bacteria are an ancient lineage and are quite ‘alien’ by animal and plant standards! Archaeobacteria are the most ancient lineage of all, and these strange bacteria often live in extreme conditions, e.g. in volcanic springs, and they are made of some very different organic chemicals than are found in other living cells.

Bacteria are the simplest cellular life-forms we know of. However, although a bacterial cell is much simpler than an animal or plant cell, they are still extremely complex, especially on the nanoscale! The earliest recognisable fossils are of bacteria which completely dominated the Earth 3.5 billion years ago! Bacteria resembling photosynthetic cyanobacteria formed large layered structures, called stromatolites along the shores of the early seas. Stromatolites still dominate in areas like the Dead Sea, but in the ancient Earth they were the dominant life-form! Bacteria like these cyanobacteria generated the oxygen in the Earth’s atmosphere (early bacteria did not require oxygen, and some still don’t and may even find it poisonous!).

In many ways bacteria are still the dominant life-form on earth today – there are more bacterial cells in your body than animal cells! (Although the bacterial cells are much smaller). Bacteria are essential to every ecosystem as they transform and recycle chemicals and elements, for example in the carbon, oxygen, nitrogen and sulphur-cycles. Inside your cells are structures called mitochondria. These structures are dynamic, constantly fusing and dividing and being moved around inside your cells, and they perform a vital function – they burn fuels like glucose to provide cells with usable chemical energy packaged in ATP molecules. These mitochondria are the descendents of bacteria that entered the ancestral cell billions of years ago! You are a composite organism since you are part bacteria!

Bacteria are generally considered to be single-celled organisms as those most closely studied historically were isolated swarmer cells, like the one above. Swarmer cells swim, crawl, glide or drift around. However, bacteria also form communities in which thousands of cells come together, held together by slime they secrete to form ‘slime cities’ or biofilms. Within these communities the bacteria communicate with each other and work together, however they remain separate as they do not generally form contact junctions with one another (as cells do in an animal or plant body) – it is rather like many separate organisms working together as a single organism. In these biofilms, slime towers (microcolonies) shed swarmer cells into the water stream above. Some bacteria develop to the next stage of multicellularity and form chains of cells (filaments) in which neighbouring cells may communicate with each other using electrical signals through special junctions. Some form minute fungus-like structures with fruiting bodies emerging from a sheet of cells to release spores.



A: *bdellovibrio* – a small predatory bacterium which uses its flagellum to swim at great speeds and gain entry into other bacteria by ramming them and, if necessary, digesting a hole through the target cell wall. Once inside its host bacterial cell it consumes the host and multiplies before erupting from the dead host.

B: non-motile rods (bacilli, a bacillus is a rod-shaped bacterium).

C: a chain of photosynthetic and nitrogen-fixing cyanobacteria. Some species are capable of moving by gliding along surfaces by a largely unknown mechanism.

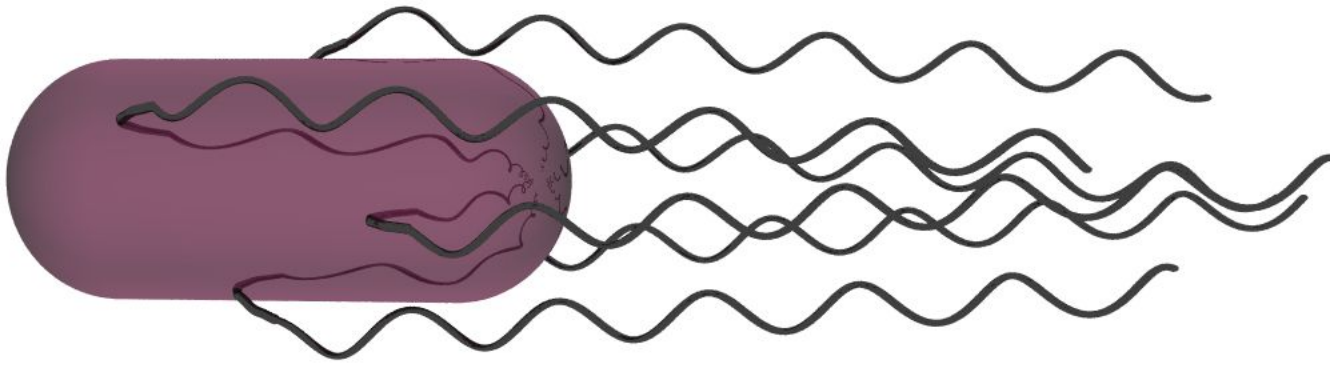
D: spherical bacteria (cocci, a coccus is a spherical bacterium) ensheathed in a slime capsule.

E: a bacillus bearing hairlike spiky appendages called pili (sing. pilus).

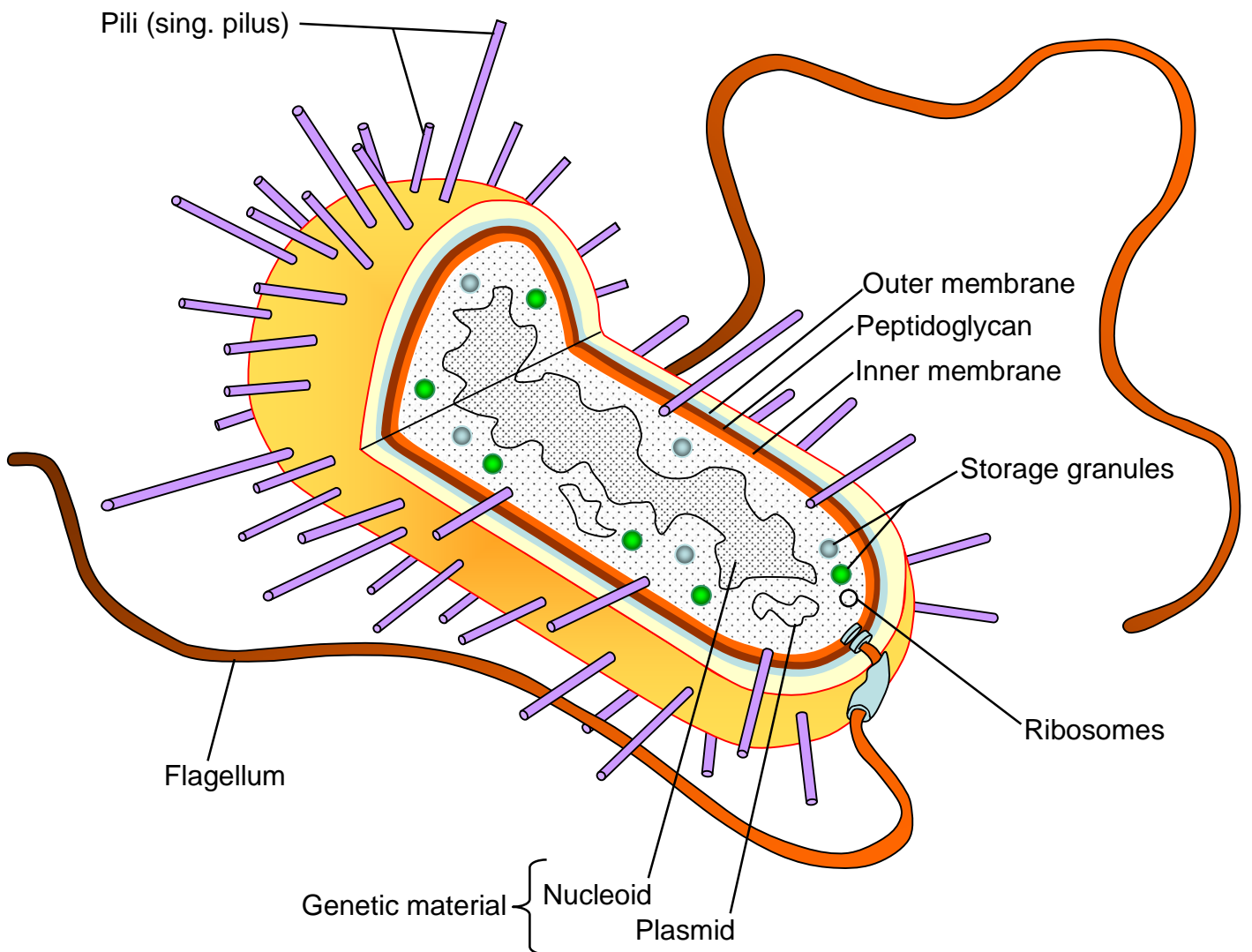
F and G: prosthecate bacteria containing appendages called prosthecae (cell extensions) which aid flotation in water, so these cells can float near the top of seas and lakes where oxygen is plentiful. F also has gas vacuoles inside it.

H is a spiral (helical) or corkscrew shaped bacterium. These bacteria rotate as they swim and so can drill their way through thick mud, or in the case of the bacterium that causes syphilis (a spirochaete) they can drill through the tissues of the body, including tough cartilage.

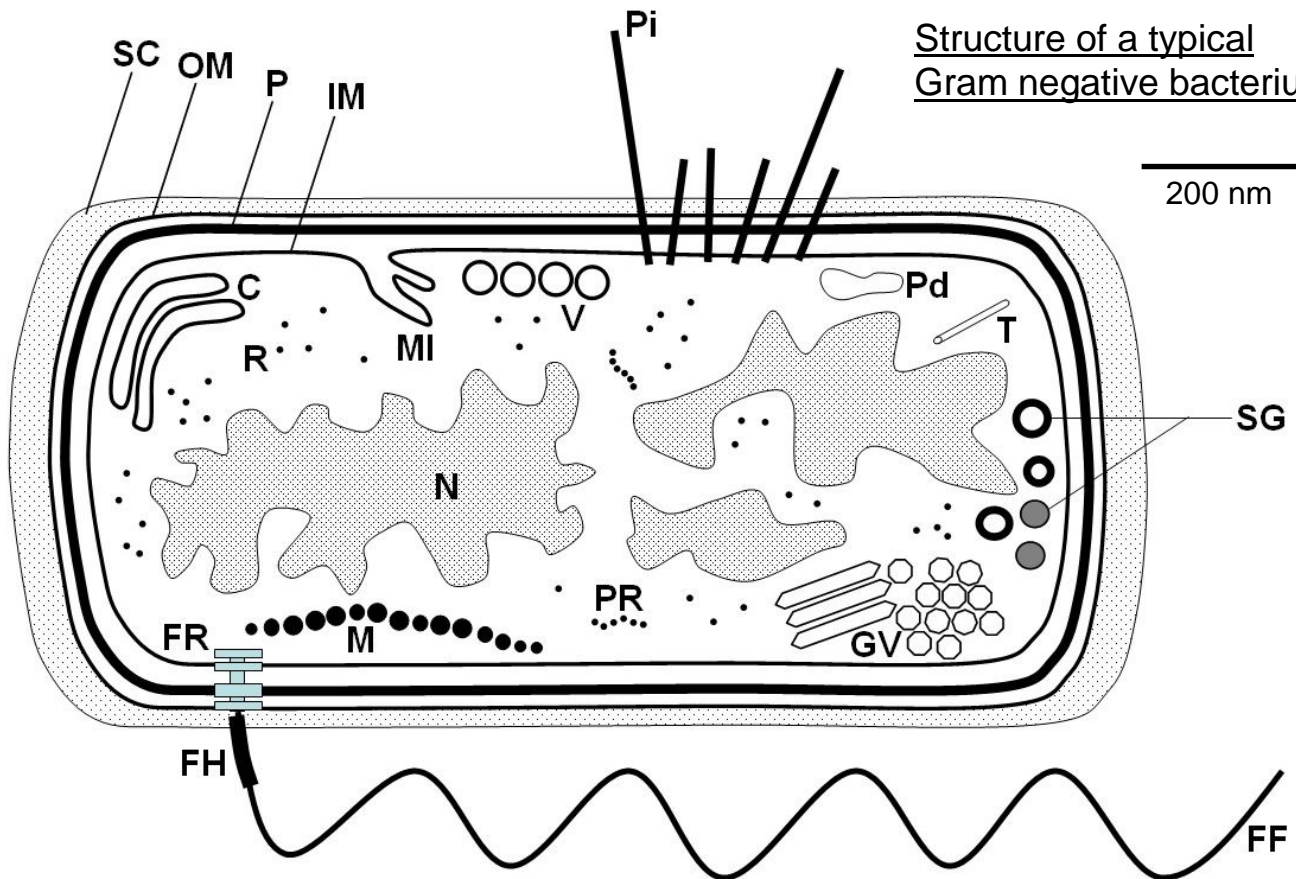
Bacteria come in a very diverse range of forms. They are neither plants nor animals, but belong instead to the prokaryote kingdom. A minority of bacteria are parasitic on other organisms, often causing disease. For example, tuberculosis, leprosy, many stomach and bowel disorders (food poisoning) and syphilis are human diseases caused by bacteria. Bacteria are distinct from viruses. Bacteria represent the simplest living cells we know of, however, they are still extremely complex. Viruses are acellular or subcellular protein packages of infectious genetic material. Viruses are not capable of independent life, but are parasites that must invade their particular host cell type, take control of the cell, and then use the cell's machinery to make more copies of themselves – viruses are pirates of the cell! Bacteriophages are viruses that attack bacteria. Some bacteria are photosynthetic, some are parasitic and some eat rocks, but most simply absorb the dead and decaying remains of other organisms. Some are commensals, which means they feed on the waste of other organisms whilst living on or inside them but cause no harm to the host, for example, 55% of the solid part of human faeces is bacteria! There are  $10^{10}$  bacteria per gram (wet weight) of faeces!



1000 nm



## Structure of a typical Gram negative bacterium



Internal membranes occur in some bacteria, especially photosynthetic species:

C: cisternae or sacs of membrane – occur as thylakoids in cyanobacteria (the site of photosynthesis);

MI: membrane invaginations - occur in purple bacteria

V: vesicles –

Motor and navigation systems - one or more flagella occur in many bacteria:

FF: flagella filament

FH: flagella hook – a flexible adaptor

FR: flagella rotor – an electric motor whose rotation drives the flagella

GV: gas vacuoles – act as flotation devices and are found in many aquatic species that require light or oxygen

M: magnetosome – found in some bacteria, act as a compass sensitive to the Earth's magnetic field

Pi: pili – optional appendages that serve multiple functions including adhesion (anchorage), cell docking and electron transport

Cell envelope - the cell envelope is equipped with various sensors that monitor the environment:

IM: inner membrane – contains generators that convert electrical energy into chemical energy (ATP)

OM: outer membrane – contains lipopolysaccharide (LPS) exotoxin

P: peptidoglycan (in the periplasm) – forms a rigid and very strong cell wall

SC: slime capsule

### Synthesis

R: Ribosomes – synthesise proteins, contained in the riboplasm,

PR: polysome, a chain of ribosomes held together by mRNA.

SG: storage granules, store excess sulphur, phosphate, carbohydrate fuels, alcohols and lipids (fats and oils)

### Control

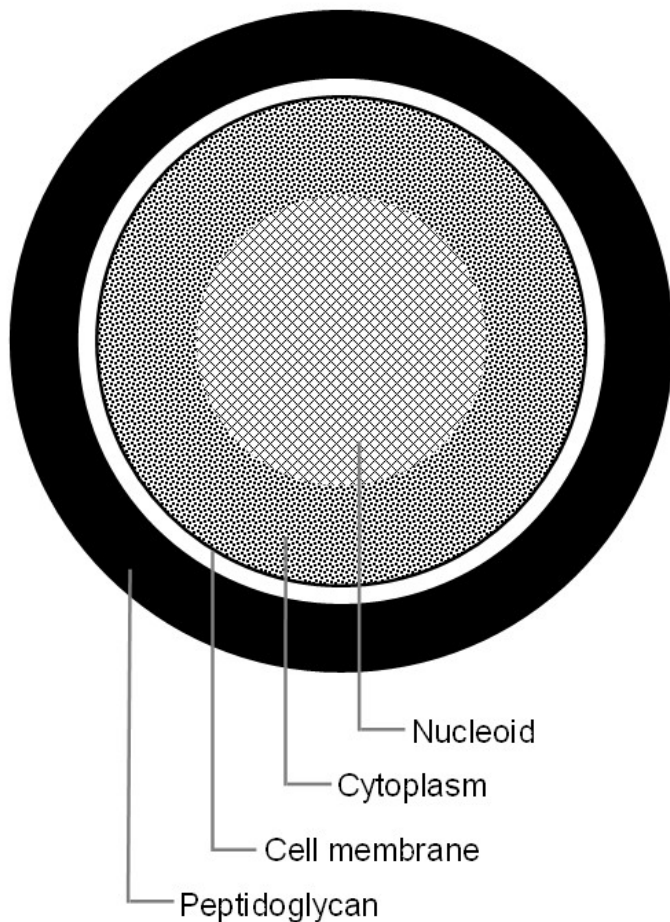
N: Nucleoid – contains the chromosome and DNA and DNA-packaging proteins, makes RNA and directs protein synthesis and hence controls the cell, stores 0.5 to 9.5 Mb of information.

Pd: Plasmid – optional mobile genetic elements that consist of small circles of DNA that can move between bacteria.

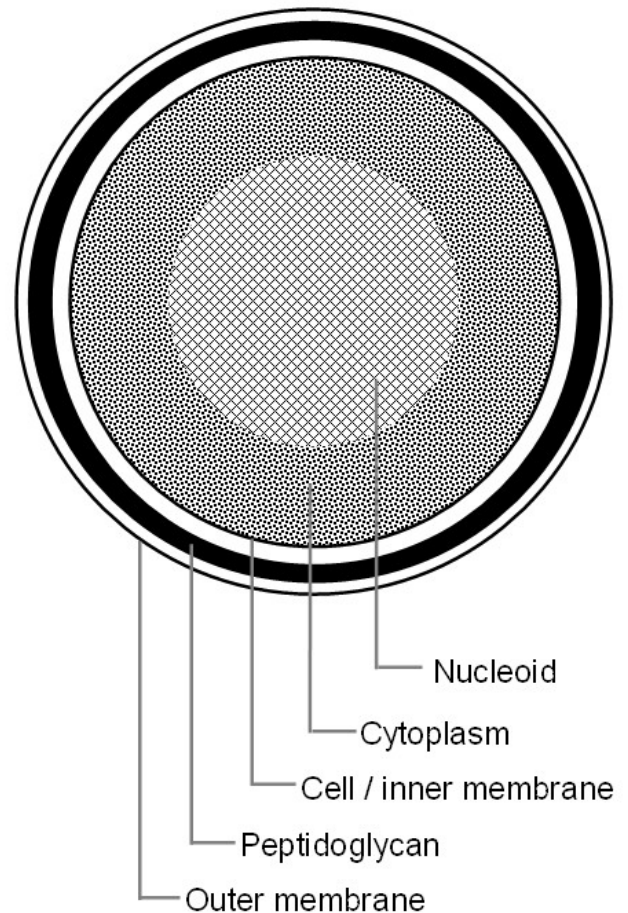
T: tubular proteins - link together to form a cytoskeletal scaffold that directs the movement of enzymes and DNA

## The Bacterial Cell Envelope

### Gram Positive



### Gram Negative



Bacteria possess cell envelopes which come in two main structural types:

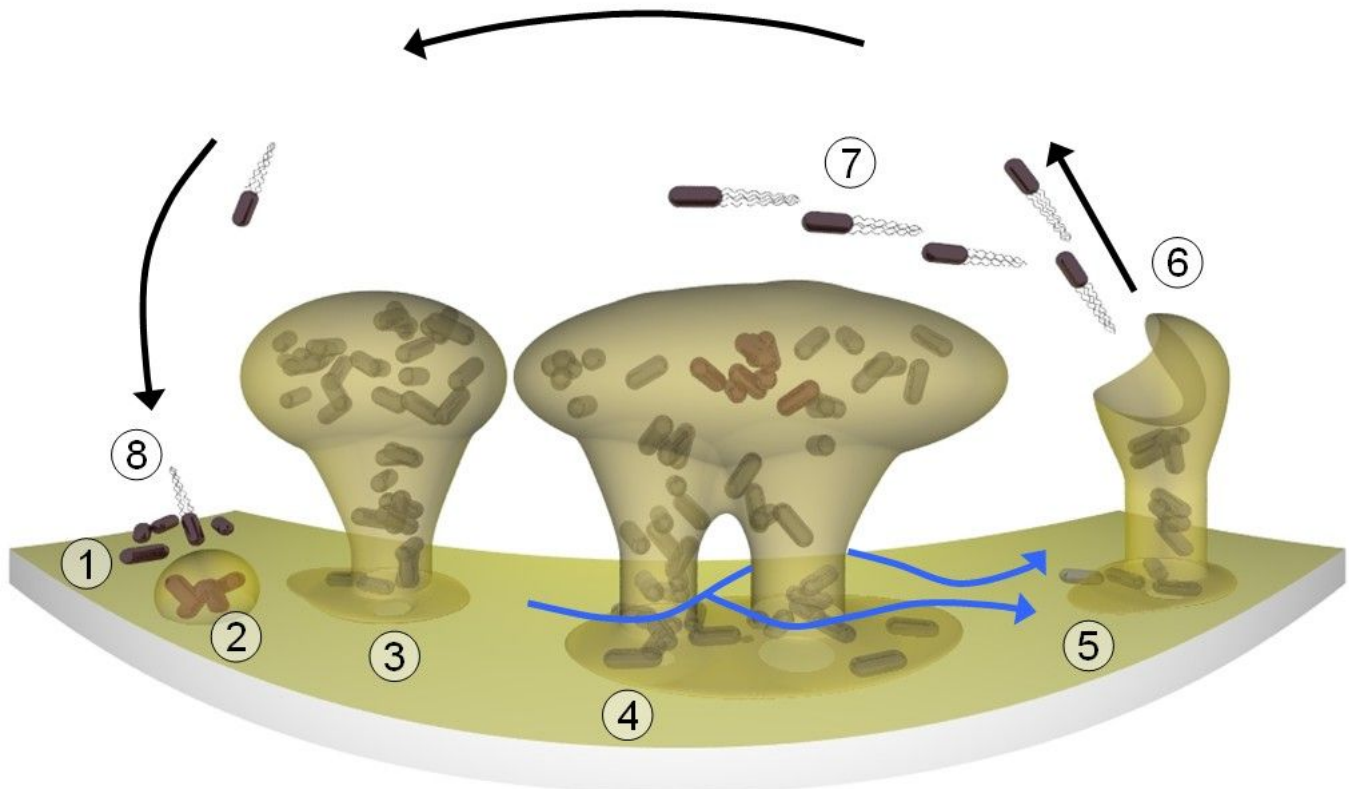
Gram positive bacteria have a thick cell wall of peptidoglycan (murein, a polymer) surrounding the cell membrane.

Gram negative bacteria typically have a thin layer of peptidoglycan sandwiched between two membranes – an inner and an outer membrane, in the periplasmic gel that fills the space between the two membranes. The outer membrane contains unusual glycolipids called lipopolysaccharides (LPS) or endotoxin. Endotoxin in the bloodstream triggers a fever response in the body. Some species of Gram negative bacteria have a different envelope structure: a cell membrane with no peptidoglycan wall, as in mollicutes, or a cell wall made of different polymers.

Gram's stain is a key tool in bacterial identification. Gram's stain colours peptidoglycan purple and stains Gram positive cells purple and Gram negative cells pink. The stain is easily decolourised from the thin layer of peptidoglycan in Gram negative cells during the staining process, so these cells retain little of the dye.

## Slime Cities: Biofilms

Bacteria generally form 'cities' in which billions of bacteria live inside a film of slime that they secrete, anchored to a surface (such as a water pipe, your intestine, or your teeth!). Often these biofilms erect towers from which swarmer cells are shed into the stream of flowing liquid above the surface.



The biofilm life-cycle. Isolated cells adhere to the substrate (1) and move across the substrate until they aggregate into groups. Once aggregated they secrete slime to form a small microcolony (2) and undergo changes in gene expression, which suppresses flagellin synthesis and causes other changes to produce a phenotype more suited to biofilm 'city' life. These microcolonies eventually grow upwards from the substrate as mushroom-shaped or cylindrical columns (3). These larger microcolonies are exposed to higher fluid flows above the lower boundary layer and this flow may be conducted through water channels in the base of the biofilm (blue arrow). Some cells begin to differentiate into flagellated swarmer cells which are released high above the substrate when the columns rupture (5). Columns may undergo several cycles of rupture and swarmer dispersal, regrowth, and rupture and swarmer dispersal. The flagellated swarmer or planktonic cells (6) are dispersed both passively by fluid flow and actively, and can even swim upstream (7) as discussed in the text. Swarmer cells may undergo several stages of cell-division in the planktonic stage, but eventually adhere to the substrate to complete the cycle (8). Additional mechanisms of cell dispersal from biofilms are discussed in the text.